EFFECTS OF PHOSPHORUS AND CASSAVA-SOYBEAN INTERCROP ON SOYBEAN NODULATION AND CASSAVA YIELD IN SOUTH-KIVU, DEMOCRATIC REPUBLIC OF CONGO

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DECLARATION

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

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DEDICATION

This work is dedicated to my family and Almighty Father for His abundant grace and mercy in seeing me through this program.

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LIST OF ACRONYMS AND ABREVIATIONS

ACIAR:	Australian Centre for International Agricultural Research
ANOVA:	Analysis of Variance
BNF:	Biological Nitrogen Fixation
CEC:	Cations Exchange Capacity
CIALCA:	Consortium for Improved Agriculture-Based Livelihoods in Central Africa
DRC:	Democratic Republic of Congo
FAO:	Food Agriculture Organization
FAOSTAT:	Food Agriculture Organization Statistics
IITA:	International Institute of Tropical Agriculture
INEAC:	National Institute for Agriculture Studying in Congo
LER:	Land Equivalent Ratio
MAP:	Month after planting
OM:	Organic Matter
SARD-SC:	Support Agriculture Research Development for Strategical Crops in Africa
TSBF:	Tropical Soils Biological Fertility

ABSTRACT

Declining land productivity and land fragmentation/scarcity associated with war and conflicts are major problems facing the small-holder farmers in Eastern Democratic Republic of Congo. The soils have low and declining soil fertility and the situation is further exacerbated by the civil war which causes displacement leading to concentration of the population in small pieces of land. Of the soil fertility related nutrients, low available phosphorus has been identified as one of the most limiting macro-nutrients to agricultural production. In Eastern Democratic Republic of Congo, cassava is priority food and cash crop and is usually intercropped with other crops. However, due to low technological know-how of the smallholder subsistence farmers on appropriate agronomic practices and soil fertility input use, agricultural productivity low. Hence, the major objective of this study was to evaluate the effect of phosphorus application on cassava intercropped with soybean productivity. The study was carried out in two locations of Eastern DR Congo, Kabare and Uvira The field experiment was laid out in a full factorial design. The factors were: cropping system at three levels (sole cassava, sole soybean and cassava-soybean intercrop) and phosphorus (P_2O_5) application at three levels (0, 45.8 and 91.6 Kg P ha^{-1}). 91.6 Kg P ha^{-1} application significantly ($p<0.05$) increased soybean grain and cassava root yields; in Kabare cassava root yield increased by 50.58% in the pure stand and 70.11% in the intercropping while in Uvira, by 43,11% in the pure stand and 55,82% in the intercropping. Soybean grains yield increased by 50.34% (Kabare long rain), 64.89 (Kabare short rain), 39.16% (Uvira long rain), 56.16% (Uvira short rain) in pure stand compared to 24.42% (Kabare long rain), 19.23% (Kabare short rain), 18.36% (Uvira long rain), 30.17% (Uvira short rain) t ha^{-1} in intercropping. Yield decreased in the intercropped soybean by 23.8 % in Kabare short rain and 39.55 % compared to sole soybean productivity in Uvira short rain, probably as a result of the competition with cassava. Soybean contributed less to the total land equivalent ratio (LER) (0.73 in Kabare long rain, 0.66 in Kabare short rain, 0.72 in Uvira long rain and 0.77 in Uvira short rain) than cassava 0.74 in Kabare long rain, 0.80 in Kabare short rain, 0.76 in Uvira long rain and 0.93 in Uvira short rain), this means that the beneficial effect of soybean on cassava was greater than the beneficial effect of cassava on soybean. Aggressivity values of soybean were negative (-0.18 in Kabare long rain, -0.20 in Kabare short rain, -0.17 in Uvira long rain and -0.18 in Uvira short rain) indicating that soybean was dominated by cassava in both locations However soybean intercropping with cassava Benefit Cost Ratio value was high than the pure soybean in both locations (2.18 in Kabare and 1.72 in Uvira). The results showed that soybean intercropped with cassava is therefore recommended in the land constraint areas to maximize land profitability and protein production.

CHAPTER ONE: 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 with nitrogen (N) and phosphorus (P) commonly deficient in these soils (Bationo, 2009). About 55 % of the soils in the sub-humid zones have inherent low reserves of essential nutrients particulary where there is limited use of inorganic inputs among the small-scale farmers in Sub-Saharan Africa (Gruhn *et al*., 2000). Soil fertility depletion is, therefore, a major contributor to low agricultural productivity in small- holder farms in Democratic Republic of Congo (Sanchez and Jama, 2002).

African agriculture is mainly dominated by small-holder farmers who have limited access to land, markets, credit and technology besides low crop production occasioned by low and declining soil fertility from year to year. In response to the mentioned constraints, agricultural intensification is a default approach adopted by most smallholder farmers in sub-Saharan Africa (SSA), but unfortunately, they do so on less productive and increasingly on marginal areas (Thandar, 2014). As a remedy informed by farming experience, farmers have identified crops suitable for different soils based on soil fertility status. Based on this, cassava is often considered the suitable crop for soils of low fertility gradient (poor soils) and not requiring fertilizer; although it responds to fertilizer application (Fermont *et al.*, 2010; Pypers *et al.*, 2011). Small-holder farmers rarely apply inorganic fertilizer to cassava crop. As a result of the limited use of nutrient inputs, soil fertility decline due to nutrient mining is the major cause of decreasing cassava production in Central Africa (CIALCA, 2006).

In Eastern Democratic Republic of Congo, cassava occupies an important position in its rural economy because it constitutes a staple food for a bigger proportion of the population. Statistics have shown that, about 70% of cultivated land in the Democratic Republic of Congo (DRC) is under Cassava production. By 2011, the cultivated land under cassava crop was estimated at about 2 million hectares (FAOSTAT, 2011).

Soybean is slowly gaining popularity among small holder farmers in Eastern DR Congo due to tis benefit in human nutrition. In the highlands of South-Kivu, DRC, soybean farming is increasingly being practiced among smallholder farmers, although its productivity is low (Pypers *et al.*, 2011). The low productivity is attributed to, among other factors, continuous cropping with little or no external nutrient input to replenish soil fertility (Lunze *et al.*, 2012); most farmers having no access to improved varieties, and most farmers are limited in their possibilities to improve soil fertility. Manure is available in limited quantities whereas mineral fertilizer is practically absent (Pypers *et al.*, 2011).

Farmers practice intercropping with a wide array of crops, consisting ordinarily of a major crop and other minor crops. However, it is pertinent that the selection of compatible crops be given priority as this depends on their growth habit, land, light, water and fertilizer utilization (Thayamini and Brintha, 2010). According to Banik *et al.* (2006) the advantages of intercropping include soil conservation, lodging resistance, and weed control over the mono-cropping. Introduction of leguminous crop species into cropping systems has been recognized as an important approach to soil fertility improvement (Mpangane *et al.*, 2004). Since intercropping increases light interception, it reduces growth of late emerging weeds (Takim, 2012).

A better nutrient use efficiency is expected from more diverse systems, either multi-specific such as intercropping (Tilman *et al.*, 2002). Intercropping is gaining popularity among smallholder farmers as long as it offers the possibility of yield advantage relative to sole cropping through yield stability and improved yield through efficient utilization of nutrients (Bhatti *et al.*, 2006). According to Ahmad *et al.* (2001), soybean can successfully be intercropped with non-legume to efficiently use the land.

Legumes are highly compatible with cassava in terms of growth pattern, canopy development and nutrient demands, as they require mostly P and can satisfy part of their N requirement (Giller, 2001). Phosphorus is not only a macro-nutrient in most crop production systems, but it is an essential element. It plays an important role in crop maturation, root development, photosynthesis, N fixation and other vital processes). As a nutrient, it is the second to nitrogen in importance (Davis and Westfall, 2009). In the soil, P is present in the soil solution, soil organic matter or occurs as inorganic P. Unlike nitrogen, phosphorus cannot be fixed from the atmosphere. It is generally regarded as the nutrient that is most limiting in tropical soils including the low pH Eastern Democratic Republic of Congo soils (Phiri *et al*., 2010).

Phosphorus (P) is the most limiting nutrient in the soils of south Kivu (CIALCA, 2009). These soils are known to be P fixing due to higher concentrations of free Fe and Al oxides (Vandamme, 2007) caused by low soil pH. Many studies have suggested that the legume could facilitate the acquisition of P by the intercropped non-legume crop via exudation of organic acids (Li *et al*., 2007) or phosphatase enzymes (Gunes *et al*., 2007). According to Flores-Sanchez *et al*. (2013), extensive root system of cassava in intercropping with legume leads to a better absorption of water and nutrients.

1.2 Statement of the problem

Due to fixation of applied P in low pH soils, higher amounts of nutrients are required to satisfy both the soil fixation and soybean-cassava production needs in Eastern DRC. Although cassava is able to grow and give reasonable yields in low fertile soils, intercropping can still be beneficial as soybean is potential source of N through atmospheric fixation and ultimate transfer of symbiotically fixed nitrogen (N) from legumes to intercropped crops. The practice of legume intercropping is common among smallholder farmers, but scientific information on cassava-soybean intercropping are limited despite potential advantages for soil fertility restoration and increased options for plant protein sources for poor households. Therefore, there is a need to identify the optimal P fertilizer rate application for increased and sustained cassava and soybean yields under small-holder cassava-soybean intercropping system.

1.3 Objectives

The overall objective of this study was to enhance cassava productivity through cassava-soybean and phosphorus application intercropping systems. The specific objectives were to:

i) Evaluate the effect of cassava-soybean intercrop and phosphorus application on cassava and soybean productivity in Kabare and Uvira.
ii) Examine the effect phosphorus application on soybean nodulation of cassava-based cropping systems in Kabare and Uvira
iii) Evaluate the yield advantage of cassava and soybean in intercropping systems over the pure stand in Kabare and Uvira.
iv) Perform an economic analysis to determine the profitability of cropping systems.

1.4 Hypotheses

The specific objectives were based on the hypotheses that**:**

1. Phosphorus application has no effect on yield of cassava and soybean in sole and intercropping systems and the economic return,
2. There is no effect of phosphorus application on soybean nodulation cassava-based cropping systems,

3. There are differences in yield advantages of cassava and soybean intercropping systems.
4. Phosphorus application in the intercropping systems has an effect on cassava and soybean profitability

1.5 Justification of the study

Democratic Republic of Congo has a need for development and adoption of technologies that can counteract the present downward spiral of soil fertility decline. Technologies for nitrogen (N) replenishment have readily been developed through biological practices such as Biological Nitrogen Fixation (BNF). Scientific information on the interactive effects of soybean intercropped with cassava on their yields and soil fertility in Eastern DRC are limited.

1.6 Significance of the study

Information generated from this study will facilitate better understanding of the factors governing the production of cassava cropping systems (intercropping with soybean) under local conditions of South-Kivu. It also generated information on the optimization of phosphorus application for cassava production. The information can be used as a guide in cassava-soybean intercropping to improve crop yield while maintaining soil nutrient conditions. The findings contribute to knowledge on the use of phosphorus and soybean combined and how to adapt these management practices to current local conditions through maximizing agronomic efficiency of the applied nutrients.

1.7 Conceptual frameworks

Soil fertility depletion and high mineral fertilizer cost results in declining soil fertility in cassava and soybean cropping systems in DR Congo. This led to decreasing soil nutrient availability and crop yields. Mineral fertilizer in cassava and soybean cropping systems may improve food security; increase cassava and soybean yields and facilitate the nodulation and therefore the BNF (Figure 1.1).

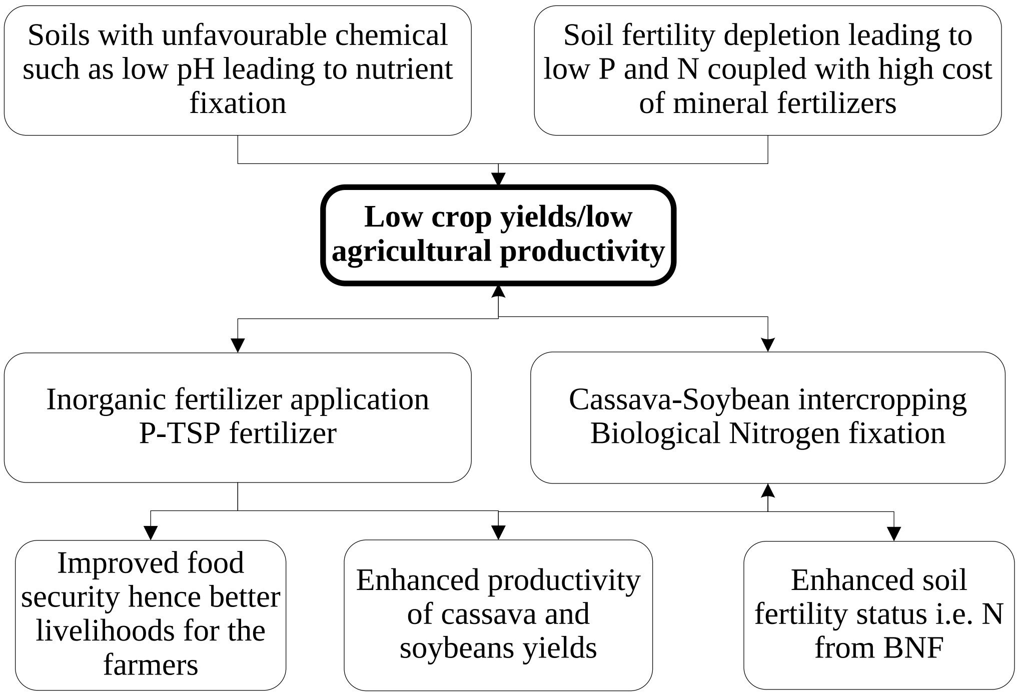


Figure 1.1: Conceptual framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Overview

This chapter covers literature review on cassava production, soil fertility, phosphorus application and cassava-soybean intercropping systems. The literature reviews are presented in three sections following the study objectives: the origin and importance of cassava in Democratic Republic of Congo; origin and importance of soybean in Democratic Republic of Congo; intercropping in improving crop production; cassava-soybean intercropping effects on yields and returns; availability and role of phosphorus in crop production; yield advantage of intercropping cassava with soybean over pure stand and finally a summary of the chapter highlighting research gaps.

2.4 Role of intercropping in improving crop production

Intercropping increases and diversifies productivity per unit area when compared to sole cropping (Sullivan, 2003). Intercropping with a legume reduces the amount of nutrients taken from the soil as compared to a maize monocrop. In absence of nitrogen fertilizer, intercropped legumes will fix nitrogen from the atmosphere and not compete with maize for nitrogen resources (Adu-Gyamfiet al., 2007). Intercropping of nitrogen fixing crop and non-fixing one gives greater productivity than mono-cropping (Searan and Brintha, 2009).

Bankandsharma (2009) reported that cereal-legume intercropping systems were superior to mono-cropping. Most French bean intercropping (Pandita, 2001).

Akinnifesi *et al*. (2006) revealed that without nitrogen fertilizer application, gliricidia/maize intercropping systems gave high maize yield. West and Griffith (1992) observed maize yield was increased by 26% in maize/soybean strip intercropping. Moreover, Tsubo *et al*. (2005) found that in maize/bean intercropping, maize yield was not affected. Kipkemoi *et al*. (2001) reported that land equivalent ratio (LER) in a maize/soybean intercropping system was greater than one under intercrop. Muoneke *et al*. (2007) found that the productivity of intercropping maize/soybean in different maize planting density indicated yield advantage of 2-6.3% as depicted by the LER of 1.02-1.63 showing efficient utilization of land resource by growing the crops together. Raji (2007) also reported higher production efficiency in maize/soybean intercropping systems. Addo-Quaye *et al*. (2011) found that LER was greater than unity, implying that it would be more productive to intercrop maize/soybean than growing them in monoculture. Allen and Obura (1983) observed LER of 1.22 and 1.10 for maize/soybean intercrop in two consecutive years. Abera *et al*. (2005) observed that the LER values ranged from 1.15 to 1.42 indicating more productivity and land use efficiency of maize (*Zea mays*) and climbing bean (*Phaseolus vulgari* L.) intercropping in terms of food production per unit area than separate planting.

Scientists have reported that one component crop of an intercropping system may act as a barrier or buffer against the spread of pests and pathogen. Maize is susceptible to many insects (Drinwater *et al.*, 2002) and diseases (Flett et *al.*, 1996). Intercropping appears to be a very promising cultural practice in reducing these pest attacks. Similarly, Sekamatte *et al*. (2003) reported that soybean and groundnut are more effective in suppressing termite attack than common beans. The average percentage of maize stalk borer infestation was significantly greater in mono-cropped (70%) than in intercropped maize with soybean (Martin, 1990). Similarly, Ferdu *et al*. (2001) reported that sole maize had significantly higher incidence of stalk borer and cob worms than intercropped treatments. Intercropping maize/cowpea reduced the stem borer (Henrik and Peeter, 1997). Maize leaf hopper (*Dalbus maindis* L.*)* was reduced under intercropping (Power, 1990).

Climbing genotypes of common beans that are most susceptible to angular leaf spot (*Phaeoisariopsis griseola*) had less diseased pods in the bean intercrop with maize than in the monocrop and also anthracnose (*Colletotrichum lindemuthianum*) on pods of a susceptible bean cultivar was less intense in the intercrop with maize than in the sole crop (Vieira *et al*., 2009). A second crop either provides a reduced area for weeds to get a foothold or reduces weed biomass through competition or allelopathy. Intercropping maize with legumes considerably reduced weed density in the intercrop compared with maize pure stand due to decrease in the available light for weeds in the maize-legume intercrops, which led to a reduction of weed density and weed dry matter compared with sole crops (Bilalis *et al*., 2010). Intercropping maize and sorghum (*Sorghum bicolor* L.) with desmodium (*Desmodium* spp.) effectively controlled witch weed (*Striga hermonthica)* (Khan *et al*., 2007). Other investigators showed that a cover crop of velvet bean [*Mucuna deeringiana* (Bort) Merr.] reduced weed biomass by 68% in maize (Caamal-Maldonado *et al.*, 2001). Also Muhammad-Azim *et al*. (2011) suggested that weed germination could not be affected by intercropping. However, the growth of weeds could be affected by intercropping legume with maize and had a significant effect on suppressing the weed density and improving the biological yield of maize.

2.5 Cassava-soybean intercropping effects on yields and returns

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). Besides improving soil fertility (Dahmardeh *et al*., 2010) and stabilizing higher yield (Dapaah *et al*., 2003), the benefits associated with intercropping are reducing risk of crop failure, decreasing disease severity (Zinsou *et al*., 2005), controlling weed pressure (Hernández *et al*., 1999) and achieving more efficient utilization of environmental resources relative to the pure cropping system (Li *et al*., 2006).

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 in only three 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 tuber formation 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 subsequent 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).

Cassava-legume intercropping can greatly increase total biomass yield without affecting cassava biomass production as reported by Borin and Frankow-Lindberg (2005). Intercropping with leguminous plants (common beans, cowpea, groundnut, pigeon pea or soybean) generally increases productivity (Land Equivalent Ratio 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). 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-mung bean intercrop; Ennin and Dapaah (2008) in cassava-legume intercrops; Sikirou and Wydra (2004) 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 (Lebot, 2009).

The tuberization 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 Mohamed Asmatullah *et al*. (2007) revealed that the economic benefits could be achieved by intercropping with groundnut relative to the pure cassava in the cassava-groundnut intercrop.

2.6 Availability and role of phosphorus in crop production

2.6.1 Effect of phosphorus on soybean and cassava production

Phosphorus is one of the essential elements in the plant growth. Phosphorus availability for soybean growth is frequently low because P reacts with iron, aluminum and calcium in soil to form insoluble phosphates. The use of phosphate fertilizer can lead to substantial increases in soybean yields if soil test values for phosphorus are in the low and very low ranges. Maurya and Rathi (2000) found that the application of phosphorus 75 kg P ha^{-1} enhanced the plant height. Fahmina *et al*. (2013) tested four level of P as P_2O_5 (0, 15, 30, 50 kg P_2O_5 ha^{-1}) and reported that application of different levels of phosphorus showed that plant height and number of branch/ plant increased significantly up to 50 kg P_2O_5 ha^{-1}. On the other hand, number of pods/plant, thousand seed weight, grain yield and biological yield increased significantly up to 30 kg P_2O_5 ha^{-1}. Mahamood *et al.* (2009) observed that phosphorus application increased plant height, leaf area, number of branches, crop growth rate, relative growth rate, number of pods per plant of soybean. Mahamood *et al.* (2009) reported that application of 30 kg P ha^{-1} produced significantly higher number of branches than at 0 kg P ha^{-1} and increased the root length density, shoot dry weight per plant, leaf area index, number of pods per plant, and 100-seed weight of soybean. Abdll-Aziz and Abdul-Latif. (2013) showed that phosphorus rate significantly increased both grain yield and 100 seed weight. Kazi *et al*. (2002) found that a seed yield reduction of 10% was recorded when the P rate was reduced from 90 to 60 kg/ha.

Majumdar *et al*. (2001) stated that P significantly increased the grain and straw yields, pods per plant, 100-seed weight, oil and protein content and their yields and N, P and S uptake by soybean. Application of P_2O_5 up to 80 kg/ha significantly increased the yield of soybean. Rezende *et al*. (2001) observed that the fresh matter, dry matter and hay yield and quality increased as phosphorus rates increased. Phosphorus rates did not alter soybean grain yield and other characteristics. Rehm *et al*. (2001) reported that soybean yield increased resulting from the use of phosphate fertilizer varied from 268 to 940 kg ha^{-1} when soil test values were in the low and very low range, respectively.

2.6.2 Effects of phosphorus on soybean nodulation

Low soil fertility is widely considered as a major factor contributing to low productivity and non-sustainability of existing production systems and long-term food insecurity (Mekuria *et al*., 2004). Mekuria and Waddington (2002) also reported that low soil fertility is a direct contributor to reduced productivity and a major source of inefficiency in the returns to other inputs and management committed to smallholder farms, including nitrogen (N) fertilizer, seed and labour. Legumes have unusual advantage in obtaining nitrogen through Biological Nitrogen Fixation (BNF) process by participating in a symbiotic relationship with *Rhizobium* spp. The ability of legumes to fix atmospheric nitrogen in their nodulated roots and plant residues left after harvesting represent a valuable source of organic N. There are several reports indicating increasing the nitrogen content in non-legume plants due to the intercrops of these plants with plants of leguminosae family (Eskandari, 2009).

Biological Nitrogen Fixation by legumes is a key process in Low External Input Agricultural technologies as it potentially results in a net addition of nitrogen to the system. However, the quantity of the nitrogen fixed by legumes is difficult to quantify and varies according to the species involved and the location (Buttery *et al*., 1992). The importance of BNF as a primary source of nitrogen for agriculture has diminished in recent decades as the amount of nitrogen fertilizer increased for the production of food and cash crops (Park and Buttery, 1989). In recent years, however, the international emphasis on environmentally sustainable development focus on the use of renewable resources, which include attention on the potential role of Biological Nitrogen Fixation (BNF) for supplying nitrogen for agriculture (Peoples *et al.*, 1995). Currently the subject of BNF is of a great practical importance because excessive use of N fertilizers causes problems of acidification and the overuse of N and P fertilizers cause water pollution in the form of eutrophication (Brady and Weil, 2008). Nitrogen fixation is an energy-demanding process and dependent on photosynthesis. If the intercrop non-legume is taller than the legume crop, shading will occur and photosynthesis and subsequently Nitrogen fixation will be reduced (Dressen and Telele, 2017). Phosphorus is important in relation to early infestation stage of nodulation. The effect is directly on the bacteria and not on the plant (Crews *et al*., 2005). It has been suggested that, as nodulated plants have less well developed root systems than non-nodulated plants, the ability of nodulated plants to capture nutrients particularly phosphorus, is decreased (Carlsson et al, 2006). Phosphorus deficiency limits nitrogen fixation (BNF) and it is likely that the potential contribution to tropical crop production systems has been limited by uncorrected phosphorus deficiency (Giller and Merckx, 2003).

Several physiological and metabolic features were associated with the lowering of the N_2 fixing activity in the nodules under non-optimal P nutrient supply. Phosphorus has stimulating effects on nodule growth and nitrogenase activity in nodules of legumes, nodule number and nitrogenase activity (Tang *et al.*, 2001). Phosphorus fertilization in legumes is of great importance, as it affects nodulation, growth and yield. Poor nodulation and poor plant vigor have been observed in beans grown in soils low in extractable phosphorus. Fertilizer phosphorus increases bean yields and causes optimum nodulation earlier during bean growth (Boddey *et al.*, 2006).

The increase of whole plant growth and plant nitrogen concentration in response to increased soil P supply has been observed for several leguminous species including soybean (Israel, 1993). Nodules develop when a root hair (growing out from active roots) is infected by rhizobium bacteria. Plant tissue develops around the infected area, forming the nodule and site of bacterial growth and the fixation of elemental N from the soil.

The critical level of available P for cassava is only about 5 ppm, compared with 10-15 ppm for maize, common beans and soybeans (Howeler, 2002). The lack of a response to P application and the low critical level in the soil is due to a highly effective symbiosis between the fibrous roots of cassava and vesicular-arbuscular (VA) mycorrhizal fungi in the soil. The hyphae of the fungus grow in the root cortex and may extend as far as 1.0 cm from the root into the surrounding soil. Soluble P in this zone around each root can be absorbed by the fungus and transported via the hyphae into the cassava roots, thus increasing markedly the volume of soil from which the plant can absorb P. Cassava is highly mycotrophic, and without this mycorrhizal symbiosis cassava would not be able to survive and prosper on low-P soils (Howeler, 1991).

2.7 Yield advantage of intercropping cassava with soybean over pure stand

The assessing criteria of yield advantages of intercropping were distinguished in to three situations: first where intercropping must give full yield of main crop and some yield of a second crop (Willey, 1981). This is applicable where the primary requirement was for a full yield of some staple food crop; second where the combination intercrop yields must exceed the higher sole crop yield; third where the combined intercrop yield must exceed a combined sole crop yield (Ajeigbe *et al.*, 2006). Indices help in the interpretation of complex data and allow comparison of results from different studies with the use of the same index and to compare absolute yield, protein yield, multiple cropping indices, diversity index, and in economic terms, gross returns from intercrop and sole crop. Various indices such as land equivalent ratio (LER), relative crowding coefficient (K), competitive ratio (CR), aggressivity (A), growth monetary value (GMV), net return (NR) and area-time equivalent ratio (ATER), have been developed to describe the competition and possible economic advantage in intercropping (Ghosh., 2004). Among indices being used for assessing competition between intercrops, land equivalent ratio (LER) is the most commonly used for intercrop versus sole crop comparisons (Agegnehu *et al.*, 2006). In research trials, the researcher's mixture and pure stand in separate plots.

Yields from the pure stands, and from each separate crop from within the mixture, are measured. From these yields, an assessment of the land requirements per unit of yield can be determined. This information tells the yield advantage the intercrop has over the pure stand, if any it also gives an idea on how much additional yield is required in the pure stand to equal the amount of yield achieved in the intercrop. The calculated figure is called the Land Equivalent Ratio (LER). The LER concept was proposed by Willey (1979) to be used as an index of combined yield for evaluating the effectiveness of all forms of intercropping. As an index of combined yield, LER provides a quantitative evaluation of the yield advantage due to intercropping (Willey, 1979). LER could be used either as an index of biological efficiency to evaluate the effects of various agronomic variables (e.g. fertility levels, density and spacing, comparison of cultivar performance, relative time of sowing and combinations) on an intercrop system in a locality or as an index of productivity across geographical locations to compare a variety of intercrop systems (Oroka and Omoregie, 2007).

The LER is calculated as: LER= (LER_{crop1} + LER_{crop2}), where $LER_{\mathbf{crop1}}$ = (Y_{si}/Y_{ss}), and $LER_{\mathbf{cop2}}$ = (Y_{ci}/Y_{cs}), where Y_{ss} and Y_{cs} are the yields of crop1 and crop2 as sole crops respectively, and Y_{si} and Y_{ci} are the yields of crop1 and crop2 as intercrops (Mead and Willey, 1980).

When LER measures 1.0, it indicates that the amount of land required for plant ‘i’ and plant ‘j’ grown together is the same as that for the plant ‘i’ and ‘j’ in pure stand (*i.e.*, there is no advantage to intercropping over pure stand). When LER>1, a large area of land is needed to produce the same yield of sole crop of each component than with an intercropping. For example, LER of 1.25 implies that the yield produced in the total intercrop would have required 25%more land if planted in pure stands. LER below 1.0 shows a disadvantage to intercropping. For example, if the LER was 0.75, then the intercrop yield was only 75% of that of the same amount of land that grow pure stands. LER gives an accurate assessment of the biological efficiency of intercropping and this is a useful tool in research. It is, however, important to present actual yields along with LER in reporting the results of intercropping studies. Generally, the value of LER is determined by several factors including density and competitive ability of the component crop in mixture, crop morphology and duration and management variables that affect individual crop species. It has been suggested that in density studies of cereal-legume intercrop systems, the sole crop yield used as standardization factor for estimating LER should be at the optimum density of the crop. This avoids the confounding of beneficial interactions between components with a response to change in densities. The values of LER follow the density of the legume component rather than that of the cereal (Ofori and Stern, 1987).

Differences in competitive ability affect the relative performance of component crops and thus the LER value of different cereal- legume intercrop systems. 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 favors the yields of crops, indicating yield advantage (Dariush *et al.*, 2006). However, if the total LER is less than 1, the *Phaseolus vulgaris* L gave high maize equivalent yield over sole maize yield (Hauggaard-Nielsen, 2001) and kernel yield of maize was unaffected in maize/French beans intercropping negatively affects the yields of the crops when the crops were intercropped relative to both crops separately (Edje, 1987).

2.8 Yield gaps

Where intercropping systems have been studied, especially in West Africa, the findings as a whole indicate that there are yield advantages over the component crops grown as sole crops (Fussell and Serafini, 1985). Ofori and Stern, (1987), reported that intercropping produces higher and suitable yield in wide range of component combinations. According to Agboola and Fayemi (1977), intercropping maize with Phaseolus *aureu, Vigna unguiculata and Calopogonium mucunoids* increase its mean grain yield by 0.5 tons/ha over the control. Although intercropping reduces the yield of component crops but total productivity and net return has been found higher in intercropping system than sole cropping (Nyambo *et al*., 1980).

The report by Goswami *et al.* (1999) on intercropping soybean with sorghum and arhar (*Cajanus spp.)* showed that there was an increase in soybean equivalent yield and net return. Rashid *et al*. (2005) reported that mung bean associated with sorghum substantially increased income than sole cropping of sorghum. Rashid *et al*. (2006) found that grain yield of sorghum with intercrops of mung bean or guar increased over sole cropping. Singh and Jha

(1984) observed that intercropping of sorghum was more economical as compared to sole cropping system of either crop. Net return obtained from intercropping was 7 to 54 percent more than sole cropping. Shahapurkar (1985) recorded higher net income per hectare from paired rows of maize and soybean intercropping system compared to net income from maize crop alone. Barik *et al*. (2006) stated that sorghum and groundnut intercropping system appeared to be more advantageous from value of land equivalent ratio (LER), relative value total (RVT) and relative net return (RNR). Similarly, Singh and Balyan (2000) indicated that sorghum + cluster bean in paired row planting pattern (30/90 cm) proved as the best intercropping system with maximum total productivity and net return. Similarly, Singh and Balyan (2000) indicated that intercropping systems registered significant increase in total productivity (sorghum equivalent) over sole sorghum.

2.9 Summary and research gaps

Research on intercropping systems has shown advantage in both soil fertility and crop yields, particularly for cereal crop which is the staple food crop for smallholder farmers, beside its other advantage for soil conservation, minimizing incidence of pest and disease and insurance against crop failure,. However, lack of participatory approaches and fragmentation of land under farmer's conditions, mainly the inclusion of resource-less farmers, could not allow easy adoption by these smallholders. Moreover, most of the studies that have been done on intercropping systems were focused on non-legume crop yields, which were not able to show clearly the nodulation by the legume component, probably due to difficult on the measurements procedures. Therefore, it is necessary more research that involves smallholder farmers for sustainable. Also, there is need for proper handle of several issues of accessibility and affordability of improving economic status of smallholder farmer. The practice of legume intercropping is common among smallholder farmers, but scientific studies are rare despite potential advantages for soil fertility restoration and increased options for plant protein sources for poor households. Scientific information on nodulation, by soybean intercropped with cassava are rare, if not completely absent in Eastern Democratic Republic of Congo. The study reported here sought to bridge this knowledge gap with a view to increase the productivity of cassava and soybean intercropping systems.

CHAPTER THREE: MATERIALS AND METHODS

3.1. Description of the Study area

The study was carried out in two locations of Eastern DR Congo i.e Kabare and Uvira (Fig. 3.1). Kabare is located in a higher altitude region while Uvira is in a lower atitude.

3.1.1 Kabare site

Kabare site is situated between 28^o 48' to 28^o 51'E and 2^o 10' to 2^o 30'S, 45 km North-west of Bukavu city. The altitude ranges between 1450 m to 2400 meter above sea level. The rainfall pattern in Kabare is bimodal with two cropping seasons namely season ''A'' starting mid-September ending mid-January and season ''B'' starting mid-February ending mid-June, followed by a 4 months dry period in which the cumulative rainfall is beyond 100 mm. The average daily temperatures vary between 19^o and 31^{o}C (Anonymous, 2005). The prevailing climate is typical of tropical savannah (winter in dry season), influenced by a sub-tropical moist forest bio zone. The predominant soil type is Ferralsols with low natural fertility (Vandamme, 2009).

3.1.2 Uvira site

Uvira site is characterized by a dry savannah climate, with a dry season of 6-7 months (April-October; but longer in the south than in the north of the site) and an average temperature of 24°C. Total annual rainfall is 800-900 mm/year in the lower plain and 1200- 1300 mm/year on the valley slopes. April is the wettest month, with 140-160 mm rainfall in the lower plain and 180-200 mm in the hills. The soils in Uvira are sandy, and the combination of intense rains and steep valley slopes causes high rates of erosion. This is a main reason of the Plain's high soil degradation and low suitability for agricultural production, despite good natural soil fertility.

3.2 Initial soil fertility

In order to characterize the soil of the experimental fields, samples were taken across the fields experiment in a W manner at a depth of 0-30 cm using the soil auger and bulked for laboratory analysis. In the laboratory, the soil samples were air-dried, crushed using a wooden mortar and pestle and then sieved through a 2 mm mesh.

The sieved samples were stored in polythene bags for laboratory chemical and physical analyses at the IITA laboratory in D.R Congo.

Table 3.1: Some physic-chemical soil characteristics of the experimental sites before the experiment

	Physical proprieties				Chemical proprieties				
	Particle size distribution (%)			Textural class	pH (H_2O)	C (%)	N (%)	K	P
	Clay	Sand	Silt						
Kabare	67	8	25	C	5.81	1.9	0.13	0.5	20
Uvira	27	63	10	SL	6.31	1.0	0.08	0.5	11

OC: Organic Carbone, K: Exchangeable Potassium, P: Exchangeable Phosphorus; C= Clay, SL= Sandy loam

The initial soil characterization of the study site (Table 3.1) indicated pH in water 5.81 at Kabare site while in Uvira the pH in was 6.31 indicating that the soils were moderately acidic and neutral in Kabare and Uvira respectively. The mean soil available P was low in Uvira (11 mg kg^{-1} at 0-30cm) and high in Kabare (20 mg $kg^{-1,}$ at 0-30 cm depth). The mean soil exchangeable K was low at Kabare also in Uvira with an average of 0.5 me/100 g soil. The soils at the experimental site had low organic C (1.9% in Kabare and 1.0% in Uvira) and total N (0.13% in Kabare and 0.08% in Uvira). This gives a C: N ratio of 14.6 in Kabare and 12.5 in Uvira which is known to enhance N mineralization in both sites. According to the soil particle size analysis, at Kabare the soil had 67% clay, 8% sand and 25% silt therefore classified as clay in texture, while in Uvira the soil had 27% clay, 63% sand, and 10% silt therefore is classified Sandy loam in texture.

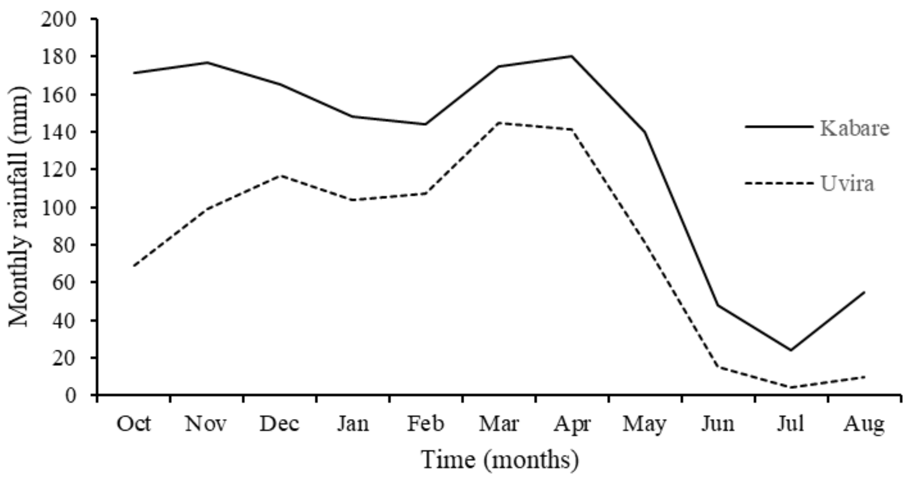
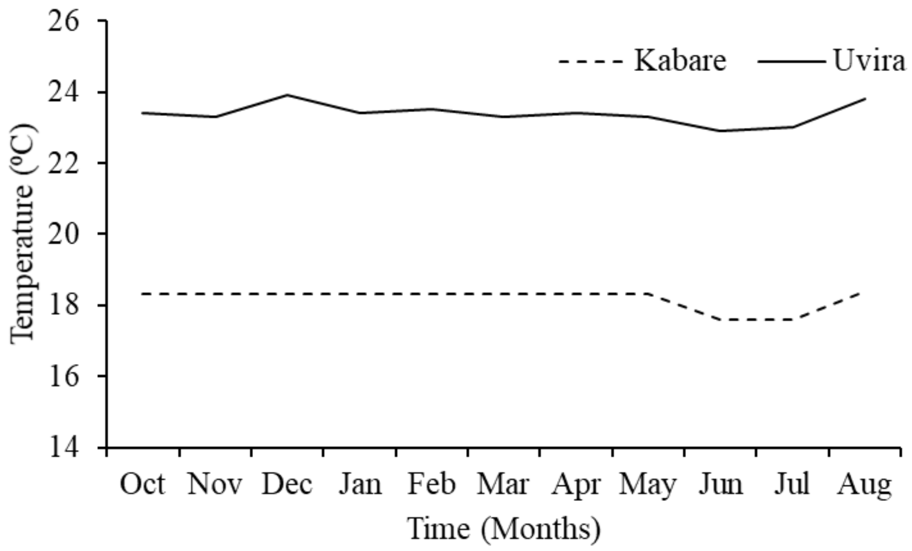


Figure 1.1 Rainfall distributions during the long and the short season in Kabare and Uvira



Months after planting

Figure 3.2 Average monthly (2015-2016) temperature in Kabare and Uvira

3.2. Experimental design and treatments

The field experiment was laid as a full factorial design replicated 3 times in each site. The first factors were; farming systems at three levels (sole cassava, cassava-soybean and sole soybean) while the second factor was phosphorus (P_2O_5) rates at three levels (0, 45.8 and 91.6 Kg ha^{-1}). The plots were spaced at 1 m from each other (figure 3.4).

Cassava			**Cassava-soybean**			**Soybean**		
0 kg P_2O_5	**45.8 kg P_2O_5**	**91.6 kg P_2O_5**	**45.8 kg P_2O_5**	**0 KG P_2O_5**	**91.6 kg P_2O_5**	**0 KG P_2O_5**	**45.8 kg P_2O_5**	**91.6 kg P_2O_5**

Figure 3.4: Layout of the field experiment

3.3 Experiment establishment and management

The field was cleared of grass and weeds ploughed using a hand hoe to a depth of 20 cm and racked to obtain a fine and uniform seedbed. Fertilizers were applied by banding at 10 cm away from the planting line, in a 2 cm deep trench then covered. For a 10 to 12 months' crop of cassava, 120 kg Urea, 60 kg TSP and 80 kg KCl per hectare was applied as per recommendation (FAO, 2013) while 100 Kgha^{-1} of urea, 60 Kgha^{-1} for TSP and 60 Kgha^{-1} for KCl; urea and KCl were applied at blanket treatment in all plots. Weeding was done three times in the sole crop plots and two times in the intercrop plots.

Planting cassava and soybean was done in October and November 2015 in Kabare and Uvira sites, respectively. Cassava was planted for one year but soybean for two seasons (long rain and short rain season). Soybean was sown at a spacing of 50 cm between the rows and 20 cm within the rows (100,000 plants ha^{-1} in the long rain season 2015 and 75,000 plants ha^{-1} in the short rain season 2016 due to cassava canopy development). Soybean was planted in four parallel lines with planting bed between the two lines of cassava. After the first planting, soybean was harvested after 3 to 4 months after planting while cassava was harvested 10 months after planting.

3.4. Soil Analysis

Soil samples were collected before planting at a depth of 0-20cm at planting using an auger. The samples were mixed and a composite for each block prepared and sub-sampled. The sub-samples were then analyzed for soil available P, total N, organic C, soil pH 1:1 soil water ratio, exchangeable bases (K^+) and soil particles size.

3.4.1 Soil pH

This was determined using the glass electrode pH meter in a 1:1 soil to distilled water (soil: water) ratio. A 10 g soil sample was weighed into a 100 ml beaker. To this 25 ml distilled water was added from a measuring cylinder, stirred thoroughly and allowed to stand for 30 minutes. After calibrating the (EUTECH model) pH meter with buffer solutions at pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension.

3.4.2 Available phosphorus

Five grams of soil was weighed and transferred into a 50 ml centrifuge tube. Thirty ml of Bray-1 extracting solution (0.025 N HCl + 0.03N NH4F) was added. Soil suspension was shaken for five minutes via a mechanical reciprocating shaker and allowed to stand for 2 minutes and then centrifuged for 10 minutes at 3000 rpm. Working standards in Bray 1 extractant using 5 clean 250 ml volumetric flasks were prepared. Volumes of 0, 2, 4, 8, 12, 16 and 20 ml of stock 250 mg P ml^{-1} of KH_2PO_4 (A.R. grade) solution were pipetted into each 250 ml volumetric flask and made up to the 250 ml mark using $Bray^{-1}$ solution. The working standards contained respectively 0, 1, 2, 4, 6, 8 and10 mg P ml^{-1} in 250 ml volumetric flasks respectively. One ml of the clear supernatant solution (sample), blank and the standard solutions were pipetted into a set of clean 15 ml centrifuge tubes. Six ml of distilled water was added and mixture shaken vigorously followed by the addition of 2.0 ml of molybdate-HCl reagent. Finally, 1.0 ml of 1.76 % solution of ascorbic acid (reducing reagent) was added to the mixture and was vigorously shaken. The mixture was allowed to stand undisturbed for 6 minutes for development of the blue coloration after which the percent transmittance values were recorded at 650 nm wavelength on a colorimeter or visible range spectrophotometer. A graph of absorbance against concentration (mg kg^{-1}) P was plotted. The unknown samples were read and mg kg^{-1} P obtained by interpolation on the graph plotted. The P content was determined by comparing the recorded values to a standard curve plotted using standard P solutions after the percent transmittance (%T) was converted to absorbance by the formula: Absorbance = 2- log T

Calculation: mg P kg^{-1} = C x 6, where C= Concentration derived from the standard curve and 6= Dilution factor

3.4.3 Soil organic carbon

Two grams of soil sample was weighed into a 500 ml Erlenmeyer flask. A blank was included. Ten milliliters of 0.1667M (1.0N) potassium dichromate solution was added to the soil and the blank flask followed by 20 ml of concentrated sulphuric acid. The mixture was swirled and allowed to stand for 30 minutes on an asbestos sheet. Distilled water (200 ml) and 10 ml concentrated ortho-phosphoric acid were added and allowed to cool. One milliliter of diphenylamine indicator was added and titrated with 1.0 M ferrous sulphate solution.

Calculation: % Organic C = $\frac{(\text{m.e.K2Cr2O7} - \text{m.e FeSO4}) x\ 0.003\ x\ f}{\text{wt.of soil}}$ x 100, where m.e (milli-equvalent) = Normality of solution x ml of solution used, 0.003= m.e wt. of C in grams (0.003).

3.4.4 Total nitrogen

A 10 g air dried soil sample was weighed into a Kjeldahl digestion flask and 10 ml distilled water added to it for 10 minutes to moisten. Thirty millilitres concentrated sulphuric acid and one spatula full selenium mixture were added, mixed carefully and digested for 2 hours until a clear and colour less digest was obtained. The digest was allowed to cool and then decanted into a 100 ml volumetric flask which was made up to mark with distilled water. A 10 ml aliquot of the digest was transferred to the Kjeldahl distillation apparatus and 20 ml of 40% NaOH solution was added followed by distillation. The distillate was collected in 10 ml of 4% boric acid. Using bromocresol green and methyl red as indicator, the distillate was titrated with 0.1 *N*HCl till blue colour changes to grey and then suddenly flashes to pink. A blank distillation and titration was also carried out to take care of traces of nitrogen in the reagents as well as the water used.

Calculation: %N = $\frac{(\text{A} - \text{B}) \text{x } 1.4 \text{ x N x V}}{\text{s x t}}$**,** where N = Normality of HCl used in titration, A= ml HCl used in sample titration, B= ml HCl used in blank titration, 1.4=1.4 x 10^{-3} x 100% (14= atomic weight of N), V= total volume to digest, s= mass of air dry soil sample taken for digestion in g (10 g) and t= volume of aliquot taken for distillation (10 ml).

3.5. Data collected

3.5.1 Effect of cassava-soybean intercrop and phosphorus application on cassava and soybean yield and the economic return

3.5.1.1 Soybean

- **Plant height**

Data on initial stand count of the crop was recorded from the net plot area. Plant height was measured at 50% full podding using a wooden ruler (in cm) from base to top of ten randomly selected plants per net plot and the average was taken for analysis.

- **Stem diameter**

Plant stem diameter was measured at 50%full podding using a veneer caliper (in cm) (3D model) from ground level to 5 cm up the ground of ten randomly selected plants per net plot and the average was taken for analysis.

- **Shoot biomass yield**

From the two border rows on each of the treatment plots, ten plants were randomly chosen and cut to the ground level for shoot dry matter determination at 50% flowering. Plant materials were then put in large brown envelopes and oven dried at 60 °C for 72 hours. The dried plant materials were then weighed and biomass dry weight determined using a weighing balance (KERRO BL10000).

- **Grain yield**

Soybean was harvested at physiological maturity. Pods were removed from the plants after harvesting. The pods were then air-dried and threshed. The grains were oven dried at 60 °C for 72 h and the dry weights recorded. The dry weights were then extrapolated to estimate the grain yield per hectare. The drying was done to moisture 12%.

3.5.1.2 Cassava

- **Plant height at harvest**

Plant height was measured using a ruler (in cm) from base to the apex of eighteen randomly selected plants per net plot and the average was determined for analysis.

- **Stem diameter at harvest**

Plant stem diameter was measured at maturity using a veneer caliper (in cm) (3D model) from ground level to 5 cm up the ground of ten randomly selected plants per net plot and the average was taken.

- **Above ground biomass yield at harvest**

From the two border rows on each of the treatment plots, ten plants were randomly chosen and cut to the ground level for shoot biomass. Plant materials were then put in large brown envelopes and oven-dried at 60 °C for 72 hours. The dried plant materials were then weighed and biomass dry weight determined using a weighing balance (KERRO BL10000).

- **Root yield at harvest**

Cassava storage roots at maturity of eighteen plants per plot were separated in marketable tubers (sufficiently large and good quality) and non-marketable tubers (small or poor quality) and the yield was measured and then converted on 10000 m^2 basis.

3.5.1.3 Economic analysis

The economic analysis was conducted to evaluate the profitability of cassava and soybean intercrop using partial budgeting. A simple financial analysis was also conducted to evaluate the profitability of three cropping systems (cassava – soybean intercrop, sole cassava and sole soybean). 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 by 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 (Waddington *et al*, 1990). Total costs included input costs (seed, cutting and inorganic fertilizer) and labour costs (land preparation, planting, weeding and harvesting) in the different treatments.

The labour was valued at a wage of \$ 1.5 in Kabare and Uvira sites for 8 hours working days. For seed, grain price was \$0.5 kg^{-1}. Cassava stems were valued both as an input (planting material) and as produce at \$ 0.03 m^{-1}. Total benefits were estimated using the unit prices for the grains of soybean, and fresh cassava root yields at the local markets. Economic analysis did not take leaf production into account. An exchange rate of 1000 Congolese francs to \$ 1 was used. The Benefit Cost Ratio (BCR) of fertilizer application through the cropping systems was calculated as the ratio of total benefits over total costs and was considered favorable when exceeding 1 as invested by the farmer (Waddington *et al.*, 1990).

3.5.2 Effect of phosphorus application on soybean nodulation and yield in intercropping systems

Nodulation: Nodule number and nodule dry weight

At 50 % flowering, ten consecutive plants were randomly harvested from the row next to the border row and roots gently dug out. The plants were cut at about 5 cm above the ground. The plant roots were then washed through a 1 mm mesh sieve in water to remove soil particles after which nodules were detached. The number of nodules on each plant was then counted and recorded. The nodules were then put in an envelope and oven dried at 60 °C for 72 h and the dry weights recorded using a weighing balance (KERRO KB10000).

3.5.3 Biological performance of cassava intercropped with soybean

The competitive behavior of component crops in different cassava-soybean planting patterns was determined in terms of land equivalent ratio and aggressivity index by using the following formulae.

- Land equivalent ratio (LER), which measures the effectiveness of intercropping in using the environmental resources compared to sole cropping, was obtained according to Mead and Willey (1980). The LER values were calculated as: LER= (LER cassava + LER soybean), where LER $_{cassava}$ = (Ysi/Yss), and LER cassava = (Yci/Ycs), where Yss and Ycs are the yields of cassava and soybean as sole crops respectively, and Ysi and Yci are the yields of cassava and soybean as intercrops, respectively.
- **Aggressivity (A)** is a measure of competitive relationships between two crops in mixed cropping (Willey, 1979). This was expressed according to Dhima et al (2007) as follows: Acassava = (Ysi/Yss x Zsp) – (Yci/Ycs x Zcp) and Asoybean= (Yci/Ycs x Zcp) – (Ysi/Yss x Zsp). Thus if Acassava= 0, both crops are equally competitive, if Asoybean is positive, then it is dominant and if Asoybean is negative, then soybean is weak; the same for cassava.

3.7 Data Analysis

Analysis of variance was carried using General Linear Model of ANOVA using R console software (R Core, 2015). The location, cropping systems, phosphorus application (considering as fixed variables) and their interactions on yield and nodulation were estimated with a Generalized Linear Mixed Model (GLM), taking replication as a random variable. Mean separation was carried out using Standard Error of Differences (SED) at 5% probability level. An economic analysis of the profitability of the phosphorus application in cropping systems was carried. Biological performance of the intercropping was determined considering the values of LER and AI.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1. Overview

This chapter comes out with a detailed presentation of the results and their discussions. The findings are presented in three sections following the study objectives. Section 4.2 presents and discusses results of the effect cassava-soybean intercrop and phosphorus application on cassava and soybean production in Kabare and Uvira. Section 4.3 evaluate the soybean nodulation in cassava intercrop in response to phosphorus application in Kabare and Uvira and lastly, section 4.4 the yield advantages of cassava and soybean grown in intercropping over the pure stand in Kabare and Uvira.

4.2 Effect of cassava-soybean intercrop and phosphorus application on cassava and soybean production

4.2.1 Cassava shoot biomass and root yield (t ha^{-1})

There was significant difference (*P*<0.05) between the phosphorus levels, the cropping systems and sites in the cassava biomass and root yields. Site (S), Cropping systems (S) and phosphorus rates (S) interaction showed a significant effect (*P*<0.05) on cassava biomass and root yields (Table 4.1). In Kabare, sole cassava crops (39.38 t ha^{-1}) produced higher root yield than the intercropped cassava plants (36.42 t ha^{-1}). For the phosphorus rates, 91.6 kg P_2O_5 ha^{-1} recorded the highest root yield (44.21 t ha^{-1}). In Uvira, sole cassava crops (31.19 t ha^{-1}) produced higher root yield than the intercropped cassava plants (29.34 t ha^{-1}). For the phosphorus rates, 91.6 kg P_2O_5 ha^{-1} recorded the highest root yield (34.79t ha^{-1}). Comparing the two sites, Kabare recorded the highest cassava root yield (37.90 t ha^{-1}) than Uvira (30.27 t ha^{-1}**).**

The higher yields of erected cassava yields obtained can be explained by the fact that the variety grew taller in height and therefore was not affected by competition for light relative to soybean crop. That could be due to the fact that soybean did not compete with cassava for light, water and nutrients. Fukai and Trenbath (1993) pointed out that when two species are associated, the crops interact in such a way that when one exerts a negative effect on the other, the principal of competition is established. However, the cassava yield in pure stand was same as in intercrop in Kabare (but not Uvira) especially for 91.6 kg P2O5. The varying maturity dates of the component crops led to a reduction in competitive effects of soybean on cassava fresh tuber yield. Fertilization had a positive effect on root sink strength (storage root number). A positive correlation (r^2=0.56, figure 4.1) between storage root yield and biomass yield, which has also been reported in cassava (Vine and Ahmad, 1987).

Table 4.1: Cassava biomass and root yield (t ha^{-1}) as affected by the cropping systems and phosphorus rates application in Kabare and Uvira

Treatment		Kabare		Uvira	
		Shoot biomass yield (t ha^{-1})	Root yield (t ha^{-1})	Shoot biomass yield (t ha^{-1})	Root yield (t ha^{-1})
Cassava in pure stand	0 kg P_2O_5	14.39^{b}	29.99^{c}	10.15^{b}	24.99^{c}
	45.8 kg P_2O_5	14.67^{b}	42.98^{ab}	10.37^{b}	32.81^{b}
	91.6 kg P_2O_5	17.67^{a}	45.16^{a}	16.54^{a}	35.78^{a}
Cassava intercropped with soybean	0 kg P_2O_5	11.32^{c}	25.43^{d}	6.58^{d}	21.19^{d}
	45.8 kg P_2O_5	11.60^{c}	40.56^{b}	9.86^{c}	33.80^{b}
	91.6 kg P_2O_5	15.01^{ab}	43.26^{ab}	12.02^{b}	33.02^{b}
P value CS		0.041^{*}	0.013^{*}	0.002^{**}	0.017^{*}
P value PR		$<.001^{***}$	$<.001^{***}$	$<.001^{***}$	$<.001^{***}$
*P value CS*PR*		0.002^{**}	0.048^{*}	0.004^{**}	$<.001^{***}$
SED CS		0.648	0.740	0.2455	0.124
SED PR		0.707	0.539	0.504	0.190
*SED CS*PR*		0.859	0.718	0.588	0.252

Means with the same letter down the column are not significantly different; CS: Cropping systems, PR: Phosphorus rate, SED: Standard Error of difference

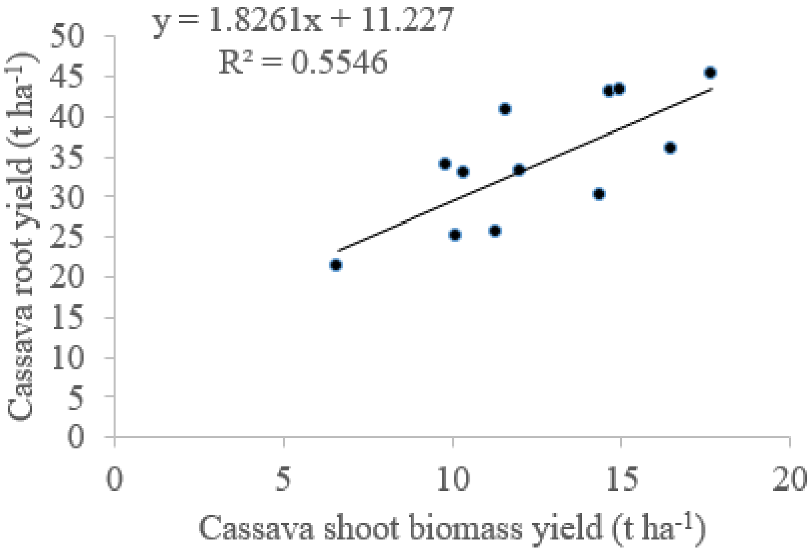


Figure 4.1: Relationship between cassava shoot biomass and grain yield in Kabare and Uvira.

In Kabare, sole cassava crops (15.56 t ha^{-1}) produced higher biomass than the intercropped plants (12.64 t ha^{-1}). Furthermore, from the phosphorus rates, 91.6 kg P_2O_5 ha^{-1} recorded the highest biomass yield either for sole cassava crops (17.67 t ha^{-1}) or the intercropped plants (15.01t ha^{-1}). In Uvira, the same trend was observed; sole cassava crops (12.28 t ha^{-1}) produced higher biomass than the intercropped plants (9.49 t ha^{-1}). The 91.6 kg P_2O_5 ha^{-1} treatment recorded the highest biomass yield either for sole cassava crops (16.54t ha^{-1}) or the intercropped plants (12.02 t ha^{-1}). The differences observed in biomass yield between the two cropping systems could be explained by the competition pressure between plants differing in species and discrepancies in nutrients utilization. Soybean is a light feeder crop compared with cassava but its rooting ability gives it an advantage to benefit from underground nutrients and stored soil moisture in horizons where soybean roots might not reach (Ogoke *et al*, 2006). This increases reliance of soybean plant to the subsequent nutrients and moisture, thereafter being exhaustively utilized by the cassava plant (Oguzor, 2007). In cassava, as in other crops, growth of aerial biomass has priority over root growth (Wardlaw, 1990). But above-ground biomass is usually more sensitive to sub-optimal P supply than roots. The results form Table 4.1 confirmed that trend, as aerial biomass was more responsive to P application. Aerial apices were identified earlier as active sinks for assimilates, thus competing with the roots for carbohydrates (Tan and Cock, 1979).

4.2.2 Cassava stems diameter and height (cm)

There was significant difference ($P<0.05$) between the phosphorus levels, the cropping systems and sites in the cassava stem diameter and height. Site (S), Cropping systems (S) and phosphorus rates (S) interaction had not significant effect ($p<0.05$) on cassava stem diameter and height (Table 4.2). In Kabare, the highest cassava plant stem diameter was observed in sole cassava plots with the average value of 3.23 cm. For the phosphorus rates, 45.8 and 91.6 kg P_2O_5 ha^{-1} were the best with the values of 2.82and 3.04 cm at harvest, respectively. In Uvira, the same trend was observed. Generally, soybean had affected the cassava plant stem diameter in a negative but consistent manner, although there were no significant differences among the intercrops. Cassava performed well in sole cropping, and the intercropped cassava did not reveal higher stem diameter than the sole cassava. The highest cassava plants stem diameter were recorded with sole cassava at harvest, with the average value of 2.56 cm. For the phosphorus rates, 45.8 and 91.6 kg P_2O_5 ha^{-1} were the best with the values of 2.24 and 2.45 cm at harvest. The best interactions were sole cassava*45.8 kg P_2O_5 ha^{-1} and sole cassava*91.6 kg P_2O_5 ha^{-1} with the cassava plant stem diameter values of 2.53 and 2.82 cm at harvest, respectively.

The stem diameter of cassava plant was relatively smaller in intercropping with soybean than that in sole cassava. The difference was however insignificant and this probably indicates the impact of competition between the two crops for the available resources in the field including space, nutrients, light, water and soil exploration. This argument is in line with the results of Alhaji (2008) who found that intercropping of different varieties of cowpea with maize affected the plant height, leaf area and leaf area indices of maize.

Table 4.2: Cassava stem diameter and height (cm) as affected by the cropping systems and phosphorus rates application in Kabare and Uvira

Treatment		Kabare		Uvira	
		Cassava stem diameter (cm)	Cassava stem height (cm)	Cassava stem diameter (cm)	Cassava stem height (cm)
Cassava in pure stand	0 kg P_2O_5	2.81[ab]	196.21 [a]	2.34 [ab]	163.51 [a]
	45.8 kg P_2O_5	3.32 [a]	219.06 [a]	2.53 [a]	170.99 [a]
	91.6 kg P_2O_5	3.55 [a]	224.87 [a]	2.82 [a]	173.97 [a]
Cassava intercropped with soybean	0 kg P_2O_5	2.33 [b]	176.95 [a]	1.93[b]	147.46 [a]
	45.8 kg P_2O_5	2.57 [b]	172.43 [a]	1.94[b]	143.69 [a]
	91.6 kg P_2O_5	2.53 [b]	193.22 [a]	2.15[b]	147.50 [a]
P value CS		<.001*	0.008**	0.001**	0.013*
P value PR		0.075[ns]	0.041*	0.372 [ns]	0.590[ns]
*P value CS*PR*		0.027*	0.082 [ns]	0.029*	0.490 [ns]
SED CS		0.050	6.23	0.041	5.68
SED PR		-	7.40	-	-
*SED CS*PR*		0.175	-	0.139	-

Means with the same letter down the column are not significantly different; CS: Cropping systems, PR: Phosphorus rate, SED: Standard Error of differences

4.2.3 Soybean shoot biomass and grain yields

The use of different cropping systems and phosphorus rates were highly significant at ($p<0.05$) on the shoot biomass and grain yields of Soybean. The cropping systems and phosphorus levels interaction was also highly significant ($p<0.05$) and showed the same response in both Kabare and Uvira (Table 4.3). The Kabare and Uvira soil showed a significant difference at ($p<0.05$) in the shoot biomass. Phosphorus fertilization in both cropping systems significantly influenced the shoot biomass yield. It was observed that soybean plants that were supplied with phosphorus in pure stand grew larger than the plants grew in intercropping, thus gave a higher shoot biomass than control P treatments, and this was in relation with amount of nodules and could suggest that the amount of nitrogen fixed is a function of shoot dry weight and influenced by phosphorus as earlier observed by Mallarino and Rueben (2005). The reason is related to the fact that application of P affects positively the nodulation and improves the above ground biomass of plants (Majumdar *et al.*, 2001). Abayomi *et al*. (2008) reported that P is an essential component of vegetative growth and enhanced increment in shoot biomass of legumes. Dugje *et al*. (2009) showed that phosphorus is often the most deficient nutrients, and when an optimum level is applied, it improves the weight of shoot biomass. The increase in biomass due to increasing P application could also be supported by work of Sinclair and Vadez (2002) which showed that phosphorus deficiency results in stunted shoot growth due to reduced cell division and reduced cell enlargement. This indicates that omission of P from optimum nutrition of soybean dramatically reduces shoot dry matter yield of soybean. This is attributed to the fact that phosphorus is required in large quantities in shoot where metabolism is high and cell division is rapid (Ndakidemi and Dakora, 2007). The current results are in agreement with reports by other workers (Bly *et al*.,1997, Alpha *et al*., 2007) who found that proper P improved the shoot P uptake and increased shoot biomass and grain yields. Chiezey *et al*. (2009) suggested that the application of P stimulated leaf expansion, hence more light interception for photosynthetic activity, high assimilated accumulation and seed yield which are important determinants of seed yield increase with P application. These resulted in increased grains yield. Phosphorus deficiency generally decreases plant biomass accumulation by limiting interception of photosynthetically active radiation (PAR) rather than reducing efficiency of conversion of PAR into dry matter. The varieties that also take shorter period to their vegetative growth time are more productive under limited resources and the reverses could probably have higher vegetative yield. Comparable investigation reported by Zeidan (2007) and Ermanetal (2009) also indicated that increasing phosphorus levels from 0 to 60 kg P_2O_5 ha^{-1} increased the general biomass of lentil and field pea plants and decreased at 90 kg P_2O_5 ha^{-1} for field pea

Table 4.3: Soybean biomass (t ha^{-1}) and grain yield (t ha^{-1}) as affected by the cropping systems and phosphorus rates application in Kabare and Uvira

Treatments		Soybean biomass yield (t ha^{-1})				Soybean grain yield (t ha^{-1})			
		Long rain season		Short rain season		Long rain season		Short rain season	
		Kabare	Uvira	Kabare	Uvira	Kabare	Uvira	Kabare	Uvira
Cassava intercropped with soybean	0 kg P_2O_5	0.79 ^{d}	0.66^{c}	0.66^{c}	0.49^{d}	1.45 ^{d}	1.20^{d}	0.94 ^{c}	0.73^{c}
	45.8 kg P_2O_5	0.97 ^{c}	0.75 ^{bc}	0.85^{b}	0.63^{c}	1.92^{c}	1.53^{c}	1.45 ^{b}	1.25 ^{b}
	91.6 kg P_2O_5	1.03 ^{bc}	0.82 ^{b}	1.15 ^{a}	0.86^{ab}	2.18 ^{bc}	1.67 ^{bc}	1.55 ^{ab}	1.14^{b}
Soybean in pure stand	0 kg P_2O_5	0.93^{c}	0.77^{bc}	0.72^{bc}	0.54^{c}	2.17^{bc}	1.72 ^{b}	1.56^{ab}	1.16^{b}
	45.8 kg P_2O_5	1.25^{b}	0.96^{ab}	0.98 ^{ab}	0.74^{b}	2.57 ^{a}	1.98^{a}	1.70^{a}	1.28 ^{b}
	91.6 kg P_2O_5	1.55^{a}	1.18^{a}	1.20 ^{a}	0.92^{a}	2.70^{a}	2.04 ^{a}	1.86^{a}	1.51 ^{a}
P value CS		0.29 ^{ns}	0.014 *	0.016 *	0.151 ^{ns}	0.313 ^{ns}	0.002 **	0.032 *	0.548 ^{ns}
P value PR		<.001***	0.009**	0.049 **	<.001***	<.001***	<.001***	<.001***	<.001***
*P value CS*PR*		0.972 ^{ns}	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***
SED CS		-	0.026	0.026	-	-	0.005	0.087	-
SED PR		0.020	0.063	0.050	0.047	0.037	0.075	0.030	0.072
*SED CS*PR*		-	0.073	0.059	0.065	0.050	0.087	0.067	0.088

Means with the same letter down the column are not significantly different; CS: Cropping systems, PR: Phosphorus rate, SED: Standard Error of differences

The current results are in agreement with those of Pauline *et al* (2010) and Aise *et al.* (2011) who reported similar findings of higher grain yields of soybean under the condition of the proper P application.

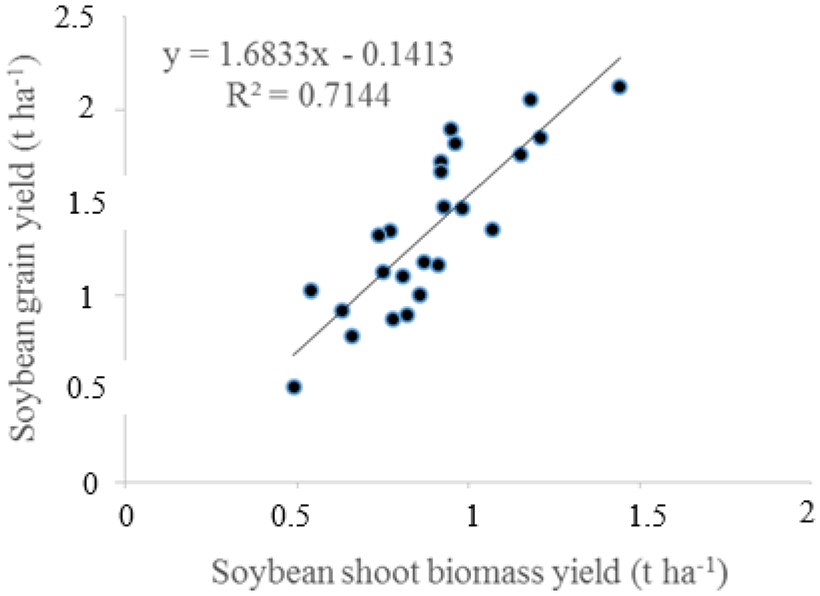


Figure 4.2: Relationship between soybean shoot biomass and grain yield in Kabare and Uvira

The shoot biomass yield was significantly and positively correlated (r^2=0.71) with grain yield (Figure 4.2). So, in this system, the role of P in both pure stand and intercropping systems in enhancing the growth of soybean and increasing the yield of soybean shown in this study.

4.2.4 Soybean plant diameter and height

There were significant differences in the interactions between cropping systems, phosphorus application ($p<0.05$) on soybean plants diameter and height in the long rain 2015 (Table 4.4). The plant height and stem diameter of pure stand soybean increased with the increasing amount of P application in both pure stand and intercropping. The tallest plants of 54.48 cm height and stem diameter of 1.10 cm (Table 4.4) were observed when soybean was planted at levels of P_2O_5 (91.6 kg ha^{-1}) in pure stand. Shorter plants (28.39 to 39.28 cm) and wider stem diameter (0.92 to 1.10 cm) were observed in P-fertilization and thinner stem diameter (0.752 cm) in the zero-P control, respectively. The plant height of soybean was significantly increased with the increase of P application in this system, but the performance was different in Uvira, short rain season 2016, the maximum stem diameter (1.10 cm) was retained at the level of 91.6 kg P_2O_5 ha^{-1} in pure stand at Kabare, long rain season 2015. Both P and cropping systems significantly affected the growth of soybean, but the interaction had not induced a significant effect on plant height in the short rain season 2016 (Table 4.4). Phosphorus is essential and indispensable nutrient for crop growth. With respect to growth character, it was observed that the plant height and stem diameter increased significantly with P application. Plant height increased with increased P application up to 91.6 kg P_2O_5 ha^{-1}. This could be due to the fact that P being essential constituent of plant tissue significantly influences the plant height of crop (Shahid *et al.*, 2009), they also observed significant improvement in plant height of soybean by P-fertilization. The plant height and stem diameter of bothpure stand and intercropping increased markedly with increased P application up to 91.6 kg P_2O_5 ha^{-1}. The present findings are in conformity with the results obtained by Da-Bing Xiang *et al*. (2012) who reported increase in plant height of soybean at high than at low P application. P application improved the growth development of soybean (that is, wider stem diameter; higher plant height, Table 4.4). The competition of cassava over soybean plants in the intercropping was evidenced by the plant height, stem diameter, number of root nodules, nodules dry weight, biomass and grain yield recorded in the soybean plants grown under sole cropping system than in the intercrop system. The results of the present study show that the application of 45.8 and 91.6 kg P ha^{-1} resulted in significant increase in plant height per plant in both years of study. The positive response of soybean to P application in this study was obviously due to the low available P of the experimental site (Table 3.1). It has been observed that the soybean crop response to P is dependent on soil available P (Mallarino and Rueben, 2005). However, the results were in contrast with the report of Chiezey (1999) who observed no response to P application in spite of the low level of the element in the soil. Other workers have shown that the application of P is important for growth, development and yield of soybean (Kakar *et al*., 2002)

Table 4.4: Soybean plant diameter (cm) and plant height (cm) as affected by the cropping systems and phosphorus rates application in Kabare and Uvira

Treatments		Soybean stem diameter (cm)				Soybean stem height (cm)			
		Long rain season		Short rain season		Long rain season		Short rain season	
		Kabare	Uvira	Kabare	Uvira	Kabare	Uvira	Kabare	Uvira
Cassava intercropped with soybean	0 kg P_2O_5	0.62 **a**	0.77 **a**	0.67 **c**	0.46 **c**	44.12**a**	31.54 **d**	28.39 **d**	25.88 **b**
	45.8 kg P_2O_5	0.80 **a**	0.89 **a**	0.69 **c**	0.56 **b**	46.61 **a**	41.19 **c**	48.57 **b**	29.37 **b**
	91.6 kg P_2O_5	0.88 **a**	0.99 **a**	0.75 **b**	0.59 **b**	47.72 **a**	44.34 **c**	54.48 **a**	29.88 **b**
Soybean in pure stand	0 kg P_2O_5	0.64 **a**	1.02 **a**	0.68 **c**	0.54 **b**	40.28**a**	42.51 **c**	36.14 **c**	35.24 **a**
	45.8 kg P_2O_5	0.82 **a**	1.06 **a**	0.76 **b**	0.62 **ab**	49.29 **a**	54.83 **b**	53.18**a**	38.56 **a**
	91.6 kg P_2O_5	0.92**a**	1.11 **a**	0.92 **a**	0.68 **a**	50.69 **a**	60.12 **a**	53.86 **a**	41.71**a**
P value CS		0.29 **ns**	0.006**	0.028*	0.031*	0.805 **ns**	<.001***	0.087 **ns**	0.019*
P value PR		<.001***	0.001**	0.029*	0.045*	<.001 ***	<.001***	<.001***	0.135 **ns**
*P value CS*PR*		0.972 **ns**	0.107 **ns**	0.034*	0.049*	0.114 **ns**	0.022*	0.045*	0.179 **ns**
SED CS		-	0.031	0.034	0.030	-	0.483	-	3.055
SED PR		0.040	0.031	0.044	0.037	1.847	0.778	1.593	-
*SED CS*PR*		-	-	0.052	0.044	-	0.915	1.001	-

Means with the same letter down the column are not significantly different; CS: Cropping systems, PR: Phosphorus rate, SED: Standard Error of differences

4.3 Effect of phosphorus application on soybean nodulation cassava-based cropping systems

4.3.1 Soybean nodule number (ha^{-1}) and nodules weight

The results showed that cropping and phosphorus rate application significantly (P<0.05) affected nodule numbers and the interaction between P and cropping systems improved nodules number and weight (Table 4.5). The combined use of 91.6 P in sole cropping system at Kabare was the most effective in nodule weight increase, followed by 45.8 P in sole cropping system at Kabare, 91.6 kg P_2O_5 ha^{-1} in intercropping system at Kabare, 91.6 kg P_2O_5 ha^{-1} in sole cropping system at Uvira. These results were in agreement with Weisany *et al* (2013) who documented the crucial role of P nutrient element in enhancing nodule weight. Similarly, Asuming-Brempong *et al.* (2013) observed increased nodulation in legumes with increased P levels while Amba *et al.* (2013) recorded increased nodulation of selected grain legumes with P application. The fact that phosphorus was able to increase nodule weight underlines the influence phosphorus has on nodule development through its basic functions as an energy source. The lowest and the highest nodule fresh weight was recorded when soybean was not with P (control: 0 kg P_2O_5 ha^{-1}) in intercropping and 91.5 kg P_2O_5 ha^{-1} in sole cropping system respectively (Table 4.5). This agrees with the results obtained by Olaleye *et al.* (2011), who showed that the application of 60 kg P_2O_5 ha^{-1} enhanced nodulation compared to the various conventional fertilization methods used by producer. Significant increase in nodulation was also observed by Okeleye and Okelana (2000). These observations are logically sound because phosphorus initiates nodule formation as well as influences the efficiency of the rhizobium-legume symbiosis thereby enhancing nitrogen fixation (Haruna and Aliyu, 2011). The observed increase in nodule number following application of phosphorus in sole cropping system concurred with the findings of Nyoki *et al* (2013) that there is an interactive effect of phosphorus on legumes nodulation. This may be attributed to phosphorus stimulating root growth and initiating nodule formation (Asuming-Brempong *et al*., 2013). Results showed that sole cropping and phosphorus application had significantly higher nodules dry weight (kg ha^{-1}) (Figure 4.9). Visual observations also showed that with increasing number of nodules $plant^{-1}$ and therefore per ha, nodules became smaller in size and weighed less, presumably because of competition for photosynthate. Reduction in mean nodule size observed in this study was associated with significantly higher nodule efficiency (expressed as g N fixed g^{-1} nodules) with significant reductions in weight $nodule^{-1}$, suggesting a better rhizobial activity. Similarly, the effects of P application in improvement of Biological Nitrogen fixation have been reported in other studies (Owolade *et al*, 2006; Pauline *et al*, 2010 and Rezende *et al*., 2010). Sanginga *et al*. (2000) applied 20, 40, and 60 kg P_2O_5 ha^{-1} to 94 cowpea lines. All the cowpea lines nodulated and the number and weight of nodules increased with the addition of P. Phosphorus application is beneficial in enhancing nodulation in any cropping systems. This is buttressed by the fact that the control treatment produced fewer numbers of nodules than treatments with nutrient supplementation (Nyoki and Ndakidemi, 2013).

Table 4.5: Soybean effective nodules number (ha^{-1}) and nodules weight ($kg\ ha^{-1}$) as affected by the cropping systems and phosphorus rates application in Kabare and Uvira

Treatments		Soybean nodules number (ha^{-1})				Soybean nodules weight ($kg\ ha^{-1}$)			
		Long rain season		Short rain season		Long rain season		Short rain season	
		Kabare	Uvira	Kabare	Uvira	Kabare	Uvira	Kabare	Uvira
Cassava intercropped with soybean	0 kg P_2O_5	6111^{c}	4222^{c}	4667^{c}	2956^{c}	14.30^{c}	10.66^{c}	10.92^{b}	6.50^{d}
	45.8 kg P_2O_5	13791^{b}	7222^{b}	13130^{b}	7467^{ab}	25.46^{b}	15.10^{a}	26.00^{a}	15.58^{b}
	91.6 kg P2O5	14145^{b}	8778^{ab}	15948^{ab}	7700^{a}	27.31^{b}	20.54^{a}	28.71^{a}	18.02^{a}
Soybean in pure stand	0 kg P_2O_5	8909^{c}	4778^{c}	4469^{c}	5444^{b}	20.85^{bc}	9.28^{c}	10.46^{b}	12.22^{a}
	45.8 kg P_2O_5	16333^{ab}	8333^{ab}	15351^{a}	8778^{a}	32.04^{a}	19.50^{b}	27.63^{a}	18.34^{a}
	91.6 kg P_2O_5	20083^{a}	9889^{a}	17650^{a}	9000^{a}	36.15^{a}	20.62^{a}	31.77^{a}	21.06^{a}
P value CS		0.046*	0.013*	0.214^{ns}	0.049*	0.046*	0.031*	0.324^{ns}	0.047*
P value PR		<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***	<.001***
*P value CS*PR*		0.049*	0.004**	0.028*	0.029*	0.003**	0.005*	0.011*	0.026*
SED CS		3612	276	-	1684	7.01	0.79	-	3.70
SED PR		1454	862	1718	939	2.84	1.91	3.38	2.16
*SED CS*PR*		2797	998	2536	1415	5.43	2.22	4.60	3.17

Means with the same letter down the column are not significantly different; CS: Cropping systems, PR: Phosphorus rate, SED: Standard Error of differences

The poor performances of nodulation could be due to the development in the soil of endogenous *bacteria* strains which sometimes could possess incompatible effects on soybean variety used in this study. Differences in the amount and dry weight of nodules in soybean indicates that even though all the plants may have succeeded in forming nodules, not all the nodules contained effective bacteria that contributed effectively Biological Nitrogen Fixation. There was more shedding in case of intercropping and hence less nodulation and therefore the activities of nitrogenase, the enzyme that catalyzes the reaction thus affecting nodulation (Danso *et al*., 2002). The moisture has an influence on the number of rhizobia in the soil which in turn causes reduction in N_2 fixation showing that the major contribution of soybean to soil fertility in cropping systems lies in its ability to fix atmospheric Nitrogen (Giller, 2001). There was a variation in nodulation of soybean to phosphorus application in the two study areas. The highest nodulation was obtained in Kabare site. This could be due to the variability of environmental conditions between the two sites and also due to the physical-chemical characteristics of soils as reported by Vriezen *et al*. (2007). Soils of Kabare had slightly better nutrients contents (nitrogen, carbon and available phosphorus) than those of Uvira. The control treatment had a lower nodule number in both sites, with Kabare recording 84,111 and Uvira recording 69,091 compared to 91.6 kg P_2O_5 ha^{-1} and 45.8 kg P_2O_5 ha^{-1} (table 4.5). This confirms the effect of phosphorus on soybean nodulation and production.

4.4 Yield advantage of cassava and soybean in intercropping systems over the pure stand

4.5.1 Cassava-soybean Land Equivalent Ratio (LER)

In Kabare, as for the effect of intercropping pattern on land equivalent ratio of cassava and soybean, the highest partial LER of cassava and soybean were found with 2 Cassava: 8 Soybean in both cropping seasons as shown in Table (4.7). The highest partial LER advantages were found with 2Cassava: 8 Soybean where 91.6 kg P_2O_5 ha^{-1} was applied in the long rain season with the values of 0.76 and 0.26 for cassava and soybean, respectively and with 2 cassava: 6 soybean where 40 kg P ha^{-1}in the short rain season with the values of 0.71 and 0.04 for cassava and soybean, respectively. This means that the highest total LER advantage (yield advantage on land area basis) was 1.02 and 0.75 in the long and short rain season, respectively (Table 4.7) showed, also, that yield advantage came mostly from cassava. In other words, cassava 0.72 yield advantage and soybean yield 0.03 yield advantages and the simple addition of both advantages thus gave 0.75 total yield advantages in the long rain season. As long as the corresponding values in the short rain season were 0.67, -0.03 and 0.64 LER advantage of cassava, soybean and cassava + soybean, respectively. It means that soybean -0.03 yield disadvantage in the short rain season. Indeed, the higher LER advantage (yield advantage) of cassava compared to soybean indicated that cassava was the dominant crop and soybean was the dominated one. Table (4.7) shows that LERs advantage for cassava was greater than those for soybean and values of both crops were positive in the long rain season 2015 which indicated that LER for each crop was greater. This implies that the beneficial effect of Cassava on soybean was greater than the beneficial effect of soybean on cassava and the competition between cassava and soybean plants followed, to some extent, mutual cooperation category in the long rain season. Whereas in the short rain season 2016, the corresponding values were positive for cassava and negative for soybean which indicated that the competition followed the compensation category and cassava only got benefit from soybean. In Uvira, the total LER advantages were 0.70 and 0.72 in the long and short rain season, respectively.

Table 4.7. Effect of cassava-soybean intercrop and phosphorus application on cassava-soybean Land Equivalent Ration (LER) and aggressivity index (AI) in Kabare and Uvira

	Partial LER			Aggressivity Index	
Treatment	Cassava	Soybean	Total LER	Cassava	Soybean
			Kabare-2015		
0 kg P_2O_5	0.68	0.67	1.35	0.17	-0.17
45.8 kg P_2O_5	0.76	0.75	1.51	0.19	-0.19
91.6 kg P_2O_5	0.78	0.77	1.57	0.17	-0.17
			Kabare-2016		
0 kg P_2O_5	0.87	0.63	1.50	0.22	-0.22
45.8 kg P_2O_5	0.74	0.63	1.37	0.21	-0.21
91.6 kg P_2O_5	0.78	0.74	1.51	0.18	-0.18
			Uvira-2015		
0 kg P_2O_5	0.70	0.63	1.33	0.15	-0.15
45.8 kg P_2O_5	0.77	0.74	1.51	0.22	-0.22
91.6 kg P_2O_5	0.82	0.78	1.60	0.12	-0.12
			Uvira-2016		
0 kg P_2O_5	0.85	0.63	1.48	0.22	-0.22
45.8 kg P_2O_5	0.99	0.81	1.81	0.18	-0.18
91.6 kg P_2O_5	0.94	0.87	1.81	0.15	-0.15

The yield advantage came mostly from cassava. In other words, cassava yielded 0.73 yield advantages and soybean yield -0.03 yield disadvantages and the simple addition of both advantages thus gave 0.70 total yield advantages in the long rain season. The corresponding values in the short rain season were 0.68, 0.04 and 0.72 LER advantage of cassava, soybean and cassava + soybean, respectively. It means that soybean also 0.04 yield advantage in the short rain season. Indeed, the higher LER advantage (yield advantage) of cassava compared to soybean indicated that cassava was the dominant crop and soybean was the dominated one. Additionally, LERs advantage for cassava was greater than those for soybean and values of cassava was positive and negative for soybean in the first season which indicated that LER for cassava crop was greater than that expected. This means that the beneficial effect of soybean on cassava was greater than the beneficial effect of cassava on soybean and the competition between cassava and soybean plants was greater in the long rain season 2015. Whereas in the short rain season 2016, the corresponding values were positive for both crops which indicated that the compensation category and both crops got benefit. If the values of Land Equivalent Ratio (LER) become over the unity under intercropping system, this means that the superiority of this system over the sole cropping system. In this work the highest value of LER was obtained from intercropping systems in the LR 2015 and SR 2016 in plots where phosphorus was applied. According to Matusso *et al*. (2014), one of the most important reasons for intercropping is to ensure that there is an increase and diverse productivity per unit area compared to sole cropping. Muoneke *et al.* (2007) found yield advantage of intercropping system of 2-63% with LER of 1.02-1.63 showing efficient utilization of land resource. Of the most researches which involved different intercropping systems, none of them reported LER values less than one and this is evidenced in the studies conducted a number of studies (Raji 2007, Addo-Quaye *et al*.,2011; Allen and Obura 1983; Samba *et al*. 2007 and Osman *et al*. 2011). A review conducted by Matusso *et al*. (2014) found that intercropping of cereal and legumes is widespread among smallholder farmers due to the ability of the legume to cope with soil erosion and declining levels of soil fertility. Similar results were obtained by El-Gizy (2001) using bean with eggplant or pepper, Abou-Hussein et al (2005) using onion and lettuce, Abd El-Lateef and Hafez (2012) using bean with squash and Abd El-Gaid *et al.* (2014) using with bean and tomato. The land equivalent ratio (LER) was greater when cassava intercropped with soybean. As indicated by the report of Oguzore (2007), the probable reason might be due to the fact that the shade effect of cassava on soybean hampered photosynthetic activity of the soybean which resulted in low soybean yield. LER values were greater than one in the intercropping system indicating the yield advantage of intercropping over sole cropping of cassava and soybean. Raghuwanshi *et al* (1994) also reported a higher LER in intercropping as compared to sole crops. It is possible to harvest from a hectare of intercropping equal to that from 1.5 hectare of sole cropping of cassava and x hectare of soybean. However, LER in intercropping treatments compared with mono cropping of cassava and soybean was ascribed to better utilization of natural (land and light) and added (phosphorus) resources.

Results are in accordance of Abdel Malik *et al* (1991) work in cotton-mung bean cropping systems; they found that the intercropped cotton utilized there sources more competitively than mung bean, which appeared to be dominated. For aggressivity index (AI), results showed that all values of cassava were positive and those of soybean were negative indicating that cassava was the dominant crop and soybean was the dominated one. In Kabare, aggressivity of both crops were higher with cassava in the plots where phosphorus has not been applied and in the plots where 20 kg P ha^{-1} were applied in the first season but in the short rain season, it was higher in the plots where 20 kg P ha^{-1}. In Kabare, the highest aggressivity value was obtained with 2 Cassava: 6 Soybean intercropping pattern (i.e. in the short rain season 2016) but in Uvira, with 2 Cassava: 8 Soybean intercropping pattern (i.e. in the long rain season 2015); which indicated that there was bigger difference in the competitive abilities of cassava and soybean plants, i.e., bigger differences between the actual and expected yield with that intercropping pattern. This agreed with the findings of Oroka and Omoregie (2007) who obtained higher aggressivity in cowpea over rice at higher population densities. The competitive ratio which measures the degree with which one crop competes with the other showed that sorghum had higher competitive indices than cowpea in all the planting patterns except 1S:2C arrangement. Regardless of the planting patterns, a positive sign with values of cassava indicated the dominant behavior of soybean over the intercrops, which had negative 'AI' values. Soybean proved to be less competitive with cassava as there was a little difference among the aggressivity values phosphorus rate application. This is in line with Gomaa and Radwan's (1991) work; they reported the dominant effect of cotton having a positive 'AI' value when grown in association with mung bean and mash bean. Dhima *et al*. (2007) reported that if LER and relative crowding coefficient (K) values are higher, then there will be an economic benefit expressed with MAI values. Krantz *et al*. (1976) also reported higher monetary returns from systems involving intercropping of legumes and non-legumes compared to sole non-legume cropping which was attributed to better utilization of resources.

4.5 Economic analysis in cassava-soybean intecrop

Results of economic analysis of cassava-soybean intercrop presented on Table 4.6 revealed that cassava and soybean intercropping was more profitable than the pure soybean and pure cassava in response to phosphorus application. There was a significant difference of Total Benefit (TB), Net Benefit (NB) and Benefit Cost Ratio (BCR) in Kabare and Uvira.

Table 4.6: Economic analysis in the cassava and soybean intercrop as affected by cropping systems in response to phosphorus application in Kabare and Uvira sites.

Sites	Cropping systems	Phosphorus	TB	TC	NB	BCR
Kabare	Cassava-soybean	0 KG P_2O_5	1533.04	958.33	574.71	1.60
Kabare	Cassava-soybean	45.8 kg P_2O_5	2443.40	1006.33	1437.06	2.43
Kabare	Cassava-soybean	91.6 kg P_2O_5	2654.02	1054.33	1599.69	2.52
Kabare	Sole cassava	0 KG P_2O_5	1174.57	975.00	199.57	1.20
Kabare	Sole cassava	45.8 kg P_2O_5	1800.07	1023.00	785.07	1.75
Kabare	Sole cassava	91.6 kg P_2O_5	1900.90	1071.00	829.90	1.77
Kabare	Sole soybean	0 KG P_2O_5	471.19	308.33	162.85	1.34
Kabare	Sole soybean	45.8 kg P_2O_5	500.85	324.33	276.52	1.53
Kabare	Sole soybean	91.6 kg P_2O_5	454.85	340.33	114.52	1.54
Uvira	Cassava-soybean	0 KG P_2O_5	1230.86	943.33	287.53	1.30
Uvira	Cassava-soybean	45.8 kg P_2O_5	1964.36	991.33	973.03	1.89
Uvira	Cassava-soybean	91.6 kg P_2O_5	1961.28	1039.33	921.94	1.98
Uvira	Sole cassava	0 KG P_2O_5	1075.56	975.00	100.56	1.10
Uvira	Sole cassava	45.8 kg P_2O_5	1299.51	1023.00	276.51	1.27
Uvira	Sole cassava	91.6 kg P_2O_5	1432.00	1071.00	361.00	1.34
Uvira	Sole soybean	0 KG P_2O_5	312.47	308.33	4.13	1.01
Uvira	Sole soybean	45.8 kg P_2O_5	387.35	324.33	63.01	1.16
Uvira	Sole soybean	91.6 kg P_2O_5	394.85	340.33	54.52	1.19
$SED_{(treatments)}$			284.5^{***}	-	260.1^{**}	0.28*
$SED_{(sites)}$			164.5^{ns}	-	150.2^{*}	0.16^{**}

*** = $p < 0.001$, **= $p < 0.01$, * = $p < 0.05$, **ns** =Not Significant, TB= total benefits, TC= total costs, NB= net benefits and BCR= benefit-cost

The lowest total and net benefits were recorded when soybean was grown as the sole crop in both sites in long and short rain seasons (Table 4.6). This might be partly because of the higher total cost but mostly because of lower soybean grain yields. Neither total benefits nor net benefits differed between the cassava intercropping with soybean, sole cassava and sole soybean in both sites (long and short rain seasons). Maximum total and net benefits were recorded when soybean was intercropped with cassava (Table 4.6). This might be due to the fact that soybean seed was considerably less expensive and the seed rate was lower. This could also be due to the less labour requirement to harvest and thresh soybean. This corroborate the fact that sole soybean TB and NB were lower in both sites (long and short rain seasons). The benefit-cost ratios (BCR) were more favorable in both the cassava intercropping with soybean and sole cassava in both sites (LR 2015 and SR 2015). Cassava intercropping with soybean was largely profitable over the pure soybean in both sites and a bit profitable than pure. This might be due to better cassava root yields in the cassava-soybean intercropping system in both sites recorded (LR 2015 and SR 2015). 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 authors also found that the cassava-cowpea intercropping system increased economic benefits over the pure cassava.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5. 1 Conclusions

In Kabare, cassava stem diameter and height were affected by the cropping systems. The sole cassava performed better compared to intercropped cassava plant crops. Phosphorus rate of 91.6 kg P_2O_5 ha^{-1} led to better performance of cassava compared to the control. In Uvira, the same trend was observed. Soybean plants growth parameters at 50% of soybean full podding was influenced by the cropping systems and phosphorus application in long and short rain seasons in both sites. Except in Kabare (Long rain season 2015) where the intercropping systems did not affect the soybean stem diameter and plant height. The good performances of soybean plants were observed under the sole cropping systems. Also, both 45.8 and 91.6 kg P_2O_5 ha^{-1} had a positive effect on soybean performance. Intercropping negatively affected soybean due to competition for nutrients and shading from cassava due to their erect architecture. Hence, for cassava production, sole cropping and 91.6 P_2O_5 kg ha^{-1} was the best combination. Intercropping negatively affect soybean production.

Soybean nodulation was affected by the cropping systems and phosphorus rates. Phosphorus being a key element in nodule formation, 45.8 kg P_2O_5 ha^{-1} and 91.6 kg P_2O_5 ha^{-1} applied led to a higher number of effective nodules. Cropping systems, either sole cropping or intercropping, did not affect the nodulation in both sites.

Yield advantages analysis showed that cassava was dominant crop and soybean was the dominated one. Cassava had higher LER compared to soybean. This means that the beneficial effect of soybean on cassava is greater than the beneficial effect of cassava on soybean. Aggressivity index values of cassava were positive while those of soybean were negative. Hence, cassava-soybean intercropping system and phosphorus application is essential in increasing the productivity and profitability of cassava intercropping system.

5.2 Recommendations

This study has addressed some of the issues that will boost cassava and soybean production in the Kabare (Kabare) and Uvira (Uvira) locations in Eastern Republic Democratic of Congo. From the results of this work, it is recommended to apply phosphorus fertilizer in order to increase cassava and soybean productivity in both sole and intercropping. The cassava was still responding to P hence farmers can apply more than 40Kg/ha P and still get returns.

Soybean nodulation can be improved – e.g. by inoculation for ernhance yield advantage of cassava and soybean grow in intercropping systems. However prospective studies need to be carried out on the following aspects:

a) Need to determine optimum and economically optimum rates of the phosphorus to be applied in Kabare and Uvira for soybean production grown in intercropping with cassava.

b) Carry out a deep study on phosphorus solubilization in cassava-based cropping systems with soybean; a study on appropriated method (^{15}N) and/or MPN evaluating the Biological Nitrogen Fixation and/or nodulation in cassava based cropping systems with soybean and any other legumes

c) Soybean can be intercropped with cassava in the land constraints areas to maximize land profitability and protein production.

REFERENCES

Abd El-Gaid, M.A., Al-Dokeshy, M.H., Nassef and Dalia, M.T. (2014). Effects of intercropping system of tomato and common bean on growth, yield components and land equivalent ratio in New Valley governorate. Asian Journal of Crop Science 1-8.ISSN 1994-7879 / DOI: 10.3923/ajcs2014.

Abd El-Lateef, A.A. and Hafez, M.R. (2012). Intercropping effect of squash on productivity of faba bean under Sinai conditions, J. Biol. Chem. Environ. Sci., 7: 459-478.

Abdel Malik, K.K.I., Abdel Quadir, A.E.M. and El-Razaz, M.M. (1991). Studies on the effect of intercropping maize in cotton fields, Assiut J. Agric. Sci., 22(1), 337-349.

Abdll-Aziz, A. and Abdul-Latif, M. (2013). Contribution of rhizobium and phosphorus fertilization to biological nitrogen fixation and grain yield of soybean in the Tolon district. University of Science and Technology, Kumasi, MSc Thesis.

Abou-Hussein, S.D., Salman, S.R., Ab del-Mawgoud, A.M.R. and Ghoname, A.A. (2005). Productivity, quality and profit of sole or intercropped green bean (*Phaseolus vulgaris* L.) crop. Journal of Agronomy, 4: 151- 155, ISSN 1812-5379.

Addo-Quaye, A.A., Darkwa, A.A. and Ocloo, GK. (2011). Yield and productivity of component crops in a maize-soybean intercropping system as affected by time of planting and spatial arrangement. J. Agric. Biol. Sci. 6(9): 50-57.

Adu-Gyamfi, J.J., Myaka, F.A., Sakala, W.D., Odgaard, R., Vesterager, J.M., Høgh-Jensen, H. (2007). Biological nitrogen fixation and nitrogen and phosphorus budgets in farmer-managed intercrops of maize-pigeon pea in semi-arid southern and eastern Africa. Plant and soil 295: 127-136.

AfDB (2010). Agriculture sector strategy 2010 - 2014.Agriculture and Agro-industry Department and Operational Resources and Policies Department. African Development Bank Group.

Agboola A.A. and Fayemi A.A. (1977). Preliminary trials on the intercropping of maize with different tropical legumes in Western Nigeria. J. Agric. Sci. 1971; 77:219-225

Agegnehu, G., Ghizam, A., and Sinebo, W. (2006). Yield performance and land-use efficiency of barley and faba bean mixed cropping in Ethiopian highlands. Europe Journal Agronomy, 25, 202-207.

Ahmad, G., Qureshi, Z., Khan, D.S. and Iqbal, A. (2001). Study on the intercropping of soybean with maize. Sarhad J. Agric. 17(2): 235-238.

Alpha, Y.K, Robert, A., Joshua, K. and Lucky, O. (2007). Influence of phosphorus application on growth and yield of soybean genotypes in the tropical savannas of northeast Nigeria. Arch. Agron. Soil Sci., 53(5): 539-552.

Alves, A.A.C., 2002. Cassava botany and physiology. In: Hillocks, R.J., Thresh, J.M. and Bellotti, A. (Ed.). Cassava: Biology, Production and Utilization. CABI, Wallingford, UK, pp. 67-90.

Amanullah, M.M., Somasundaram, E., Vaiyapuri, K. and Sathyamoorthi, K. (2007). Intercropping in cassava-a review. Agric.Rev. 28: 179-187.

Amba, A. A., Agbo, E. B., and Garba, A. (2013). Effect of nitrogen and phosphorus fertilizers on nodulation of some selected grain legumes at Bauchi, Northern Guinea Savana of Nigeria. Int. J. Biosci, 3, 1-7.

Amba, A.A.; Agbo, E.B.; Voncir, N. and Oyawoye, M.O. (2011). Effect of phosphorus fertilizer on some soil chemical properties and nitrogen fixation of legumes at bauchi. Continental Journal of Agricultural Science, 5 (1): 39 – 44.

American University. Foreign Areas Studies Division, 1971. Area handbook for the Democratic Republic of the Congo (Congo Kinshasa). Washington, D.C.: U.S. Government Printing Office.

Bakiman Badylon Kawanda (2012). "DRC Cassava Farmers Reap Rewards from New Methods". IPS News. Retrieved 31 March 2015.

Banik, P.; Midya, B.K.; Sarkar and Ghose, S.S. (2006). Wheat and chickpea intercropping systems in an additive series experiment: advantages and weed smothering. Eur. J. Agron., 24: 325 – 332.

Baohui Song, Mary, A., Marchant and Shuang Xu (2006). "Competitive Analysis of Chinese Soybean Import Suppliers—U.S., Brazil, and Argentina" (PDF). American Agricultural Economics Association Annual Meetings. Research in Agricultural and Applied Economics, University of Minnesota. Archived from the original (PDF) on September 5, 2013.

Bationo, A., Kihara, J., Vanlauwe, B., Kimetu, J., Waswa, B. S., and Sahrawat, K. L. (2008). Integrated nutrient management: concepts and experience from

Sub-Saharan Africa. Integrated nutrient management for sustainable crop production, 467-521.

Bekere, W., and Hailemariam, A. (2012). Influences of Inoculation Methods and Phosphorus levels on Nitrogen Fixation Attributes and Yield of Soybean (Glycine max L.). At Haru, Western Ethiopia. American Journal of Plant Nutrition and Fertilization Technology, 2(2), 45-55.

Bekunda, M. A., Bationo, A. and Ssali, H. (1997). Soil fertility management in Africa: A review of selected research trials. pp. 63-79. In: R.J. Buresh et al. (Eds.) Replenishing soil fertility in Africa. SSSA Spec. Publ. 51. SSSA, Madison, WI.

Bhat, Rajeev, Alias, Abd Karim; Paliyath and Gopinadham (2012). Progress in Food Preservation. John Wiley and Sons. ISBN 978-1-119-96202-1.

Bhatti, I.H., Ahmad, R., Jabbar, A., Nazir, M.S. and Mahmood, T. (2006). Competitive behaviour of component crops in different sesame-legume intercropping systems. Int'l. J. Agric. & Biol. 8 (2): 165-167.

Bhunu, S.M. and Bolema, G.L. (2015). "Improving cassava production and supply systems" (pdf). SNV Netherlands Development Organisation.

Bidiaka Sylvain (2015). "Delivery of Vitamin A Cassava in Democratic Republic of Congo (DRC)". Biofortification: The Second Global Conference - IFPRI INFO.

Bly, A. and Woodard, H.J. (1997). Soybean growth and yield response to residual fertilizer phosphorus bands. J. Plant Nutr, 20(11): 1527- 1538.

Boddey, R.M., Reis, V.M., Alves, B.J.R. and Urquiaga, S. (2006). Biological Nitrogen Fixation in agroecosystems. Pp. 177–189 in 'Biological approaches to sustainable soil Systems', ed. by N. Uphoff et al. CRC Press: Boca Raton, FL.

Borin, K. and Frankow-Lindberg, B.E. (2005). Effects of legumes-cassava intercropping on cassava forage and biomass production. J. Sustainable Agri. 27(2): 139-151.

Brady, N.C. and Weil, R.R. (2008). The Nature and proprieties of soils.15th Edition. Soil science http:/lccn.lov.gov/2016008568

Bremmer, J.M. and Mulvamy, C.S. (1982). Nitrogen Total. In : Methods of soil analysis. Page, A.L. et al (eds) Part 2. Agronomy Monograph 9.2nd edition p595-624.ASA and SSSA, Madison, Winconsin.

Bruinsma Jelle (2003). World Agriculture: Towards 2015/2030: an FAO Perspective. Earth scan. ISBN 978-1-84407-007-7.

Buttery, B.R., Park S.J. and, Hume, D.J. (1992). Potential for increasing nitrogen fixation in grain legumes. Can J Plant Sci 72, 323-349

Caamal-Madonado, A., Torres-Barraga, A., Nez-Osornio, J.J.J., Anaya, A.L. (2001). The use of Allelopathic legume cover and mulch species for weed control in cropping systems. Agronomy Journal 93(1) : 27.36

Carlsson G., Palmborg C. and Huss-Danell K. 2006. Discrimination against 15N in three N2-fixing Trifolium species as influenced by Rhizobium strain and plant age. Acta Agriculturae Scandinavia B56, 31–38

Carsky, R.J. and Toukourou, M.A. (2005). Identification of nutrients limiting cassava yield maintenance on a sedimentary soil in southern Benin, West Africa. Nutreint Cycling in Agroecosyst. 71(2): 151-162.

Cenpukdee, U. and Fukai, S. (1992). Cassava/legume intercropping with contrasting cassava cultivars. 1. Competition between components crops under three intercropping conditions. Field Crops Research, 29: 113 – 133.

Chen, C., Westcott, M., Neill, K., Wichman, D. and Knox, M. (2004). Row Configuration and Nitrogen Application for Barley–pea intercropping in Montana. Agron J 96: 1730-1738.

Chien, S.H., Carmona, G., Menon, R.G., Hellums, D.T. (1993). Effect of phosphate rock sources on biological nitrogen fixation by soybean. Fertil. Res. 34(2): 153-159.

Chiezey, U.F. (1999). Effects of phosphorous, magnesium and zinc fertilizers on the yield and yield components of soybean (Glycine max (L) Merrill) in the northern Guinea savanna of Nigeria. Trop. Oilseeds J. 4: 1-8

Chiezey, U.F. and Odunze, A.C. (2009). Soybean response to application of poultry manure and phosphorus fertilizer in the sub-humid savanna of Nigeria. J. Ecol. Nat. Environ., 1(2): 25-31.

CIALCA (2009). Final Report Phase I- CIALCA January 2006- December 2009.

Crews T., Brockwell, J. and Peoples, M. (2005). Host–rhizobia interaction for effective inoculation: evaluation of the potential use of the ureide assay to monitor the symbiotic performance of tepary bean (Phaseolus acutifolius A. Gray). Soil Biology and Biochemistry 36, 1223–1228.

Da-Bing Xiang, Tai-Wen Yong, Wen-Yu Yang, Yan-Wan, Wan-Zhuo Gong, Liang Cui, and Ting Lei (2012). Effect of phosphorus and potassium nutrition on growth and yield of soybean in relay strip intercropping system. Scientific Research and Essays Vol. 7(3), pp. 342-351

Dahmardeh, M. (2013). Intercropping two varieties of Maize (Zea mays L) and Peanut (Arachis hypogaeaL): Biomass yield and intercropping advantage. Int. J. Agric. And Forestry, 3(1), 7-11

Dahmardeh, M., Ghanbari, A., Syahsar, B.A. and Ramrodi, M. (2010). The role of intercropping maize (Zea mays L.) and Cowpea (Vigna unguiculata L.) on yield and soil chemical properties. African Journal of Agricultural Research, 5, 631-636.

Dakora, F.D. (1996). Using indigenous knowledge to increase agricultural productivity in Africa. In: Normann H, Sny man I, Cohen M (eds) Indigenous Knowledge and its Uses in Southern Africa. Human Science Research Council (HSRC) Press, Pretoria, South Africa.

Dakora, F.D. (2003). Defining new roles for plant and rhizobial molecules in sole and mixed plant cultures involving symbiotic legumes. New Phytol 158: 39–49

Dakora, F.D. (1985). Nodulation and nitrogen fixation by groundnut in amended and un-amended field soil in Ghana: 324-329 In: Biological fixation in Africa. Ssali, H. and S. O. Keya (eds). Proceedings of the first conference of the African association for biological nitrogen fixation (AABNF) held in Nairobi, Kenya, 23 to 27 July 1984: 250 pp.

Dapaah, H.K., Asafu-Agyei, J.N., Ennin, S.A. and Yamoah, C.Y. (2003). Yield stability of cassava, maize, soybean and cowpea intercrops. J. Agric. Sci. 140: 73–82

Dariush, M., Ahad, M. and Meysam, O. (2006). Assessing the Land Equivalent Ratio (LER).of two corn (Zea mays L.) varieties intercropping at various Nitrogen Levels in KARAJ, IRAN. J. Central European Agri. 7(2): 359-364.

Davis, J. and Westfall, D. (2009). Fertilizing Corn. Colorado Extension Fact Sheet No. 0.538. http://www.ext.colostate.edu/pubs/crops/00538.html

DeMooy, C.J. and Pesek, J. (1996). Nodulation responses of soybeans to added phosphorus, potassium and calcium salts, Agron. J. 58: 275-280.

Dhima, K.V., Lithourgidis, A.A., Vasilakoglou, I.B. and Dordas, C.A. (2007). Competition indices of common vetch and cereal intercrops in two seeding ratio. Field Crop Research, 100, 249-256.

Dixon, R.O.D. and Wheeler, C. T. (1986). Nitrogen fixation in plants. Blackie. Glasgow, 82 pp.

Dommergues, Y., Duhaux, E. and Hoang, G.D. (1999). Les arbres fixateurs d'azote : Caractéristiques fondamentales et rôle dans l'aménagement des écosystèmes méditerranéens et tropicaux, (éds) Espaces, Paris: 475 pp.

Dressen, T. and Telele, T. (2017). Review on Effects of Inter and Intra Row Spacing on Yield and Yield Components of Soybean (Glycine max (L.) Merrill) in Ethiopia. Journal of Biology, Agriculture and Healthcare, ISSN 2224-3208, Vol.7, No.7.

DSRP (2005). Document de Stratégie de Réduction de la Pauvreté. Province du Sud-Kivu. République Démocratique du Congo, Ministère du Plan, Unité de Pilotage de Processus du DSRP, Kinshasa. 96 p.

Dufour, D., O'Brien, G.M. and Best Rupert (1996). Cassava flour and starch: progress in research and development. CIAT. ISBN 978-958-9439-88-3.

Edje, O.T (1987). Mixed cropping systems: Concepts and definitions. Paper presented at Root and Tuber Crops Research and Training Course, Kumasi, Ghana.

El-Edward, A.A., Edris, A.S., Abo-Shetaia, A.M. and Abd-El-Gawad, A.A. (1985). "Intercropping soybean with maize", Amm. Agric. Sci., 30(1), 237-248.

El-Gizy, S.M. (2001). Intercropping of bean with pepper or eggplant increased productivity. Egypt. J. Hort., 28: 27–40.

Ennin, S.A. and Dapaah, H.K (2008). Legumes in sustainable maize and cassava cropping systems in Ghana. Agric. Food Sci. J. Ghana 7: 519-540.

Enyi, B.A.C. (1973). Effects of intercropping maize or sorghum with cowpeas, pigeon peas or beans. Experimental Agriculture, 9: 83-90.

Eskandari (2009). Intercropping of cereals and legumes for forage production Not Sci. Biol., 1 (1) (2009), pp. 7-13

Ezulike, T.O., Udealor, A., Anebunwa, F.O. and Unamma, R.P.A. (1993). Pert damage and productivity of different varieties of yam, cassava, and maize in intercross. Agric. Sci. Technol. 3(1): 99 -102.

Facts On File, Inc., 2009. Encyclopedia of the Peoples of Africa and the Middle East. Infobase Publishing. ISBN 978-1-4381-2676-0.

Fageria, N.K., Zimmerman, F.J.P. and Batigar, V.C. (1995). Lime and priterathon on growth and nutrient uptake by upland rice, wheat, common bean and corn in an Oxisol. J. Plant Nutr. 18: 2519-2532.

Fahmina Akter, M.D., Nurul Islam, A.T.M. Shamsuddoha, M.S.I., Bhuiyan and Sonia Shilpi (2013). Effect of Phosphorus and Sulphur on Growth and Yield of Soybean (Glycine max L.). International Journal of Bio-resource and Stress Management, 4(4):555-560.

FAO (2006). Plant nutrition for food security, a guide for integrated nutrient management. FAO Fertiliser and Plant Nutrition Bulletin. No.16, 121pp. Rome, fixation through plant and soil management. Plant and Soil 174:101.KluwerAcademicPublishers. Netherlands.

FAO, 2011.FAOSTAT.Food and Agriculture Organization of the United Nations. http://faostat.fao.org/default.aspx

FAO. 2004. The state of Food and Agriculture 2003-2004: Agricultural Biotechnology—Meeting the needs of the poor? Food and Agriculture Organization of the United Nations Rome: FAO. http://www.fao.org/WAICENT/FAOINFO/ECONOMIC/ESA/en/pubs_sofa.htm

Farrow, A., Busigye, L. and Bagenze, P. (2006). Characterisation of mandate areas for the Consortium for Improved Agriculture-Based Livelihoods in Central Africa (CIALCA).Project Annual Report.

Ferguson, R.B., Shapiro, C.A., Dobermann, A.R. and Wortmann, C.S. (2006). Fertilizer recommendation for soybean. Neb Guide G859, University of Nebraska, Lincoln. http://extension.unit.edu/publications

Fermont, A.M. (2009). Cassava and soil fertility in intensifying smallholder farming systems in intensifying smallholder farming systems of East Africa. PhD thesis, Wageningen University, Wageningen, NL.ISBN 978-90-8585-399-2.

Fisher, N.M. (1977). Studies in mixed cropping, seasonal difference in relative productivity of crop mixtures and pure stands in the Kenya highlands. Experimental Agriculture, 31: 187-191.

Flores-Sanchez, D., Pastor, A., Janssen, B.H., Lantinga, E.A., Rossing, W.A.H. and Kropff, M.J. (2013). Exploring Maize-Legume intercropping systems in South West Mexico Agroecology and Sustainable Food Systems.

Food and Agricultural Organization of the United Nations, Statistics Division (FAOSTAT). 2015. Retrieved 23 May2016.

Fox RH and Kang BT (1977). Some major fertility problems of tropical soils. In "Exploiting the legume rhizobium symbiosis" Vincent, JM, Whitney AS, Bose J (eds) Tropical Agriculture. College of Tropical Agriculture Misc. Pub.p. 145. Hawaii.

Fujita, K., Ofosu, K.G. and Ogata, S. (1992). Biological nitrogen fixation in mixed legume-cereal cropping system. Plant and Soil 144: 155-175.

Fukai, S. and Trenbath, B.R. (1993). Processes determining intercrop productivity and yields of component crops. Field Crops Research, 34: 247- 271.

Fussell, L.K. and Serafini, P.G. (1985). Crop association in the semi-arid tropics of West Africa: research strategies, past and future. In Abdul- Rahaman, I. (2006).Time of planting soybean as an intercrop and its effects on the yield of maize. BSc. Dissertation, Faculty of Agric, UDS, Tamale, Ghana. Pp 1-30.

Fustec, J., Lesuffleur, F., Mahieu, S. and Cliquet, J.B. (2010). Nitrogen rhizodeposition of legumes. A review. Agron Sustain Dev 30:57-66.

Gahoonia, T.S. and Nielsen, N.E. (2004). Barley genotypes with long root hairs sustain high grain yields in low-P field. Plant Soil 262: 55-62.

Gahoonia, T.S., Claasen, N. and Jungk, A. (1992). Mobilization of phosphate in different soils by ryegrass supplied with ammonia and nitrate. Plant Soil 143: 241-248. .

Gee, W.G., and Or, D. (2002). Particle-Size Analysis. p. 255–293. In: Dane, J., and G.C. Topp (eds.). Methods of Soil Analysis. Book Series: 5. Part 4. Soil Science Society of America. USA.

Ghosh, P.K. (2004). Growth, yield, competition and economics of groundnut/cereal fodder intercropping systems in the semi-arid tropics of India. Field Crops Research, 88, 227-237.

Ghosh, P.K., Manna, M.C., Bandyopadhyay, K.K., Ajay, Tripathi, A.K., Wanjari, R.H., Hati, K.M., Misra, A.K., Acharya, C.L. and Subba Rao, A. (2006). Interspecific interaction and nutrient use in soybean/sorghum intercropping system. Agron. J. 98: 1097-1108.

Giller, K.E. and Merckx, R. (2003). Exploring the boundaries of N_2 fixation in cereals and grasses: a hypothetical framework. Symbiosis 35, 3–17.

Giller, K.E. and Wilson, K.J. (1991). Nitrogen Fixation in Tropical Cropping Systems. CAB International, Wallingford, U.K. 313 p.

Giller, K.E. (2001). Nitrogen Fixation in tropical Cropping Systems 2nd ed. CAB International. Willing ford. Oxen, UK.2001; 323

Gomaa, M.A. and Radwan (1991). "The effect of intercropping cotton plant with soybean on yield and yield components of soybean plant", Annals of Agric. Sci., Moshtohor, 29 (2), 745-756.

Goswami, S.R., Soni, S.N and Kurmvanshi, S.M. (1999). Economic feasibility for soybean intercropping system with jowar and arhar under rainfed condition. Adv. Plant Sci.12 (2):461-463

Gunes, A., Inal, A., Alpaslan, M., Eraslan, F., Bagci, E.G. and Cicek, N. (2007). Salicylic acid induced changes on some physiological parameters symptomatic for oxidative stress and mineral nutrition in maize (Zea mays L.) grown under salinity. J. Plant Physiol., 164: 728-736.

Haruna, I.M. and Aliyu, L. (2011).Yield and economic returns of sesame (Sesam umindicum L.) as influenced by poultry manure, nitrogen and phosphorus at Samaru, Nigeria. Elixir Agric, 39, 4884-4887.

Hauggaard-Nielsen, H. and Jensen, E. (2005). Facilitative Root Interactions in Intercrops. Plant and Soil 274: 237-250.

Hauggaard-Nielsen, H., Ambus, P. and Jensen, E.S. (2001). Interspecific competition, N use and interference with weeds in pea–barley intercropping. Field Crops Res. 70:101–109

Hernández, A., Ramos, R. and Sánchez, J. (1999). Spacing and timing of intercropping cassava and beans: land equivalency ratio. Agronomica Meso americana 10(11): 63-66.

Hinsinger, P. (2001). Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: A review. Plant Soil 237: 173-137.

Howeler, R.H. (1991). Long-term effect of cassava cultivation on soil productivity. Field Crop. Res. 26, 1–18.

Howeler, R.H (2002). Cassava mineral nutrition and fertilization. In: Hillocks, R.J., Thresh, J.M., Bellotti, A.C. (Eds.), Cassava, Biology, Production and Utilization. CABI, Wallingford.

Israel, D.W. (1993). Symbiotic dinitrogen fixation and host- plant growth during development of and recovery from phosphorus deficiency. Physiol. Plant. 88, 294-300

Jama, B., Palm, C.A., Buresh, R.J., Niang, A., Gachengo, C., Nziguheba, G. and Amadalo, B. (2000). Tithonia diversifolia as a green manure for soil fertility improvement in Western Kenya: A review. Agrofor. Syst. 49:201–221. doi:10.1023/A:1006339025728

Jensen, E.S. (1996). Barley uptake of N deposited in the rhizosphere of associated field pea. Soil Biol Biochem 28: 159–168.

Kahiluoto, H., Ketoja, E. and Vestberg, M. (2000). Promotion of utilization of arbuscular mycorrhiza through reduced P fertilization. 1. Bioassays in a growth chamber. Plant Soil 227: 191–206.

Kakar, K.M., Tariq, M., Taj, F.H. and Nawab, K. (2002). Phosphorous use efficiency of soybean as affected by phosphorous application and inoculation. Pak. J. Agron. 1(1):49-50.

Kamara, A.Y., Abaidoo, R., Kwari, J.D. and Omoigui, L. (2007). Influence of P application on growth and yield of soybean genotypes in the tropical Savannas of northeast Nigeria. Archives of Agronomy and Soil Science.2007; 53: 1-14.

Kazi, B.R., Oad, F.C, Jamro, G.H, Jamali, L.A and Kumar, L. (2002). Yield of soybean as affected by water stress and phosphorus levels. Pakistan-Journal-of-Applied-Sciences. 2002, 2: 5, 560-562

Khieu Borin, B., Frankow-Lindberg, B.E. (2005). Effects of Legumes-Cassava Intercropping on Cassava Forage and Biomass Production, Journal of Sustainable Agriculture, 27:2, 139-151, DOI: 10.1300/J064v27n02_09

Landers, J.N. (2007). Tropical crop–livestock systems in conservation agriculture: The Brazilian experience. Integrated Crop Management Vol. 5–2007.FAO. Rome, Italy

Lebot, V. (2009). Tropical root and tuber crops: cassava, sweet potato, yams, aroids. CABI, Wallingford, UK.

Lesoing, G.W. and Francis, C.A. (1999). Strip intercropping effects on yield and yield components of corn, grain sorghum, and soybean. Agronomy Journal, 9: 809 – 813.

Li, M., Osaki, M., Rao, I.M. and Tadanu, T. (1997). Secretion of phytase from the roots of several plant species under phosphorous-deficient conditions. Plant Soil 195: 161-169.

Li, L., Sun, J., Zhang, F., Guo, T., Bao, X., Smith, F.A. and Smith, S.E. (2006). Root distribution and interactions between intercropped species. Oecologia 147(2): 280-290.

Lithourgidis, A.S., Dordas, C.A., Damalas, C.A. and Vlachostergios, D.N. (2011). Annual intercrops: an alternative pathway for sustainable agriculture. Review article. Aus. J. Crop Sci. 4: 396-410.

Lodwig, E.M., Hosie, A.H.F., Bourde`s, A., Findlay, K., Allaway, D., Karunakaran, R., Downie, J.A. and Poole, P.S. (2003). Amino-acid cycling drives nitrogen fixation in the legume–Rhizobium symbiosis. Nature 422: 722-726.

Lunnan, T. (1989). Barley-pea mixtures for whole crop forage. Effect of different cultural practices on yield and quality. Nor J Agr Sci 3:57-71.

Lunze, L. (2000). Possibilités De Gestion De La Fertilité De Sol Au Sud-Kivu Montagneux. Cahiers du CERPRU No. 14, pp. 23–26.

Mahmood, T., Ashraf, M. and Shahbaz, M. (2009). Does exogenous application of glycine betaine as a pre-sowing seed treatment improve growth and regulate some key physiological attributes in wheat plants grown under water deficit conditions? Pak. J. Bot., 41(3): 1291-1302.

Majumdar, B., Venkatesh, M.S., Lal, B., Kailash, K. and Kumar, K. (2001). Response of soybean (*Glycine max*) to phosphorus and sulphar in acid alfisol of Meghalaya. Indian –Journal- of agronomy.46:3,500-505.

Mallarino, A.P. and Rueben, D. (2005). Phosphorous and potassium fertilization and placement methods for corn-soybean rotations managed with No-Till and Chisel plough tillage. Iowa State University, Northern Research and Demonstration Farm ISRF 04-22.

Mandimba, G.R. and Mondibaye, R. (1996). Effects of inoculation and N-fertilization on soybean grown in Congo soil. Biological Agriculture and Horticulture, 13: 197 – 204.

Mann, J.D. and Jaworski, E.G. (1970). Comparison of stresses which may limit soybean yields. Crop Science, 10: 620-624.

Matusso, J.M.M., Mugwe, J.N. and Mucheru-Muna, M. (2014). Potential role of cereal legume intercropping systems in integrated soil fertility management in smallholder farming systems of sub-Saharan Africa. Res. J. Agric. Environ. Manage. 3(3): 162-174.

Maurya, B.M. and Rathi, K.S. (2000). Growth and development of soybean as influenced by intercropping with pigeon pea and phosphorus level. Gujarat Agricultural University. Research Journal 26(1), 1-5

Mbah, E.U. and Ogidi, E. (2012). Effect of soybean plant populations on yield and productivity of cassava and soybean grown in a cassava-based intercropping system. Tropical and Subtropical Agro ecosyst. 15(2): 241-248.

Mbwika, J.M. Lukombo, Singi, Mvuangi, Khonde (2015). "Cassava Sub-Sector Analysis – Draft Field Survey Report" (pdf). Disaster risk reduction: East and Central Africa. Retrieved 31 March 2015.

Mclean, E.O. (1982). Soil pH and lime requirements. In : Page, A.L. et al (eds) Part 2. Agronomy Monograph 9.2nd edition p595-624.ASA and SSSA, Madison, Winconsin.

Mead, R. and Willey, R.W. (1980). The concept of LER and advantage in yields from intercropping. Experimental Agric., 16, 217–228.

Mekuria, T., Neuhoff, D. and Kopke, U. (2004). The Status of Coffee Production and The Potential For Organic Conversion In Ethiopia. Conference on International Agricultural Research for Development.

Mekuria, M. and Waddington, S.R. (2002). Initiative to encourage farmer adoption of soil fertility technologies for maize based cropping systems in South Africa. In: Bournelt, C.B., F. Place and Aboud, AA. (eds) Natural Resource Management in African Agriculture: Understanding and improving current Practices. CABI, in Association with the International Centre for Research in Agroforestry (ICRAF), Wallingford, UK.

Midmore, D.J. (1993). Agronomic modification of resource use and intercrop productivity. Field Crops Res 34:357-380.

Mohammed, S.A.A. (2012). Assessing the Land Equivalent Ratio (LER) of Two Leguminous Pastures (Clitoria and Siratro) Intercropping at Various

Cultural Practices and Fencing at ZALINGEI–Western Darfur State-Sudan. ARPN J. Sci. Technol. 2(11): 1074-1080.

Morales-Rosales, E.J. and Franco-Mora, O. (2009). Biomass, yield and land equivalent ratio of Helianthus annus L. in sole crop and intercropped with Phaseolus vulgaris L. in high valleys of Mexico. Trop. Subtrop. Agro ecosyst. 10(3): 431-439.

Mpangane, P.N.Z, Ayisi, K.K., Mishiyi, M.G., and Whitbread, A. (2004). Grain yield of maize, grown in sole and binary cultures with cowpea and lablab in the Limpopo Province of South Africa. Tropical Legumes for Sustainable Farming Systems in Southern Africa and Australia. In: Whitbread, A.M., and B.C. Pengelly (eds.), ACIAR Proceedings No.115: 106-114.

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

Mugendi, D., Mucheru-Muna, M., Pypers, P., Mugwe, J., Kung'u, J., Vanlauwe, B., and Roel, M. (2010). Maize Productivity as Influenced by Organic Inputs and Mineral Fertilizer in a Nitisol Soil in Meru South District.19th World Congress of Soil Science, Soil Solutions for a Changing World.1 – 6 August 2010, Brisbane, Australia.

Mugwe, J., Mugendi, D., Mucheru-Muna, M., Merckx, R.,Chianu, J. and Vanlauwe, B. (2009). Determinants of the decision to adopt integrated soil fertility management practices by smallholder farmers in the central highlands of Kenya. Expl Agric. 45:61–75. Cambridge University Press doi: 10.1017/S0014479708007072. Printed in the United Kingdom.

Muoneke, C.O., Ogwuche, M.A.O. and Kalu, B.A. (2007). Effect of maize planting density on the performance of maize/soybean intercropping system in a guinea savannah agro-ecosystem. Afr. J. Agric. Res. 2(12):667- 677.

Ndakidemi, P.A. and Dakora, F.D. (2007). Yield components of nodulated cowpea (Vigna unguiculata) and maize (Zea mays) plants grown with exogenous phosphorus in different cropping systems. Animal Production Science, 47(5), 583-589.

Nelson, D.W. and Summers, L.S. (1982). Total carbon, organic carbon and organic matter. In : Page, A.L. et al (eds) Part 2. Agronomy Monograph 9.2nd edition p539-579.ASA and SSSA, Madison, Wisconsin.

Nweke, F., Spencer, D. and Lynam, J. (2002). The Cassava transformation: Africa's Best-Kept Secret. Mich. St. Univ. Press, East Lansing, USA. In: Carsky, R.J and Toukourou, M.A. (2005). Identification of nutrients limiting cassava yield maintenance on a sedimentary soil in southern Benin, West Africa. Nutr. Cycling in Agro ecosyst. 71: 151-162.

Nweke, F. (2015). "The Cassava Transformation in Africa". Food and agricultural Organization (FAO)

Nyambo, D.B.T., Matimate, A. L., Komba and Jana, R.K. (1980). Influence of plant combination and planting configurations on three cereal (maize, sorghum and millet) intercropped with two legumes (soybean and green gram). Proc. 2nd Symp. Intercropping in Semi-Arid Areas. Morogoro, Tanzania. August 4-7.

Nyoki, D., and Ndakidemi, P.A. (2013).Economic benefits of *Bradyrhizobium japonicum* inoculation and phosphorus supplementation in cowpea (*Vigna unguiculata* (L) Walp) grown in northern Tanzania. American Journal of Research Communication, 1(11), 173-189.

Ofori, F. and Stern, W.R. (1987). Cereal-legume intercropping systems. Advances in Agronomy 41, 41-90.

Ogoke, I.J., Carsky, R.J., Togun, A.O. &and Dashiell, K. (2003). Effect of P fertilizer application on N balance of soybean crop in the Guinea savanna of Nigeria. Agriculture ecosystem and environment, 100, 153-159

Ogoke, I.J., Togun, A.O., Carsky, R.J. and Dashiell, K.E. (2006). N2 fixation by soybean in the Nigerian moist savanna: effects of maturity class and phosphorus fertilizer. Tropicultura.

Oguzor, NS. (2007). Yield characteristics and growth of cassava–soybean intercropping. Agric. J. 2(3):348-350.

Olasantan, F.O. and Lucas, E.O. (1992). Intercropping maize with crops of differing canopy heights and similar or different maturities using different spatial arrangements. Journal Agriculture Science and Technology, 2: 13-22.

Olofintoye, T.J. (2007). Effects of phosphorous fertilizer on growth and yield of soybean (Glycine max (L) Merrill).Unpublished M.Sc. dissertation, University of Ilorin, Nigeria. 80pp.

Olsen, S.R. and Sommers, L.E. (1982). Phosphorus. In : Page, A.L. et al (eds) Part 2. Agronomy Monograph 9. 2nd edition 91.6 kg P2O53-430. ASA and SSSA, Madison, Winconsin.

Oroka, F.O. and Omoregie, A.U. (2007). Competition in rice-cowpea intercrops as affected by nitrogen fertilization and plant population. Scientia Agricola (Piracicaba, Braz), 64, 621-629.

Osman, E.B.A. and Awed, M.M.M. (2010). Response of sunflower (Helianthus annuus L.) to phosphorus and nitrogen fertilization under different plant spacing at new valley Ass. Univ. Bull. Environ. Res, 13: 14-19.

Owolade, O. F., Akande, M.O., Alabi, B. S. and Adediran, J. A. (2006). Phosphorus level affects brown blotch disease, development and yield of cowpea. World Journal of Agricultural Sciences, 2(1), 105-108.

Park, S.J., Buttery, B.R. (1988). Nodulation mutants of white bean (Phaseolus vulgaris) induced by ethyl methane sulfonate. Can J Plant Sci 68, 199-20

Patel Raj (2008). Stuffed and Starved From Farm to Fork, the Hidden Battle for the World Food System. London: Portobello Books Ltd. pp. 169–173. ISBN 1-933633-49-2.

Pauline, M.M., John, B.O.O., Jude, J.O.O., Anthony, W. and John, H. (2010). Effect of phosphorus fertilizer rates on growth and yield of three soybean (Glycine max) cultivars in Limpopo Province. Afr. J. Agric. Res., 5(19): 2653-2660.

Peoples, M.B., Herridge, D.F. and Ladha, J.K. (1995). Biological Nitrogen Fixation: An efficient source of nitrogen for sustainable agricultural production? Plant and Soil 174: 3-28.

Phiri, AT. (2009). Assessing the Potential of Improving Maize Yield using Legume Residues and Tundulu Rock Phosphate, a Master of Science Thesis Submitted to the Faculty of Environmental Sciences, University of Malawi Bunda College of Agriculture.

Polthanee, A. and Kotchasatit, A. (1999). Growth, yield and nutrient content of cassava and mungbean grown under intercropping. Pak. J. Biol. Sci. 2(3): 871-876.

Raghuwanshi, R.K.S., Umat, R., Gupta, A.K., and Gurjar, N.S. (1994). "Performance of soybean-based intercropping systems in black cotton soils under different fertility levels", Crop Res. Hisar, 8(2), 233-238.

Rahman, M.M., Amano, T. and Shiraiwa, T. (2009). Nitrogen use efficiency and recovery from N fertilizer under rice-based cropping systems. Australian J. Crop Sci. 3: 336-351.

Raji, J.A. (2007). Intercropping soybean and maize in a derived savanna ecology. Afr. J. Biotechn. 6(16): 1885-1887.

Rashid, A., H. Himayatullah, Khan, R. U. and Khan, M. (2005). Effect of intercropping on the yield and net monetary system of sorghum production. Sarhad J. Agric. 21(4):771-775.

Rayar, A.J. (2000). Sustainable agriculture in Sub-Saharan Africa: The role of Soil Productivity. 2000; 164-188.

Rehm, G.W, Lamb, J.A., Robert, P.C. , Rust, R.H . and Larson, W.E. (2001). Soybean grain yield response to phosphate application across a glacial till landscape. Proceedings-of-the-5th-International-Conferenceon-Precision Agriculture,-Bloomington,-Minnesota,-USA,-16-19-July, 2000, publ. 2001, 1-8.

Rehmet, G. and Schmitt, M. (1997). Potassium for crop production. Available (on line). www.extension.edu/distribution/DC6794.html

Rezende, P.M, Andrade, M.J.B., Resende, G.M. and Botrel, E.P. (2001). Maximization of soybean (*Glycine max* (L.)Merrill) exploration. Effects of cutting time and P fertilizer upon regrowth grain hay yield. Science Agro Technology. 2001, 25: 2, 311-320

Riaz, M.N. (2006). Soy Applications in Food. Boca Raton, FL: CRC Press. ISBN 0-8493-2981-7.

Sacks, F. M.; Lichtenstein, A., Van Horn, L., Harris, W., Kris-Etherton, P. and Winston, M. (2006). "Soy Protein, Isoflavones, and Cardiovascular Health: An American Heart Association Science Advisory for Professionals from the Nutrition Committee". Circulation. American Heart Association Nutrition Committee. 113 (7): 1034–1044. PMID 16418439

Sanchez, A., Ysunza, F., Beltran-Garcia, M.J., Esqueda, M. (2002). Biodegradation of viticulture wastes by Pleurotus: a source of microbial and human food and its potential use in animal feeding. J. Agric. Food Chem., 50 (9): 2537-2542

Sanginga, N., Lyasse, O., and Singh, B.B. (2000). Phosphorus use efficiency and nitrogen balance of cowpea breeding lines in a low P soil of the derived savanna zone in West Africa. Plant and Soil, 220(1-2), 119-128.

Sanginga, N., Dashiell, K., Okogun, J.A. and Thottappilly, G. (2002). Nitrogen fixation and N contribution in promiscuous soybeans in the Southern Guinea Savanna of Nigeria. Plant and soil 195: 257-266.

Schou, J.B., Jeffers, A.I. and Streeter, J.G. (1978). Effects of reflectors, black boards, shades applied at different stages of plant development on yield of soybean. Crop Science, 18: 29-34.

Shahid, M.Q., Saleem, M.F., Khan, H.Z. and Anjum, S.A. (2009). Performance of soybean (Glycine max L.) under different phosphorus levels and inoculation. Pak. J. Agri. Sci., 46(4): 237-241.

Shahapurkar, P. R. 1985. Intercropping studies in maize (*Zea mays* L.). *M. Sc. (Agri.) Thesis*, Unpublished. University of Agricultural Sciences. Bangalore (India).

Sikirou, R. and Wydra, K. (2004). Persistence of Xanthomonas axonopodispv .Vignicola in weeds and crop debris and identification of Sphenostylis stenocarpa as a potential new host. Eur. J. Plant Pathol. 110: 939-947.

Singh, K. and Balyan, J. S. (2000). Performance of sorghum (Sorghum bicolor) plus legume intercropping under different planting geometries and nitrogen levels. Indian J. Agron.45 (1):64-69

Singh, S.P. and Jha, D. (1984). Stability of sorghum based intercropping system under rainfed conditions. Indian J. Agron. 29(1):101-106.

Snapp, S.S. and Silim, S.N. (2002). Farmer preferences and legume intensification for low nutrient environments. Plant Soil 245:181–192.

Strange, R.N. and Gullino, M.L. (2009). The Role of Plant Pathology in Food Safety and Food Security. Springer Science & Business Media. ISBN 978-1-4020-8932-9.

Szumigalski, A. and Van Acker, R.C. (2008). Land Equivalent Ratios, light interception, and water use in annual intercrops in the presence or absence of in-crop herbicides. Agron. J. 100(4): 1145-1154.

Takim, F.O. (2012). Advantages of Maize-Cowpea intercropping over sole cropping through competition indices. Journal of Agriculture and Biodiversity Research.2012; 1(4):53-59.

Tang, Z., Bharadwaj, R., Li, B. and Yu, H. (2001). Mad2-Independent inhibition of APCCdc20 by the mitotic checkpoint protein BubR1. Dev Cell 1(2):227-37

Thayamini, H. S. and Brintha, I. (2010). Review on Maize based intercropping. Jou. of Agro., 9(3), 135-145. http://dx.doi.org/10.3923/ja.2010.135.145

Thomas, G.W. (1982). Exchangeable cations. In: Page, A.L. et al (eds) Part 2. Agronomy Monograph 9.2nd edition p159-165.ASA and SSSA, Madison, Winconsin.

Unkovich, M., Herridge, D., Peoples, M., Cadisch, G., Boddey, R.M., Giller, K.E., Alves, B.J.R. and Chalk, P. (2008). Measuring Plant-associated Nitrogen Fixation in Agricultural Systems. ACIAR (Australian Council for International Agricultural Research). Available at: http://www.aciar.gov.au/publication/MN13 , Monograph No. 136, 258 pp.

Vandamme, E. (2008). Nutrient deficiencies in soils of Walungu, South- Kivu, Democratic Republic of Congo, Memoire, Katholieke Universiteit Leuven/Belgique, inédit 119 pp.

Vriezen, J.A., De Bruijn, F.J. and Nüsslein, K. (2007). Responses of rhizobia to desiccation in relation to osmotic stress, oxygen, and temperature. Applied and environmental microbiology, 73(11), 3451-3459.

Weisany, W., Raei, Y. and Allahverdipoor, K.H. (2013). Role of some of mineral nutrients in Biological Nitrogen Fixation. Bull Env Pharmacol Life Sci, 2, 77-84.

Wiersema, J.H. and León, B. (1999). World Economic Plants: a Standard Reference. CRC Press LLC.

Willey, R.W. (1979). Intercropping-its importance and research needs. Part I. Competition and yield advantages. Field Crop Abstracts 32, 1-10

Willey, R.W. and Rao, M.R. (1980). A competitive ratio for quantifying competition between intercrops. Experimental Agriculture, 16, 117-125.

Willey, R.W. (1979). Intercropping: Its importance and research needs. Part1. Competition and yield advantage. Field Crop Abstracts, 32: 1-10.

Willey, R.W., Matarajan, M., Reddy, M.S., Rao, M.R., Nambiar, P.T.C., Kammainan, J. and Bhatanagar, V.S. (1980). Intercropping studies with annual crops. In J.C. Homeless (Ed) "Better crops for food" (Pp83-97).Ciba foundation symp.

World Bank (1996). Natural Resource Degradation in Sub-Sahara Africa. Restoration of soil fertility. Africa Region. World Bank, Washington D.C. USA.

Yan, F., Schubert, S. and Mengel, K. (1996). Soil pH changes during legume growth and application of plant material. In Proceedings of the twenty-seventh annual conference of the Agronomy Society of New Zealand 23: 236–242.

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

Zhang, P., Jaynes, J., Dotyjus, I., Gruissen, W. and Pounti-Kaerlas, J. (2003). Transfer and expression of an artificial storage protein (ASPI) gene in cassava (Manihot esculenta Crantz). Transgenic Res. 12:243-250.

Zinsou, V., Wydra, K., Ahohuendo, B. and Hau, B. (2005). Genotype-environment interactions in symptom development and yield of cassava genotypes in reaction to cassava bacterial blight. European J. Plant Patholog. 111(3): 217-233.