EVALUATION OF NITROGEN FIXING POTENTIAL OF SOME GRAIN LEGUMES AND THEIR RESIDUAL EFFECTS ON MAIZE YIELD IN THE SEMI-DECIDUOUS FOREST ZONE OF GHANA

BY

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A Thesis submitted to the Department of Crop and Soil Sciences, Faculty of Agriculture, College of Agriculture and Natural Resources, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

In partial fulfillment of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

IN

AGRONOMY

By:

ADO MUHAMMAD

DECLARATION

I do hereby declare that this thesis titled "*Evaluation of nitrogen fixing potential of some grain legumes and their residual effects on maize yield in the semi- deciduous forest zone of Ghana*" was written by me and that it is the record of my own research work. It is neither in part nor in whole been presented for another degree elsewhere. Works of other scientists cited and all assistance received are duly acknowledged.

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ABSTRACT

Field experiments were conducted at the Plantation Crops Section of the Department of Crop and Soil Sciences, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana during the 2014 and 2015 major and minor rainy seasons to evaluate the nitrogen fixing potential of some grain legumes and their residual effects on yield of maize. In the 2014 major cropping season, five varieties each of groundnut, soybean and cowpea were planted out in a randomized complete block design and replicated four times. In the minor season of the same year, the haulms were left on their respective plots and maize variety *Abontem* was planted on each plot with a plot treated with recommended fertilizer rate (90 kg N, 60 kg P_2O_5 and 60 kg K_2O /ha). In the 2015 major season, four varieties of soybean inoculated at a rate of 10 g of inoculant per1 kg of soybean seeds and three levels of inorganic N (0, 30 and 60 kg/ha) were laid out in a randomized complete block design and replicated four times. In the following minor rainy season of the same year, the haulms were left on their respective plots. Maize variety *Abontem* was planted on all plots and a plot treated with recommended fertilizer rate. Results of the study indicated that groundnut produced the highest haulm N followed by soybean and cowpea. Among the groundnut varieties, Manipinta, Nkatiesari and Jenkaar produced the highest haulm N, while Manipinta produced the highest grain yield. Among the soybean varieties, Quashie and Songda produced the highest haulm N than other varieties, while Sonqu-panqu produced the highest grain yield. Among the cowpea varieties,

Hewale produced the highest haulm N than other varieties, while Asontem produced the highest grain yield. All haulm-incorporated plots produced higher grain yield of maize than the plot treated with recommended fertilizer rate except Asetenapa and Asontem cultivated plots. Residual N from groundnut produced higher grain yield of maize than the soybean and cowpea treatments. The Haulm produced from Quashie significantly gave the highest grain yield of maize (2482 kg/ha). In 2015, under sole inoculation, Salintuya-1 and Songda produced the highest haulm N. Quashie and Songda produced the highest haulm N at 30 kg/ha N while Quashie produced the highest haulm N at 60 kg/ha while Sonqu-panqu produced the highest grain yield under all conditions. All haulm-incorporated plots produced lower grain yield of maize compared to the recommended fertilizer rate. Under sole inoculation, haulms from Quashie and Sonqu-panqu produced higher grain yield of maize. Haulms from Songda produced the highest grain yield at 30 kg/ha N and that of Salintuya-1 gave the highest maize grain yield at 60 kg/ha N. Manipinta and Jenkaar among the groundnut varieties were found to have the highest nitrogen fixing potential while Manipinta produced the highest grain yield. Quashie and Songda among the soybean varieties were observed to have the highest nitrogen fixing potential, while Sonqu-panqu produced the highest grain yield. Hewale among the cowpea varieties emerged as having the highest nitrogen fixing potential and Asontem produced the highest grain yield. Inoculation and inorganic N are beneficial to soybean production as indicated in this study, but further research is needed to ascertain the actual level of N for the different varieties of soybean. As par the economic evaluation of grain legumes production in this study, under favourable weather conditions, farmers can obtain financial benefits, ranging from earning more income from the sale of the grains to utilization of the haulms for the production of maize. These, will not only improve their standard of living, but also contribute to the country's GDP.

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DEDICATION

This work is dedicated to my late parents (may their souls rest in peace), my family and my principal supervisor Professor Joseph Sarkodie-Addo.

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LIST OF ABBREVIATIONS

ABBREVIATION	MEANING
BNF	Biological Nitrogen Fixation
CGR	Crop Growth Rate
CIMMYT	International Wheat and Maize Improvement Centre
ECEC	Effective Cation Exchange Capacity
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
HI	Harvest Index
IFDC	International Fertilizer Development Centre
ICRISAT	International Crop Research Institute for the Semi-Arid Tropics
KNUST	Kwame Nkrumah University of Science and Technology
LSD	Least Significant Difference
RCBD	Randomized Complete Block Design
SARI	Savanna Agricultural Research Institute
TND	Total Nitrogen Difference
UK	United Kingdom
UNEP	United Nations Environment Programme
USA	United States of America
USDA/NNDSRR	United States Department of Agriculture, National Nutrient Database for Standard Reference Release
WAP	Weeks After Planting

CHAPTER ONE

GENERAL INTRODUCTION

1.0 Background

Nitrogen (N) is the most important limiting nutrient in both natural and agricultural systems, despite the fact that approximately 80% of the atmosphere is nitrogen gas (N_2). Nitrogen gas is unusable by most living organisms. Macro and microorganisms can die of nitrogen deficiency, surrounded by the nitrogen they cannot use. All organisms use the ammonia (NH_3) form of nitrogen to manufacture amino acids, proteins, nucleic acids and other nitrogen-containing components necessary for life (Lindermann and Glover, 2003; Mikkelsen and Hartz, 2008). Currently, most of the usable nitrogen is supplied through a chemical process (e.g. the Haber-Bosch process which converts atmospheric nitrogen into ammonia using very high quantities of energy) or through mining mineral deposits (Anonymous, 2013).

Irrespective of whether these fertilizers are produced chemically or by mining, the energy and environmental costs of their production and use are exorbitant (Anonymous, 2013). Over application of inorganic nitrogen can result in negative effects such as leaching, pollution of waters and atmosphere with nitrous oxide and other oxides of nitrogen, and ammonia. It can also lead to destruction of microorganisms and beneficial insects, crop susceptibility to disease attack, acidification or alkalization of the soil or reduction in soil fertility, thus causing irreparable damage to the agricultural system (Byrnes, 1990). Over supply of N also leads to softening of plant tissues resulting in plants that are more sensitive to diseases and pests (Chen, 2006). Chemically, applied nitrogen when used in excess reduce the colonization of plant roots with mycorrihizae and inhibit symbiotic N fixation by rhizobia. It also enhances the decomposition of soil organic matter, which leads to degradation of soil structure (Chen, 2006).

An alternative, cheaper and safer way to add nitrogen to the soil, which has been used since the beginning of agriculture and still the basis of some cropping systems, is biological nitrogen fixation (Anonymous, 2013). Plants especially legumes and bacteria form a symbiosis in which nitrogen from the atmosphere is fixed into the plant tissues. The nitrogen is also used by bacteria for its growth and development and later released to the soil. Plants also benefit from N fixed by the bacteria when the bacteria die and release nitrogen to the environment or when bacteria live in close association with the plant. (Anonymous, 2013).

Some legumes have better potential of fixing nitrogen than others. Common beans have poor fixing potential (less than 57 kg per hectare) and fix less than their nitrogen needs. Other grain legumes, such as peanut, cowpea, soybean and faba bean have very good nitrogen fixing potentials and can obtain all of their nitrogen needs through nitrogen fixation, other than that absorbed from the soil. These legumes may fix up to 280 kg of nitrogen per hectare and often not usually fertilized. In fact, they usually do not respond to nitrogen fertilizer as long as they are capable of fixing nitrogen (Peoples *et al.*, 1989).

Research has shown that the amount of nitrogen returned to the soil during or after a legume crop, helps to improve the fertility of the soil, by improving the soil conditions or by adding more nitrogen. Nitrogen rhizodeposition of grain legumes may represent a significant pool in crop rotations. The percentage of N rhizodeposition according to Mayer (2003) relative to total plant N constituted between 12% and 16%, relative to residual N 35% – 44% and about 80% of below ground plant N. Based on field data, N rhizodeposition contributes between 6 and 68 kg N ha^{-1} and results in more positive N balances for grain legumes.

Rhizodeposition could be a key to understanding the positive crop rotation effects.

Incorporation of legume residues into the soil was reported to have significant contributions to succeeding cereal crops. Researchers including Okito *et al*. (2004), Tanimu *et al*. (2007), Hayat *et al.* (2008), Bonsu and Asibuo (2013) have reported significant contributions of legume residues to succeeding cereal crop yields.

Many researchers have attempted to quantify the contributions of the legume residues to succeeding cereal yields: ranging from the incorporation of the sole residues to supplementing the residues with mineral fertilizers. However, comparison has not been made between recommended fertilizer rate application and the sole residues to ascertain their actual contributions.

1.2 Problem statement

The continued depletion of soil nutrients and the potential environmental pollution of the application of inorganic sources of fertilizers in Africa necessitates harnessing more appropriate, safer and alternative solutions for sustainable crop production. The use of legume plants in cropping systems to improve the plant nutrition system and reduce the impact of environmental pollution will enhance the production of better crop yield and sustained soil fertility.

1.3 Justification of the study

Ecological considerations require an understanding of the relative contribution of N_2-fixing components of the N-cycle. Understanding the amount of N_2 fixed by legumes as influenced by soil management or cultural practices allows development of efficient agricultural and agro-forestry production systems. Legume crops are important because of their ability to fix atmospheric nitrogen through symbiosis with *rhizobia*. Increasing population in third world countries like Ghana calls for increased food crop production. Farmers in this part of the world are normally poor and cannot afford the purchase of chemical fertilizers, hence an alternative must be provided for them. In addition, most farmers are not good managers of crop residues, which can supplement all the nutrient needs of crops to enhance crop production.

1.4 Objectives of the study

The main objective of the study was to determine the nitrogen fixing potential of some selected grain legumes and their residual effects on maize yield.

1.3.1 Specific objectives

(I) Determine the nitrogen fixing potentials of some groundnut, soybean and cowpea varieties in Ghana.

(II) Assess the contribution of the residue N of groundnut, soybean and cowpea to maize grain yield.

(III) Evaluate the effect of inorganic N with inoculation on growth, grain yield and N fixation of soybean.

(IV) Compare the contribution of residue N and recommended fertilizer rate application to maize growth and yield.

(V) Determine the financial benefit of legume production and subsequent use of haulm and recommended fertilizer rate application on maize yield.

CHAPTER TWO

LITERATURE REVIEW

2.1 Plant nutrients

The plant environment (aerial and soil) must provide the optimum conditions for normal growth and development of the plant (Panda, 2010). One of these conditions is the plant nutrients, which are crucial for the attainment of maximum yield (IRRICIMMYT, 2009). Nutrients are varied depending on their importance and quantity required by the plants. Carbon (C), hydrogen (H), and oxygen (O) are found in air and water; hence, little manipulation can be done in terms of their supply. Nitrogen

(N), potassium (K), magnesium (Mg), calcium (Ca), phosphorous (P), and sulphur (S) are found in the soil. They are used in relatively large amounts by the plant and are called macronutrients (Hodges, 2002; Anonymous, 2015). There are other elements found in the soil that are used in much smaller amounts, these are called micronutrients, or trace elements: iron (Fe), zinc (Zn), molybdenum (Mo), manganese (Mn), boron (B), copper (Cu), cobalt (Co), and chlorine (Cl) (Hodges, 2002). The low requirement of the trace elements can be attributed to the fact they participate mainly as constituents of hormones and enzymatic reactions (Hodges, 2002; Panda, 2010).

The macronutrients are further subdivided into primary and secondary. Nitrogen, phosphorus and potassium are considered primary macronutrients; these are needed in large quantities by plants for their survival, but are usually lacking in the soil because of environment and soil type (Panda, 2010). The soil usually has enough quantities of the secondary macronutrients (calcium, magnesium and sulphur) so fertilization is not always needed (Anonymous, 2015). The challenge lies greatly in the supply of the primary macronutrients. These can be obtained from different sources: they can be obtained organically (through farmyard manure, compost, crop residues etc.), inorganically through some chemical processes (such as the Haber Bosch processes that converts atmospheric nitrogen into chemical nitrogen using very high quantities of energy) which is highly expensive in terms of their environmental and energy costs (Anonymous, 2013). In this case, they may be inadequate to the plants or incompatible with the environment. There must be some cheaper, compactible and sufficient means of supplying these nutrients to augment the unavailability in the soil.

The optimum supply of these nutrients is critical not only to the plant, but to the well-being of the soil environment and subsequently to the ecosystem. For example, excess supply of these nutrients is detrimental, causing undesirable environmental impact such as pollution of soil and underground water in addition to poor quality growth and development of the plants (UNEP, 2014). Nitrogen, phosphorus and potassium are among the most limiting nutrients for plant growth as they play different but crucial roles in the plant physiological processes and nitrogen being the most limiting nutrient to the plant physiological processes (Mmbaga *et al*, 2014). Nitrogen is limiting because it is nearly absent in new soils (Vitousek and Howarth, 1991). The physiological basis for nitrogen limitation compared to phosphorus stems from the fact that there is substantial mobility of the element across ecosystem boundaries even when obtained from atmospheric sources

(Vitousek and Howarth, 1991; Raich *et al*., 1996). Nitrogen is also more readily lost through leaching, volatilization and denitrification to the atmosphere (Evans and Seeman, 1989).

2.2 Nitrogen.

The most important of the primary macronutrients is nitrogen, because it is required by plants in the largest quantity (IRRI-CIMMYT, 2009). It is also the nutrient responsible for controlling growth in plants. Nitrogen is a vital plant nutrient because it is a major part of nucleic acids and chlorophyll and all amino acids, which are the building blocks of all proteins, including enzymes, which control virtually all biological processes (Thomas and Vincent, 2012). However, it is the most commonly deficient in many soils and costly to produce, leading to low agricultural yields (Gutschick, 1981; Montanez, 2000; Anonymous, 2013). Deficiency leads to low protein levels, chlorosis, a stunted appearance of plants that develop thin, spindly stems, susceptibility to greater disease attack, abnormality in the growth and development of the plant and poor yields (Brady and Weil, 1999). It is then of paramount importance to consider the right amount, at the right time and a safer source so that the maximum benefits of the nutrient are harnessed (Mikkelsen and Harts, 2008). Widespread occurrence of nitrogen limitation is a major concern in the terrestrial and marine ecosystem. In the long run the modern intensive agricultural system will be nitrogen limiting. Hence, there is a good relationship between the nitrogen availability and photosynthesis in the terrestrial ecosystem (Field and Mooney, 1986).

The greatest source of nitrogen in the present day crop production systems are the inorganic fertilizers and the most important element in inorganic fertilizers is nitrogen because it contributes more than 70% of the increment in crop yields (Danso and Eskew, 1984). Unfortunately only 30 to 50% of the inorganic nitrogen applied is used by the crops, the rest is lost to the environment by volatilization to the atmosphere or leached into to the ground where they serve as pollutants in the soil and underground water (Danso and Eskew, 1984). Sustainability of nitrogen supply concerns not only its availability to the plants, but the protection of the ecosystem from pollution. Since the most important present day source is through addition of chemical fertilizers to the soil which is always not safe to the environment and costly to use. Thus, other sources must be harnessed for a sustainable agriculture. Nitrogen can be easily supplied to the crop through biological N_2 fixation, a symbiotic process between legumes and bacteria which is very important in nature as it uses less energy and therefore safer to the environment. This association between legumes and bacteria could therefore be an important component of sustainable agriculture (Montanez, 2000).

2.3 Biological nitrogen fixation

Some organisms have the ability to convert atmospheric nitrogen to ammonium, a process referred to as N_2 fixation. This is a special ability of some organisms (bacteria, actinomycetes, and cyanobacteria) to form special, mutual and beneficial relationships with plants (O'Hara, 1998). Symbiotic relationship between bacteria and plants has been known for a long time. Current study indicates that no plant fixes its own nitrogen, but in symbiotic association with certain bacteria called *rhizobia* (Cheng, 2008). Legumes are capable of forming symbiotic association with bacteria found in their nodules, a notable aspect of legumes. The most important and abundant symbiotic association between bacteria and plants is the association of *Rhizobia* with legumes (Danso and Eskew, 1984).

Biological N_2 fixation is considered very important in nature, because it is the safest means of supplying nitrogen to the plants through symbiotic association with bacteria (Loynachan, 2005). Legume seed coat contains different types of flavonoids in large quantities. These flavonoids act as chemo-attractant for the corresponding root nodule forming bacteria and induce *rhizobium* node gene (Mylona *et al*., 1995). As the roots of legumes grow, nodules are formed in two stages: infection and organogenesis (Hopkins and Hüner, 2004, Taiz *et al.*, 2015). *Rhizobia* bacteria infect the root hairs where they begin to multiply. As a response to this colonization, the legume forms nodules, which are structures that form around the *Rhizobia*.

Within these nodules, *Rhizobia* bacteria are able to continue multiplying and converting the N_2 from the soil air to ammonium. The legume plant supplies the carbohydrate (photosynthates produced by the plant) for bacterial growth while the bacteria fix atmospheric N_2 into NH_4^+; this is converted to plant useable amino acids to be used by the plant for its growth and development (Russelle, 2008). However, the presence of nodules is not a sufficient indicator that nitrogen is being converted to ammonium (Giller, 2001). Effective nodules generally have pink to red interiors, and concentrate around the taproot. On the other hand, non-effective nodules are generally smaller with white, green or brown interiors. The nodule establishment occurs due to the sequence of multiple interactions.

Biological nitrogen fixation (BNF) coupled with photosynthesis are considered the basis of all life on earth (Cheng, 2008). Biologically fixed nitrogen (ranging between 200 to 300 kg N ha^{-1}) has been obtained in association between *rhizobium* and legumes (Mohammadi *et al*, 2012). This has represented a vast amount of renewable and promising source of nitrogen in agriculture (Werner and Newton, 2005). It contributes the highest quantity of nitrogen to the ecosystem (contributes up to 20% of the annual total of fixed nitrogen by the biological systems (Quispel, 1974).

Some legumes have better nitrogen fixing potentials than others (Lindermann and Glover, 2003). Soybeans fix more nitrogen than cowpeas, but produces higher nitrogen depletion, because of the greater proportion of nitrogen removed with the seeds (Muhammad *et al*, 2010). In another study, Eaglesham (1981) using the difference method estimated the N_2 fixed by four cowpea cultivars ranged from 49101 kg N_2-fixed ha^{-1} per cycle. With 25 kg ha^{-1} fertilizer starter nitrogen applied, there was a positive soil nitrogen balance of 2-52 kg N ha^{-1}. Herridge (1982) reported that a fully symbiotic crop will enrich the soil with nitrogen, while the partly symbiotic crop may have no effect, and the non-symbiotic crop will reduce soil N level. In the latter case, a subsequent non-legume crop may require supplemental inorganic nitrogen. Ngwu (2005) reported that Desmodium had higher nitrogen fixing potential than cowpea. Keston *et al*. (2012) reported that groundnuts and pigeon pea were similar, but were both better than soybeans in terms of nitrogen fixation. Common beans have poor fixing ability (less than 57 kg per hectare) and so fix less than their nitrogen needs. Supplementary N (35-57 kg) was needed to obtain maximum yield per hectare of beans in New Mexico (Robert and Idowu, 2015).

Intercropping of legumes together was reported to have beneficial effect on nitrogen fixation when there is no shading. In a trial conducted by Keston *et al*. (2012) pigeon pea/groundnut mixed cropping gave more nitrogen compared to the sole crops planted separately, but pigeon pea/soybean interaction lowered the amount of nitrogen obtained compared to the sole crops planted separately. The bacteria forming symbiotic association with legumes in biological nitrogen fixation can be found living naturally in the soil or they have to be introduced artificially.

When introduced artificially this is referred to as inoculation (Silva and Uchida, 2000).

2.3.1 Factors affecting biological nitrogen fixation

Several factors may influence the amount of N_2 fixed. These factors can be grouped into edaphic, climatic and biotic factors (Montanez, 2000; Liu *et al*., 2011). These factors may affect the microsymbiont, the host plant or both. Whatever the case, biological nitrogen fixation can be seriously impaired leading to reduction in yield. Generally, for vigorous and the proper functioning of the host plant there is need for all of the factors mentioned in the right form and time (Weisany *et al*., 2013). Six main edaphic factors limiting biological nitrogen fixation are excessive soil moisture, drought, soil acidity, P deficiency, excess mineral N, and deficiency of Ca, Mo, Co and B. Drought conditions can reduce nitrogenase activity leading to decreased nodule weight. Exposing plants to moisture stress for ten days showed the nodule cell wall degraded resulting in senescence (Ramos *et al*., 2003).

Phosphorus level control the growth and nitrogenase activity directly or indirectly (Liu *et al*., 2011). P deficiency reduces nitrogen fixation by reducing nodule mass. There is high demand for P in BNF because it requires a lot of energy in the form of ATP (Ali *et al*., 2010). Enhanced grain yield of legumes due to phosphorus application has been reported (Ahiabor *et al.,* 2014). The presence of excess amount of nitrogen makes the bacteria 'lazy' or the nitrogen fixing process switched off (Reed *et al*., 2011), but its low requirement as a starter dose in oil seeded legumes and high-yielding varieties has been reported to boost growth and yield (Osborne and Riedell, 2011; Achakzai, 2012). Khan *et al*. (2014) reported that application of Mo and Fe improves growth, yield and biological nitrogen fixation of chickpea.

For optimum nitrogen fixation to take place there must be availability of all nutrients except nitrogen. Thus, the availability of sufficient nitrogen in the soil can drastically reduce the amount of N_2 fixed. It has been observed that when a plant has a choice between applied nitrogen in the soil and symbiotic nitrogen fixation, it tends to choose the former. This is why in the presence of high nitrogen in the soil, legume nitrogen fixation is inhibited (Singh and Usha, 2003). Similar situation arises when a legume is intercropped with cereal the former compete for the applied nitrogen in the soil that was supposed for utilization by the cereal. Such competition may limit the productivity of the cereal (Singh and Usha, 2003).

The two major climatic factors that greatly influences biological nitrogen fixation are temperature and light (Mulongoy, 2015). The survival of inoculant bacteria under high temperature is usually low and thus higher number of inoculant bacteria is needed at intense temperatures (Keyser and Li, 1992). Competition for light in dense canopies in intercropped system may limit the use of light and subsequent reduction in biological fixation (Montanez, 2000). The plant nitrogenase activity reduces dramatically because of formation of ineffective nodules at high temperature (Hungria and Franco, 1993).

Among biotic factors, the absence of the required rhizobia species constitute the major constraint in the N_2 fixation process. The other limiting biotic factors could be excessive defoliation of host plant, crop competition, and insects and nematodes (Keyser and Li, 1992; Mulongoy, 2015).

Severe environmental conditions such as salinity, unfavourable soil pH, nutrient deficiency, mineral toxicity, extreme temperature conditions, low or extremely high levels of soil moisture, inadequate photosynthates and disease conditions can affect plant growth and development. As a result, the persistent *rhizobium* strains will not be able to perform root infection and N_2 fixation in their full capacity (Zahran, 1999; Montanez, 2000). Under saline conditions, the accumulation of Na^+ reduces the plant growth, nodule formation and symbiotic N_2 fixation capacity (Sousssi *et al*., 1998; Kouas *et al*., 2010). Extreme soil pH can reduce the rhizobial colonization in the legume rhizosphere. N_2 fixation has been reported to be inhibited by low soil pH (Van Jaarsveld *et al*., 2002). The characteristics of highly acidic soils ($pH < 4$) are low level of phosphorous, calcium and molybdenum along with aluminum and manganese toxicity, which affect both plant and rhizobia. Low soil pH conditions, severely affect nodulation and N_2 fixation more than plant growth. Highly alkaline (pH > 8) soils tend to be high in sodium (Na^+), chloride (Cl^-), bicarbonate (HCO_3) and borate (BO_3^-) which reduces N_2 fixation (Bordeleau and Prevost, 1994). Deficiency of some nutrients has been reported to decrease N_2 fixation especially sulphur (Islam *et al.,* 2012). Symbiotic N_2 fixation varies according to the carbon allocation to the nodules in relation to endogenous factors, current photosynthesis, crop growth rate and other competing sinks for carbon (Voisin *et al*., 2003).

2.4 Measurement of N_2 fixation

Biological nitrogen fixation (BNF) has gained a lot of attention as a major process by which nitrogen is added to the ecosystem. More efforts are increasingly geared towards improving the nitrogen fixed. However, one of the major setbacks is the method used to estimate the amount of nitrogen fixed. With that, reliable information can be obtained as to whether actual N_2 fixation is adequate and subsequently the most effective BNF can be established (Mulongoy, 2015). There has been so far no single most effective method of determining absolute amount of fixed nitrogen. Each method in use has its advantages and limitations, but a method can be used based on the level of technological advancement of an area (Peoples *et al*., 1989; Farooq and Azam, 2003). Because of wide variation on the reported data for N_2 fixed which has been due to the type of method used, a good methodology should be adopted that can differentiate the soil N from the fixed nitrogen. Some commonly used methods for estimating biological nitrogen fixed are as follows:

2.4.1 Estimation of dry matter

This is the easiest and simplest way of estimating BNF. It is based on the assumptions that legumes meet up to 90% of their N requirements through BNF and the fact that biomass yield of crops is dependent on the N content; dry matter accumulation by plants could be used as a measure to compare efficiency of N_2 fixation (Farooq and Azam, 2003). The method can be used to screen large number of rhizobial strains and different plant cultivars. The major limitation of this method is that quantitative estimates of fixed N are difficult to obtain because of inherent differences in the cultivars for exploiting the native soil N (Hardarson and Danso, 1993).

2.4.2 Nodule number and weight

Nodule number and weight has been found to be positively correlated with the amount of N_2 fixed (Hardarson and Danso, 1993). This can be used to assess the efficiency of the BNF systems of different crops. The contribution of any legume to any production systems lies in the formation of effective nodules, which supply the needed nitrogen (Peoples *et al*., 1989). Effective nodulation can be gauged by the degree of pink or red colouration of the nitrogen-fixing bacteroid tissue inside the nodules (Peoples *et al*., 1989).

2.4.3 Total nitrogen difference method (TND)

The method relies on the assumptions that similar amount of native soil N are made available to the plants irrespective of their genetic differences (whether they are leguminous or non-leguminous). The Kjeldahl N analysis which is used to analyse samples and the results given in % N, makes this method more time consuming. However, it provides more information compared to the dry matter method on the amount of N_2 fixed. The amount of N_2 fixed can thus be determined by using the expression: N_2 fixed = N uptake by legume – N uptake by reference crop (Farooq and Azam, 2003).

This means that the leguminous and non-leguminous plants will have equal access to the soil available N or that mineralized under the influence of plants. This method does not, however, account for the inherent differences in plant types in affecting the mineralization and availability of N (Peoples *et al*., 1989). The differences might be great as cereals are found to obtain higher amount of soil N as compared to legumes. In addition, no consideration is given to the rooting characteristics and hence the soil volume/depth being explored by for N acquisition. However, such assumptions are difficult because it is a well-known fact N uptake by plants is significantly affected by different plant types. The real advantage of this method is that fertilizer application is not required (Hardarson and Danso, 1993).

2.4.4 Acetylene reduction assay

It is cheap, rapid, sensitive and accurate method of determination of N_2 fixed. It is based on the activity of the nitrogenase, an enzyme that is involved in the reduction of several compounds including N. Its ability to reduce acetylene (C_2H_2) to ethylene (C_2H_4) is used in measuring the N_2 fixed at any time (Unkovich *et al*., 2008). The enzyme activity is monitored by frequent sampling of the air stream containing small concentrations of ethylene passing over the nodules followed by measurement of acetylene (Farooq and Azam, 2003). Detached nodules from the plants are incubated with a known volume of acetylene in closed containers and the ethylene released measured (Mulongoy, 2015). The limitation is that not all nodules can be recovered from the plants, thus error may arise from those plant whose nodule were not completely recovered. (Peoples *et al*., 1989).

2.4.5 Xylem-solute technique

The xylem-solute technique is used for legumes that transport most of their fixed N in the form of ureides, allantoin and allantoic acid. Other legumes export fixed N mainly as amides, asparagine and glutamine (Hardarson and Danso, 1993). Nitrogen containing compounds originating from BNF are incorporated into via glutamine synthesis and glutamine oxoglutarate aminotransferase pathway to glutamine and glutamate. The compounds undergo Transamination to produce aspartate and other amino acids. Some of the amino acids are incorporated into purines, which are oxidatively degraded to yield ureides. These compounds are chemically different from those obtained from soil N and are transported to the aerial parts in the xylem sap. Samples of the sap obtained can be analyzed to give an insight as how much the plant depends on BNF for N (Farooq and Azam, 2003). Generally, actively functioning BNF system export amide or ureides from the roots to the shoots, while those depending mainly on soil N have xylem sap rich in NO_3^- because of negligible NO_3^-reductase activity at the root level. Relative concentrations of the ureides and NO_3^- has been used as a rough estimate to measure N_2 fixation ability of a legume (Unkovich *et al*., 2008). The method has also been used to measure the tolerance level of NO_3^- of the BNF system, which is important when legumes are grown with cereals and some chemical fertilizers are applied. The major limitations of this method is the fact that minimum NO_3^- reductase should occur at the root level. However, such conditions are hard to meet because of genotypic differences in the level of nitrate reductase. Another limitation is that it provides short-term results. If an estimate of seasonal fixation is required, repeated measurements must be carried out with sequential sampling from the crop (Peoples *et al*., 1989)

2.4.6 ^{15}N isotopic method

Most of the methods for measuring BNF, rarely distinguish between the different sources of N; however, the isotopic method provides a more convenient way to do that. This method employs the use of the stable N isotope (^{15}N). There are two stable isotopes of N, the ^{14}N and ^{15}N. The heavy isotope, ^{15}N, occurs in the atmosphere at constant abundance of 0.3663 atoms percentage (Peoples *et al*., 1989). The ^{15}N isotope dilution method, like the difference method, requires a nonfixing control to estimate the relative contribution of soil and fertilizer N. In this method, the fixing crop and a non-fixing control are grown in soil to which ^{15}N has been added as a small amount of labeled nitrate or ammonium. The N difference and ^{15}N enrichment techniques were reported to give comparable estimates (Loges *et al*., 2000). The method provides a time-averaged estimate of the proportion of legume N derived from nitrogen fixation. The major limitations of this method are the requirement of high-level technology equipment, which may not be available especially in poor countries and the high cost of ^{15}N labelled material (Peoples *et al*., 1989).

2.5 Inoculation

Inoculation is a process of introducing the desired commercial bacteria to the roots of the desired leguminous plant to promote nitrogen fixation. This is achieved by applying the inoculum directly to the seeds prior to planting or through in-furrow application (Bogino *et al.*, 2011). Bacteria that nodulate legumes are currently classified into 6 genera (*Rhizobium, Bradyrhizobium, Mesorhizobium, Azorhizobium* and *Allorhizobium* (Loynachan, 2005). *Rhizobia* capable of nodulating soybean belong to six species of the three genera: *Bradyrhizobium, Mesorhizobium* and *Sinorhizobium* (Van Berkum and Eardly, 1998). *Rhizobium* association is the most elaborate and efficient among the known biological systems that fix atmospheric nitrogen (Moriones, 1983). Proper inoculation can supply as much as 90% of crop requirement of nitrogen (Anonymous, 1998). However, if legumes are not inoculated, yields often remain low, regardless of the amount of nitrogen applied. Nodules apparently help the plant to use nitrogen fertilizer efficiently. It is worthy to note that the rhizobia are specific to the legumes they nodulate (Loynachan, 2005).

It is advisable to inoculate fields only when there is no specific rhizobia in the soil to nodulate a legume, hence, the major objective of inoculation is to maintain a high level of rhizobia on the seeds and the soil to hasten the colonization of rhizosphere and subsequent efficient nodulation with maximum yields (Deaker *et al*, 2004). Therefore, inoculants should be recommended to a soil when there is good reason to believe that population of bacteria is low. (a) When a newly cleared land is put to production. (b) The legume to be cultivated has not been grown on the land for the past four years or more. (c) When the pH is low and (d) When the levels of the nitrogen in the soil is low (Albareda *et al*., 2009). Successful inoculation must be achieved for the bacteria to come in contact with the seed and ultimately with the roots. In most cases, the in-furrow application is recommended more compared to either the use of sticking agents onto the seeds or ordinarily mixed with the seeds, because there less stress on the bacteria in most in-furrow applications (Bogino *et al.*, 2011).

Experiment conducted by Albareda *et al*. (2009) showed that determined parameters were significantly higher when soybean was inoculated compared to the un-inoculated. In their experiment, varying the concentration of *rhizobia* strain did not have significant effect on parameters and persistence of rhizobia strains depended on the type of soil and soil conditions especially pH. Significant increase in agronomic parameters were also recorded by Diaz *et al*. (2009) when soybean were inoculated with rhizobia compared to the un-inoculated with grain quality not affected in both cases. However, they observed that early season application of nitrogen resulted in no benefit for soybean yield or quality. Inoculation of legumes improved significantly the biological nitrogen fixation (Fabián, 2012), but compatibility of the bacterial strain to the legume was also a factor to consider for higher nitrogen fixation. Soybean- *Bradyrhizobium* symbiosis can fix as much as 300 kg N ha^{-1} under optimum condition (Keyser and Li, 1992).

2.6 Inoculation and inorganic nitrogen application

There are periods in the growth of legumes when the nitrogen fixing ability is not properly developed to meet the requirement of the nitrogen. Two critical points are considered; at early stage before the development of nodules, before the formation of symbiosis and at later stage during pod filling stage when most of the nodules must have died. During these stages, the crop may suffer nitrogen deficiency except when there is sufficient nitrogen in the soil to meet the crop needs. At the two stages, N demand of the crop could be met with application of nitrogen fertilizer (Albareda *et al.,* 2009). N fertilizer application at such periods of critical needs during early stage of growth is a starter dose. Starter fertilizer is a small quantity of fertilizer applied at planting or early growth stage to enhance the development of emerging seedlings.

Eaglesham *et al*. (1982) observed that cowpea cultivars increased soil nitrogen at low, but not at high, fertilizer inputs. In Africa and India, a starter dose of 10-15 kg/ha N were recommended for groundnut production until the symbiotic nitrogen fixation activity starts. Based on those studies higher doses of nitrogen inhibits nitrogen fixation (Vara Prasad *et al*., 2009). Many researchers reported positive response of nitrogen by plants at the early stages of growth (Flannery, 1986; Starling *et al*., 1998; Wesley *et al*., 1998; Osborne and Riedell, 2011). However, reduced nodule formation was reported with rates beyond 56 kg ha^{-1} (Beard and Hoover, 1971). Inoculation of soybean with *Bradyrhizobium japonicum* coupled with different starter doses of phosphorus in an experiment by Bekere (2012) was reported to significantly increase nodule number per plant, nodule volume, nodule dry weight, shoot nitrogen content and plant height compared to the un-inoculated and inoculated with no starter doses of phosphorus. Hence, they concluded that starter doses of phosphorus coupled with inoculant improved measured parameters. Organic manure with *rhizobium* coupled with starter dose of nitrogen significantly increased growth and yield of groundnut (Sulfab *et al.*, 2011).

2.7 Legume residual nitrogen

Crop residues contain large amounts of assimilated carbon (C) and other nutrients such as nitrogen, phosphorus and potassium. Hence, there is a tendency of crop residue application to soils to trigger favourable cycling of these nutrients with sequestration of carbon (Zhang *et al*., 2008). Quality of crop residue is measured by the concentration of the nitrogen in relation to carbon, which allow faster decomposition (Schomberg *et al*., 1994). Incorporation of legume residues, which proportionately have more nitrogen and decompose faster to meet the nitrogen demand of the cereal crops, may represent a valuable input of organic nitrogen supply (Peoples and Craswell, 1992).

Management of nitrogen in cereal crops is a major way of success in sustaining productivity in nitrogen limiting soils (McDonald, 1989). Because it is required in very large quantities to produce economic yields thus, continued production means continued soil depletion. Generally, nitrogen can be supplied directly to the soils by chemical means through application of inorganic fertilizer, organic manure, or by residue management. Inorganic application is a quite bit easier, but the persistent high cost coupled with low per capita income in the African farming system seems to darken future dependence on sustainable agriculture. Organic forms such as farmyard manure seems bulky and cannot be transported over long distances (Bakht *et al*., 2009). The only readily available resources may be crop residues (Bakht *et al*., 2009). The use of legume residues is a low cost approach to improving soil fertility but the major setback may be the residue type and quality (Mwangi *et al*., 2013).

Residual nitrogen contributions to subsequent crop can be in several ways. Research has shown that the amount of nitrogen returned to the soil during or after a legume crop, helps to improve the fertility of the soil, by improving the soil conditions or by adding more nitrogen (Egbe and Ali, 2010). It is also believed that some legumes excrete some of the nitrogen fixed into the soil through rhizodeposition during the growth of the crop, but present evidence suggests that the amounts released under field conditions are small. Nitrogen rhizodeposition of grain legumes though small, may represents a significant pool in crop rotations (Mayer, 2003). The percentage of N rhizodeposition according to Mayer (2003) relative to total plant N constituted between 12% and 16%, relative to residual N of 35% – 44% and about 80% of below ground plant N. Based on field data, N rhizodeposition contributes between 6 and 68 kg N ha^{-1} and results in more positive N balances for grain legumes (Mayer, 2003). N rhizodeposition could be a key to understand the positive crop rotation effects.

Preceding crops of green gram and black gram reduced the nitrogen requirement of a succeeding wheat crop by 30-60 kg N ha^{-1} compared with a reduction of 30 kg ha^{-1} after pigeon pea or soybean (Narwal *et al*., 1983). Incorporating some legume species in to the soil even after one or two years of growth considerably reduce the amount of N fertilizer required by a cereal crop (Hayat *et al*., 2008). Results from the above studies indicated that yields of cereals following legumes increased but the increase depended on the proportion of nitrogen retained in the non-harvest residues and their rate of mineralization.

Adding residues to the soil has long been known to improve soil fertility. In an experiment by Bakht *et al.* (2009), legume residues produced higher grain and straw yields of wheat compared to direct application of inorganic nitrogen. Adeleke and Haruna (2012) observed increased total nitrogen in the top soil after cropping of legumes. Subsequent residual nitrogen after that produced significantly better yields of maize when supplemented with lower rates of nitrogen as compared to maize following maize. Other researchers including Adjei-Nsiah *et al*. (2008) observed similar trends of increased soil fertility after legumes.

Incorporation of crop residue was observed to have made significant contribution to succeeding cereal crops (Bharambe *et al*., 2002). Mbah and Nneji (2011) showed that addition of residues improves both the chemical and physical properties of the soil and resulted in higher yields of maize. The main residual effect of a legume will depend on the proportion of nitrogen retained in the non-harvested residues and their rate of mineralization. Mughogho *et al*. (1982) observed that yield of subsequent maize crops was increased by the incorporation of cowpea residues that made available to the corn crop the equivalent of 40-80 kg of fertilizer N ha^{-1}. Research conducted by Hayat *et al*. (2008), showed legume-cereal sequence improved biomass and grain yields. Sakala *et al.* (2000) showed that application of green manures increased maize grain yield when used as sole green manures or in combination with inorganic fertilizers compared to sole maize following another sole maize. Other workers including Okito *et al.* (2004), Tanimu *et al.* (2007), Bonsu and Asibuo (2013) have reported significant contributions of legume residues to succeeding cereal yields. Addition of legume residues gave comparable grain yield of maize with the recommended inorganic fertilizer recommendations (Nyalemegbe and Osakpa, 2012). Significant tuber yield increase was also reported when cassava was intercropped with soybeans at later stages of their growth (from 8 months after planting) indicating that yield increases were as a result of biologically fixed nitrogen from the soybeans compared to when sole cassava was planted (Umeh and Mbah, 2010).

2.8 Residue management

Effective residue management with efficient tillage operation is a way towards improving soil health and reducing carbon dioxide emission thus improving carbon sequestration. The retention of even small amounts of surface residues can conserve soil organic matter and nutrients, decrease water runoff and increase infiltration, decrease evaporation, and control weeds. Residue retention increased on average measured parameters (grain yield by 1.31times, straw yield by 1.39 and N uptake of 1.31 and 1.64 times in grain and straw respectively) of wheat (Bakht *et al.*, 2009). Physico-chemical properties of soil were observed to increase in a no-tillage system compared to conventional tillage (Roldán *et al*., 2003). Al-Kaisi and Yin (2005) showed that adopting less intensive tillage such as no-till and better crop residue cover increases carbon storage. In a study conducted by Olaoye (2002), reduced tillage (no-tillage and disc harrowing) was observed to improve agronomic performance of cowpea (grain yield and number of pods) compared to maximum tillage (mouldboard ploughing followed by disc harrowing, disc ploughing followed by disc harrowing and disc ploughing followed by two pass of disc harrowing).

Retaining residue in a no-till system has also been reported to show great benefits on measured parameters (Malhi *et al*., 2006). Surface application of residues in a no-till system created a more favourable soil moisture and temperature ranges compared to incorporation of the residues into the soil or burning (Al-Kaisi and Yin, 2005; Malhi *et al*., 2006). Other researchers have reported that residues retained on the surface maintains soil nutrients such as phosphorus and potassium, hence can be effective in sustaining crop productivity in the long run (Adama *et al*., 2000). Surface application of residues has been more efficient because tilling is generally not necessary to incorporate the nitrogen into the soil because of its leaching ability (Anonymous, 2015).

2.9 Decomposition and mineralization of crop residues

Decomposition is a sequence of biological, chemical and physical processes leading to the mineralization of plant constituents. In photosynthetic process light, water, carbon dioxide and nutrients are used in life forming processes, when the life comes to an end the enclosed nutrients are made available to the next life through decomposition for subsequent uptake by the plants, in yet another cycle of life forming process (Frank, 2010). The dominant pathway for nutrient return to the soil begins with senescence of plant tissue leading to decay which begins through autolysis and subsequently by the activity of saprophytic organisms and terminates with the production of carbon dioxide, water and simple mineral salts. Nutrients especially nitrogen (N) and phosphorus (P) are again made available to growing plants (Rosenani *et al*., 2003). Since they are the most limiting nutrients in crop production, decomposition of residues is seen as one of the most prominent means of adding these nutrients to the soil. Hence, decomposition is one of the basic processes in the recycling of nutrients in nature. Crop residue decomposition is carried out by a community of microorganisms such as bacteria and fungi in the soil (Majumder *et al*., 2008). The residues are decomposed to release the nutrients in them into the soil in a process of mineralization. The mineralized nutrients may be converted to organic nutrients, in which case the nutrients are immobilized. The two processes of mineralization and immobilization occur simultaneously in soil. The overall strength of the two processes determines whether there is net mineralization or net immobilization (Cabrera *et al.*, 2005).

The rate at which plant residue decompose and mineralize depends on many factors: chemical and physical characteristics of the residue, soil water, soil temperature, soil nutrient status, soil microbial biomass, soil aeration and drying and rewetting events (Cabrera *et al.*, 2005). Maximum decomposition occurs in soils which are near wet to field capacity of about 55% water filled pore space, excess moisture decrease the activities of the microorganisms because of decrease in the availability of oxygen. At about 40% water, filled pore space decomposition tend to slow, while dry soils do not support any activity of the microorganisms. Decomposition proceeds slowly at low temperatures, while at higher temperature it may eventually stop. Essentially no decomposition occur at freezing point and temperatures above 41 ^{o}C. The composition of organic residues strongly affects it decomposability, residues that are low in nitrogen but high in fibre are very slow to decompose while those with high nitrogen and low in fibre are fast to decompose. These occur even under optimum conditions. In other words, C: N ratio play a significant role in the decomposability of plant residues. Crop residue with low C: N ratio are more easily decomposable. This is an indication of the number of microorganisms the residues can support (Cabrera *et al.*, 2005). The ability of a soil to decompose crop residues is also an indicator of the health status of the soil that is, the more microorganisms present in the soil the more readiness of the decomposition while all other factors are not limiting (Frank, 2010). The quantity of biomass produced by a legume is not necessarily an indication of its effectiveness in improving soil fertility. The quality of residues depend on the nutrients released upon their decomposition (Mwangi *et al*., 2013). These in turn depend on nutrient concentration in the residues. Consequently residue quality, decomposition and mineralization rate need to be evaluated (Mwangi *et al*., 2013).

2.10 Distribution and importance of legumes

Legumes are plants in the family *Leguminosae* (or *Fabaceae*). They are the third largest family of angiosperms after *Orchidaceae* and *Asteraceae*, and second only to *Poaceae* (grasses) in terms of agricultural and economic importance (Lewis *et al*., 2005). They are a group of plants which were first to be domesticated, because they are cosmopolitan. They have proved to be adaptive to all soil types and varieties are found in almost all inhabited continents of the world (Prado, 2000). They are grown agriculturally, primarily for their seeds, for livestock forage and silage, and as soil-enhancing green manure. They are notable in that most of them have symbiotic nitrogen-fixing bacteria in structures called root nodules. Wellknown legumes include alfalfa, clover, peas, beans, lentils, lupines, mesquite, carob, soybeans, peanuts and tamarind. In fact, they contain a far more number of useful members even among the larger families of Asteraceae and Orchidaceae (Saslis-Lagoudakis *et al*., 2011). Some of their most important features are discussed below:

2.10.1 Nitrogen fixation

Many legumes contain symbiotic bacteria called *Rhizobia* in the root nodules of their root systems (Plants belonging to the genus Styphnolobium are one exception to this rule). These bacteria have the special ability of fixing nitrogen from atmospheric nitrogen (N_2) into ammonia (NH_3). The chemical reaction is represented as follows: $N_2 + 8H^+ + 8^{e-} \rightarrow 2NH_3 + H_2$.

Ammonia is then converted to another form, ammonium (NH_4^+), usable by some plants by the following reaction: $NH_3 + H^+ \rightarrow NH_4^+$. This arrangement means that the root nodules are sources of nitrogen for legumes, making them relatively rich in plant proteins (Mulongoy, 2015). All proteins contain nitrogenous amino acids. Nitrogen is therefore a necessary ingredient in the production of proteins. Hence, legumes are among the best sources of plant protein. This important role of fixation of atmospheric nitrogen (N_2) is a result of two dependent or consequential roles of legumes that is the ability to increase soil fertility and high levels of protein in the herbage and hence its high forage or mulching quality. In addition to their major potential in fixing atmospheric nitrogen to the soil, legumes help in solubilizing insoluble P in the soil, improve soil physical environment, increase soil microbial activity, smother weeds and restores organic matter (Ghosh *et al.*, 2007).

Nitrogen fixed by legumes is passed to the soil from the top growth through litter fall or the above-ground parts left in the field. For example following harvest of some of the seeds the remaining may be incorporated into the soil. Amino acids inside these remaining plant parts is released back into the soil. In the soil, the amino acids are converted to nitrate (NO_3^-), making the nitrogen available to succeeding plants, thereby serving as nutrient source for future crops. Nitrogen can also be returned back to the soil through deposition of excretory materials from herbivores as farmyard manure.

The ability to fix atmospheric nitrogen makes legumes good components within the various farming systems because they provide residual nitrogen and reduce the need for mineral nitrogen fertilizers by associated non-legumes. Intensification of lowinput agricultural production has led to a rapid increase in soil degradation and nutrient depletion in many parts of sub-Saharan Africa, constituting serious threats to food production and food security (Sanginga *et al*., 2001). Nitrogen depletion in maize-based systems in some farmers' fields in West African savanna is estimated to be 36-80 kg N ha^{-1} per year (Sanginga *et al*., 2001) and it has been obvious since the mid-1990s that fertilizer use is necessary if sustainable agricultural production in smallholder farms is to be raised to levels that can sustain the growing population.

Assuming that only seeds are harvested, net soil nitrogen accrual from the incorporation of grain legume residue can be as much as 140 kg N ha^{-1} depending on the legume variety (Giller, 2001). This N tends to be released quickly when legume residues are incorporated into the soil and can contribute to substantial improvements in yield of subsequent crops. This is higher than the 50 kg nutrient ha^{-1} fertilizer use across sub-Saharan Africa recommended by African Heads of States at the Fertilizer Summit held in 2006 in Abuja, Nigeria (IFDC, 2007).

2.10.2 Industrial uses

Legume seeds have become an industrial basic material with a wide range of nonfood uses (Schuster-gajzágó, 2015). Legumes have been used to produce biodegradable plastics, oils, gums, dyes and inks. They have also been used in traditional medicines. Isoflavones obtained from soybeans have been reported to reduce the risk of cancer. Soybeans and Soy food phytoestrogens have been suggested as possible alternatives to hormone replacement therapy for postmenopausal women. Biodiesel fuel is also produced using soybeans (Graham and Vance, 2003).

2.10.3 Nutritional benefits

Protein calorie malnutrition (PCM) is a major problem in the third world countries (Iqbal *et al*., 2006) because conventional sources of protein (milk, meat and eggs) is beyond the purchasing power of majority of the population. An alternative source may be plant proteins from legumes. Legumes have been known to be highly nutritious as both humans and animals foods. As expected, the fixation of N leads to generally higher protein levels in the plants' tissues (Mannetje *et al.,* 1980). Legumes are a significant source of protein (lysine, leucine, arginine folate, and thiamin), dietary fiber, carbohydrates and micronutrients (manganese, magnesium, potassium, calcium, copper, iron and zinc). Legumes such as groundnut and soybean are also major sources of edible oil, protein and other industrial byproducts. But the major constraints are that legumes contain some anti-nutritional factors and the proteins in legumes are only lysine rich which can complement the cereals but absence in sulphur rich proteins (Iqbal *et al*., 2006). Legumes are also valuable sources of antioxidants and heart-healthy nutrients (Singh *et al*., 2007).

Residues of grain legumes as well as herbaceous and fodder tree legumes provide an excellent source of high quality feed to livestock especially during dry seasons when animal feeds are in short supply. In the sub-humid savanna zone of West Africa, natural pastures are improved by under-sowing with legumes to provide high quality fodder. Increase in productivity of animals fed from planted forage legumes have been reported and could be much better than those that are grazed on natural pastures (Tarawali *et al*., 1999).

2.11 Soybean (*Glycine max* (L) Merrill)

2.11.1 Distribution and importance of soybeans

Soybean is believed to have originated from Manchuria, China, and it is considered among the major crops to have been cultivated in China even before 2500 BC. It was moved to the western world around the 19th century AD. It gained prominence due to its high contents in protein and oil. From the western world, it gradually spread to Africa and other regions of the world (Anonymous, 2010c). The largest producer of soybean is the USA with 51% followed by Brazil (20%), Argentina (10%) and China (10%) (Anonymous, 2010c). In Africa, few countries are significant soybean producers. The largest soybean producer is Nigeria with 39% followed by South Africa (35%), Uganda (14%), Zimbabwe (6%), Egypt (3%) and

Zambia (3%) (Shurtleff and Aoyagi, 2009). Recent report showed Ghana trails in soybean production, and most of the needed soybean for industrial uses is imported from Brazil (Daily Guide, 2014). Increased soybean production should be encouraged to meet the ready market since the country has great potentials to export the commodity (Anonymous, 2010b).

2.11.2 Source of food and feed

Soybean is one of the most economically important beans. The major reasons behind the importance of soybeans lies in the fact that it contains high protein (which is good in essential amino acid balance), lipids and many biologically active compounds and other micronutrients (Colibar *et al*., 2009) and is grown in almost every part of the world. It is good for food (soy-milk, soy-cheese, condiment, Tom Brown and many infant and weaning foods). Based on proximate analysis of 100g seeds, soybean contains 446 kcal of energy, 36.30 protein, 19.94 oil and 9.3 fibre. It also contains minerals such as Ca, Fe, Mg, P, K, Na and Zn and vitamins such as vitamin C, thiamin, riboflavin, niacin, vitamin B-6, vitamin A and E (USDA/NNDSRR28, 2015a). As a source of an excellent vegetable oil, it has been estimated that soybean seeds contain about 20% oil on a dry matter basis, and this is 85% unsaturated and cholesterol-free. Soybean cake is an excellent livestock feed, especially for poultry, while the haulms provide good feed for sheep and goats (Dugje *et al*., 2009).

2.11.3 Improvement in soil fertility

A notable feature of soybean that makes it more attractive among other legume counterparts is its high ability to fix substantial amount of nitrogen through association with rhizobia bacteria; hence, it requires low external supply of nitrogen to meet its nitrogen requirements during growth. Being a rather short duration crop, soybean when shelled the seeds are used as human food, the crop biomass which remains after that is applied into the soil to sustain soil fertility (Singh, 2010).

2.12 Groundnuts (*Arachis hypogaea* L)

2.12.1 Distribution and importance of groundnuts

Groundnut belongs to the leguminous family, but not related to other nuts like walnut and cashew. It is referred to as a nut because of its nature of having flowers above the ground while the pods are formed below the ground. Groundnut originated in South America. The term *Arachis hypogaea* is derived from the Greek words "arachos" which means weed and hypogaea, which means an underground chamber. The name is given to it because it produces its pods underground. The name groundnut is used in the countries of Asia, Africa, Australia and Europe, while in the North and South America it is commonly called peanut. Earliest archeological records revealed that groundnut cultivation dates back to Peru about 3750-3900 years ago. From there it was dispersed through South and Central America and then to other parts of the world (Vara Prasad *et al*., 2009). The largest producer of groundnut in the world is China with 37% followed by Africa 25% then India with 21%, the Americas, 8% and Oceania 6%. In Africa, groundnut is mainly grown in Nigeria, Sudan, Senegal, Chad, Ghana, Congo and Niger (Vara Prasad *et al*., 2009).

2.12.2 Nutritional importance of groundnut

As an important subsistence crop grown throughout the tropics, groundnut is of great nutritive value. Based on proximate analysis of 100g of raw groundnut seeds there is 567 kcal of energy, 25.80g protein, 49.24g of oil, and 8.5g of fibre. It also contains many minerals: Ca, Fe, Mg, P, K, Na and Zn and vitamins such as thiamin, riboflavin niacin, vitamin B-6, folate DFE and vitamin E (USDA/NNDSRR28, 2015b). The oil is used in various cooking; the cake obtained after extraction of the oil is an important component of the diet in many Nigerian dishes and soups. The haulms and cake are also used to feed animals.

2.12.3 Nitrogen fixation

The ability to withstand water deficit during the activities of nitrogen fixation is an important quality in choosing a legume for rotation purposes in the tropical environments. Soil dehydration has been shown to adversely affect nitrogen fixation in many legumes. A notable quality in comparison with other grain legumes is that peanut nitrogen fixation activity has been reported as relatively insensitive to drought compared to soybeans, pigeon pea and cowpea (DeVries *et al.*, 1989).

2.13 Cowpea (*Vigna unguiculata*, L. Walp.)

2.13.1 Cowpea distribution and importance

Cowpea is one of the earliest food consumed by man and has been used for food since Neolithic age (Iruhvwu, 2015). The name cowpea might have emanated because it is an important hay for cows in the Southeastern United States and other parts of the world (Timko *et al.*, 2007). Its origin is believed to be Africa, as the wild specie exists only in Africa and Madagascar (Iruhvwu, 2015). In northern

Nigeria, *Gayan gayan* a type of wild cowpea is commonly found growing in cultivated and fallowed farmlands. Domestication of this crop is still uncertain, but must have been probably domesticated by farmers in West Africa. The crop was first introduced to India from Africa in Neolithic period from there spread to other parts of the world (Timko *et al*., 2007). Lack of archaeological evidence has resulted in contradicting views supporting Africa, Asia or South America as origin. It was introduced from Africa to Indian subcontinent around 2000 to 3500 years ago at the same time as sorghum and millet. Some others are of the view that as early as 300 BC, cowpea was in Europe and possibly North Africa from Asia. Others have a different view that it originated from the northern part of South Africa due to the presence of large primitive varieties in these regions and from there it moved to Mozambique and Tanzania. At present, cowpea is grown throughout the tropics and subtropics (Iruhvwu, 2015).

2.13.2 Nutritional importance of cowpea

Proximate analysis of 100g of cowpea seeds indicates 343 kcal of energy, 23.85g protein, 2.07g lipid, 59.64 carbohydrates and 10.7g fibre. It contains Ca, Fe, Mg P, K, Na and Zn, vitamin C, thiamin, riboflavin, niacin, vitaminB-6, Folate and vitamin A (USDA/NNDSRR28, 2015c). Cowpea can be consumed freshly cooked, the dried seeds can be eaten when cooked, can also be used in the preparation of several dishes of West African origin (*Moi-moi, Akara*, etc.). It is used in making condiment to enrich the local soups.

2.13.3 Improvement and maintenance of soil fertility

Cowpea is a major component of the tropical agriculture because of its multiple uses. Improvement in soil fertility due to its high nitrogen fixing ability, green manuring, cover cropping that helps with an excellent erosion control and suppressing of weeds and improves the availability of phosphorus in the soil, meeting the cash needs of many farmers in West Africa. Its drought tolerance makes it an excellent crop in rain fed agriculture. It can also be used in the production of high quality hay or silage in combination with other cereals (Valenzuela and Smith, 2002; Chiamaka, 2014).

2.14 Maize (*Zea mays*)

2.14.1 Maize distribution and importance

Maize originated from the Mesoamerican region, which is now Mexico and Central America. Evidence from archaeology shows that for over 6000 years, maize was domesticated in the regions of southwestern United States, Mexico and Central America. The Portuguese later introduced maize to Southeast Asia from the America. Maize was later introduced to Spain after the return of Columbus from America, and from Spain, it went to France, Italy and Turkey (Anonymous, 2010a). The Portuguese also introduced maize to India and to China and later it was introduced to Philippines and the East Indies. Maize is now widely grown in many countries including the USA, China, Brazil, Argentina, Mexico, South Africa, Rumania, Yugoslavia and India (Anonymous, 2010a). The largest world producer of maize is the USA with 307.10 million metric tons (MMT), followed by China (162.50 MMT), Brazil (54 MMT), Mexico (24 MMT), Argentina (15 MMT), India

(18.50 MMT), France (14.70 MMT), South Africa (11.50 MMT), Canada (10.30 MMT) and Italy (9.60 MMT). Other important maize producing countries include Ukraine, Philippines, Nigeria, Egypt, Vietnam, Serbia, Hungary, Russia, Romania, Thailand, Ethiopia, Turkey, Poland and Zimbabwe (Chand, 2010).

Maize is cultivated in all parts of Ghana, with the majority grown in four regions (Brong Ahafo region (29%), Eastern region (19%), Ashanti region (14%) and Central region (12%)). Others are Northern region (9%), Upper West region (5%), Volta region (5%) and Western region (5%) (MoFA, 2011).

2.14.2 Nutritional importance of maize

Maize is a staple food for over 50% of the population of sub-Saharan Africa. Based on proximate analysis of seeds it contains a great proportion of carbohydrates, some protein, lipid and fibre. Others are Ca, Fe, Mg, Na and Zn. vitamin C, thiamin, Riboflavin, niacin, vitamin B-6 and Folate DFE (USDA/NNDSRR28, 2015d). It is used in the preparation of many African dishes and drinks. The raw grains are used to feed animals especially poultry, while the stems are used as fodder to feed large animals.

2.14.3 Industrial uses

Maize is processed to biofuel and maize grain makes a good biofuel feedstock due to its starch content and its comparatively easy conversion to ethanol (Larson, 2008). Starch is also produced from it, this involving enzymatic conversion into products such as sorbitol, dextrin (help keep crayons in shape and easy for children to use), sorbic and lactic acid. It is a constituent of many household items such as beer, ice cream, syrup, shoe polish, glue, fireworks, ink, batteries (cornstarch is used as an electrical conductor in batteries), mustard and cosmetics. Corn starch is a common ingredient in many cosmetic and hygiene items, including deodorants), drugs (paracetamol, Aspirin, cough syrup etc.), candies, paint, diapers, baby powders because of the absorbent nature of cornstarch, matchsticks, in carpets, other textile products, glue and other adhesives, toothpaste, dish detergent, paper, clothing dyes, explosives and soaps. In fact, a vast list of products found in a grocery store contain maize in some form. (Anonymous, 2009; 2015). Maize is also used in the manufacture of plastic related products such as food containers and plastic food packaging, disposable dishware, and even gift cards. Plastics from maize use up to 68% less fossil fuels during production than traditional plastics, and this was estimated to emit 55% less greenhouse gases. Moreover, plastics from maize are more biodegradable. With the menace of plastic from petroleum, more emphasis is placed on this new technology for a safer environment.

CHAPTER THREE

GENERAL MATERIALS AND METHODS

3.1 Location of experimental site

The study was conducted at the Plantation crops Section of the Department of Crop and Soil Sciences, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. The site is located within the semi deciduous forest zone of Ghana (6º 41.850' N 1º 31.545' W). The climate is warm, moist with bimodal annual rainfall (major and minor rainy seasons). The major rainy season starts from March to July while the minor rainy season is from September to November. Following the minor rainy season is a short dry season from late November to early March. The soil of study site is a light-textured, well-drained, sandy loam with an overlying reddish-brown and gravelly light clay (Asiamah, 1998).

3.2 Initial characterization of soil of the experimental site

Composite samples of the soil of the experimental site were collected at depths of 0–15 cm and 15-30 cm in a random manner. Four samples were prepared, placed in soil bags, labelled and taken to the laboratory for chemical and physical analyses.

3.2.1 Soil organic carbon

Soil organic carbon was determined using the Walkey-Black method as described by Nelson and Sommers (1982). The result was then multiplied by the van Bemmelen factor (1.724) to obtain the organic matter.

3.2.2 Soil total nitrogen determination

Soil total nitrogen was determined by the Kjeldahl procedure as described in Soil Laboratory Staff (1984) involving three successive phases: digestion, distillation and titration. A 0.5 g of soil sample was digested in 5 ml of concentrated sulphuric acid (H_2SO_4). Few drops of 30% hydrogen peroxide (H_2O_2) were added to the solution with selenium as a catalyst. This procedure ensured the conversion of organic nitrogen to ammonium sulphate. The resultant solution was made alkaline by the addition of 5 ml of 40% sodium hydroxide (NaOH). Ammonia was distilled into 2% boric acid and titrated against standard hydrochloric acid (0.02 *N* HCl) (Bremner and Mulvaney, 1982)

3.2.3 Available phosphorus

Available phosphorus was determined using the Bray P_1 method (Olsen and Sommers, 1982). The method is based on the production of a blue complex of molybdate and orthophosphate in an acid solution. A 10 μg P/mL standard substock solution was diluted to produce standard series of 0, 0.8, 1.6, 2.4, 3.2, and 4.0 μg P/mL. These were subjected to colour development and their respective absorbance values read on a spectrophotometer at a wavelength of 660 nm. A standard line graph was constructed using the readings.

A 2.0 g of soil sample was then weighed into a 50 ml shaking bottle and 20 ml of Bray-1 extracting solution (0.03 *N* NH_4F + 0.025 *N* HCl) added. The sample was shaken for one minute and then filtered through No. 42 Whatman filter paper. Ten millilitres of the filtrate was pipetted into a 25 ml volumetric flask and 1 ml each of molybdate reagent and reducing agent added for colour development. The absorbance was measured at 660 nm wavelength on a spectrophotometer. The concentration of P in the extract was obtained by comparing the results with the standard curve.

3.2.4 Exchangeable basic cations

Neutral 1.0 *M* ammonium acetate (NH_4OAC) was used to extract the exchangeable cations (Black, 1986). Sodium and K^+ ions were measured by flame photometry while Ca^{2+} and Mg^{2+} were determined by ethylenediaminetetraacetic acid (EDTA) titration.

3.2.5 Exchangeable acidity

Extraction of hydrogen and aluminum anions was done with unbuffered 1.0 *M* KCl as described by Page *et al*. (1982), thereafter the exact quantity was determined by titration (Thomas, 1982).

3.2.6 Effective cation exchange capacity

Effective cation exchange capacity (ECEC) was determined by summing the exchangeable cations obtained in the extraction of exchangeable bases plus exchangeable acidity.

3.2.7 Soil pH

Soil pH was determined using a glass electrode (H19017 Microprocessor) pH meter. Soil suspension of 1:1 soil-water ratio was made using 20 g of soil and 20 ml of distilled water and stirred for 30 minutes. The pH meter, which was previously calibrated with buffer solutions of pH 4 and 7 was immersed in the soil suspension, and the pH value recorded.

3.2.8 Particle size distribution

The distribution of particle size in the soil sample was determined by the improved Bouyoucos hydrometer method (Bouyoucos, 1963). Before taking readings with the hydrometer, the soil aggregates were broken down both physically and chemically. Physical disaggregation was achieved by grinding the soil sample. The sample was then treated with hydrogen peroxide to remove organic matter. The clay particles have the tendency to attract one another and must be chemically disaggregated with sodium hexametaphosphate. This chemical binds to the clay particles, giving them a negative charge. The negatively charged particles repel each other and aid in keeping the clay particles in suspension for long periods of time. The density of the soil suspension was determined with a hydrometer calibrated to read in grams of solids per litre after the sand settles down and again after the silt settles. Corrections were made for the density and temperature of the dispersing solution.

3.2.9 Determination of plant total nitrogen

The Kjeldahl digestion procedure was used to determine the nitrogen content of the plants material. Organic and mineral nitrogen was reduced to NH_3. A 0.5 g sample was digested in a 10 ml concentrated sulphuric acid in the presence of selenium mixture as catalyst. The NH_3 was recovered by distillation and estimated by titration with 0.1 *M* HCl using bromocresol green-methyl red as indicator (Soils Laboratory Staff, 1984).

3.2.10 Determination of seed crude protein

Crude protein which is the total protein equivalent including nitrogen from both protein and non-protein sources employs the Kjeldahl method of nitrogen analysis. It was obtained by continuous degradation of the sample until only nitrogen ammonia remained. The value was multiplied by 6.25 to get the actual crude protein content (AOAC, 1995).

3.3 Data collected from legumes trials

3.3.1 Plant height

Five plants were randomly selected from the middle rows in each plot and tagged. The plant height was measured using a measuring tape. The height was obtained by measuring from the ground level to the highest growing point at 4, 6 and 8 WAP.

3.3.2 Canopy diameter

The tagged plants were used to measure the canopy diameter. Canopy diameter was obtained by measuring the width of the canopy of each plant.

3.3.3 Number of branches

Number of branches per plant were counted using the tagged plants.

All growth parameters were measured in 2014 and in 2015 cropping seasons.

3.3.4 Nodulation

Five plants were randomly selected from the second rows. These were carefully dug, washed in a sieve to remove soil adhering materials. All nodules from each plant were removed and counted. Number of fixing nodules were determined by splitting the nodules open and counting those with pink colouration. Percent of effective nodules was calculated as the ratio of effective nodules to total number of nodules. The nodules were oven dried at 70 °C for 48 hrs and the weights recorded to obtain the nodule dry weight.

3.3.5 Shoot dry weight

Five plants were randomly selected from the second rows of each plot at 4, 6 and 8 WAP. These were dug, washed and dried to constant weight at 80 °C for 3 days. The dried plant materials were weighed to determine the shoot dry weight for each treatment.

3.3.6 Crop growth rate

The shoot dry weight taken at 4, 6 and 8 WAP were used to calculate the crop growth rate (CGR) as:

$$CGR = \frac{W_2 - W_1}{T_2 - T_1} \quad \text{(Hunt, 1978)}$$

where:

W_1 and W_2 = dry weight at first and second sampling (in grams)

T_1 and T_2 = Time of first and second sampling (in weeks)

3.3.7 Relative growth rate

The shoot dry weight taken at 4, 6 and 8WAP was used to calculate the relative growth rate (RGR) as:

$$RGR = \ln W_2 - \ln W_1 \quad \text{(Hunt, 1978)}$$

$T_2 \square T_1$

where:

W_1 and W_2 = dry weight at first and second sampling (in grams)

T_1 and T_2 = Time of first and second sampling (in weeks)

3.3.8 Number of pods per plant

The number of pods per plant was obtained as the average of number of pods obtained from the five tagged plants.

3.3.9 Mean seed weight

Mean seed weight was obtained by counting five sets of 100 seeds from dried seeds for each plot. These were weighed individually and from which the mean weight was obtained.

3.3.10 Grain yield

Plants from the central rows of each plot excluding the two border rows on each side were harvested and sun dried for two weeks, threshed and weighed at about 13% moisture content. This was converted to per hectare basis to obtain the grain yield per hectare.

3.4.2 Estimation of nitrogen fixation

The Total Nitrogen Difference (TND) method described by Hanssen (1994) was used to estimate the amount of nitrogen fixed by the different legumes. Total N from the reference crop, maize (*Obaatanpa*) variety was subtracted from that of the legume crop using the formula below.

Total fixed N (kg/ha) = N uptake in legume - N uptake in reference crop

N uptake = dry matter x % N

$$\%Ndfa = \frac{\text{N uptake in legume - N uptake in reference crop}}{\text{N uptake in legumes}} \times 100\ \%$$

(Adapted from Konlan *et al*., 2013)

where

% Ndfa = percentage of nitrogen derived from atmosphere

3.5. Haulm management

Haulms from legume trials were sun dried for two weeks in mesh bags to avoid losses and to complement the differences in harvesting days of the varieties.

Haulms were chopped with cutlass and spread evenly on their respective plots. Surface application of haulms in a no-till system was adopted because it creates a more favourable soil moisture and temperature conditions. The no-till system also helped to conserve the rhizodeposited nitrogen in each plot. Nitrogen rhizodeposition of grain legumes represents a significant pool in crop rotations (Mayer, 2003). Crop haulms retained on the soil surface provide soil and water conservation benefits. These benefits result mainly from the physical presence of the haulms, which moderates the forces of wind and water, reducing the potential for soil erosion. Surface haulms aid water conservation by (a) protecting soil aggregates against dispersion, thereby reducing the potential for the development of a surface seal that could reduce water infiltration; (b) slowing water flow across the surface and so providing more time for infiltration; and (c) reducing evaporation

(López *et al*., 2003). Other benefits of surface haulms include greater soil organic matter (SOM) concentration, soil temperature moderation and increased soil biological activity, all of which are also important for sustaining crop production (Mbah and Nneji, 2011). More importantly, the haulms were left on the soil surface to depict farmers practice.

3.6 Data collected from maize trials

3.6.1 Plant height

Five plants were randomly tagged from the middle rows of each treatment plot; their height was measured using a measuring tape as a vertical distance from the ground level to highest living part of the plant, and the mean height calculated for each plot at 4, 6 and 8 WAP.

3.6.2 Stem girth

Stem diameter was measured from the five-tagged plants using vernier caliper.

3.6.3 Leaf area

Leaf area was calculated using the

equation: Leaf area = (L x W) *K*

where:

L= leaf length

W= leaf width

K = constant for cereals (0.75) (adapted from Aikins *et al*., 2012)

3.6.4 Biomass yield

All maize plants from the central rows were cut at the time of harvest from the ground level, sun dried to constant weight and weighed to obtain the biomass yield.

3.6.5 Cob weight

Husks were removed from individual maize cobs and the cobs weighed to obtain the weight.

3.6.6 Grain yield

Grains from individual cobs were removed with a manual grain remover and sun dried to a constant moisture. The dried grains were then measured to obtain the grain yield per plot.

3.6.7 Harvest index

Harvest index is the ratio of grain yield to plant biomass produced. It was determined by dividing the grain yield by the total biomass yield.

$$HI = \frac{GY}{TY}$$ (Bange *et al*., 1998)

where:

HI = harvest index

GY = grain yield

TY = total yield

3.6.8 Mean seed weight

Hundred seeds were randomly picked from each plot and weighed. The procedure was repeated five times; from these the mean weight was obtained.

3.7 Economic analysis

A profit appraisal was carried out to measure the effect of the project on the individual or participants based on the benefits derived. The economic analysis using the benefit to cost ratio was employed using the input cost and the financial gain in monetary value from the production system. The economic analysis of a project is a good tool in estimating the profit accruing to the project entity or to the project participants, because both feasibility and profitability of a crop are determined by their ultimate financial returns (Hayat *et al*., 2004).

Benefit cost ratio (BCR) was calculated as:

$$BCR = \frac{\text{Net income}}{\text{Total cost}}$$ (adapted from Sirajul Islam *et al*., 2012)

where:

Net income = gross income - cost of production.

The cost of production = cost of inputs

In order to estimate production cost and revenue in the production of legumes and subsequently maize from the haulms obtained in 2014 and 2015 major and minor rainy seasons, the following assumptions were made based on the prevailing market prices.

Estimated input and output (GH¢) based on prevailing market prices of the study area

Input and output	Equivalent monetary value
NPK fertilizer (15:15:15)	GH¢ 130/50 kg
Urea fertilizer (46% N)	GH¢ 130/50 kg
Cost of inoculant (legume fix)	GH¢ 1.4/10 g
Cost of soybean seeds	GH¢ 4.5/kg
Cost of groundnut seeds	GH¢ 4.5/kg
Cost of cowpea seeds	GH¢ 4.5/ kg
Cost of maize seeds (*Abontem*)	GH¢ 4/kg
Equivalent cost of groundnut haulm	GH¢ 20/ 50 kg
Equivalent cost of soybean haulm	GH¢ 15/50 kg
Equivalent cost of cowpea haulm	GH¢ 16/50 kg
Cost of soybean	GH¢ 200/ 100 kg
Cost of cowpea	GH¢ 300/ 100 kg
Cost of groundnut	GH¢ 400/100 kg
Cost of maize	GH¢ 200/100 kg

Note: 250 g inoculant at 10 USD and exchange rate of GH¢ 3.5 to 1 USD

3.9 Data analysis

All data were subjected to Analysis of Variance using the GenStat 9th Edition (GenStat, 2007). Where the F values were significant, means were compared using the Least Significant Difference (LSD) method at 5%.

CHAPTER FOUR

Experiment One

Evaluation of growth, yield and nitrogen fixating potential of soybean, groundnut and cowpea varieties

4.1. Introduction

Recent progress in understanding the importance of legumes in nitrogen fixation has been stimulated by the importance of nitrogen in agriculture (Adams *et al*., 2015). The need to have efficient, safer, cheaper and sustained crop production has also stimulated the use of legume haulms as a source of nitrogen to subsequent cereal crops. The nitrogen fixation process of bacteria in association with legumes is not without problems. Several factors influence the amount of nitrogen fixed, including the amount of nitrogen in the soil, response of inoculation, compatibility of the legume, bacteria present and diseases (Keyser and Li, 1992).

Due to their vast usage and importance, legumes have been specially used to improve soil fertility. Their ability to form symbiotic association with rhizobia to fix atmospheric nitrogen in their tissues is of paramount importance for the development of an efficient and sustainable crop production. This can be achieved through understanding of the amount of N_2 fixed by legumes as influenced by soil management or cultural practices (Peoples *et al.,* 1989). Most of the legume research recently focused mainly on improving the bacteria aspect of the BNF neglecting the host plant, not knowing that it is only in extreme cases that bacteria are a serious limitation in BNF. This situation is especially important in less developed countries, where other inputs pose more serious limitations to crop production than bacteria (Thomas and Vincent, 2012). This study was therefore conducted to determine growth, yield and nitrogen fixation of the three commonest legumes grown in Ghana (cowpea, groundnut and soybean) and to determine their residual fertility on maize growth and yield.

4.2 Materials and Methods

The study was carried out at the Plantation Crops Section of the Department of Crop and Soil Sciences, KNUST. Following land preparation, five varieties each of cowpea, groundnut and soybean were sown. The groundnut varieties were Nkatiesari, Sumnut-22, Manipinta, Jenkaar and Chinese; the soybean varieties were Jenguma, Salintuya-1, Songda, Sonqu-panqu and Quashie; and the cowpea varieties were Hewale, Asomdwee, Asetenapa, Videza and Asontem. All seeds were obtained from the Crops Research Institute of the Council for Scientific and Industrial Research, Fumesua near Kumasi. The varieties as treatments were arranged in a randomized complete block design and replicated four times.

Soybean and groundnut varieties were sown on 5th May 2014. Two seeds were placed per hole with a spacing of 75 cm x 5 cm (soybean) and 30 cm x 15 cm (groundnut). Cowpea varieties were sown at 2 seeds per hole with a spacing of 60 x 20 cm on 10th June to synchronize the timing of harvests for the three crops. Thinning was done two weeks after seedling emergence. Plots were weeded with a hoe twice at four and eight weeks after planting.

Cowpea plots were sprayed at 5 , 6 and 7 week after sowing with a *Lambdacyhalothrin* applied at the rate of 600 ml ha^{-1} as recommended by manufacturer.

The entire plots were fenced with rubber mesh to prevent the attack by squirrels on maturing groundnut crop.

4.3 Results

4.3.1 Plant height

Table 4.1 presents the results of groundnut plant height. Plant height differed significantly ($P<0.05$) among the different varieties throughout the sampling periods. Sumnut-22 and Chinese were significantly ($P<0.05$) taller than the other varieties at 4 and 6 WAP. At 8 WAP, a similar trend was observed except that Manipinta was not statistically different from the tallest plants.

Table 4.2 shows that significant ($P<0.05$) differences existed in heights of soybean varieties at 4 and 6 WAP. At 4 WAP, Jenguma produced significantly the tallest plants than all other varieties except Sonqu-panqu. All other treatment differences were not significant. At 6 WAP, Sonqu-panqu produced the tallest plant but this effect was significantly ($P<0.05$) higher than those of the Salintuya-1 and Quashie varieties only. At 8 WAP, varietal differences were not significant ($P>0.05$).

With cowpea, Asontem produced significantly ($P<0.05$) taller plants than all other varieties at 4 WAP, and all but Asomdwee at 6 WAP (Table 4.3).

Table 4.

1. Plant height of groundnut varieties at 4, 6 and 8 weeks after planting in 2014 major rainy season

Parameter	Plant height (cm)		
	Weeks After Planting (WAP)		
Variety	4	6	8
Jenkaar	12.62	20.90	38.70
Manipinta	15.50	30.40	56.85
Sumnut-22	21.30	35.25	56.50
Chinese	20.65	39.25	60.32
Nkatiesari	12.47	21.20	37.80
LSD (0.05)	1.35	1.56	0.80
CV (%)	5.3	3.4	1.0

Table 4. 2. Plant height of soybean varieties at 4, 6 and 8 weeks after planting in 2014 major rainy season

Parameter	Plant height (cm)		
	Weeks After Planting (WAP)		
Treatment	4	6	8
Jenguma	30.65	60.57	85.0
Quashie	27.10	57.35	82.2
Salintuya-1	26.90	57.92	87.1
Songda	27.10	60.75	87.2
Sonqu-panqu	28.55	63.75	89.0
LSD (0.05)	3.05	4.34	NS
CV (%)	7.0	4.7	7.7

Table 4.

3. Plant height of cowpea varieties at 4 and 6 weeks after planting in 2014 major rainy season

Parameter	Plant height (cm)	
	Weeks After Planting (WAP)	
Treatment	4	6
Asetenapa	43.27	136.8
Asomdwee	45.10	145.2
Asontem	53.10	154.2
Hewale	47.35	124.8
Videza	42.90	125.9
LSD (0.05)	4.35	17.36
CV (%)	6.1	8.2

4.3.2 Canopy diameter

The results of groundnut canopy diameter are presented in Table 4.4. Significant (P<0.05) difference was observed in canopy spread during the three sampling periods. At 4 WAP, the Sumnut-22 produced higher canopy diameter than all the other varieties. Canopy spread of Chinese was also significantly higher than the other varieties, all of which had similar effects. At 6 WAP, Sumnut-22 and Chinese produced similar canopy spread, and their effect was significantly higher than the other varietal effects. Treatment differences among the other varieties were not significant (P>0.05). At 8 WAP, treatment effect of Chinese was significantly higher than all the other varietal effects. Canopy spread of Nkatiesari was also higher than the other varietal effects.

Table 4.

4. Canopy diameter of groundnut varieties at 4, 6 and 8 weeks after planting in 2014 major rainy season

Parameter	Canopy diameter (cm)		
	Weeks After Planting (WAP)		
Treatment	4	6	8
Jenkaar	18.85	28.25	46.25
Manipinta	19.95	28.75	44.72
Sumnut-22	24.10	32.47	47.17
Chinese	22.45	34.25	53.30
Nkatiesari	18.60	29.90	49.00
LSD (0.05)	1.40	1.88	2.38
CV (%)	4.4	4.0	3.2

The results for canopy diameter for soybeans is presented in Table 4.5. Significant ($P<0.05$) differences among the varieties was observed in the first and second sampling periods. Jenguma had significantly the least effect at 4 WAP, and this was significantly lower than all other varietal effects. At 6 WAP, Quashie recorded the highest effect, which was significantly higher than that of Jenguma. Canopy spread for all varieties was not significantly ($P>0.05$) different from each other at 8 WAP.

Canopy diameter of cowpea varieties showed that on both sampling days, Asontem produced the highest canopy spread, and this was significantly higher than all other varietal effects except Hewale at 4 WAP (Table 4.6).

Table 4.

5. Canopy diameter of soybean varieties at 4, 6 and 8 weeks after planting in 2014 major rainy season.

Parameter	Canopy diameter (cm)		
	Weeks After Planting (WAP)		
Treatment	4	6	8
Jenguma	25.30	37.80	69.8
Quashie	31.35	46.90	78.9
Salintuya-1	30.80	45.50	76.7
Songda	30.45	44.50	75.7
Sonqu-panqu	31.35	43.70	75.9
LSD (0.05)	3.10	8.13	NS
CV (%)	6.7	12.1	9.6

Table 4. 6. Canopy diameter of cowpea varieties at 4 and 6 weeks after planting in 2014 major rainy season

Parameter	Canopy diameter (cm)	
	Weeks After Planting (WAP)	
Treatment	4	6
Asetenapa	39.2	48.2
Asomdwee	40.80	51.0
Asontem	50.00	58.9
Hewale	45.75	51.6
Videza	40.40	46.3
LSD (0.05)	4.460	7.23
CV (%)	6.7	9.2

4.3.3 Number of branches per plant

Table 4.7 shows that number of branches for groundnut was significantly ($P<0.05$) different at 4, 6 and 8 WAP among the different varieties. At 4 WAP, Nkatiesari produced the highest number of branches, whilst Chinese recorded the lowest number. At 6 WAP, Nkatiesari and Jenkaar varietal effects were similar, and either effect was significantly higher than in all varieties. At 8 WAP, the Jenkaar produced the highest number of branches, which was significantly higher than all other varietal effects.

Table 4. 7. Number of branches per plant of groundnut varieties at 4, 6 and 8 weeks after planting in 2014 major rainy season

Parameter	Number of branches per plant		
	Weeks After Planting (WAP)		
Variety	4	6	8
Jenkaar	31.30	67.40	141.45
Manipinta	30.05	58.40	90.45
Sumnut-22	31.50	59.98	89.27
Chinese	27.70	49.20	94.82
Nkatiesari	33.65	64.90	121.27
LSD (0.05)	1.51	3.24	2.31
CV (%)	3.2	3.5	1.4

Table 4.8 presents the results of number of branches per plant for soybean. At 4 WAP, all varieties had similar effects except Sonqu-panqu, which effect was significantly lower than Quashie. At 6WAP, varietal effects were similar. At 8

WAP, Quashie had significantly (P<0.05) the highest number of branches. The effect of Sonqu-panqu was higher than the effect of Salintuya-1. Table 4.9 shows cowpea varietal effects were not significant (P>0.05) on both sampling days.

Table 4. 8. Number of branches per plant of soybean varieties at 4, 6 and 8 weeks after planting in 2014 major rainy season.

Parameter	Number of branches per plant		
	Weeks After Planting (WAP)		
Treatment	4	6	8
Jenguma	6.95	13.10	19.17
Quashie	7.40	14.85	29.95
Salintuya-1	6.70	13.80	16.22
Songda	7.25	14.25	17.97
Sonqu-panqu	6.45	12.90	20.10
LSD (0.05)	0.91	NS	3.67
CV (%)	8.5	12.3	11.5

Table 4. 9. Number of branches per plant of cowpea varieties at 4 and 6 weeks after planting in 2014 major season

Parameter	Number of branches	
	Weeks After Planting (WAP)	
Treatment	4	6
Asetenapa	8.7	21.30
Asomdwee	9.55	21.35
Asontem	10.05	20.15
Hewale	10.10	24.25
Videza	9.15	22.60
LSD (0.05)	NS	NS

CV (%)	10.0	10.4

4.3.4 Crop growth rate

Crop growth rate (CGR) of the three crops are presented in Table 4.10. Crop growth rate was significantly different (P<0.05) among the varieties of groundnut. At 4-6 WAP, the crop growth rate of Nkatiesari was significantly higher than all other varieties, except that of Manipinta. During the second sampling (6-8 WAP), varietal effect of Nkatiesari was significantly higher than all varieties except Jenkaar. Crop growth rate for Chinese was significantly (P<0.05) lower than all other varieties on both occasions. Among the soybean varieties, CGR was highest in the Quashie on both occasions, and this was significantly higher than all varietal effects at 4-6 WAP, and all but Songda varietal effect on the second sampling. The Sonqu-panqu varietal effect was the lowest at 4-6 WAP, while that of Jenguma was lowest during the second sampling (6-8 WAP). Among the cowpea varieties, the Hewale varietal effect was significantly higher (P<0.05) than all other varietal effects at both samplings. Crop growth rate of the Asontem was significantly lower than all other varietal means during the second sampling. However, its growth rate was statistically similar to the other varieties during the first sampling.

4.3.5 Relative growth rate

The results of the relative growth rate (RGR) of the crops are shown in Table 4.11. Significant (P<0.05) difference among the groundnut varieties in terms of RGR was observed. At the first stage, Nkatiesari recorded significantly higher RGR than all varieties, Manipinta also recorded significantly higher RGR than the rest of the varieties. In the second sampling, the highest RGR was also recorded in the

Nkatiesari, which was significantly higher than all the other varieties. The least RGR was measured in the Chinese at both samplings. Significant (P<0.05) differences among the soybean varieties in terms of their RGR was observed in the two stages (Table 4.11). At the first sampling, Quashie recorded the highest RGR, which was significantly higher than the other varietal effects. Jenguma and Songda which were similar in RGR were significantly better than Salintuya-1 while Sonqupanqu recorded significantly (P<0.05) the lowest RGR. At the second sampling, Songda and Quashie had significantly similar RGR, Jenguma and Salintuya-1 varieties were significantly better than Sonqu-panqu, which recorded the least. Among the cowpea varieties, Hewale had the highest RGR, which was significantly higher than all other varieties at the first sampling, and all but Asomdwee varietal effect at second sampling. Asetenapa recorded the least RGR effect during the second sampling period.

Table 4. 10. Crop growth rates of groundnut, soybean and cowpea in 2014 major season

Groundnut	CGR1	CGR2	Soybean	CGR1	CGR2	Cowpea	CGR1	CGR2
	(g m-2 wk-1)			(g m-2 wk-1)			(g m-2 wk-1)	
Chinese	11.75	14.12	Jenguma	11.50	11.38	Asetenapa	9.60	5.50
Jenkaar	18.25	19.62	Quashie	19.75	28.00	Asomdwee	10.81	11.00
Manipinta	22.50	16.25	Salintuya-1	12.38	18.12	Asontem	10.12	8.38
Nkatiesari	24.12	21.62	Songda	15.38	26.88	Hewale	18.88	18.88
Sumnut-22	19.12	17.12	Sonqu-panqu	10.25	13.12	Videza	11.75	9.00
LSD (0.05)	2.30	2.12	LSD (0.05)	1.39	2.71	LSD (0.05)	2.37	1.38
CV (%)	7.8	7.7	CV (%)	6.5	9.0	CV (%)	12.6	8.5

CGR1 = crop growth rate at 4-6 WAP, CGR2 = crop growth rate at 6-8 WAP.

Table 4. 11. Relative growth rates of groundnut, soybean and cowpea in 2014 major season

Groundnut	RGR1	RGR2	Soybean	RGR1	RGR2	Cowpea	RGR1	RGR2
	(g g^{-1}day^{-1})			(g g^{-1}day^{-1})			(g g^{-1}day^{-1})	
Chinese	0.15	0.14	Jenguma	0.28	0.18	Asetenapa	0.54	0.16
Jenkaar	0.21	0.16	Quashie	0.32	0.26	Asomdwee	0.53	0.25
Manipinta	0.28	0.14	Salintuya-1	0.21	0.20	Asontem	0.51	0.21
Nkatiesari	0.32	0.18	Songda	0.28	0.28	Hewale	0.66	0.27
Sumnut-22	0.24	0.15	Sonqu-panqu	0.14	0.16	Videza	0.51	0.18
LSD (0.05)	0.03	0.01	LSD (0.05)	0.04	0.04	LSD (0.05)	0.03	0.02
CV (%)	7.9	4.8	CV (%)	9.7	12.1	CV (%)	3.7	7.1

RGR1 = relative growth rate at 4-6 WAP, RGR2 = relative growth rate at 6-8 WAP

4.3.6 Grain yield

Grain yield results of the varieties are presented in Table 4.12. Yield among groundnut varieties was significantly (P<0.05) different. Sumnut-22 produced the highest yield, which was significantly higher than that of the other varieties except Manipinta. Grain yield of Nkatiesari was significantly lower than all other treatment means.

Among soybean varieties, Sonqu-panqu produced significantly the highest grain yield (P<0.05). Jenguma, Quashie and Songda varieties produced the least grain yield.

Asontem produced the highest grain yield among the cowpea varieties, which was significantly higher than all other varieties. The yield of Asetenapa was lower than all other varieties except Videza.

Table 4. 12. Grain yield of groundnut, soybean and cowpea varieties without inoculation in 2014 major rainy season

Groundnut	Yield (kg/ha)	Soybean	Yield (kg/ha)	Cowpea	Yield (kg/ha)
Chinese	476	Jenguma	822	Asetenapa	666
Jenkaar	507	Quashie	827	Asomdwee	1090
Manipinta	580	Salintuya-1	849	Asontem	1444
Nkatiesari	397	Songda	788	Hewale	1013
Sumnut-22	617	Sonqu-panqu	1181	Videza	718
LSD (0.05)	48.1	LSD (0.05)	58.0	LSD (0.05)	67.6
CV (%)	6.1	CV (%)	4.2	CV (%)	4.4

4.3.7 Mean 100 seed weight

The results for seed weight of crops are shown in Table 4.13. Significant (P<0.05) differences were observed among groundnut varieties with Manipinta producing significantly (P<0.05) the heaviest seeds than all other varieties. Sumnut-22 produced significantly higher seed weight than the other varieties whose seed weights were similar.

There was significant (P<0.05) difference in the measured parameter among the soybean varieties. Sonqu-panqu produced significantly the heaviest seed weight than all other varieties, all of which had similar weights.

Among the cowpea varieties, Asomdwee recorded the highest mean seed weight, which was significantly higher than those of the Hewale and Videza varieties only. Seed weight of Asontem was also higher than those of Hewale and Videza varieties.

Table 4. 13. Mean 100 seed weight of groundnut, soybean and cowpea varieties without inoculation in 2014 major rainy season

Groundnut	100 seed weight (g)	Soybean	100 seed weight (g)	Cowpea	100 seed weight (g)
Chinese	40.18	Jenguma	12.50	Asetenapa	12.75
Jenkaar	42.50	Quashie	12.50	Asomdwee	13.88
Manipinta	50.25	Salintuya-1	12.75	Asontem	13.38
Nkatiesari	40.75	Songda	12.25	Hewale	11.50
Sumnut-22	46.50	Sonqu-panqu	15.00	Videza	11.75
LSD (0.05)	2.70	LSD (0.05)	1.14	LSD (0.05)	1.50
CV (%)	4.0	CV (%)	5.7	CV (%)	7.7

4.3.8 Number of pods

Significant (P<0.05) difference was observed in number of pods plant^{-1} among groundnut varieties (Table 4.14). Sumnut-22 produced significantly (P<0.05) the highest number of pods while Chinese, Jenkaar and Manipinta varieties had significantly similar effects and were significantly better than Nkatiesari. Nkatiesari had significantly the least number of pods. The results for pod yield among soybean varieties are shown in Table 4.14. Significant (P<0.05) differences were observed. Sonqu-panqu produced significantly (P<0.05) the highest number of pods. The other varieties were statistically similar in number of pods plant^{-1}. Asontem produced significantly (P<0.05) the highest number of pods (Table 4.14). Hewale produced significantly higher pod number than all other varieties. The Asetenapa varietal effect was significantly lower than all other varieties except Videza.

Table 4. 14. Number of pods per plant of groundnut, soybean and cowpea varieties without inoculation in 2014 major rainy season

Groundnut	No. of pods/plant	Soybean	No. of pods/plant	Cowpea	No. of pods/plant
Chinese	28.60	Jenguma	78.0	Asetenapa	13.10
	28.48		78.5		19.66
Jenkaar		Quashie		Asomdwee	
	28.35		79.2		26.82
Manipinta		Salintuya-1		Asontem	
	23.55		76.2		21.80
Nkatiesari		Songda		Hewale	
	32.20		93.8		15.20
Sumnut-22		Sonqu-panqu		Videza	
	2.94		7.12		1.95
LSD (0.05)		LSD (0.05)		LSD (0.05)	
	6.8		5.7		6.6
CV (%)		CV (%)		CV (%)	

4.3.9 Haulm yield

Significant (P<0.05) difference was observed among the groundnut varieties with respect to haulm yield (Table 4.15). Jenkaar produced significantly (P<0.05) the highest haulm yield of 4.0 t/ha. Sumnut-22 and Nkatiesari varieties had similar haulm yields, which were significantly higher than that of Manipinta, though, the yield of Nkatiesari was not statistically different from that of Manipinta. Chinese produced significantly the least haulm yield.

Haulm yield varied significantly (P<0.05) among the soybean varieties with Songda producing the highest haulm yield, while Jenguma produced the least haulm yield (Table 4.15).

The results for haulm yield of cowpea varieties are presented in Table 4.15. Significant (P<0.05) differences were observed among the varieties. Hewale significantly produced the highest haulm yield. Asomdwee and Videza produced similar haulm yields and both were significantly higher than that of Asontem and Asetenapa varieties. Asetenapa produced significantly (P<0.05) the least haulm yield which was < 2.0 t/ha.

Table 4. 15. Haulm yield of groundnut, soybean and cowpea grown without inoculation during the major rainy season of 2014

Groundnut	Haulm yield (t/ha)	Soybean	Haulm yield (t/ha)	Cowpea	Haulm yield (t/ha)
Jenkaar	4.01	Jenguma	2.07	Asetenapa	1.65
Manipinta	3.68	Quashie	3.19	Asomdwee	2.27
Sumnut-22	3.84	Salintuya-1	2.59	Asontem	2.00
Chinese	2.55	Songda	3.43	Hewale	3.69
Nkatiesari	3.79	Sonqu-panqu	2.27	Videza	2.24
LSD (0.05)	0.15	LSD (0.05)	0.15	LSD (0.05)	0.07
CV (%)	2.8	CV (%)	3.6	CV (%)	2.0

4.3.10 Nodule number

Nodule number of groundnut varieties are shown in Table 4.16. Nodule number differed significantly (P<0.05) among groundnut varieties. Nkatiesari produced significantly (P<0.05) the highest number of nodules. Chinese produced significantly more nodules compared to Manipinta and Sumnut-22 varieties while Manipinta and Sumnut-22 produced statistically similar number of nodules (P > 0.05).

Nodule number among soybean varieties in 2014 was significantly (P<0.05) different (Table 4.16). Quashie, Sonqu-panqu and Salintuya-1 varieties produced significantly the highest number of nodules, though the effect of Salintuya-1 was not significantly different from that of Songda. The least number of nodules produced by Jenguma was not also statistically different from that of Songda.

There was significant (P<0.05) differences among the varieties of cowpea in their nodule number (Table 4.16). Asetenapa and Videza produced significantly (P<0.05) the highest number of nodules, while Asomdwee, Asontem and Hewale which were statistically similar in nodule number produced significantly (P<0.05) the lowest nodules.

Table 4. 16. Nodule numbers of groundnut, soybean and cowpea varieties without inoculation in 2014 major rainy season

Groundnut	Nodule number/plant	Soybean	Nodule number/plant	Cowpea	Nodule number/plant
Chinese	67.75	Jenguma	19.25	Asetenapa	69.80
Jenkaar	80.30	Quashie	24.25	Asomdwee	43.80
Manipinta	63.05	Salintuya-1	22.25	Asontem	43.20
Nkatiesari	84.25	Songda	20.25	Hewale	46.80
Sumnut-22	61.05	Sonqu-panqu	24.25	Videza	65.50
LSD (0.05)	3.59	LSD (0.05)	2.77	LSD (0.05)	7.38
CV (%)	3.3	CV (%)	8.2	CV (%)	8.9

4.3.11. Percent effective nodules

The results of percent effective nodules of groundnut are presented in Table 4.17. Chinese, Manipinta and Sumnut-22 varieties produced similar effective nodules which was significantly (P<0.05) higher than those of Nkatiesari and Jenkaar varieties.

Significant (P<0.05) difference were observed in percent effective nodules among the soybean varieties (Table 4.17). Sonqu-panqu and Songda varieties produced similar effective nodules, which were significantly higher than all varieties. Quashie recorded the least number of effective nodules.

Results show that all cowpea varieties produced similar effective nodules except Hewale, whose effect was significantly lower than that of Asetenapa.

Table 4. 17. Percent effective nodules per plant of groundnut, soybean and cowpea varieties without inoculation in 2014 major season.

Groundnut	% effective nodules/plant	Soybean	% effective nodules/plant	Cowpea	% effective Nodules/plant
Chinese	76.25	Jenguma	76.25	Asetenapa	80.00
Jenkaar	63.75	Quashie	52.50	Asomdwee	72.50
Manipinta	77.50	Salintuya-1	70.00	Asontem	75.00
Nkatiesari	68.75	Songda	82.50	Hewale	67.50
Sumnut-22	76.25	Sonqu-panqu	87.50	Videza	77.50
LSD (0.05)	5.54	LSD (0.05)	5.48	LSD (0.05)	11.85
CV (%)	5.0	CV (%)	4.8	CV (%)	10.3

4.3.12 Nodule dry weight

The results of nodule dry weight of groundnut are presented in Table 4.18. There were significant differences among the groundnut varieties. Nkatiesari produced the heaviest nodules than all other varieties. The nodule dry weight of Jenkaar was also higher than that of the other varieties. Manipinta and Sumnut-22 varieties were similar and their effects were significantly ($P<0.05$) lower than that of Chinese.

Among the soybean varieties, Quashie and Sonqu-panqu were statistically similar in nodule dry weight, which was not significantly different from that of Salintuya-

1. Songda and Jenguma produced the least nodule dry weights.

Among the cowpea varieties, Asetenapa gave the highest nodule dry weight. Videza varietal effect was higher than all other varieties, while Asomdwee, Asontem and Hewale varietal effects were similar and significantly the least.

Table 4. 18. Nodule dry weight of groundnut, soybean and cowpea varieties without inoculation in 2014 major rainy season

Groundnut	Nodule dry weight (g)	Soybean	Nodule dry weight (g)	Cowpea	Nodule dry weight (g)
Chinese	0.14	Jenguma	0.12	Asetenapa	0.22
Jenkaar	0.17	Quashie	0.15	Asomdwee	0.14
Manipinta	0.13	Salintuya-1	0.14	Asontem	0.14
Nkatiesari	0.18	Songda	0.13	Hewale	0.15
Sumnut-22	0.13	Sonqu-panqu	0.15	Videza	0.20
LSD (0.05)	0.01	LSD (0.05)	0.02	LSD (0.05)	0.02
CV (%)	3.3	CV (%)	8.2	CV (%)	8.9

4.3.13 Nitrogen fixed

4.3.13.1 Haulm N

The haulm N of groundnut varieties are presented in Table 4.19. There were significant ($P<0.05$) differences in haulm N among the groundnut varieties. Nkatiesari, Manipinta and Jenkaar varieties produced similar haulm N and were significantly the highest. Sumnut-22 varietal effect was higher than that of Chinese, which produced the least varietal effect. Like groundnut, the soybean varieties showed significant differences in haulm N ($P<0.05$). Songda gave the highest haulm N. Haulm N of Quashie was higher than the other varieties. Haulm N was higher in the haulm of Salintuya-1 than that of Jenguma and Sonqu-panqu varieties, while Jenguma and Sonqu-panqu varieties were statistically at par. Among the cowpea varieties, the haulm N was significantly (P<0.05) different. Hewale produced the highest N. The haulm N of Asomdwee and Videza varieties were similar and significantly higher than the haulm N of Asetenapa and Asontem varieties. Asontem produced the least haulm N.

Table 4. 19. Haulm N of groundnut, soybean and cowpea varieties without inoculation in 2014 major rainy season

Groundnut	Haulm N (kg/ha)	Soybean	Haulm N (kg/ha)	Cowpea	Haulm N (kg/ha)
Chinese	32.96	Jenguma	22.60	Asetenapa	10.28
Jenkaar	81.48	Quashie	42.76	Asomdwee	15.35
Manipinta	79.70	Salintuya-1	34.63	Asontem	9.40
Nkatiesari	79.57	Songda	46.19	Hewale	39.42
Sumnut-22	70.57	Sonqu-panqu	21.36	Videza	15.13
LSD (0.05)	7.94	LSD (0.05)	0.56	LSD (0.05)	2.54
CV (%)	7.5	CV (%)	1.1	CV (%)	9.2

4.3.13.2 Seed N

The results for groundnut seed N was significant among the different varieties (Table 4.20). Manipinta produced the highest seed N. Seed N of sumnut-22 was higher than that of Jenkaar, while that of Jenkaar was higher than that of Nkatiesari. Chinese significantly produced the least seed N.

Among the soybean varieties, Salintuya-1 and Sonqu-panqu were statistically at par but the effect of Salintuya-1 was not different from that of Quashie. Jenguma produced the least seed N values.

Among the cowpea varieties, Asontem and Hewale produced similar seed which were the highest. Asomdwee gave higher seed N than all other varieties. Asetenapa and Videza seed N were the least.

Table 4. 20. Seed N of groundnut, soybean and cowpea varieties without inoculation in 2014 major rainy season

Groundnut	Seed N (kg/ha)	Soybean	Seed N (kg/ha)	Cowpea	Seed N (kg/ha)
Chinese	3.16	Jenguma	19.52	Asetenapa	10.76
Jenkaar	9.14	Quashie	21.26	Asomdwee	21.05
Manipinta	13.27	Salintuya-1	23.48	Asontem	25.53
Nkatiesari	5.51	Songda	19.51	Hewale	24.59
Sumnut-22	11.40	Sonqu-panqu	27.14	Videza	10.54
LSD (0.05)	0.48	LSD (0.05)	3.79	LSD (0.05)	1.11
CV (%)	3.6	CV (%)	11.1	CV (%)	3.9

4.3.13.3. Total fixed N

Results for total fixed N for groundnut are presented in Table 4.21. Total fixed N was significantly (P<0.05) different among the groundnut varieties. Manipinta and Jenkaar were similar in the total N fixed. The N fixed by Nkatiesari was significantly higher than that of other varieties. Fixed N of Chinese was the least.

Among the soybean varieties, total N fixed showed significant differences. Songda fixed the highest N. the N fixed by Quashie was higher than the other varieties. Jenguma produced the least fixed N.

For cowpea varieties total fixed N was significant (P<0.05). Hewale fixed the highest N. Nitrogen fixed by Asomdwee was higher than that of other varieties.

Asontem fixed more N than that of Videza and Asetenapa. Asetenapa fixed the least N.

Table 4. 21. Total fixed N of groundnut, soybean and cowpea varieties without inoculation in 2014 major season.

Groundnut	Fixed N (kg/ha)	Soybean	Fixed N (kg/ha)	Cowpea	Fixed N (kg/ha)
Chinese	36.11	Jenguma	42.13	Asetenapa	21.04
	90.62		64.02		36.41
Jenkaar		Quashie		Asomdwee	
	92.97		58.11		34.93
Manipinta		Salintuya-1		Asontem	
	85.08		65.69		64.00
Nkatiesari		Songda		Hewale	
	81.96		48.50		25.67
Sumnut-22		Sonqu-panqu		Videza	
	1.57		0.99		1.05
LSD (0.05)		LSD (0.05)		LSD (0.05)	
			1.2		1.9
CV (%)	1.3	CV (%)		CV (%)	

4.3.13.4. Nitrogen derived from the atmosphere

The results for nitrogen derived from the atmosphere (%Ndfa) for groundnut varieties are presented in Table 4.22 Significant (P<0.05) varietal difference were observed. Manipinta, Nkatiesari, Jenkaar and Sumnut-22 varieties derived similar amount of N from the atmosphere. Chinese derived the least N from the atmosphere.

Ndfa among Soybean varieties was significant (P<0.05). Salintuya-1, Quashie and Songda produced the highest but similar Ndfa. The least Ndfa was recorded by Sonqu-panqu and Jenguma varieties.

Among the cowpea varieties, Hewale was the highest in Ndfa. The Ndfa by Asomdwee and Asontem was similar and higher than that of other varieties. Videza and Asetenapa produced the least value with respect to Ndfa.

Table 4. 22. Percentage Ndfa of groundnut, soybean and cowpea varieties without inoculation in 2014 major rainy season

Groundnut	%Ndfa	Soybean	%Ndfa	Cowpea	%Ndfa
Chinese	64.12	Jenguma	68.07	Asetenapa	51.92
Jenkaar	82.20	Quashie	76.27	Asomdwee	64.74
Manipinta	82.56	Salintuya-1	74.99	Asontem	64.22
Nkatiesari	81.38	Songda	76.55	Hewale	76.35
Sumnut-22	80.38	Sonqu-panqu	71.26	Videza	56.38
LSD (0.05)	5.28	LSD (0.05)	3.26	LSD (0.05)	5.51
CV (%)	4.4	CV (%)	2.9	CV (%)	5.7

4.4 Discussion

4.4.1 Growth and development of varieties

Growth was measured as plant height, canopy width and branch production in the varieties. The crop growth rate as well as relative growth rate were also measured. There were differential crop and varietal responses in all parameters.

4.4.1.1 Plant height

Varietal differences in groundnut with respect to the parameters have been reported (Konlan *et al*., 2013) and attributed to genetic differences. Differences in plant height observed among soybean and cowpea varieties could be attributed to genetic variability (Talaka *et al*., 2013; Haruna *et al*., 2015); Ekpo *et al*. (2012). Agyeman *et al*. (2014) also reported genetic differences in plant height among cowpea varieties. Compatibility of some of the legume varieties with local rhizobia and soil environment might also explain the differences in growth characteristics (Keyser and Li, 1992).

4.4.1.2. Canopy diameter

Canopies are stacks of loose leaves on the plants. The arrangement and direction of canopy help in determining the amount of light capture during photosynthesis. Canopy spread was significantly different among the varieties in all the sampling periods of the three crops. The significant differences observed suggest a great tendency of some crops performing better than others, because the wider the canopy the higher the light capture and subsequently the greater the photosynthetic activity (Matloobi, 1998). It could also be attributed to their genetic differences and interactions with the local environment (Anonymous, 1992).

4.4.1.3 Number of branches

Significant difference were observed in the number of branches recorded among the groundnut and soybean varieties at 4, 6 and 8 WAP. However, varietal differences was not significant in the cowpea varieties at the two sampling periods. Non-significant differences in number of branches among the cowpea varieties contradicts the findings of Ekpo *et al*. (2012) and Agyeman *et al*. (2014) who reported significant difference in the cowpea varieties tested. Significant differences in number of branches among the groundnut and soybean varieties is attributable to the genetic differences or differences in responsiveness by the different varieties of the legumes to the environment (Maurya *et al*., 2014; Haruna *et al*., 2015). Generally, CGR and RGR values at first sampling were higher than the values at the second sampling and this conforms the findings of many workers, who observed decrease in growth rate as a result of increasing canopy size, which may prompt leaf shading (Konlan *et al*., 2013; Olayinka and Etejere, 2015). Decrease in photosynthesis due to ageing may also account for a decline in growth rate at later stages of growth.

4.4.2 Yield and yield components

4.4.2.1 Grain yield

Crop and varietal differences in yield parameters measured in the present study conforms to the reports of many reseachers (Antwi *et al*., 2012; Mulualem *et al*., 2012; Mapuwei *et al*., 2014; Haruna *et al*., 2015) have reported significant differences in yields of the soybean and cowpea varieties. However, Adjei-Nsiah *et al*. (2008) reported non-significant yield difference in the cowpea tested despite large differences in growth habit. Yield differences reported in this trial were probably based on the genetic differences of the varieties since there was no difference in environmental factors.

4.4.2.2 Mean 100 seed weight

Seed weight has been a quality attribute on which many farmers base their selection (Mulualem *et al*., 2012). Significant differences were observed among the varieties, which is probably due to genetic differences. Oyatokun and Oluwasemire (2014), Haruna *et al*. (2015) and Henshaw (2008), have reported differences in seed weight in the varieties they studied. Henshaw (2008) stated that difference in seed weight among cowpea varieties is one of the most discriminating physical property of cowpea that could be used as a criterion for selecting a variety for different end uses.

4.4.2.3 Number pods

There were significant differences in the number of pods per plant among the legumes tested (Table 4.14). Kumar *et al*. (2014) and Maurya *et al*. (2014) reported significant variability in pod production in the varieties studied. Significant difference in pod yield of groundnut varieties irrespective of harvest time starting from physiological maturity has also been reported (Kombiok *et al*., 2012). Ekpo *et al*. (2012) and Agbogidi and Egho (2012) reported significant differences in pod weight among cowpea varieties. Differences in number of pods recorded among the legumes was mainly due to the genetic differences among the varieties.

4.4.2.4 Haulm yield

Legumes tested significantly differed in the haulm produced in 2014. Among the groundnut varieties without inoculation, Jenkaar significantly produced the highest quantity of haulm (Table 4.15). Within the soybean varieties without inoculation, Songda produced the highest quantity of haulm. While among the uninoculated cowpea varieties, Hewale significantly produced the largest quantity of haulm. Significant difference in haulm yield of groundnut varieties conforms to the work of Konlan *et al*. (2013). The significant differences in haulm among cowpea varieties confirms the findings of Omokanye *et al*. (2003) and Antwi *et al*. (2012) and indicates their different abilities to produce dry matter. It may also be a reason for their differences in yield, which meant more yield less haulm and vice versa because of less leaf retention at pod maturity.

4.4.3 Nodulation

Nodules provide a suitable environment for the nitrogenase enzyme complex of bacteria to convert nitrogen gas from the atmosphere into ammonium, which will be assimilated by the plant (Chan and Gresshoff, 2016). All the crops and varieties nodulated freely with the naturalized rhizobia in the soil, although varietal differences was evident. Sarkodie-Addo *et al*. (2006) reported significant difference in nodulation in soybean and stated that soybean lines nodulated freely with natural cowpea bacteria and differences among lines was attributed to genotypic variations. Many workers have reported significant differences in nodule numbers among different varieties of legumes. However, increased number of nodules may not necessarily signify efficiency as many factors affect nitrogen fixation. The process of nodulation in legumes is controlled by efficiency of the local rhizobia, environmental factors, and nutritional factors as well as endogenous plant factors such as phytohormones, plant nodulation reception systems and autoregulation of nodulation.

4.4.4 Nitrogen fixation

There were significant differences among all crop varieties on haulm N, seed N, fixed N and nitrogen derived from the atmosphere. It has been observed that not all symbioses fix N with equal effectiveness, as a given strain of *Rhizobium* will nodulate and fix different amounts of N in symbiosis with a range of cultivars of the same plant species (Hiep *et al*., 2002; Adjei-Nsiah *et al*., 2008; Klogo *et al*., 2016)

Experiment Two

Effects of legume residual nitrogen on growth and grain yield of maize

4.5 Introduction

Optimum yield of crops require supply of nutrients, the most important of which is nitrogen. Most of the depleted soils in Africa are usually low in nitrogen because the inorganic fertilizers are usually costly for many African farmers to procure. One way to address this problem is by incorporating legumes into the cropping system, since they have a special symbiotic relationship with nitrogen-fixing bacteria called *rhizobium* to fix atmospheric nitrogen. Legumes may provide a relatively low-cost method of replacing nitrogen in the soil, enhancing soil fertility and boosting subsequent crop yields (IRRI- CIMMYT, 2009). Legumes may be incorporated into the cropping system through many ways, such as green manuring, intercropping, legume-cereal rotations and leguminous shrubs. Legumes grown in rotation with cereals may be regarded as a double advantage: provides the farmer a useful harvest, while at the same time the haulms are used to improve the fertility of the soil. However, the haulms incorporated in this system may not contain all of the nitrogen fixed by the crop, since much of it is stored in seeds harvested. Nevertheless, with soils of the forest belt, which contain an appreciable quantity of organic matter, this method may prove effective.

Besides the transfer of nitrogen and other nutrients by legume haulms to succeeding cereal crops such as maize, benefits of adding haulms to the soil are relatively high. Addition of legume residues has been reported to reduce soil temperature, crusting of soil surface, evaporation, emergence of weeds, sandblasting of the seedlings and improved rainfall infiltration leading to increase in yield (Newman *et al*., 2014). Most of the studies of nitrogen transfer to cereals conducted with legume haulms used mineral fertilizers to supplement the residual nitrogen. Those that compared the full doses of the fertilizers with some of the legume haulms used crops of less significance to farmers. There is therefore the need to produce maize using haulms left after harvesting grains of economic importance to ascertain if the double advantage (i.e. grains and haulm) can be harnessed.

4.6 Objectives

The objectives of this study were to:

(i) determine the growth and yield of maize following application of legume haulms.

(ii) compare maize growth and grain yield from legume haulms and recommended fertilizer rate application.

4.7 Materials and Methods

Following harvesting of crops from the 2014 major season trial, crop haulm for each plot were spread evenly on their respective plots. To avoid contamination of plots, the field was not ploughed. Emerging weeds were slashed down using cutlass. The maize variety, *Abontem* was planted in each plot at a spacing of 80 x 40 cm at 3 seeds per hole. Immediately following planting, the whole field was sprayed with glyphosate (*N-(phosphonomethyl) glycine*), a broad-spectrum herbicide at the rate of 900 g active ingredient per hectare.

Seedlings were thinned after 2 weeks to 2 per hill. Each replication had a plot attached to their ends, which were planted with the same variety. These plots, however received the recommended fertilizer rate (90 kg N, 60 kg P and 60 kg K/ha) (Adu *et al*., 2014). All cultural practices were timely carried out.

4.8 Results

4.8.1 Maize plant height, leaf area and stem girth

Results of plant height, leaf area and stem girth are as presented in Table 4.23. Varietal differences during all sampling periods were evident. Generally, plant height, leaf area and stem girth of maize plants were higher in the groundnut and cowpea haulm amended plots than soybean haulm plots. Among the varieties, there was no consistent pattern except in soybean plant height, leaf area and stem girth which were consistently higher in the Quashie haulm plots than all the other varieties. At most of the sampling periods for the measured parameters, the recommended fertilizer rate treatment was significantly ($P<0.05$) higher than all other treatment effects.

4.8.2 Grain yield, seed weight and protein content

Results of the above parameters are presented in Table 4.24. Seed yield varied among crops and varieties. There was no consistent pattern within each crop variety. Results shows that all haulm-incorporated plots resulted in significantly higher ($P<0.05$) maize grain yield than the plots that received the recommended fertilizer rates except Asetenapa and Asontem plots. Quashie haulm incorporated treatment produced the highest seed yield.

Mean seed weight among all treatments were not significantly ($P>0.05$) different from one another (Table 4.24).

The highest crude protein content was recorded in the Manipinta haulmincorporated plot (Table 4.24), but this was similar to the recommended fertilizer rate effect and Chinese, Asetenapa, Salintuya-1 and Songda haulm incorporated plots.

Table 4. 23. Plant height, leaf area and stem girth of maize as affected by legume haulms application at 4, 6 and 8 weeks after planting in 2014 minor season.

Parameter	Plant height (cm)			Leaf area (cm^2)			Stem girth (cm)		
	Weeks after planting			Weeks after planting			Weeks after planting		
	4	6	8	4	6	8	4	6	8
Haulms									
Jenkaar	85.65	182.1	210.7	241.3	501.8	589.5	3.58	5.94	6.57
Manipinta	85.25	177.2	210.8	260.0	502.9	590.2	4.00	6.12	6.90
Sumnut-22	86.75	186.0	208.0	265.8	503.7	800.0	3.68	6.00	6.84
Chinese	91.35	183.6	202.8	280.3	500.5	607.2	4.06	5.72	7.35
Nkatiesari	78.35	172.4	192.4	206.6	482.1	588.8	3.24	5.96	8.06
Asetenapa	78.40	159.8	183.8	231.8	443.5	541.5	3.20	5.80	6.58
Asomdwee	89.90	187.2	209.8	290.3	503.8	782.7	4.13	5.82	6.56
Asontem	80.25	161.4	190.8	219.3	418.7	536.5	3.23	4.88	5.66
Hewale	93.50	181.0	202.8	290.4	482.7	613.3	4.21	6.08	6.79
Videza	86.81	177.6	205.4	251.8	442.1	558.5	3.71	5.36	6.28
Jenguma	75.65	153.4	183.5	206.1	388.4	511.1	3.06	5.22	5.97
Quashie	84.25	183.2	203.1	250.6	475.8	583.8	3.87	6.28	6.94
Salintuya-1	83.00	169.6	190.4	233.1	423.7	537.5	3.44	5.08	5.96
Songda	74.15	159.6	189.6	189.8	448.4	549.0	3.23	6.18	7.05

Sonqupanqu	76.95	166.9	195.3	230.4	476.7	820.2	3.41	5.46	6.26
NPK	95.00	185.0	203.8	332.6	542.2	847.6	4.50	6.34	7.18
LSD (0.05)	10.33	26.94	NS	15.71	84.52	45.6	0.33	0.49	0.27
CV (%)	8.6	10.9	8.0	4.4	12.6	5.1	6.3	11.9	2.9

NPK at recommended rate of 90 kg N, 60 kg P_2O_5 and 60 kg K_2O/ha

Table 4. 24. Maize yield, seed weight and crude protein as affected by legume haulms application at harvest in 2014 minor season.

Parameter	Maize yield (kg/ha)	Mean 100seeds (g)	Crude protein (%)
Haulms			
Jenkaar	2266	20.13	11.84
Manipinta	2015	19.80	13.03
Sumnut-22	2255	20.23	11.39
Chinese	2255	20.73	12.30
Nkatiesari	2457	20.83	11.86
Asetenapa	1890	19.58	12.98
Asomdwee	2344	19.43	11.98
Asontem	1999	19.68	12.62
Hewale	2260	20.25	11.69
Videza	2103	20.23	12.22
Jenguma	2090	18.03	12.02
Quashie	2482	20.33	11.30
Salintuya-1	2180	20.38	12.31
Songda	2135	18.50	12.36
Sonqu-panqu	2187	19.33	11.42
NPK	1911	19.43	12.98
LSD (0.05)	99	NS	0.82

CV (%)	3.2	9.3	4.8

NPK at recommended rate of 90 kg N, 60 kg P_2O_5 and 60 kg K_2O/ha

4.9 Discussion

4.9.1 Growth and development of maize

Treatments effects on growth and development of maize were significant throughout the sampling periods except for plant height at 8 WAP. Generally, recommended fertilizer rate application, produced significantly more robust plants at the early stages of growth of the maize (4 WAP). At later stages of growth (6-8 WAP) (Table 4.23), the maize plants treated with the recommended fertilizer rate were similar to many of the haulm treatments. For example, plant height in the recommended fertilizer rate treatment was higher than groundnut haulmincorporated plots at 4 WAP sampling, but at 8 WAP, all but Chinese and Nkatiesari haulm treatments were higher than the recommended fertilizer rate. This means that at early stages of growth, the recommended fertilizer rate, which had readily available nutrients for the plants, supported faster growth than the haulm treatments, which were yet to start decomposing, and releasing the nutrients embedded within them.

Legume haulms release their nutrients only when the soil meet certain requirements of temperature and soil moisture, these conditions are mostly the right environment for the activities of the microorganisms that will decompose them. This also corresponds with the plant time of highest need. So nutrients are released slower than they are from inorganic fertilizers (Liu *et al*., 2014). This slow-release method reduces the risk of nutrient leaching, but it takes time to supply nutrients to plants. In contrast, inorganic fertilizers provide this nutrition in plant-ready form immediately. Crews and Peoples (2004) stated that chemical fertilizers release their nutrients faster into the soil i.e. without the need for decomposition. But it is only upon decomposition and mineralization, that legume haulms release nutrients embedded within them which subsequently become available for uptake by plants (Mwangi *et al*., 2013). In many instances also, haulm decomposition, makes the nitrogen tied up or immobilized until decomposition is complete. Thus temporary immobilization delay their availability to plants during the nutrient transformation processes (Bengtson, 2004; Cabrera *et al*., 2005; Anonymous, 2014).

4.9.2 Yield and yield components of maize

Significant differences were observed between treatments on yield and yield components of maize (Table 4.24). Legume haulms produced higher maize yield and yield components compared to the recommended fertilizer rate. This means that by the reproductive stage, decomposition of haulms might have been completed resulting in higher nutrient release from those treatments. Legume haulms are known to have lower C:N ratio that favour faster mineralization (Cabrera *et al*., 2005). In other studies, legume haulms in combination with mineral fertilizers have been reported to improve yield and yield components of succeeding crops compared to single application of legume haulms (Egbe and Ali, 2010; Gani, 2012; Nyalemegbe and Osakpa, 2012; Olusegun, 2014). Sole application of legume haulms, which outperformed the recommended fertilizer rate application in this trial, contradicts the findings of Habonayo *et al*. (2010) who reported lower yields of yam amended with sole haulms of soybean compared with soybean haulms plus inorganic fertilizers.

Yield increases obtained from legume haulms compared to recommended fertilizer rate application in this trial might have been due to improvement in soil properties and availability of nutrients made by the legume haulms when incorporated into the soil (Egbe and Ali, 2010). Phosphorous availability for example increases with application of legume haulms (Amusan *et al*., 2011). Incorporation of legume haulms not only improve soil properties and increase nitrogen supply, but also increase the supply of P to the subsequent crop (Alamgir *et al*., 2012). Agyenim *et al*. (2015) also reported increment in biomass P after incorporation of legume haulms. It is a well-known fact that application of legume haulms to the soil improves the physico-chemical properties of the soil by increasing the organic matter content, which may also improve the soil structure. Increased organic matter might have improved the CEC, which in turn increased the availability of some other nutrients. Many workers have reported improved soil properties with addition of organic matter (Habonayo *et al*., 2010; Gani, 2012).

Experiment Three

Inoculation and N application on growth, N-fixation and yield of soybean varieties

4.10 Introduction

The incorporation of soybean into the cropping system has been due to its high ability to fix atmospheric nitrogen through the symbiotic association with rhizobia (Dugje *et al*., 2009). In addition, its ability to withstand insect attack has made the cultivation more attractive among the poor farming families. It can also be grown in between trees to improve the fertility of the plantation fields (Shurtleff and Aoyagi, 2009). One of the major problems with soybean is the yield gap within and between countries because of differing environmental conditions. This can be closed by improving crop management practices that will address specific site constraints (Baijukya *et al*., 2013). Maximum yield and utilization can be achieved by selecting among different varieties to obtain the most suitable variety based on the soil and climatic conditions of the local environment (Mapuwei *et al*., 2014). Notwithstanding, other management practices may need to be employed to further improve yields

Artificial inoculation of legumes with appropriate strain of rhizobium can be another effective way of increasing growth and yield thereby closing the yield gap (Tairo and Ndakidemi, 2013). Improved yields of some legumes have been reported with inoculation (Albareda *et al*., 2009). Although yield increment has been reported due to use of inoculants, there is still potential for further yield increase when additional avenues are explored (Mweetwa *et al*., 2014).

It has been shown that supplementary fertilizer application during early growth can lead to improved performance (Cheema and Ahmad, 2000; Ruark, 2009). Previous workers have studied the effect of inorganic N among soybean varieties. However, most of N level used might have been too low. Most of the starter N used in Ghana falls within the range of 20-30 kg N/ha while the recommended NPK in the area of study is 90 kg N, 60 kg P_2O_5 and 60 kg K_2O/ha (Adu *et al*., 2014). An improved approach of this study was to increase the N levels to investigate the effects of such higher levels of N on the soybean performance especially under multiple cropping systems practiced by farmers. This experiment was therefore set up to determine the effect of inoculated soybean and inorganic N on growth, yield and nitrogen fixation.

4.11 Materials and Methods

The study was conducted at the Plantation Crops Section of the Faculty of Agriculture, KNUST during the major rainy season of 2015. Random samples of the soil of the experimental site were collected at depths of 0–15 cm and 15-30 cm, following ploughing and harrowing of the field to determine the initial fertility status. Four varieties of soybean (Salintuya-1, Songda, Sonqu-panqu and Quashie) were inoculated with legume fix inoculant at 10g/ 1kg of seeds and three levels of inorganic N fertilizer at the rate of 0, 30 and 60 kg N ha^{-1}. The inoculant was applied using the method of Woomer *et al*. (1994). Maize variety (*Obaatanp*a) was used as a reference crop to determine nitrogen fixation. Seeds were obtained from the Crops Research Institute of the Council for Scientific and Industrial Research, Fumesua near Kumasi. The treatments were arranged in a randomized complete block design (RCBD) and replicated four times. Seeds were sown on 11th May 2015 at 2 seeds per hole at a spacing of 75 cm x 5 cm in plots measuring 2 m x 5 m. Thinning was done to one plant per hill two weeks after seedling emergence. Plots were weeded with a hoe twice at four and eight weeks after planting.

4.12 Results

4.12.1 Plant height

Plant height results following inoculated soybean and inorganic N application at 8 WAP are presented in Table 4.25. Varietal differences following sole inoculation was not significantly different (P>0.05). Inoculated soybean and inorganic N application (30 and 60 kg N/ha) did not result in significant changes except Sonqupanqu that produced significantly taller plants than all other varieties at 30 kg/ha N application.

Table 4. 25. Plant height of soybean as affected by inoculated soybean and inorganic N at 8 WAP in 2015 major rainy season.

	Plant height (cm)		
	N rates in kg/ha		
Inoculated	0	30	60
Quashie	59.8	60.9	56.3
Salintuya-1	59.7	61.7	59.6
Songda	62.0	60.6	59.6
Sonqu-panqu	60.7	73.8	66.0

LSD (0.05)	7.8
CV (%)	8.7

4.12.2 Canopy diameter

The results of canopy diameter measured at 8 WAP are presented in Table 4.26. Sole inoculation (0 kg N/ha) did not significantly affect canopy diameter. Inorganic N application significantly affected canopy diameter at the two rates. At 30 kg/ha, Songda produced significantly lower canopy diameter than Quashie, Salintuya-1 and Sonqu-panqu varieties. At 60 kg/ha N, Sonqu-panqu produced was significantly higher canopy diameter than all other varieties except Salintuya-1. Generally, canopy diameter at 30 kg/ha N was higher than at 60 kg/ha N application.

Table 4. 26. Canopy diameter of soybean as affected by inoculated soybean and inorganic N at 8 WAP in 2015 major rainy season

	Canopy diameter (cm)		
	N rates in kg/ha		
Inoculated	0	30	60
Quashie	51.80	53.97	49.56
Salintuya-1	49.28	53.06	50.47
Songda	51.59	50.61	47.04
Sonqu-panqu	50.47	55.30	52.99
LSD (0.05)	2.93		
CV (%)	4.0		

4.12.3 Number of branches

Number of branches were significantly affected by inoculation alone (0 kg N/ha) (Table 4.27). The Sonqu-panqu produced significantly lower number of branches than those of Quashie and Songda varieties. Inorganic N application did not affect branch production.

Table 4. 27. Number of branches of soybean as affected by inoculation and inorganic N at 8 WAP in 2015 major season.

	Number of branches		
	N rates in kg/ha		
Inoculated	0	30	60
Quashie	19.70	18.55	18.90
Salintuya-1	17.65	20.35	19.60
Songda	20.40	17.35	16.40
Sonqu-panqu	14.25	18.40	16.95
LSD (0.05)	4.11		
CV (%)	15.7		

4.12.4 Crop growth rate

The result for crop growth rate (CGR) is as shown in Table 4.28. There was significant interaction of inoculated soybean and inorganic N on CGR at the two sampling periods. At the first stage (4-6 WAP), under sole inoculation, Songda produced the highest dry matter accumulation. Sonqu-panqu produced significantly higher dry matter than other varieties. Quashie significantly recorded the least dry matter accumulation. Salintuya-1 obtained the highest CGR at 30 kg/ha. Quashie, Songda and Sonqu-panqu varieties were significantly similar and the least. At 60 kg/ha N application, the Sonqu-panqu varietal effect was significantly lower than that of all other varieties.

The second stage of CGR showed significant (P<0.05) inoculated soybean and inorganic N interaction. Salintuya-1 accumulated significantly the highest dry matter under sole inoculation except that of Quashie. At 30 kg/ha N application, Salintuya-1 and Sonqu-panqu varieties produced significantly the highest dry matter. At 60 kg/ha, the Salintuya-1 varietal effect was the highest, and this was significantly higher than all other varietal effects. The Songda varietal effect was the least.

Table [1]. 28. Crop growth rate as affected by inoculated soybean and inorganic N in 2015 major rainy season.

	Crop growth rate (g m^2 wk^{-1})					
	4-6WAP			6-8WAP		
	(N rates kg/ha)			(N rates kg/ha)		
Inoculated	0	30	60	0	30	60
Quashie	1.50	3.25	3.75	11.25	11.38	7.25
Salintuya-1	2.38	6.25	4.38	12.38	13.88	12.62

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[1] .12.5 Relative growth gate

The relative growth rate (RGR) as affected by inoculated soybean and inorganic N are presented in Table 4.29. There was significant (P<0.05) interaction at the two stages of RGR. At the first stage (4-6 WAP) under sole inoculation, Songda and Sonqu-panqu varieties, which had similar effects, produced significantly higher

Songda	5.88	3.75	4.12	9.88	8.50	6.00
Sonqu-panqu	4.38	3.38	2.62	4.75	14.75	10.50
LSD(0.05)	1.05			1.52		
CV (%)	19.2			10.3		

RGR than both Quashie and Salintuya-1 varieties. At 30 kg/ha N, the Salintuya-1 varietal effect was significantly higher than all other varietal effects. All other varietal effects were similar.

At the second sampling under sole inoculation, Quashie and Salintuya-1 varieties had similar effects and this was significantly the highest. The effect of Songda was significantly higher than that of Sonqu-panqu. Following the application of 30 kg/ha N, Sonqu-panqu varietal effect was the highest, while the effect of Songda was the least. At 60 kg/ha N, the effect of Sonqu-panqu was the highest, followed by Salintuya-1 and the least effect was produced by Quashie and Songda varieties.

Table 4. 29 . Relative growth rate as affected by inoculated soybean and inorganic N in 2015 major rainy season.

	Relative growth rate (g g^{-1} wk^{-1})					
	4-6WAP			6-8WAP		
	(N rates kg/ha)			(N rates kg/ha)		
Inoculated soybean	0	30	60	0	30	60
Quashie	0.05	0.10	0.10	0.27	0.24	0.16
Salintuya-1	0.07	0.18	0.15	0.27	0.26	0.24
Songda	0.18	0.11	0.12	0.21	0.19	0.14
Sonqu-panqu	0.19	0.12	0.10	0.16	0.36	0.29

LSD(0.05)	0.02	0.03
CV (%)	10.2	8.8

4.12.6 Grain yield

Grain yield as affected by inoculated soybean and inorganic N are presented in Table 4.30. Significant (P<0.05) interaction between inoculated soybean and inorganic N was observed in soybean yield. Under sole inoculation, Sonqu-panqu produced significantly higher yield than all other varieties. Grain yield of Quashie and Salintuya-1 varieties were similar, but either effect was significantly higher than yield of Songda. At both N rates, yield of Sonqu-panqu was significantly higher than all other varietal yield. Under both N rates, grain yield of Quashie was significantly higher than that of Salintuya-1 and Songda. Salintuya-1 and Songda produced the lowest grain yield under both N rates.

Table 4. 30. Grain yield as affected by inoculated soybean and inorganic N in 2015 major rainy season.

	Grain yield (kg/ha)		
	N rates in kg/ha		
Inoculated soybean	0	30	60
Quashie	353.2	408.5	365.8
Salintuya-1	341.2	318.8	224.5
Songda	272.8	314.0	236.8
Sonqu-panqu	585.2	685.2	539.8
LSD (0.05)	33.62		

CV (%)	6.0

4.12.7 Mean seed weight

The results for mean 100 seed weight as affected by inoculated soybean and inorganic N are presented in Table 4.31. Significant (P<0.05) interaction between the two factors was observed. Under all conditions, Sonqu-panqu produced significantly the heaviest seeds than the other varieties, all of which had similar seed weight.

4.12.8 Number of pods

Number of pods for soybean varieties as affected by inoculated soybean and inorganic N rates are presented in Table 4.32. Significant (P<0.05) interaction between the two factors was recorded. Under sole inoculation, Sonqu-panqu produced the highest number of pods but this was significantly higher than that of Quashie only. Quashie produced significantly lower number of pods than Songda and Salintuya-1 varieties. Pod number of the Songda was the highest following application of 30 kg/ha N. The number of pods of Sonqu-panqu was also higher than that of Quashie and Salintuya-1. At 60 kg/ha N, pods number was the highest in the Sonqu-panqu, followed by that of Songda, Quashie and Salintuya-1 varieties.

Table 4. 31. Mean seed weight as affected by inoculated soybean and inorganic N in 2015 major rainy season.

	Seed weight (g)		
	N rates in kg/ha		
Inoculated soybean	0	30	60
Quashie	11.80	10.43	10.88

Salintuya-1	10.18	11.18	10.45
Songda	10.20	10.25	9.88
Sonqu-panqu	13.18	13.38	12.93
LSD (0.05)	1.55		
CV (%)	9.6		

Table 4.32. Number of pods as affected by inoculated soybean and inorganic N in 2015 major season.

	Number of pods		
	N rates in kg/ha		
Inoculated soybean	0	30	60
Quashie	122.19	129.74	103.62
Salintuya-1	154.55	134.29	102.45
Songda	155.70	205.42	153.16
Sonqu-panqu	158.55	185.20	162.29
LSD (0.05)	7.53		
CV (%)	3.6		

4.12.9 Haulm yield

The results of soybean haulm as affected by inoculated soybean and inorganic N are presented in Table 4.33. Significant (P<0.05) interaction between the factors was recorded. Under sole inoculation, haulm yield of Salintuya-1 and Songda were similar and were the highest. Haulm yield of Quashie was significantly higher than that of Sonqu-panqu. Following application of 30 kg/ha N, the highest haulm yield was produced by Quashie, followed by Songda, Salintuya-1 and Sonqu-panqu. At 60 kg/ha N, haulm yield of Quashie was also the highest, followed by Salintuya-1, Songda and Sonqu-panqu varieties.

Table 4.

33. Haulm yield as affected by inoculated soybean and inorganic N in 2015 major rainy season.

	Haulm yield (t/ha)		
	N rates in kg/ha		
Inoculated soybean	0	30	60
Quashie	2.95	3.89	3.93
Salintuya-1	3.10	3.32	2.90
Songda	3.07	3.46	2.77
Sonqu-panqu	2.62	3.15	2.36
LSD (0.05)	0.18		
CV (%)	4.1		

4.12.10 Nodule number

Results for nodule number of soybean are presented in Table 4.34. Significant (P<0.05) interaction was recorded between inoculated soybean and inorganic N dose. Under sole inoculation, Sonqu-panqu significantly produced the highest number of nodules than all the other varieties except that of Quashie. Number of nodules of Quashie was also higher than that of Salintuya-1 and Songda varieties. At 30 kg/ha N, number of nodules of Quashie and Sonqu-panqu were similar, but either effect was significantly higher than that of Salintuya-1 and Songda varieties. At 60 kg/ha N, Sonqu-panqu produced significantly higher number of nodules than all other varieties. Nodule number of Quashie was also higher than for both Salintuya-1 and Songda varieties.

Table 4.34. Number of nodules as affected by inoculated soybean and inorganic N in 2015 major rainy season

	Number of nodules		
	N rates in kg/ha		
Inoculated soybean	0	30	60
Quashie	68	51	44
Salintuya-1	50	34	21
Songda	54	35	29
Sonqu-panqu	76	58	58
LSD (0.05)	8.5		
CV (%)	12.2		

4.12.11 Percent effective nodules

Significant (P<0.05) interaction was observed between the two factors (Table 4.35). Under sole inoculation, Salintuya-1 recorded significantly the highest effective nodules than all other varieties. Percent effective nodules of Sonqu-panqu was the lowest, but this was similar to that of the Quashie. At both N rates, the Salintuya-1 varietal effect was significantly higher than all other varieties. Also at both N rates percent effective nodules in the Quashie was the lowest.

4.12.12 Nodule dry weight

Nodule dry weight as affected by inoculated soybean and inorganic N is presented in Table 4.36. There was significant inoculated soybean and inorganic N interaction

Table 4.

on nodule dry weight. Under sole inoculation, Salintuya-1and Sonqu-panqu produced significantly higher nodule dry weight than those of Quashie and Songda varieties. The effect of Sonqu-panqu was also higher than that of Quashie only. At

30 and 60 kg/ha N application, nodule dry weight of Sonqu-panqu were significantly higher (P<0.05) than that of all other varieties. In both occasions, the nodule dry weight of Quashie was significantly lower than all other varieties.

Table 4. 35. Percent effective nodules as affected by inoculated soybean and Inorganic N in 2015 major rainy season.

	Percent effective nodules		
	N rates in kg/ha		
Inoculated soybean	0	30	60
Quashie	72.50	49.50	48.50
Salintuya-1	84.00	76.00	74.00
Songda	75.75	60.00	59.50
Sonqu-panqu	69.00	61.00	61.00
LSD (0.05)	6.03		
CV (%)	6.4		

Table 4. 36. Nodule dry weight as affected by inoculated soybean and inorganic N in 2015 major rainy season

	Nodule dry weight (g)		
	N rates (kg/ha)		
Variety	0	30	60
Quashie	0.45	0.31	0.30
Salintuya-1	0.53	0.48	0.46
Songda	0.47	0.38	0.37
Sonqu-panqu	0.52	0.64	0.55
LSD (0.05)	0.05		

CV (%)	7.2

4.12.13 Nitrogen fixed

4.12.13.1 Haulm N

The effect of the interaction was significant (P<0.05) on haulm N. Under sole inoculation, Songda and Salintuya-1 varieties were similar and produced the highest haulm N; however, the effect of Salintuya-1 was not different from that of Quashie and Sonqu-panqu varieties. Following application of 30 kg/ha N, haulm N of Quashie and Songda was the highest while that of Salintuya-1 and Sonqu-panqu varieties was the least. At 60 kg/ha N, Quashie produced the highest haulm N. The haulm N of Salintuya-1 and Songda varieties was similar and higher than that of Sonqu-panqu. Sonqu-panqu varietal effect was the least.

Table 4. 37. Haulm N as affected by inoculated soybean and inorganic N at harvest in 2015 major rainy season

	Haulm N (kg/ha)		
	N rate (kg/ha)		
Inoculated soybean	0	30	60
Quashie	56.92	77.13	83.44
Salintuya-1	60.21	68.86	56.05
Songda	65.16	77.24	55.47
Sonqu-panqu	53.58	60.52	48.68
LSD (0.05)	8.06		
CV (%)	8.8		

4.12.13.2 Seed N

There was significant (P<0.05) interaction between the two factors with respect to seed N (Table 4.38). Under sole inoculation, seed N of Sonqu-panqu was the highest. The seed N of Quashie and Salintuya-1 varieties were similar and significantly higher than that of Songda. Following application of 30 kg/ha N, the highest seed N was produced by Sonqu-panqu. The seed N of Quashie was higher than that of Songda and Salintuya-1 varieties, while Salintuya-1 produced the least.

At 60 kg/ha N, the seed N of Sonqu-panqu was also the highest. The seed N of Quashie was higher than that of Salintuya-1 and Songda.

Table 4. 38. Seed N as affected by inoculated soybean and inorganic N at harvest in 2015 major rainy season

	Seed N (kg/ha)		
	N rate (kg/ha)		
Inoculated soybean	0	30	60
Quashie	8.40	12.04	9.04
Salintuya-1	8.85	7.17	2.70
Songda	4.42	7.29	2.76
Sonqu-panqu	20.66	26.51	18.92
LSD(0.05)	0.87		
CV (%)	5.7		

4.12.13.3 Fixed N

There was significant (P<0.05) interaction between inoculated soybean and inorganic N rates (Table 4.39). Under sole inoculation, fixed N of Sonqu-panqu, Salintuya-1 and Songda were similar and the highest, while Quashie, which was not significantly different from Salintuya-1 and Songda varieties, produced the least fixed N. Following application of 30 kg/ha N, Quashie, Songda and Sonqupanqu varieties produced the highest fixed N. At 60 kg/ha N, the highest fixed N was produced by Quashie, while the least fixed N was produced by Salintuya-1, Songda and Sonqu-panqu varieties.

Table 4. 39. Fixed N as affected by inoculated soybean and inorganic N at harvest in 2015 major rainy season

	Fixed N (kg/ha)		
	N rate (kg/ha)		
Inoculated soybean	0	30	60
Quashie	65.33	89.16	92.49
Salintuya-1	69.06	76.03	58.74
Songda	69.58	84.54	58.23
Sonqu-panqu	74.24	87.03	67.60
LSD(0.05)	8.64		
CV (%)	8.1		

4.12.13.4 Percent nitrogen derived from the atmosphere

There was significant (P<0.05) interaction between inoculated soybean and inorganic N (Table 4.40). Under sole inoculation, there was no significant difference between the varieties. Following application of 30 kg/ha N, Quashie, Songda and Sonqu-panqu varieties were similar and produced the highest nitrogen derived from the atmosphere. Nitrogen derived from the atmosphere of Salintuya1 was the least. At 60 kg/ha N, Quashie produced the highest nitrogen derived from the atmosphere, while Salintuya-1 and Songda varieties were similar and significantly the least.

Table 4. 40. Percent nitrogen derived from the atmosphere as affected by inoculated soybean and inorganic N at harvest in 2015 major rainy season

	Nitrogen derived from the atmosphere (%)		
	N rate (kg/ha)		
Inoculated soybean	0	30	60
Quashie	76.95	81.99	82.27
Salintuya-1	77.86	79.21	74.86
Songda	77.87	81.22	74.73
Sonqu-panqu	78.89	81.48	76.97
LSD(0.05)	2.08		
CV (%)	1.8		

4.13 Discussion

4.13.1 Growth and development

Growth was measured as plant height, canopy diameter, number of branches and relative growth rate (Tables 4.25, 4.26, 4.27 and 4.29). There was significant interaction between inoculated soybean varieties and inorganic N rates in all the sampling periods for plant height. Plants of the Sonqu-panqu were the tallest.

Varietal response to inorganic N rates on plant height was only significant with Sonqu-panqu in which optimum plant height was obtained at 30 kg/ha N. Response of inorganic N of Sonqu-panqu and non-response of the other varieties to inorganic

N suggests that the different varieties had different responses to inorganic N. Significant increase in plant height due to application of sulphur fertilizer to inoculated soybean has been reported (Hussain *et al*., 2011). Mandic *et al*. (2015) reported significant interaction of soybean cultivars and fertilizer treatments on plant height when they applied 45 kg N ha^{-1} urea prior to planting. The result obtained with Sonqu-panqu in this study contradicts the earlier findings of Mehmet

(2008) who reported maximum plant height of a soybean variety at 60 and 90 kg/ha N at an arrived optimum plant spacing. Mehmet (2008) reported that nitrogen increases yield by influencing some agronomic and quality parameters. Utilization of more nitrogen in some varieties may coincide with the high N demand of the crop and this may consequently translate to high yield (Ruark, 2009).

There was interaction of inoculated soybean and inorganic N on canopy diameter among the varieties. Most varieties recorded highest effects following N application at 30 kg N/ha rate. Reports indicate soybean plant canopy increased with fertilizer applications. Application of phosphorus has been reported to significantly affect canopy spread of soybean. For example, Ahiabor *et al*. (2014) found that optimum canopy was obtained at 45 kg P ha^{-1}. Results of the other growth parameters showed significant interaction at N rates. The indication is that for either sole inoculation, or application of N, significant interaction exists, hence growers must identify the best N application to each variety.

4.13.2 Yield and yield components

4.13.2.1 Grain yield

Results from this study indicated different yield responses of soybean varieties to sole inoculation (Table 4.30). This probably indicated differences in compatibility of the soybean genotypes to the inoculant used. Differences in yield of soybean varieties under sole inoculation have been reported (Kumaga and Ofori, 2004; Solomon *et al*., 2012). Different responses of soybean varieties were also observed with the combined application of inoculant and inorganic N at both rates. This suggests that some inoculanted soybean varieties were more tolerant to combined N than others. Dogra and Dudeja (1993) observed that sensitivity of symbiosis in legumes to combined N is strongly dependent on the plant and *rhizobium* interaction and not on the individual plant or microsymbiont. However, it has been reported that when an efficient symbiosis is established, it is not necessary to use inorganic N (Mendes *et al*., 2003).

4.13.3 Nodulation

Significant ($P<0.05$) interaction was recorded between inoculated soybean and inorganic N rates (Tables 4.34, 4.35 and 4.36). Under sole inoculation, Nodulation differed among inoculated soybean varieties. Several authors (Sarkodie-Addo *et al*., 2006; Konlan *et al*., 2013) have reported such varietal differences in nodulation. Furthermore, nodulation was adversely affected by N application. Nodulation decreased between 20-35% when N was applied at 30 kg/ha with inoculation. Urea application up to 40 kg/ha decreased nodulation compared to the control of no N

(Mendes *et al*., 2003). Number of nodules was significantly reduced because of application of starter N, in a study with *Pisum sativum* L (Achakzai, 2007).

4.13.4 Nitrogen fixation

Results of haulm N, seed N and fixed N showed significant ($P<0.05$) interaction between inoculated soybean and inorganic N rates (Tables 4.37, 4.38, 4.39). This suggests that the inoculated soybean varieties had different N requirements for N fixation. For example, for sole inoculation, difference responses to inoculation was observed. Differences in haulm and seed N due to inoculation conforms to report of Mulongoy (2015) that a strain of *Rhizobium* can nodulate and fix different amount of nitrogen with a range of cultivars of the same plant species.

Besides the above, the N rates affected the observed parameters, where different varieties responded to different N rates, however, in most varieties the optimum was produced at 30 kg N/ha. This shows that beyond 30 kg N/ha, inorganic N application was not beneficial in nitrogen fixation. Most legumes do not respond to applied nitrogen (Robert and Idowu, 2015). Because large quantities of fertilizer N inhibits N fixation, but low doses of fertilizer N can stimulate early growth of legumes and increase their overall N fixation (Mulongoy, 2015). However, some high yielding cultivars may require additional N to complement their growth and subsequently yield. Increased yield due to increased utilization of N has been reported (Bekele *et al*., 2016).

Experiment Four

Effect of recommended fertilizer rate application and inoculated soybean haulms on growth, yield and quality of maize

4.14 Introduction

The transfer of nutrients from legume haulms to subsequent cereal crops has been reported by many workers to improve yields. The major concern is mostly the nitrogen made available to the succeeding cereals through decomposing legumes haulms which is not sufficient, because nitrogen is considered the most important limiting nutrient in tropical agriculture (IRRI- CIMMYT, 2009). Since evidence exist as to such benefits of legume haulms, efforts recently focused mainly on improving the nitrogen fixing abilities of these legumes, so that more nitrogen can be harvested from the system, which can be ultimately transferred to the cereal crops. These measures in the end can greatly reduce the dependence of farmers on mineral fertilizers, which are not only costly, but also detrimental to the ecosystem (Bundy *et al*., 1997). To improve the amount of nitrogen harvested, the efficiency of the BNF system must be improved, so that more nitrogen can be fixed and subsequently the haulm quality improved.

Reports indicate that farmers can get the most benefit from inoculation when they combine it with good crop management practices. Thus, it is important to use inoculants with other inputs that improve the health and yield of the crops (Burdass, 2002). Inoculation of soybean with *Bradyrhizobium japonicum* coupled with different starter doses of phosphorus in an experiment was reported to significantly increase shoot nitrogen content compared to the un-inoculated and inoculated with no starter doses of phosphorus (Bekere, 2012). Since, the resulting haulm of legumes treated with inoculants and inorganic N are expected to contain more N in their haulms, a trial was set up to investigate how effective is the N transferred, to succeeding maize crop. Therefore the objectives of the study were:

(i) To determine the growth and yield of maize under inoculated soybean haulms.

(ii) To compare inoculated soybean haulms with recommended fertilizer rate application.

4.15 Materials and methods

Following crop harvesting in experiment three, soybean haulms from each plot were returned unto their respective plots. To avoid plots from mixing with one another, the field was not ploughed but slashed using cutlass prior to planting of maize on the plots. An additional plot was added at the end of each replication where the same maize variety was sown, but this plot received the recommended fertilizer rate (90 kg N, 60 kg P_2O_5 and 60 kg K_2O/ha) (Adu *et al*., 2014).

The maize variety (*Abontem*) was planted at a rate of 3 seeds per hill with a spacing of 80cm x 40cm. Glyphosate (*N-(phosphonomethyl) glycine*), a broad-spectrum systemic herbicide was applied at the rate of 900 g active ingredient per hectare immediately after planting. Seedlings were thinned to two per stand two weeks after planting. Weeding was manually done with hoe at fourth and sixth weeks after emergence. In this trial, *Lambda-cyhalothrin* was applied at the rate of 600 ml ha^{-1} as recommended by manufacturer to control some caterpillars emerging from the decomposing haulms.

4.16 Results

4.16.1 Plant height, leaf area and stem girth

Results of the above parameters are shown in Table 4.41. Haulm incorporation did not significantly affect all the parameters on all sampling days. However, the effect of recommended fertilizer treatment on all parameters for all sampling periods were significantly higher than those from the haulm incorporated plots.

4.16.2 Grain yield, seed weight and protein content.

Results of these parameters are presented in Table 4.42. Haulm incorporation significantly affected maize yield. Generally, Quashie haulm irrespective of N application produced the highest grain yield. Lowest grain yield was produced from Salintuya-1 haulm plots. Soybean variety interacted with N rate to affect maize grain yield. For Quashie plots, the highest grain yield resulted from inoculation only treatment, whilst N application reduced grain yield. This was also the case for Sonqu-panqu. With Salintuya-1, maize grain yield increased from inoculation to 30 and to 60 kg/ha. For Songda, application of 60 kg/ha N reduced maize grain yield. The recommended fertilizer rate treatment supported higher maize yield than haulm-incorporated plots. Seed weight results followed similar pattern as that of grain yield. For Quashie plots, application of fertilizer N to inoculation reduced mean seed weight, whereas this caused increased seed weight in Salintuya-1 plots. For Songda plots, seed weight increased up to 30 kg/ha N and subsequently declined. Adding fertilizer N to Sonqu-panqu resulted in haulms that reduced seed weight of maize. Seed weight of the recommended fertilizer treatment was similar to most of the haulm-incorporated plots.

For crude protein, the recommended fertilizer treatment effect was significantly lower than most of the haulm-incorporated plots. Incorporation of Quashie haulms resulted in highest crude protein content.

Table 4. 41. Plant height, leaf area and stem girth of maize as affected by soybean haulms at 4, 6 and 8 weeks after planting in 2015 minor rainy season

Parameter	Plant height (cm)			Leaf area (cm^2)			Stem girth (cm)		
	Weeks After Planting			Weeks After Planting			Weeks After Planting		
Haulms	4	6	8	4	6	8	4	6	8
V1N0	43.02	98.05	132.1	87.2	421.6	536.18	0.93	3.29	4.14
V1N1	41.33	91.75	131.9	72.7	414.4	561.33	0.78	3.11	3.84
V1N2	38.12	91.80	127.4	63.7	346.4	493.40	0.81	2.79	4.04
V2N0	32.65	82.55	113.1	51.8	298.7	455.00	0.62	2.45	3.33
V2N1	42.00	88.70	125.9	76.5	362.6	472.01	0.77	2.79	3.53
V2N2	39.65	89.80	121.8	74.1	383.7	495.56	0.74	3.32	3.89
V3N0	42.08	92.20	125.0	76.1	363.1	429.06	0.86	2.69	3.65
V3N1	42.60	96.20	133.3	84.0	410.1	552.30	0.80	3.35	3.83
V3N2	40.00	91.00	131.1	70.6	370.3	456.87	0.75	2.75	3.42
V4N0	40.03	98.00	136.9	73.5	564.3	495.48	0.80	3.21	3.75
V4N1	41.18	85.05	121.9	81.0	323.9	457.02	0.77	2.54	3.30
V4N2	42.80	90.20	118.2	76.2	380.0	428.00	0.80	2.78	3.50
NPK	50.56	132.95	164.1	110.1	645.4	740.89	1.12	5.02	5.41
LSD (0.05)	3.06	5.71	10.56	4.41	21.10	59.57	0.07	0.29	0.31
CV (%)	5.2	4.2	5.7	4.0	3.6	8.2	6.0	6.6	5.6

V1= Quashie, V2= Salintuya-1, V3= Songda, V4= Sonqu-panqu. N0= 0 kg N/ ha, N1= 30 kg N/ha, N2= 60 kg N/ha, NPK at recommended rate of 90 kg N, 60 kg P_2O_5 and 60 K_2O/ha

Table 4. 42. Grain yield, 100 seed weight and crude protein of maize as affected by soybean haulms at harvest in 2015 minor rainy season

Parameter	Maize yield (kg/ha)	seed weight (g)	Crude protein (%)
Haulm			
V1N0	1483	20.03	10.58
V1N1	1407	18.30	11.30
V1N2	1274	15.53	12.06
V2N0	963	15.58	13.19
V2N1	1031	16.88	12.78
V2N2	1270	17.10	11.87
V3N0	1185	16.85	12.00
V3N1	1497	18.20	10.56
V3N2	1192	16.40	12.59
V4N0	1394	18.23	10.86
V4N1	995	16.45	12.75
V4N2	990	17.10	12.97
NPK	1772	17.63	10.26
LSD (0.05)	77	0.84	0.92
CV (%)	4.2	3.4	5.4

V1= Quashie, V2= Salintuya-1, V3= Songda, V4= Sonqu-panqu. N0= 0 kg N/ ha, N1= 30 kg N/ha, N2= 60 kg N/ha, NPK at recommended rate of 90 kg N, 60 kg P_2O_5 and 60 K_2O

4.17 Discussion

4.17.1 Growth and development of maize

Treatments effect on maize plant height, leaf area and stem girth was significant. The recommended fertilizer treatment produced significantly better growth parameters than all the haulm treatments throughout the sampling periods (Table 4.41). Significant lower response of the haulm treatments with respect to maize was probably because of the different patterns of nutrient release by inorganic fertilizers and legume haulms, because inorganic fertilizers release their nutrients faster using the available moisture than the decomposing legume haulms (Suge *et al*., 2011). One of the main differences between organic and inorganic fertilizers is the timing and rate of nutrient release. Unlike inorganic fertilizers, nutrients in crop haulms are not immediately available to plants until after mineralization (Mahmoud *et al*., 2009; Bi *et al*., 2010; Faisal *et al*., 2013).

Different rates of disappearance of dry matter of incubated haulms in a study by Mwangi *et al*. (2013) indicated their differences in nutrient release rates. The quantity of haulms and the nutrients contained may also trigger differences in growth and development of the maize plants. For example, Quashie had more haulms and this has shown in a way better cumulative growth response than the haulms from other varieties.

4.17.2 Yield and yield components

There was significant difference between the treatments on maize grain yield. The recommended fertilizer rate treatment significantly produced higher maize yield. Lower response of the haulms on the measured yield parameters was probably because of the drying and rewetting events as a result of dry spells experienced during the minor rainy season, as decomposition is only possible through the activity of microorganisms with sufficient moisture. Haulm decomposition and nutrient release have been reported to be affected by many factors including soil moisture, which is paramount for the effective activity of the microorganisms and subsequent nutrients release (Thönnissen *et al*., 2000; Rosenani *et al*., 2003; Bengtson, 2004; Cabrera *et al*., 2005; Alamgir *et al*., 2012; Mwangi *et al.,* 2013; Anonymous, 2014). Results from this study have shown great inconsistency in the effects of the haulms on maize yield. But it is believed that the major factor which affect haulm breakdown and nutrient release is the quality of haulms, when other factors like soil texture, temperature and moisture are held constant. Application of high quality haulms hasten nutrient release while the opposite is the case with low quality haulms. Hence, manipulating the haulm quality through inorganic N application may allow more nutrients transfer to the succeeding crop (Bhuiyan *et al*., 1991). Other reports have a contrasting view, that soybean haulm does not leave much nitrogen after harvest and nitrogen fixation by soybean may not be a major factor in overall N fertilizer replacement effect of soybean to succeeding maize crop. Some workers have reported no consistent link between previous soybean haulm N and nitrogen fertilizer replacement value (Ketterings *et al*., 2007; Heard, 2012).

Quashie produced the highest quantity of haulms among the other varieties and this has manifested in higher yield of maize produced by the Quashie haulms. The quantity of haulm N in haulm is directly related to the amount of the haulm and the amount of N fixed is affected by the total haulm yield (Hancock, 2009). Diaz *et al*. (2009) also reported that fertilizer N application to inoculated or uninoculated soybean increased plant dry matter. Qamar *et al*. (2014) have reported nonsignificant difference in crude protein of oats because of residual N from crop haulms even though the haulms applied differed in their protein content. Sebetha *et al*. (2015) also reported that increasing levels of nitrogen increased the protein content of maize grains, but this pattern was not consistent with the present study (Table 4.42).

4.18.0 Benefit to cost ratio of groundnut, cowpea and soybean.

Results for the benefit and benefit to cost ratio of groundnut, soybean and cowpea production are presented in Table 4.43. highest benefit was produced by the cowpea variety Asontem (GH¢ 4332), while the least benefit was produced by Asetenapa (GH¢ 1480) also a cowpea variety. Generally, more profit was accrued by the cowpea (GH¢ 7393) followed by the groundnut and soybean. The best BCR was however obtained by Asontem (2.93), a cowpea variety while the least BCR was obtained by Asetenapa (1.00) from cowpea with a break-even.

4.18.1 Benefit to cost ratio of maize using haulms and recommended fertilizer rate.

Results for benefit and benefit to cost ratio of maize produced with recommended fertilizer and legume haulms are presented in table 4.44. The highest benefit was obtained by Quashie haulm (GH¢ 3724) while the least benefit was obtained by

Asetenapa (GH¢ 2835). Generally, most legumes haulm were more profitable than the recommended fertilizer treatment. On the other hand, Asomdwee (1.89) a cowpea variety obtained the best BCR, while the Manipinta (1.13) a groundnut variety produced the least BCR. Maize production was generally more feasible than the legume.

Table 4. 43. Benefit to cost ratio as of groundnut, cowpea and soybean varieties in 2014 major rainy season.

Parameter	Net benefit (GH¢)	Benefit to cost ratio
Variety		
Chinese	1904	1.32
jenkaar	2028	1.41
Manipinta	2320	1.61
Nkatiesari	1588	1.10
Sumnut-22	2468	1.72
Asetenapa	1480	1
Asomdwee	3270	2.21
Asontem	4332	2.93
Hewale	3039	2.05
Videza	2154	1.46
Jenguma	1644	1.14
Quashie	1654	1.15
Salintuya-1	1698	1.18
Songda	1576	1.10
Sonqu-panqu	2362	1.64

Table 4. 44. Benefit to cost ratio as affected by legume haulms and recommended fertilizer in 2014 minor rainy season.

Parameter	Net benefit (GH¢)	Benefit to cost ratio
Haulms		
Chinese	3383	1.23
jenkaar	3400	1.30
Manipinta	3022	1.13
Nkatiesari	3686	1.71
Sumnut-22	3383	1.27
Asetenapa	2835	1.70
Asomdwee	3516	1.89
Asontem	2998	1.69
Hewale	3390	1.46
Videza	3154	1.70
Jenguma	3135	1.78
Quashie	3724	1.78
Salintuya-1	3270	1.71
Songda	3203	1.48
Sonqu-panqu	3281	1.80
NPK	2867	1.21

NPK at recommended rate of 90 kg N, 60 P_2O_5 and 60 kg K_2O/ha

4.18.2 Benefit to cost ratio as affected by inoculated soybean and inorganic N

Results for benefit and benefit to cost ratio as affected by inoculated soybean and inorganic N are presented in table 4.45. The highest benefit was obtained Sonqupanqu plus 60 kg N/ha (GH¢ 1370), while the least benefit was from Salintuya-1 plus 30 kg N/ha (GH¢ 449). Generally losses were incurred with the least feasible production from Songda plus 60 kg N/ha (0.24), while the highest was recorded by

Sonqu-panqu plus inoculant only (0.71)

Table 4. 45. Net benefit as affected by inoculated soybean and inorganic N in 2015 major season.

Parameter	Benefit (GH¢)	Benefit to cost ratio
Treatment		
Quashie +I	706	0.43
Quashie + 30kg N	817	0.45
Quashie + 60kg N	732	0.37
Salintuya + I	682	0.42
Salintuya + 30kg N	449	0.25
Salintuya + 60 kg N	638	0.32
Songda + I	546	0.33
Songda +30kg N	628	0.35
Songda +60kg N	474	0.24
Sonqu-panqu + I	1170	0.71
Sonqu-panqu + 30kg N	1080	0.60
Sonqu-panqu + 60kg N	1370	0.69

4.18.3 Benefit to cost ratio of maize using haulms and recommended fertilizer.

The results of benefit and benefit to cost ratio of maize using haulms and recommended fertilizer in 2015 are presented in table 4.46. The highest benefit was obtained by the recommended fertilizer application (GH¢ 3543), while Salintuya-1 haulm obtained with inoculation only gave the least benefit. Under sole inoculation, haulm of Quashie (GH¢ 2965) obtained the highest benefit.

Following application of 30 kg/ha N, the highest benefit was obtained with haulms from Songda (GH¢ 2993). With the application of 60 kg N/ha, the highest benefit was from Quashie (GH¢ 2548).

The recommended fertilizer treatment (1.60) and Quashie plus inoculant (1.60) obtained the best BCR, while Salintuya (1.01) haulms from sole inoculation obtained the least. Under sole inoculation, haulm from Quashie obtained the best BCR (3.79), while Salintuya haulms obtained the least. Haulms of Songda following application of 30 kg/ha N and 60 kg/ha N obtained the best BCR (3.46 and 2.96).

Table 4. 46. Benefit and benefit to cost ratio of maize as affected by legume haulms in 2015 minor season.

Paramet	Benefit (GH¢)	Benefit to cost ratio
Haulm		
Quashie	2965	1.60
Quashie	2814	1.31
Quashie	2548	1.18
Salintuy	1925	1.01
Salintuy	2063	1.12
Salintuy	2541	1.29
Songda	2371	1.25
Songda	2993	1.49
Songda	2385	1.32
Sonqu-	2788	1.58
Sonqu-	1991	1.18
Sonqu-	1981	1.03
NPK	3543	1.60

NPK at recommended of 90 kg N, 60 kg P_2O_5 and K_2O/ha

CHAPTER FIVE

GENERAL DISCUSSION

5.1 Promiscuous nodulation of three different grain legumes

Comparative assessment of three legumes (groundnut, soybean and cowpea) used in this study indicates better nodulation in groundnut than cowpea and soybean (Table 4.16). Higher number of nodules in some legumes compared to others was mainly due to specie differences. Nodules in groundnut had smaller meristem compared to cowpea and soybean and this may probably not signify efficiency. However, groundnut nodules, though smaller, may be more densely filled with *rhizobium*-infected cells (Tajima *et al*., 2007). This is a unique relationship of nitrogen-fixing activity in groundnut. Such positive relationship has been shown by groundnut especially in the total fixed N (Table 4.21). Differences in number of nodules in the above order conforms to findings of many workers (Giller, 2001; Ennin *et al.,* 2004; Amba *et al*., 2013; Mweetwa *et al*., 2014). Differences in nodulation among varieties was also observed among the three legumes by Ara *et al*. (2009), Soe *et al*. (2012) and Agyeman *et al*. (2014). Such differences may signify differences in compatibility of the different varieties with the local *rhizobia.* This quality may be used in selecting the most compatible variety with the local *rhizobia* of the environment, because compatibility with the local rhizobia is one of the crop factors that influences the BNF efficiency (Singh, 2010). Konlan *et al*. (2013) have, however, reported similarity in nodulation among groundnut varieties.

Nodule effectiveness did not differ appreciably. On average, cowpea recorded

74.5% effective nodules which was higher than that of soybean (73.75%) and groundnut (72.5%) (Table 4.17). Similarity in percentage effectiveness may not necessarily mean similarity in number of effective nodules. Such similarities may be a result of compensatory mechanism of nodule by the legumes to maintain a reasonable number of functioning nodules at all times (Singleton and Stockinger, 1983). Similarity in percentage effective nodule of the three legumes conforms to findings of Mweetwa *et al.* (2014), who observed that effectiveness of nodules did not differ among groundnut, cowpea and soybean.

Cowpea nodule dry weight was higher than that of groundnut followed by soybean (Table 4.18). These differences might be due to the sizes and number of nodules. Cowpea nodules were similar in size to the soybean nodules and were more in number than those of soybean. Differences in nodule dry weight among legume species has been reported (Ngwu, 2005).

5.2 Nitrogen fixation of three different grain legumes

Total fixed N for the grain legumes shows that on average, groundnut recorded the highest fixed N followed by soybean and cowpea. Differences in the fixed N may be due to specie differences. Legumes species differ greatly in their N_2- fixing potentials (Hancock, 2009). Variation in fixed N among the legume varieties was observed. Such differences may be due to differences in compatibility with the local rhizobia, because one of the factors that determine the BNF efficiency is compatibility with local rhizobia (Keyser and Li, 1992). Amount of fixed N depends on the nitrogen fixation efficiency and the nitrogen that was partitioned to the harvested portion of the plant e.g. seed (Paul, 1994). For example, on average more seed N was recorded by soybean followed by cowpea and groundnut (Table 4.20). Differences in fixed N of some legumes has been reported (Marandu *et al*., 2014)

Differences in seed N was also observed (Table 4.20); on average, soybean recorded the highest seed N followed by groundnut and cowpea. Differences in seed N in the above order confirms the results of proximate analysis of these seeds (Thomas and Vincent, 2012; USDA/NNDSRR28, 2015a).

5.3 Grain yield of soybean following inoculation and inorganic N application

Inoculation of soybean resulted in decrease in yield compared to the yield of uninoculated soybean (Tables 4.12 and 4.30). This result contradicts the findings of many workers who reported increase in yield of soybean because of inoculation (Ahlam *et al*., 2004; Diaz *et al*., 2009; Albareda *et al*., 2009; Bellone *et al*., 2011; Solomon *et al*., 2012). Decrease in soybean yield in this trial might have been solely due to insufficient moisture because of unfavourable rainfall conditions experienced during the growing period. It has been reported that when water stress occur during grain filling (R5), the character most affected is the grain yield (Souza *et al*., 2012). Staton (2012) also reported that yield losses in soybean would be the greatest when moisture stress occur between the R4 and R5 stages of growth.

Following the application of 30 kg/ha N, average yield of Salintuya-1 decreased compared to sole inoculation, while yield of Quashie, Songda and Sonqu-panqu varieties increased. Different responses of starter N with different varieties of soybean has been reported (Woodard *et al*., 1997; Bekele *et al*., 2016). The result, however, contradicts the finding of Achakzai and Bangulzai (2006) who obtained optimum fresh pod yields of different varieties of pea at similar level of starter fertilizer.

5.4 Nodulation of soybean following inoculation and inorganic N application

Inoculation increased nodule production in soybean compared without inoculation. The results indicate that the soybean varieties could do better when inoculated. Ahlam *et al*. (2004); Ravikumar (2012); Solomon *et al*. (2012); Bekere (2012) and AkramJafari *et al*. (2014) have reported increase in nodulation due to inoculation. Generally, nodule numbers and effectiveness were all higher following inoculation than without inoculation. This shows that either the naturalized rhizobia are ineffective or their population is low. Increased effectiveness of nodules has been reported with application of inoculants (Ahlam *et al*., 2004; Kuehling *et al*., 2013). This means that the generally held view that tropical soils contain enough rhizobia for nodulation must be reviewed.

Nodule dry weight was increased because of inoculation; inoculated soybean produced heavier nodules than the promiscuous varieties. Bekere (2012) and Solomon *et al.* (2012) reported increment in nodule dry weight due to inoculation

Application of N adversely affected nodule numbers. Nodulation in all varieties declined with application of 30 kg N/ha. There was further decline in nodulation, except in Sonqu-panqu, at 60 kg N/ ha. The result confirms the findings of many workers who reported decrease in number of nodules because of addition of starter dose of N (Mendes *et al*., 2003; Achakzai, 2007). Amba *et al*. (2013) also reported application of N a week after planting soybean, reduced number of nodules. Many authors have attempted to explain this occurrence, but no single explanation has been found sufficient.

Percent effective nodules also declined with application of N (Table 4.35). As noted earlier, several studies had shown decline in nodulation with application of combined N, although no single satisfactory explanation had been given. Further observation shows that inorganic N was not beneficial on the effectiveness of nodules and this conforms to works of many researchers who reported decrease in nodule effectiveness with application of starter N (Dogra and Dudeja, 1993). In her work, Jenneh (2013), however, found that nodule effectiveness was not affected by the rate of N application.

On average, nodule dry weight was decreased with the application of inorganic N, because maximum nodule dry weight was obtained without N application in most of the varieties. Addition of starter N has been reported to decrease the nodule dry weight (Ahlam *et al*., 2004). Different responses to inorganic dose of N of the varieties in terms of nodule dry weight suggest differences in BNF efficiency among the varieties used in the study following application of N.

5.5 Nitrogen fixation of soybean following inoculation and inorganic N application

Total N fixed was higher following inoculation compared to the uninoculated soybean varieties the previous year. BNF is believed to increase due to inoculation because rhizobia population are enhanced. Effectiveness of the *rhizobia*-host plant symbiosis can be increased due to the increase in the population of the rhizobia in the soil. One of the factors that influence the amount of N fixed is the effectiveness of rhizobia-host plant symbiosis (Van Kessel and Hartley 2000). Increased BNF efficiency in inoculated plants is also achieved due to significantly higher levels of nitrogenase activity in the inoculated genotypes than non-inoculated because *rhizobium* has a strong stimulatory effect on nitrogenase enzymes, and thus the enzyme activity increases in inoculated plants (Alam *et al.*, 2015).

Fixed N following application of N was higher compared to sole inoculation, and maximum fixed was obtained at 30 kg N/ha in most of the varieties except Quashie. This suggest that Quashie tolerated higher N rate compared to other varieties. Dogra and Dudeja (1993) reported that such differences might be due to the differences in their host-microsymbiont interaction. Tolerance of varieties like Quashie might be used to choose a variety for multiple cropping with cereals.

5.6 Effect of residue fertility on growth and grain yield under promiscuous conditions

Generally, there was no consistent pattern of maize growth following application of haulms from the different crop varieties, probably due to inconsistent turnover of the rhizodeposited N. Mayer (2003) stated that the effect of rhizodeposition on turnover of C and N was inconsistent. However, on average residual effects of combined groundnut haulms on growth of maize were higher than the effects of cowpea and soybean. Higher combined residual effects of groundnut haulms were probably due to higher fixed N by the groundnut varieties compared to either cowpea or soybean (Table 4.19), which might have resulted in higher rhizodeposited N by the groundnut varieties. Rhizodeposition of N by legumes during growth may account to 35 – 50 % of the total nitrogen fixed (Mayer, 2003;

Peoples *et al*., 1989). In addition, differences in residual effect of legume haulms were probably due the quantity of haulms produced by each. It could also be due to nitrogen content of the various haulms of the varieties. Egbe and Ali (2010), Nyalemegbe and Osakpa (2012) and Marandu *et al*. (2014) reported significant differences in grain yield of maize because of legume haulms application. In their study, Nyalemegbe and Osakpa (2012) reported that groundnut haulms produced more maize grains than soybean and cowpea haulms.

5.7 Effect of residual fertility on growth and grain yield following inoculation

The residual effects of Quashie haulms were consistently higher in terms of growth of maize than the other varieties under all conditions. Similarly, grain yield of maize under inoculation was higher with Quashie haulms. Higher residual effect of Quashie could be a result of its genetic constitution, with a higher compatibility with the inoculant and the combined N for better BNF efficiency, which warranted higher quantity of rhizodeposited N and haulm N. Among the crop factors that determine efficiency of BNF are the genetic constitution and the compatibility with the nitrogen-fixing microbes (Singh, 2010). Differences in compatibility among soybean varieties relative to the inoculant used were reported (Meghvansi *et al*., 2010).

Following application of 30 kg N/ha, residual effect of Songda were higher than the other varieties on maize yield, while at 60 kg N/ha, Quashie and Salintuya-1 varieties produced the highest residual effects. This means that the host – rhizobium interaction of these varieties could be more effective in utilizing the applied N. Differences in residual effects following combined N application could be due to differences in the host-rhizobium interactions with the different levels of the inorganic N. This is because utilization of combined N is a result of the hostmicrosymbiont interaction and not the effect of the individual host and rhizobium separately (Dogra and Dudeja (1993; Van Kessel and Hartley 2000).

5.8 Financial analysis

5.8.1 Benefit

Benefit during the production of legumes in 2014 was generally low; this was probably because there was no any form of fertilizer application or anything that could improve yield. However, following maize in the minor season gave high benefit that could be attributed to fertilizer and haulms incorporation. The rainfall during the year was sufficient to encourage complete decomposition and mineralization of nutrients from the haulms.

In 2015, however losses were recorded in the major season legume production. Such losses were probably because of the drought condition experienced during the year. The losses were in the order of intensity from sole inoculation to 30 kg/ha N + inoculation and 60 kg/ha N + inoculation. It is evidently clear that more resources were used following the same order. Following the maize production in the minor rainy season of the same year, benefits obtained were however lower compared that obtained in the minor rainy season of 2014. Lower benefit recorded were probably because of the drought conditions during the year.

5.8.2 Benefit to cost ratio

Economics of production in the 2014 major rainy season legume production was generally low, though no losses were incurred. However, feasibility of such investments under normal conditions could be improved with the use of some form of growth enhancing materials. In the minor season of the same year investments were generally very good, such good investments were the results of low costs of input coupled with good weather conditions experienced during the year.

In 2015, the return to investment in legume production was very low below the break-even during the major rainy season, while that in the minor season was lower than that of 2014. This has shown that climatic changes can negatively affect agricultural production unless extra measures are put in place to combat such menace.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The results of this study indicated that there is variability in the nitrogen fixing potential of groundnut, soybean and cowpea. Generally, on average groundnut exhibited higher nitrogen fixing potential compared to soybean and cowpea. Also, among the varieties of these legumes differences in nitrogen fixing potential were evident.

The study indicated differences in residual contributions of the three legumes to maize growth and yield. Generally, on average residual contributions of groundnut haulms on growth and yield of maize were higher than from cowpea and soybean haulms. Among the varieties of these legumes, no consistent pattern of growth was exhibited.

Nodulation was reduced by the inorganic N rates. The application N at 30 kg/ha gave the highest N fixed in most of the soybean varieties.

The contribution of haulm to maize yield was higher than NPK fertilizer application in 2014. However, the NPK fertilization outperformed haulms mulching in 2015.

Economics of production indicated that legume haulms are potential sources of soil amendment for maize production in the semi-deciduous forest zone of Ghana.

6.2 Recommendations and future research

6.2.1 Recommendations

Based on the above conclusions, Manipinta and Jenkaar among the groundnut varieties are recommended for highest nitrogen fixing abilities, while Manipinta for higher grain yield. Quashie and Songda among the soybean varieties are recommended for maximum nitrogen fixation, while Sonqu-panqu for grain yield. Hewale among the cowpea varieties is recommended for highest nitrogen fixing potential, while Asontem for grain yield. Grain legumes haulms can be used in place of inorganic fertilizers for the production of maize in the environment where this study was conducted in as much as there is sufficient moisture to aid their decomposition.

Inoculation and inorganic N are beneficial to soybean production as indicated in this study, but further research is needed to ascertain the actual level of N for the different varieties of soybean.

Further long-term field trials are required to ascertain the major findings of this study especially under different agro-ecological zones

6.2.2 Future research

i. Future research should consider establishing inorganic N rate for the different soybean varieties, because these varieties have different requirement for inorganic N rates because of the differences in host-*rhizobium* interactions.

ii. Research should be geared towards producing more drought tolerant varieties of legumes with shorter duration, especially soybean because of climate change. Grain legumes have double advantage of providing food and enriching the soil, such benefits are only possible when drought tolerant varieties are used in the era of climate change.

REFERENCES

Achakzai, K. A. 2007. Effect of Various Levels of Nitrogen Fertilizer on Nodulation of Pea Cultivars. *Pakistan Journal of Botany*, 39(5), pp.1673– 1680.

Achakzai, K.A. 2012. Effect of various levels of nitrogen fertilizer on some vegetative growth attributes of Pea (*Pisum Sativum* L .) cultivars. *Pak. J. Bot*, 44(2), pp.655–659.

Achakzai, A.K. and Bangulzai, M.I. 2006. Effect of various levels of nitrogen fertilizer on the yield and yield attributes of Pea (*Pisum Sativum* L.) Cultivars. *Pak. J. Bot*, 38(2), pp.331–340.

Adama, C., Bagayoko, M., Traore, S. and Mason, S.C. 2000. Effect of crop residue management and cropping system on pearl millet and cowpea yield. *African Crop Science Journal*, 8(4), pp.411–418.

Adams, M.A., Simon, J. and Pfautsch, S. 2015. Woody legumes : a review from the South. *Tree Physiology*, (Sanchez 1995), pp.1072–1082.

Adeleke, M. A. and Haruna, I.M. 2012. Residual nitrogen contributions from grain legumes to the growth and development of succeeding maize crop. *ISRN Agronomy*, 2012, pp.1–5.

Adjei-Nsiah, S., Kuyper, T.W., Leeuwis, C., Abekoe, M.K., Cobbinah, J., Sakyi-Dawson, O. and Giller, K.E. 2008. Farmers' agronomic and social evaluation of productivity, yield and N_2-fixation in different cowpea varieties and their subsequent residual N effects on a succeeding maize crop. *Nutrient Cycling in Agroecosystems*, 80, pp.199–209.

Adu, G.B., Abdulai, M.S., Alidu, H., Nustugah, S.K., Buah, S. S., Kombiok, J. M., Obeng-Antwi, K., Abudulai, M. and Etwire, P. M. 2014. Recommended production practices for maize in Ghana. CSIR/AGRA, Ghana.

Agbogidi, O.M. and Egho, E. 2012. Evaluation of eight varieties of cowpea (*Vigna unguiculata* (L .) Walp) in Asaba agro-ecological environment , Delta State , Nigeria. *European Journal of Sustainable Development (2012)*, 1(2), pp.303–314.

Agyeman, K., Berchie, J.N., Osei-Bonsu, I. Tetteh, N.E. and Fordjour, J.K. 2014. Growth and yield performance of improved cowpea (*Vigna unguiculata* L.) varieties in Ghana. *Agricultural Science*, 2(4), pp.44–52.

Agyenim, K., Gyapong, B. and Ayisi, C.L. 2015. The Effect of organic manures on soil fertility and microbial biomass carbon , nitrogen and phosphorus under maize-cowpea intercropping system. *Discourse Journal of Agriculture and Food Sciences*, 3(4), pp.65–77.

Ahiabor, B., Lamptey, S., Yeboah, S. and Bahari, V. 2014. Application of phosphorus fertilizer on soybean [(*Glycine max* L. (Merril)] inoculated with *rhizobium* and its economic implication to farmers. *American Journal of*

Experimental Agriculture, 4(11), pp.1420–1434.

Ahlam, E.A., Assar, A. H. A., Hamed, F. M., Dahab, O. A. and Ahmed, E. H. 2004. Effect of *rhizobium* inoculation on nodulation and yield of soybean [*Glycine max* L. (Merr)]. pp.1–7.

Aikins, S. H. M., Afuakwa, J. J. and Owusu-Akuoko, O., 2012. Effect of four different tillage practices on maize performance under rainfed conditions. *Agriculture and Biology Journal of North America*, 3(1), 25–30. doi:10.5251/abjna.2012.3.1.25.30.

AkramJafari, F., Tayeb Saki, N. and Mani, M., 2014. The effect of different methods of r*hizobium* bacteria inoculation on biological nitrogen fixation in broad bean. *International Journal of Plant, Animal and Environmental Sciences*, 4(2), pp.346–352.

Alam, F., Bhuiyan, M. A. H., Alam, S. S., Waghmode, T. R. and Kim, J., 2015. Effect of *rhizobium* sp. inoculation on nodulation , nitrogen fixation and yield of soybean (*Glycine max*) genotypes in gray terrace soil. *Bioscience, Biotechnology and Biochemistry*, p.9.

Alamgir, M., McNeill, A., Tang, C. and Marschner, P., 2012. Changes in soil P pools during legume residue decomposition. *Soil Biology and Biochemistry*, 49(August), pp.70–77.

Albareda, M., Rodríguez-Navarro, D.N. and Temprano, F.J., 2009. Soybean inoculation: dose, N fertilizer supplementation and rhizobia persistence in soil. *Field Crops Research*, 113(3), pp.352–356.

Ali, Z., Haidar, K., Shah, S.A. and Ahmad, I., 2010. Evaluation of leguminous forage crops for nodulation, nitrogen fixation and quality yield. *American-Eurasian Journal of Agriculture and Environmental Sciences.*, 9(3), pp.269–272.

Al-kaisi, M.M. and Yin, X., 2005. Tillage and crop residue effects on soil carbon and carbon dioxide emission in corn–soybean rotations. *Journal of environmental quality*, 34(July 2004), pp.437–445.

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 Savanna of Nigeria. *International Journal of Biosciences*, 6655, pp.1–7.

Amusan, A.O., Adetunji, M. T., Azeez, J. O. and Bodunde, J. G., 2011. Effect of the integrated use of legume residue, poultry manure and inorganic fertilizers on maize yield, nutrient uptake and soil properties. *Nutrient Cycling in Agroecosystems*, 90(3), pp.321–330.

Anonymous, 1992. Crop growth analysis. In *Plants in Action*. pp. 2–7.

Anonymous, 1998. legumes and soil quality. Soil Quality Institute, Natural Resource Conservation Service, United State Department for Agriculture. Technical Note No 6.

Anonymous, 2009. Products that use Corn. https://healthhabits.files.wordpress.com, pp.1–3.

Anonymous, 2010a. Biology of Maize. Series of crop specific biology, Ministry of Environment/ Ministry of Science and Technology, India.

Anonymous, 2010b. Ghana has potential to export soybean. Available at www.modernghana.com/news/28853/1, 13/10/2015.

Anonymous, 2010c. Soya Beans - production guideline, Directorate of Plant Production, Department of Agriculture, Forestry and Fisheries, South Africa.

Anonymous, 2013. Biological nitrogen fixation by legumes. The living field; The James Hutton Available at: http://livingfield.hutton.ac.uk/science/bnf#content

Anonymous, 2014. Crop residue decomposition explained. p.2. Hutton Institute.

Anonymous, 2015. Corn for biofuel production current potential for use as a biofuel.3 pp. http://articles.extension.org/pages/27536/corn-for-biofuel.

Antwi, C., Osafo, E. L. K., Fisher, D. S. Yacout, H. M. Donkoh, A. Hassan, A. A. and Sobhy, S. M. M., 2012. Effects of cultivar, season and year on yield parameters of cowpea and the haulm's potential as ruminant feed. *Agricultural Science Research Journal*, 2(6), pp.274–279.

AOAC, 1995. Official methods of analysis (13th Ed.) Association of official analytical chemists. Washington D.C.

Ara, N., Rokonuzzaman, M. and Hasan, M. N., 2009. Effect of *Bradyrhizobium* and *Azotobacter* on growth and yield of mungbean varieties. *Journal of Bangladesh Agricultural University*, *7*(1), 7–13.

Asiamah, R.D., 1998. Soils and soil suitability of Ashanti Region. UNESCO/FAO. S.R.I Technical Report No. 193. Kwadaso-Kumasi.

Bange, M. P., Hammer, G. L. and Rickert, K. G. (1998). Temperature and sowing date affect the linear increase of sunflower harvest index. Agronomy Journal 90: 324 - 328.

Baijukya, F., Mukalama, J., Waswa, W., Boahen, S., Jibrin, J., Sanginga, J., Uwizerwa, M. and Chataika, B., 2013. Indentified soyabean, common bean, cowpea and groundnut varieties with high biological nitrogen fixation potential identified in N2Africa impact zones N2Africa Putting nitrogen fixation to work for smallholder farmers in Africa. pp.1–25.

Bakht, J., Shafi, M., Jan, M. T. and Shah, Z., 2009. Influence of crop residue management, cropping system and N fertilizer on soil N and C dynamics and sustainable wheat (*Triticum aestivum* L.) production. *Soil and Tillage Research*, 104(2), pp.233–240.

Beard, B.H. and Hoover, R.M., 1971. Effect of nitrogen on nodulation and yield of irrigated soybeans. *Agron J.*, 63:815-816.

Bekele, W., Belete, K. and Tana, T., 2016. Effect of soybean varieties and nitrogen fertilizer rates on yield, yield components and productivity of associated crops under maize/soybean intercropping at Mechara, Eastern Ethiopia.

Agriculture, Forestry and Fisheries, 5(1), pp.1–7.

Bekere, W., 2012. Growth and nodulation response of soybean (*Glycine max* L) to *Bradyrhizobium* inoculation and phosphorus levels under controlled condition in South Western Ethiopia. *African Journal of Agricultural Reseearch*, 7(30), pp.4266–4270.

Bellone, C.H., de Bellone, S.C. and Cordileone, V., 2011. Related growth parameters in soybean plants inoculated with *Azospirillum brasilense*. *Journal of Crop Improvement*, 25(5), pp.472–487.

Bengtson, P., 2004. Microbial mobilization and immobilization of soil nitrogen Per Bengtson Dissertation. University of Sweden Doctoral Thesis. 117 pp.

Bharambe, P. R., Tajuddin, A. H., Oza, S. R. and Shelke, D. K. 2002. Effect of irrigation crop residue mangement on crop and soil productivity under soya beansorghum cropping system. *Journal of Indian Society of Soil Science*, *50*(3), 233-
236

Bhuiyan, N.I., Saha, P. K., Ishaque, M. and Abedin, J. 1991. Studies on inorganic nutrients and organic residues for rice-based cropping systems in

Bangladesh. Soil Chemistry Division, Bangladesh Rice Research Institute. Joydebpur, Gazipur 170 I, Bangladesh.

Bi, G., Evans, W. B.,Spiers, J. M. and Witcher, A. L., 2010. Marigold growth and flowering, fertilizers on marigold growth. *HortScience*, 45(9), pp.1373–1377.

Black, C. A., 1986. Methods of soil analysis. Part 1. Physical and mineralogical properties, including statistics of measurement and sampling. Part 2. Chemical and microbiological properties. Agronomy series. ASA. Madison, WI.

Bogino, P., Nievas, F., Banchio, E. and Giordano, W., 2011. Increased competitiveness and efficiency of biological nitrogen fixation in peanut via infurrow inoculation of rhizobia. *European Journal of Soil Biology*, 47(3), pp.188 193.

Bonsu, P.O. and Asibuo, J.Y., 2013. Rotational effects of legumes on maize yield. *International Journal of Scientifc and Technology Research*, 2(4), pp.222 –227.

Bordeleau, L. M., and Prevost, D., 1994. Nodulation and nitrogen fixation in extreme environments. *Plant Soil,* 161**:**115–124.

Bouyoucos, G.J., 1963. Hydrometer method improved for making particle size analyses of soils. *Agronomy Journal* 53: 464 – 465.

Brady, N.C. and Weil, R.R., 1999. The Nature and Properties of Soils. 12th Edition. Simon and Schuster Co. Prentice-Hall Inc. New Jersey, USA.

Bremner, J. M. and Mulvaney, C. S., 1982. Nitrogen-total, in methods of soil analysis. Page, A. L. (ed). Methods of soil analysis. Agronomy Monography 9. American Society of Agronomy. Madison, WI. pp. 595 - 624.

Bundy, L.G., Kelling, K.A. and Good, L.W., 1997. Using legumes as a nitrogen source. Wisconsin county Extension office or Cooperative Extension Publishing, Rm. 170, 630 W. Mifflin St., Madison, Wisconsin 53703. Phone 608-262-3346.

A3517.

Burdass, D, 2002. *Rhizobium*, root nodules and nitrogen fixation. Society for General Microbiology A post-16 resource.

Byrnes, B.H., 1990. "Environmental effects of N fertilizer use—An overview," *Fertilizer Research* 26: 209-215.

Cabrera, M.L., Kissel, D.E. and Vigil, M.F., 2005. Nitrogen mineralization from organic residues: research opportunities. *Journal of environmental quality*, 34(1), pp.75–9.

Chan, P. K. and Gresshoff, P. M., 2016. Roles of plant hormones in legume nodulation. In *Encyclopedia of Life Support Systems* (Vol. VIII, p. 11).

Chand, S., 2010. Maize production: production and distribution of maize around the world. Available at: http://www.yourarticlelibrary.com/essay.

Cheema, Z.A. and Ahmad, A., 2000. Effects of urea on the nitrogen fixing capacity and growth of grain legumes. *International Journal of Agriculture and Biology*, pp.388–394.

Chen, J. 2006. The combined use of chemical and organic fertilizers and/or biofertilisers for crop growth and soil fertility. Paper presented at the international workshop on sustained management of the soil-rhizosphere system for efficient crop production and fertilizer use 20:37-43. Land Development Department, Bangkok 10900 Thailand, 2008.

Cheng, Q., 2008. Perspectives in biological nitrogen fixation research. *Journal of Integrative Plant Biology*, 50(7), pp.786–798.

Chiamaka, E.O., 2014. Growth and yield response of cowpea to NPK and rhizobia inoculation in the guinea savanna zones of Ghana*.* Ph.D. thesis KNUST.

Colibar, O., Mot, T., Onita, P. and Popovici, D., 2009. Productive effect of soybean meal. *Lucrări ştiinţifice Zootehnie şi Biotehnologii*, 42(1), pp.335–338.

Crews, T. E. and Peoples, M. B., 2004. Legume versus fertilizer sources of nitrogen: Ecological tradeoffs and human needs. *Agriculture, Ecosystems and Environment*, *102*(3), 279–297.

Daily Guide, 2014. Ghana trails in soybean production. *Daily Guide Newspaper*, 5 September 2014. Available at www.modernghana.com/news/567643/1, 13/10/2015.

Danso, S. K. A. and Eskew, D. L., 1984. Enhancing biological nitrogen fixation. *IAEA Bulletin*, 26 (2), pp.29–34.

Deaker, R., Roughley, R.J. and Kennedy, I.R., 2004. Legume seed inoculation technology - a review. *Soil Biology and Biochemistry*. 36, 1275–1288.

DeVries, J.D., Bennett, J.M., Albrecht, S.L. and Boote, K.J., 1989. Water relations, nitrogenase activity and root development of three grain legumes in response to soil water deficits. *Field Crops Res*. 21:215-226.

Diaz, D.A.R., Pedersen, P. and Sawyer, J.E., 2009. Soybean response to inoculation and nitrogen application following long-term grass pasture. *Crop Science*, 49(3), pp.1058–1062.

Dogra, R.C. and Dudeja, S.S., 1993. Fertilizer N and nitrogen fixation in legumer*hizobium* symbiosis. *Annals of Biology*, 9 (2) : 149 -164.

Dugje, I.Y., Omoigui, L.O., Ekeleme, F., Bandyopadhyay, R., Lava Kumar, P. and Kamara, A.Y., 2009. farmers' guide to soybean production in Northern Nigeria. International Institute of Tropical Agriculture, Ibadan, Nigeria. 21 pp.

Eaglesham, A. R. J., 1981. Assessing the nitrogen contribution of cowpea (*Vigna unguiculata*) in monoculture and intercropped. p. 641-646. *In* Graham, P. H. and S. C. Harris. (Ed.) Biological nitrogen fixation technology for tropical agriculture. Papers presented at a workshop held at Ciat, March 9-13, 1981. Cali, Colombia, Centro International de Agricultura Tropical.

Eaglesham, A. R. J., Ayanaba, A., Rao, V. and Eskew, D. L., 1982. Mineral N effects on cowpea and soybean crop in a Nigerian Soil. II. Amount of N fixed and accrued in the soil. *Plant and Soil* 68. 183-192.

Egbe, O.M. and Ali, A., 2010. Influence of soil incorporation of common food legume stover on the yield of maize in sandy soils of moist Savanna Woodland of Nigeria. *Agriculture and Biology of North America* 2(8), pp.84–90.

Ekpo, I. A., Agbor, R. B., Osuagwu, A N., Okpako, E. C. and Ekanem, B. E., 2012. Evaluation of eight cowpea (*Vigna unguiculata* L.Walp) species for yield and associated traits. *International Journal of Pure and Applied Sciences and Technology* 12(2), pp.1–7.

Ennin, S.A., Dapaah, H.K. and Abaidoo, R.C., 2004. Nitrogen credits from cowpea soybean groundnut. *West African Journal of Applied Ecology* 6, pp.65–74.

Evans, J.R. and Seemann, J.R., 1989. The allocation of protein nitrogen in the photosynthetic apparatus: costs, consequences, and control. *In*: Briggs W (Ed) Photosynthesis (pp 183-205). Alan R. Liss, New York, USA.

Fabián F. L., 2012. Symbiotic nitrogen fixation in nodules from ten common bean cultivars as a reliable estimator of yield during the early stages. *African Journal of Agricultural Reseearch* 7(9), pp.1400–1409.

Faisal, S., Shah, S. M., Majid, A. and Khan, A.., 2013. Effect of organic and inorganic fertilizers on protein, yield and related traits of maize varieties. *International Journal of Agriculture and Crop Sciences* pp.1299–1303.

Farooq, S. and Azam, F., 2003. An appraisal of methods for measuring symbiotic nitrogen fixation in legumes. *Pakistan Journal of Biological Sciences* 6(18), pp.1631–1640.

Field, C.B. and Mooney, H.A., 1986. The nitrogen/photosynthesis relationship in wild plants. *In*: Givnish TJ (Ed) on the economy of plant form and function (pp 2555). Cambridge University Press, Cambridge, England.

Flannery, R.L., 1986. Plant food uptake in a maximum yield soybean study. *Better Crops* 70:67.

Frank, J.O.N., 2010. Residue Decomposition. Internationl AG labs. Available at www.aglabs.com.

Gani, O.O., 2012. Effects of leguminous plant residues and NPK fertilizer application on the performance of yam (*Dioscorea rotundata*“ c.v.”ewuru) in South Western Nigeria. *Archives of Agronomy and Soil Science*. DOI:10.1080/03650340.2011.638289

GenStat, 2007. GenStat for windows (GenStat 9th edition). Lawes Agricultural trust, Rothamsted experimental station. UK.

Giller, K. E., 2001. Nitrogen fixation in tropical cropping systems, 2nd ed. Wallingford, UK: CABI Publishing.

Ghosh P. K., Bandyopadhyay, K. K. Wanjari, R. H. Manna M. C., Misra, A. K. Mahonty, M. and Subba R. A., 2007. Legume effect for enhancing productivity and nutrient use efficiency in major cropping systems-An Indian perspective: A review. *Journal of Sustainable Agriculture.* Vol 30 (1). Pp 59-86.

Graham, P.H. and Vance, C.P., 2003. Legumes: importance and constraints to greater use. *Plant Physiology*, 131, pp.872–877.

Gutschick, V.P., 1981. Evolved strategies in nitrogen acquisition by plants. *American Naturalist* 118: 607–637.

Habonayo, G., Semoka, J.M.R. and Rweyemamu, C.L., 2010. Comparative effect of farmyard manure, cowpea residues and NPK Fertilizer on maize grain yield in Morogoro. *In* Second RUFORUM Biennial Meeting 20-24 september 2010, Entebbe, Uganda. pp. 575-578.

Hancock, D.W., 2009. Quantity of nitrogen fixed. The university of Georgia coorperative extension. 2 pp.

Hanssen A. P., 1994. Symbiotic nitrogen fixation of crop legumes: achievements and perspectives. Center for Agriculture in the Tropics, Germany. p. 115.

Hardarson, G. and Danso, S. K. A., 1993. Methods for measuring biological nitrogen fixation in grain legumes. *Plant and Soil*, 152, pp.19–23.

Haruna, M. K., Turaki, Z .G. S., Bibin, A. T. S. and Wali, A. S., 2015. soybean varietal evaluation in Northern Guinea Savanna. *Journal of Biology, Agriculture and Healthcare* 5(9), pp.139–142.

Hayat, R., Safdar, A. and Faisal, S. K., 2004. Effect of nitrogen and *rhizobium* inoculation on yield, N- uptake and economics of mungbean. *International Journal of Agriculture and Biology,* (3), pp.547–551.

Hayat, R., Ali, S., Siddique, M. T. and Chatha, T. H., 2008. Biological nitrogen fixation of summer legumes and their residual effects on subsequent rainfed wheat yield. *Pakistan Journal of Botany*, 40(2), pp.711–722.

Heard, J., 2012. Don't count on nitrogen credits after soybeans in Manitoba. Manitoba Soil Fertility Facts. 2 pp.

Henshaw, F.O., 2008. Varietal differences in physical characteristics and proximate composition of cowpea (*Vigna unguiculata*). *World Journal of Agricultural Sciences*, 4(3),302–306.

Herridge, D.F., 1982. Use of the ureide technique to describe the nitrogen economy of field-grown soybeans. *Plant Physiol*. 70 (1982) 7-11.

Hiep, N., Diep, C. and Herridge, D., 2002. Nitrogen fixation of soybean and groundnut in the Mekong Delta, Vietnam. In *ACIAR Proceedings 109e*. pp. 10–18. Available at: http://aciar.gov.au/system/files/node/2110/pr109echapter02.pdf.

Hodges, C.S., 2002. Soil Fertility Basics. Soil science extension. North Carolina

State University, USA. 75pp.

Hopkins, W. G. and Hüner, N. P. A., 2004. Nitrogen assimilation. *In introduction to plant physiology.* John Wiley & sons, Inc. pp 167-185.

Hungria, M. and Franco, A. A., 1993. Effect of high temperature on nodulation and nitrogen fixation by *Phaselous vulgaris L. Plant Soil*. 145: 95-102.

Hussain, K., Islam, M., Siddique, M. T., Hayat, R. and Mohsan, S., 2011. Soybean growth and nitrogen fixation as affected by sulfur fertilization and inoculation under rainfed conditions in Pakistan. *International Journal of Agriculture and Biology*, 13(6), pp.951–955.

Hunt R.1978. Plant growth analysis. Studies in biology no.96. Edward Arnold (publishers).London.67 p.

IFDC, 2007. Africa fertilizer summit proceedings: June 9 – 13, 2006, Abuja, Nigeria. *In Africa fertilizer summit*. Special publication IFDC—SP-39, Muscle Shoals, Alabama 35662 (U.S.A.) 206 pp.

Iqbal, A., Khalil, I. A., Ateeq, N. and Sayyar Khan, M., 2006. Nutritional quality of important food legumes. *Food Chemistry*, 97(2), pp.331–335. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0308814605003687.

IRRI-CIMMYT, 2009. The importance of legumes in cereal cropping systems. IRRI-CIMMYT Fact sheet.

Iruhvwu, D., 2015. Production guidelines for Cowpeas. Directorate of plant production, Department of Agriculture, Forestry and Fisheries, South Africa. 24 pp.

Islam, M., Mohsan, S. and Ali, S., 2012. Effect of different phosphorus and sulfur levels on nitrogen. *Agrociencia*, 46(1), pp.1–13.

Jenneh, F.B., 2013. Rate and time of nitrogen fertilizer application on the growth, nitrogen remobilization and yield of soybean *(Glycine max (L) Merrill).* M. Sc. Thesis. KNUST. 82 pp.

Keston, O. N. W., Patson, C. N, George, Y. K. P. and Max, W. L., 2012. Biological nitrogen fixation in sole and doubled-up legume cropping systems on the sandy soils of Kasungu, Central Malawi. *Journal of Soil Science and Environmental Management*, 3(9), pp.224–230.

Ketterings, Q., Swink, S., Cox, B. and Czymmek, K., 2007. *"* Soybean N \credits.*"*Agronomy Fact Sheet Series*,* Fact sheet 30, Cornell University Extension.

Keyser, H.H. and Li, F., 1992. Potential for increasing biological nitrogen fixation in soybean. *Plant and Soil*, 141(1-2), pp.119–135.

Khan, N., Tariq, M., Ullah, K., Muhammad, D., Khan, I. and Rahatullah, K., 2014. The effect of molybdenum and iron on nodulation, nitrogen fixation and yield of chickpea genotypes (*Cicer Arietinum* L). *Journal of Agriculture and Veterinary Science*, 7(1), pp.63–79.

Klogo, P.Y., Avumegah, P. K., Danso, S. K. A., Glover, M. and Owusu-gyimah, V., 2016. genetic variability among soybean [*Glycine max* (Merrill)] varieties in nitrogen fixation in five Ghanaian soils. *Agricultural and Biological Sciences Journal*, 2(1), pp.15–21.

Kombiok, J.M., Buah, S. S. J., Dzomeku, I. K. and Abdulai, H., 2012. Sources of pod yield losses in groundnut in the northern savanna zone of Ghana. *West African Journal of Applied Ecology*, 20(2), pp.53–63.

Konlan, S., Sarkodie-Addo, J., Asare, E. and Kombiok, M.J., 2013. Groundnut (*Arachis hypogaea* L.) varietal response to spacing in the Guinea Savanna agroecological zone of Ghana: Nodulation and nitrogen fixation. *Agriculture and Biology Journal of North America*, 4(3), pp.324–335.

Kouas, S., Slanti, T., Salah, I. B. and Abdelly, C. 2010. Eco-physiological responses and symbiotic nitrogen fixation capacity of salt -exposed *Hedysarum carnosum* plants. *African Journal of Biotechnology,* 9(44), 7462-7469.

Kuehling, I., Huesing, B., Bome, N. and Trautz, D., 2013. Relationship between soybean varieties, rhizobia inoculation and spad-502 chlorophyll meter readings in Western Siberia. *International Symposium, Agrosym 2013*. pp. 71–76.

Kumaga, F. K. and Ofori, K., 2004. Response of soybean (*Glycine max* (L.)) to *Bradyrhizobia* inoculation and phosphorus application. *Int. J. Agric. Biol*. 2:324-327.

Kumar, K. Rai, K. Kumar, A. Singh, B.A., 2014. Study on the performance of groundnut (*Arachis hypogea* L.) genotypes for quantitative traits in Allahabad region. *Journal of Science and Technology*, 2, pp.564–569.

Larson, D., 2008. Biofuel production technologies : status, prospects and implications for trade and development. United Nations Conference on Trade and Development, UNCTAD/DITC/TED/2007/10.

Lewis, G., Schrire, B., Mackinder, B. and Lock, M., 2005. Legumes of the World. Richmond, UK: Royal Botanic Gardens, Kew.

Lindermann, W. C. and Glover, C. R., 2003. Nitrogen fixation by legumes. guide A- 129. New Mexico State University. 4pp.

Liu, G., Zotarelli, L., Dinkins, D. and Wang, Q., 2014. Controlled-release and slow-release fertilizers as nutrient management tools. IFAS Extension, University of Florida.

Liu, Y., Wu, L., Baddeley, J. A. and Watson, C. A., 2011. Models of biological nitrogen fixation of legumes. A review. *Agronomy for Sustainable Development*, 31(1), pp.155– 172.

Loges, R., Ingwersen, K. Kaske, A. and Taube, F., 2000. Methodological aspects of determining nitrogen fixation of different forage legumes, Available at: http://www.orgprints.org/00002146.

López, M. V., Moret, D., Gracia, R., and Arrúe, J. L. 2003. Tillage effects on barley residue cover during fallow in semiarid Aragon. *Soil and Tillage Research*, *72*(1), 53–64.

Loynachan, T., 2005. Nitrogen fixation by forage legumes. Department of Agronomy, Iowa State University.

Mahmoud, E., Nasser, A., Robin, P., Nouraya Akkal-Corfini and Lamyaa A., 2009. Effects of different organic and inorganic fertilizers on cucumber yield and some soil properties. *World Journal of Agricultural Sciences*, 5(4), pp.408–414.

Majumder, M., Shukla, A.K. and Arunachalam, A., 2008. Nutrient release and fungal succession during decomposition of weed residues in a shifting cultivation system. *Communications in Biometry and Crop Science*, 3, pp.45–59.

Malhi, S.S., Lemke, R., Wang, Z. H. Chhabra, Baldev S., 2006. Tillage, nitrogen and crop residue effects on crop yield, nutrient uptake, soil quality, and greenhouse gas emissions. *Soil and Tillage Research*, 90(1-2), pp.171–183.

Mandic, V., Simic, V., Krnjaja, V., Bejelic, Z., Tomic, A., Stanojkovic, D. and Ruzic, M., 2015. Effect of foliar fertilization on soybean grain yield. *Biotechnology in Animal Husbandry*, 31(1), pp.133143.

Mannetje L. T., O'Connor, K. F. and Burt, R. L., 1980. The use and adaptation of pasture and fodder legumes. *In:* Summer field R. J. and Bunting A. H. (eds). *Advances in legume science*. Royal Botanical Gardens, Kew.

Mapuwei, W. T., Masanganise, J., Chivheya, R. and Mashangana, P., 2014. An assessment of performance of soya bean (*Glycine max*) variety in low rainfall areas of Zimbabwe. *International Journal of Agricultural Research*, 5(4), pp.1–6.

Marandu, A. E. T., Semu, E., Mrema, J.P., Nyaki, A. S., 2014. Contribution of legume rotations to the nitrogen requirements of a subsequent maize crop on a Rhodic Ferralsol in Tanga, Tanzania. *Tanzania Journal of Agricultural Sciences*, 12(1), pp.2329.http://www.ajol.info/index.php/tjags/article/view/102014.

Matloobi, M., 1998. Light harvesting and photosynthesis by the canopy. *In Advances in Photosynthesis–Fundamental Aspects.* 23 pp. www.intechopen.com.

Maurya, M.K., Rai, P. K., Kumar, A. Singh, B. A. and Chaurasia, A. K., 2014. Study on genetic variability and seed quality of groundnut (*Arachis hypogaea* L .) genotypes. *International Journal of Emerging Technology and Advanced Engineering*, 4(6), pp.818-823.

Mayer, J., 2003. Root effects on the turnover of grain legume residues in soil. Ph.D. thesis. University of Kassel. 119 pp.

Mbah, C.N. and Nneji, R.K., 2011. Effect of different crop residue management techniques on selected soil properties and grain production of maize. *Journal of Agricultural Research*, 6(17), pp.4149–4152.

McDonald, G.K., 1989. The contribution of nitrogen fertilizer to the nitrogen nutrition of rain fed wheat (*Triticum aestivum*) crops in Australia: a review. *Aust. J. Agric*. 29, 455–481.

Meghvansi, M. K., Prasad, K., and Mahna, S. K., 2010. Symbiotic potential, competitiveness and compatibility of indigenous *Bradyrhizobium japonicum* isolates to three soybean genotypes of two distinct agro-climatic regions of Rajasthan, India. *Saudi Journal of Biological Sciences*, *17*(4), 303–310.

Mehmet, O.Z., 2008. Nitrogen rate and plant population effects on yield and yield components in soybean. *African Journal of Biotechnology*, 7(24), pp.4464–4470.

Mendes, I.C., Hungria, M. and Vargas, M.A.T. 2003. Soybean response to starter nitrogen and *bradyrhizobium* inoculation on a cerrado oxisol under no-tillage and conventional tillage systems (1). *Revista Brasileira de Ciencia do Solo*, 27(3), pp.81-87.

Mikkelsen, R. and Hartz, T.K. 2008. Nitrogen sources for organic crop production. *Better crops*, 92(4).

Mmbaga, G. W., Mtei, K. M., and Ndakidemi, P. A. 2014. Extrapolations on the use of *rhizobium* inoculants supplemented with phosphorus (P) and potassium (K) on growth and nutrition of legumes. *Agricultural Sciences*, *5*(5), 1207–1226.

MoFA, 2011. Ministry of food and agriculture. Agriculture in Ghana; facts and figures. Statistics, Research and Information Directorate (SRID). 58 pp.

Mohammadi, K., Sohrabi, Y., Heidari, G., Khalesro, S. and Majidi, M. 2012. Effective factors on biological nitrogen fixation. *African Journal of Agricultural Research*, *7*(12), 1782–1788. http://doi.org/10.5897/AJARX11.034

Montanez, A., 2000. Overview and case studies on biological nitrogen fixation: perspectives and limitations, FAO.

Moriones R., 1983. Use of undisturbed soil cores for evaluation of *rhizobium* strains and methods for inoculation of tropical forage legumes in a Colombian oxisol. *Plant and Soil*, 74, 237-247.

Mughogho, S. K., J. Awai, H. S. Lowendolf, and D. J. Lothwell. 1982. The effects of fertilizer nitrogen and *rhizobium* inoculation on the yield of cowpeas and subsequent crops of corn. p. 297-301 *In*: Graham, P. H. and S. C. Harris. (ed.) Biological nitrogen fixation technology for tropical agriculture. Papers presented at a workshop held at CIAT, March 9-13, 1981. Cali, Colombia, Certro Internacional de Agricultura Tropical.

Muhammad, A., Dikko, A. U., Audu, M. and Singh, A. 2010. Comparative effects of cowpea and soybean genotypes on N_2 - Fixation and N-Balance in Sokoto Dry Sub-Humid Agro-Ecological Zone of Nigeria . *Nigerian Journal of Basic and Applied Sciences*, *18*(2), 297–303.

Mulongoy, E., 2015. Technical paper 2: Biological nitrogen fixation. Available at: http://www.fao.org/Wairdocs/ILRI/x5546E/x5546e05.htm

Mulualem, T., Dessalegn, T. and Dessalegn, Y., 2012. Participatory varietal selection of faba bean (*Vicia faba* L .) for yield and yield components in Dabat district. *Wudpecker Journal of Agricultural Resarch*, 1(7), pp.270– 274.

Mwangi, P.W., Chemining, N. G., Mburu, M. W. K. and Joseph, G. M., 2013. Decomposition and nutrient release rates of selected legume residues in a cold semiarid environment of Kenya. *International Journal of Agronomy and Agricultural Research*, 3(2), pp.1–13.

Mweetwa, A.M., Mulenga, M., Mulilo, X., Ngulube, M., Banda, J.S.K., N'gandu, S. H., 2014. Response of cowpea, soya beans and groundnuts to nonindigenous legume inoculants. *Sustainable Agriculture Research*, 3(4), pp.84–95.

Mylona, P., Pawlowski, K. and Bisseling, T., 1995. Symbiotic nitrogen fixation. *The Plant cell*, 7, pp 869-885.

Narwal, S. S., Malik, D. S. and Malik, R. S., 1983. Effects of preceding grain legumes on the requirement of wheat. *Agric.* 19:143-151.

Nelson, D. W. and Sommers, L. E., 1982. Total carbon, organic carbon and organic matter. *In*: Page AL, Miller RH, Keeny DR (eds,), Methods of Soil Analysis. Part 2: Chemical and Microbiological properties, 2nd ed. American Society of Agronomy, Madison, WI.

Newman, Y.C., Wright, D.W., Mackowiak, C., Scholberg, J. M. S. and Cherr, C. M., 2014. Benefits of Cover Crops for Soil Health, IFAS Extension, University of Florida.

Ngwu, O.E., 2005. Comparative studies of nitrogen fixing potential of *Desmodium ramississimon* and *Vigna unquiculata* for soil fertility management. *Tropicultura*, 23(2), pp.110–116.

Nyalemegbe, K.K. and Osakpa, T.Y., 2012. Rotation of maize with some leguminous food crops for sustainable production on the vertisols of the Accra Plains of Ghana. *West African Journal of Applied Ecology*, 20(2).

O'Hara, G. W., 1998. The role of nitrogen fixation in crop production. *Journal of Crop Production*, *1*(2), 115–138.

Okito, A. Alves, B. J. R., Urquiaga, S. and Boddey, R. M., 2004. Nitrogen fixation by groundnut and velvet bean and residual benefit to a subsequent maize crop. *Pesquisa Agropecuaria Brasileira*, 39(12), pp.1183–1190.

Olaoye, J.O., 2002. Influence of tillage on crop residue cover, soil properties and yield components of cowpea in derived savannah ectones of Nigeria. *Soil and Tillage Research*, 64(3-4), pp.179–187.

Olayinka, B.U. and Etejere, E.O., 2015. Growth analysis and yield of two varieties of groundnut (*Arachis hypogaea* L .) as influenced by different weed control methods. *Indian Journal of Plant Physiology*, 20, pp.130-136.

Olsen, S. R. and Sommers, L. E. (1982). Phosphorus. *In* A.L. Page (eds.). Methods of soil analysis. Part 2. Chemical and microbiological properties. Second edition. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin USA.

Olusegun, O.S., 2014. Influence of NPK 15-15-15 fertilizer and pig manure on nutrient dynamics and production of cowpea, *Vigna unguiculata* L . Walp. *American Journal of Agriculture and Forestry*, 2(6), pp.267–273.

Omokanye, A.T., Onifade, O. S., Amodu, J. T., Balogun, R. O. and Kallah, M. S., 2003. Evaluation of dual-purpose cowpea (*Vigna unguiculata* (L.) Walp.) varieties for grain and fodder production at Shika, Nigeria. *Tropicultura*, 21(1), pp.42–46.

Osborne, S.L. and Riedell, W.E., 2011. Impact of low rates of nitrogen applied at planting on soybean nitrogen fixation. *Journal of Plant Nutrition*, 34(3), pp.436–448.

Oyatokun, O.S. and Oluwasemire, K.O., 2014. Evaluating starter N application to soybean with CROPGRO-soybean model in the Southern Guinea Savanna agro-Ecology of Nigeria. *Journal of Agricultural Science*, 6(8), pp.83–100.

Page, A. L., Miller, R.H. and Keeney, D. R., 1982. Methods of soil analysis. Part 2. Chemical and microbiological properties. 2nd ed. *Agronomy Series 9, ASA, SSSA, Madison, Wis.*

Panda, S.C., 2010. Agronomy. 3rd edition. Agro House, Behind Nasrani Cinema Chopasani Road, Jodhpur. AGROBIOS, India.

Paul, W.U., 1994. Managing agricultural residues. Technology and Engineering. CRC press. 464pp.

Peoples, M.B., Faizah, M.B., Rerkasem, B. and Herridge, D.F., 1989. Methods for evaluating nitrogen fixation by nodulated legumes in the field. Australian Centre for International Agricultural Research monograph No. 11, 76 pp.

Peoples, M. B. and Craswell, E. T., 1992. Biological nitrogen fixation: investments, expectations and actual contributions to agriculture. *Plant and Soil* 141: 13-39.

Prado, D.E., 2000. Seasonally dry forests of tropical South America: From forgotten ecosystems to a new phytogeographic unit. *Edinburgh J. Bot.* 57: 437–461.

Qamar, I.A., Ahmad, M., Riaz, G. and Khan, S., 2014. Performance of summer forage legumes and their residual effect on subsequent oat crop in subtropical subhumid Pothwar, Pakistan. *Pakistan Journal of Agricultural Research* 27(1).

Quispel A., 1974. The biology of nitrogen fixation. North Holland Publ. Amsterdam.

Raich, J., Russell, A. E., Crews, T. E., Farrington, H. and Vitousek, P. M., 1996. Both nitrogen and phosphorus limit plant production on young Hawaiian lava flows. *Biogeochemistry*, 32(1), pp.1–14.

Ramos, M. L. G., Parsns R., Sprent, J. I. and James, E. K., 2003. Effect of water stress on nitrogen fixation and nodule structure of common bean. *Pesquisa*

Agropecuiria Brasileira.38 (3):339-347.

Ravikumar, R., 2012. Growth effects of *Rhizobium* inoculation in some legume plants. *Int J. Curr Sci.*, pp.1–6.

Reed, S.C., Cleveland, C.C. and Townsend, A.R., 2011. Functional ecology of free-living nitrogen fixation: A contemporary perspective. *Annual Review of Ecology, Evolution, and Systematics*, 42(1), pp.489–512.

Robert, F. and Idowu, J., 2015. Nitrogen fixation by legumes, New Mexico State University Cooperative Extension Services.

Roldán, A., Caravaca, F., Hernández, M. T., García, C., Sánchez-Brito, C.,Velásquez, M. and Tiscareño, M., 2003. No-tillage, crop residue additions, and legume cover cropping effects on soil quality characteristics under maize in Patzcuaro watershed (Mexico). *Soil and Tillage Research*, 72(1), pp.65–73.

Rosenani, B., Mubarak, R. and Zauyah, S., 2003. Recycling of crop residues for sustainable crop production in a maize-groundnut rotation system. *In* Management of crop residues for sustainable crop production, Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture. 1996–2001, pp.3–22.

Ruark, M., 2009. *Nitrogen and Soybeans*, University of Wisconsin Extension Services.

Russelle, M. P., 2008. Biological dinitrogen fixation in agriculture. *In*: Nitrogen in agricultural systems. Schpers, J. S. and Raun, W.R. Eds., Agronomy Monography.

Madison. USA. Chapter 9.

Sakala, W.D., Kumwenda, J.D.T. and Saka, A.R., 2000. The potential of green manures to increase soil fertility and maize yields in Malawi. Chitedze Agricultural Research Station, P.O. Box 158, Lilongwe, Malawi.

Sanginga, N., Okogun, J. A., Vanlauwe, B., Diels, J., Carsky, R. J. and Dashiell, K., 2001. Nitrogen contribution of promiscuous soybeans in maize-based cropping systems. *In Sustaining Soil Fertility in West Africa*. 157–178 (Eds G. Tian, F. Ishida and J. D. H. Keatinge). Soil Science Society of America Special Publication Number 58, Madison, USA: SSSA.

Sarkodie-Addo, J., Adu-Dapaah, H.K., Ewusi-Mensah, N. and Asare, E., 2006. Evaluation of medium- maturing soybean (*Glycine max* (L) Merrill) lines for their nitrogen fixation potentials. *Journal of Science and Technology (Ghana)*, p.5.

Saslis-Lagoudakis, C.H., Klitgaard, B.B., Forest, F. Francis, L., Savolainen, V., Williamson, E.M. and Hawkins, J.A., 2011. The use of phylogeny to interpret cross-cultural patterns in plant use and guide medicinal plant discovery: An example from *Pterocarpus* (Leguminosae). *PloS One* 6: e22275. http://dx.doi.org/10.1371/journal.pone.0022275

Schomberg, H. H., Steiner, J. L., and Unger, P. W., 1994. Decomposition and Nitrogen Dynamics of Crop Residues: Residue Quality and Water Effects. *Soil Science Society of America Journal*, *58*, 372.

Schuster-gajzágó, I., 2015. Cultivated plants, primarily as food sources – Vol.I. Nutritional aspects of legumes. *Encyclopedia of life support systems*, I, p.7.

Sebetha, E.T., Modi, A.T. and Owoeye, L.G., 2015. Maize seed quality in response to different management practices and sites. *Journal of Agricultural Science*, 7(1), pp.215– 223.

Shurtleff, W. and Aoyagi, A., 2009. History of soybeans and soyfoods in africa (1857 - 2009): extensively annotated bibliography and sourcebook. Soyinfo Center. Lafayetti, CA 94549-0234, USA. P.O. Box 234.

Silva, J. A. and Uchida, R., 2000. Biological nitrogen fixation. *In* Plant nutrient management in Hawaii's Soils, Approaches for Tropical and Subtropical Agriculture. pp. 121–126.

Singh, B. and Usha, K., 2003. Nodulation and symbiotic nitrogen fixation of cowpea genotypes as affected by fertilizer nitrogen. *Journal of Plant Nutrition*, 26(2), pp.463–473.

Singh, G., 2010. Soybean botany, production and uses, CPI Antony Rowe. U.K. 507p.

Singh, R.J., Chung, G.H. & Nelson, R.L., 2007. Landmark research in legumes. Genome/National Research Council Canada = Genome / Conseil national de recherches Canada, 50(6), pp.525–537.

Singleton, P. W. and Stockinger, K. R., 1983. Compensation against ineffective nodulation in soybean. *Crop Science*, *23*(1), 69.

Sirajul Islam, M. D., Ahmad, A., Mahmud, S., Tusher, T. R. and Khanom, S., 2012. Effects of organic fertilizer on the growth and yield of lettuce (*Lactuca sativa* L .) used as vegetable. *International Journal of Agricultural Science*, *2*(3), 116–128

Soe, K. M., Bhromsiri, A., Karladee, D., and Yamakawa, T., 2012. Strains on growth, nodulation, nitrogen fixation and seed weight of different soybean varieties. *Soil Science and Plant Nutrition*, *58*(3), 319–325.

Soils Laboratory Staff, 1984. Analytical methods of the service laboratory for soil, plant and water analysis. Part I: Method for soil analysis. Royal Tropical Institute, Amsterdam.

Solomon, T., Pant, L. M. and Angaw, T., 2012. Effects of inoculation by *Bradyrhizobium japonicum* strains on nodulation, nitrogen fixation, and yield of soybean (*Glycine max* L. Merill) Varieties on Nitisols of Bako, Western Ethiopia. *International Scholarly Research Network*, 2012, p.e261475

.
Sousssi, M., Ocaña, A. and Lluch, C. 1998. Effect of salt stress on growth, photosynthesis and nitrogen fixation in chickpea (*Cicer aretinum L.*). *Journal of Experimental Botany*. 49: 1329-1337.

Souza, G.M., Catuchi, T. A., Bertolli, S. C. and Soratto, R. P., 2012. Soybean under water deficit : physiological and yield responses, Available at: http://www.intechopen.com/books/a-comprehensive-survey-of-internationalsoybean-

Staton, M., 2012. Moisture stress and high temperature effects on soybean yields. Michigan State University Extension.

Starling, M.E.; Wesley Wood, C. and Weaver, D.B., 1998. Starter nitrogen and growth habit effects on late-planted soybean. *Agron. J.*, 90:658-662

Suge, J.K., Omunyin, M.E. and Omami, E.N., 2011. Effect of organic and inorganic sources of fertilizer on growth, yield and fruit quality of eggplant (*Solanum Melongena* L). *Archives of Applied Science Research*, 3(6), pp.470–479.

Sulfab, H. A., Mukhtar, N. O., Hamad, M. E., Adam, A.I., 2011. Effect of bioorganic and mineral nitrogen starter dose on growth and production of groundnuts (*Arachis hypogaea* L.) in Malakal Area. *Journal of Science and Technology*, 12(2), pp.13 – 22.

Tairo, E. V and Ndakidemi, P.A., 2013. *Bradyrhizobium japonicum* inoculation and phosphorus supplementation on growth and chlorophyll accumulation in soybean (*Glycine max* L .). *American Journal of Plant Sciences*, pp.2281–2289.

Talaka, A., Rajab, Y.S., Mustapha, A.B., 2013. Growth performance of five varieties of soybean (*Glycine Max*. [L.] Merill) under rainfed condition in Bali Local Government Area of Taraba State-Nigeria. *Journal of Agricultural and*

Veterinary Science. Vol.2, Issue 4.

Taiz, L., Zeiger, E., Møller, I. M. and Murphy, A., 2015. Plant physiology and development, Sixth Edition. Published by Sinauer Associates.

Tajima, R., Lee, O., Abe, J., Lux, A. and Morita, S., 2007. Nitrogen-fixing activity of root nodules in relation to their size in Peanut (*Arachis hypogaea* L .). *Plant Production Science*, *10*(4), 423–429.

Tanimu, J., Odunze, A. C. and Tian, G., 2007. Effect of incorporation of leguminous cover crops on yield and yield components of maize. *World Journal of Agricultural Sciences*, 3(2), pp.243–249.

Tarawali, G., Manyong V.M., Carsky R.J., Vissoh P.V., Osei-Bonsu P. and Galiba M., 1999. Adoption of improved fallows in West Africa: lessons from mucuna and stylo case studies. *Agroforestry systems,* 47:93-122.

Thomas, G. W. 1982. Exchangeable cations pp. 159-165. In: Page, A. L., Miller R. H. and Keeney, D. R. (eds). Method of soil analysis. Part 2, Agronomy Monograph 9, American Society of Agronomy. Madison, Wisconsin.

Thomas, R.S. and Vincent, V., 2012. The future of grain legumes in cropping systems. *Crop and Pasture Science*, 63, pp.501–512.

Thönnissen, C., Midmore, D. J., Ladha, J. K., Olk, D. C. and Schmidhalter, U., 2000. Legume decomposition and nitrogen release when applied as green manures to tropical vegetable production systems. *Agronomy Journal*, 92(2), pp.253–260.

Timko, M.P., Ehlers, J.D. and Roberts, P. A, 2007. Cowpea. Genome mapping and molecular breeding in plants, volume 3 pulses, sugar and tuber crops C. Kole (Ed.), Springer-Verlag Berlin Heidelberg 2007 3, 19p.

Unkovich, M., Herridge, D., Peoples, M., Cadisch, G., Boddey, B., Giller, K. and Chalk, P. 2008. Measuring plant-associated nitrogen fixation in agricultural systems. Australian Centre for International Agricultural Research. ACIAR Monograph No. 136. 260pp.

Umeh, S.I. and Mbah, B.N., 2010. Measuring the benefits of biological nitrogen fixation of soybean (*Glycine max* (I.) Merrill) in cassava (*Manihot esculenta* crantz) and soybean intercrop. *African Journal of Agricultural Research*, 5(24), pp.3354–3359.

UNEP, 2014. The nitrogen cascade UNEP Year Book 2014 emerging issues update: Excess nitrogen in the environment. 6 pp.

USDA/NNDSRR28, 2015a. Basic Report 16108 , Soybeans, mature seeds, raw.

USDA/NNDSRR28, 2015b. Basic Report 16087 , Peanuts , all types , raw.

USDA/NNDSRR28, 2015c. Basic Report 16060 , Cowpeas, catjang , mature seeds , raw.

USDA/NNDSRR28, 2015d. Basic Report 11900 , Corn , sweet , white , raw.

Valenzuela, H. and Smith, J., 2002. Cowpea. College of Tropical and Human

Resources (CTAHR). University of Hawaii at Manoa.

Van Berkum, P., Eardly, B.D., 1998. Molecular evolutionary systematics of the Rhizobiaceae. *In*: Spaink, H.P., Kondorosi, A., Hooykaas, P.J.J. (Eds.). The Rhizobiaceae, Molecular Biology of Model Plant-Associated Bacteria. Kluwer Academic Publishers, Dordrecht.

Van Jaarsveld, C. M., Smit, M. A. and Krüger, G. H. J. 2002. Interaction amongst soybean [*Glycine max* (L.) Merrill] genotype, soil type and inoculants strain with regards to N_2 fixation. *Journal of Agronomy and Crop Science,* 188: 206-211.

Van Kessel, C. and Hartley, C., 2000. Agricultural management of grain legumes: Has it led to an increase in nitrogen fixation? *Field Crops Research*, *65*(2-3), 165– 181.

Vara Prasad, P.V., Kakani, V. G. and Upadhyaya, H. D., 2009. Growth and production of groundnut, in soils, plant growth and crop production, [Ed. Willy H. Verheye], in Encyclopedia of life support systems (EOLSS), developed under the auspices of the UNESCO, Eolss Publishers, Oxford, UK.

Vitousek, P.M. and Howarth, R. W., 1991. Nitrogen limitation on land and in the sea : How can it occur ? *Biogeochemistry*, 13, pp.87–115.

Voisin, A. S., Salon, C., Jeudy, C. and Warembourg, F. R. 2003. Root and nodule growth in *Pisum sativum* L. in relation to photosynthesis: analysis- using ^{13}C-labelling. *Annals of Botany*. 92: 557-563.

Weisany, W., Yaghoub, R. and Kaveh, H.A., 2013. Role of some of mineral nutrients in biological nitrogen fixation. *Experimental Agriculture*, 2, pp.77–84.

Werner, D. and Newton, W. E., 2005. Nitrogen fixation in agriculture, forestry, ecology, and the environment. Springer Publication.

Wesley, T.L., Lamond, R.E., Martin, V.L. and Duncan S.R., 1998. Effects of late-season nitrogen fertilizer on irrigated soybean yield and composition. *J. Prod. Agric*. 11:331–336.

Woodard, H.J., Bly, A. and Winther, D., 1997. The effect of M - pact application on growth and yield parameters of soybean and corn in Eastern South Dakota. (24496 and 25796). www.sdstate.edu/ps/research/soil-fertility/reports.

Woomer, P. L., Martin, A. Albrecht, D. V. S., Resek and Scharpenseel, H. W., 1994. The importance and management of soil organic matter in the tropics. Pp 4780. *In*: The biological management of the soil fertility (eds.): Woomer, P. L. and Swift, M. J. Wiley and Sons.

Zahran, H. H., 1999. *Rhizobium*-legume symbiosis and nitrogen fixation under severe conditions and in an arid climate. *Microbiology and Molecular Biology Reviews* 63:968–989.

Zhang, Q., Yang, Z. and Wu, W., 2008. Role of crop residue management in sustainable agricultural development in the North China Plain. *Journal of Sustainable Agriculture*, 32(1), pp.137–148.

APPENDIX

Appendix 1 Initial soil status of the experimental site at 0 – 15 cm and 15 – 30 cm in 2014.

Parameter	2014	
	0 -15 cm	15 – 30 cm
Sand (%)	79.12	80.76
Silt (%)	12.81	9.72
Clay (%)	8.07	9.52
Available P (mg/Kg)	5.18	3.89
Base Saturation (%)	98.01	98.20
Exchangeable cations		
K	0.12	0.22
Ca	3.74	3.2
Mg	1.07	0.8
Na	0.07	0.14
(Al + H)	0.1	0.08
ECEC (c mol/Kg)	5.03	4.44
Organic Carbon	1.09	0.57
pH 1:1 (H_2O)	5.79	5.56
Total N (%)	0.1	0.08
Texture	Loamy sand	Loamy sand

Appendix 2 Initial soil status of the experimental site at 0 – 15 cm and 15 – 30 cm in 2015.

Parameter	2015	
	0 -15 cm	15 – 30 cm
Sand (%)	77.12	84.76
Silt (%)	13.36	5.05
Clay (%)	9.52	10.19
Available P (mg/Kg)	5.13	4.12
Base Saturation (%)	94.07	98.29
Exchangeable cations		
K	0.14	0.21
Ca	2.67	2.67
Mg	1.87	1.6
Na	0.08	0.12
(Al + H)	0.3	0.08
ECEC (c mol/Kg)	5.06	4.68
Organic Carbon	1.22	1.06
pH 1:1 (H_2O)	5.71	5.6
Total N (%)	0.1	0.1
Texture	Sandy loam	Loamy sand

Appendix 3 Summary of weather data during the year 2014.

Month	Min T° (°C)	Max T° (°C)	Relative humidity (%)	Rainfall (mm)
January	33.1	22.6	85	58.6
February	33.3	22.2	79	62.0
March	33.7	22.7	81	93.5
April	33.8	23.1	80	128.6
May	32.1	22.7	83	103.4
June	30.9	22.5	85	270
July	28.7	21.5	87	914
August	27.7	20.9	90	74.2
September	29.3	21.3	89	162.9
October	30.3	21.7	86	138.2
November	32.1	22.4	83	107.2
December	32.1	21.8	77	10.8

Source: Ghana meteorological agency, KNUST agrometeorological station, Kumasi, Ghana.

Appendix 4 Summary of weather data during the year 2015.

Month	Min T° (°C)	Max T° (°C)	Relative humidity (%)	Rainfall (mm)
January	17.8	33.4	62	2.4
February	22.2	33.4	83	53.7
March	22.2	33.5	82	108.5
April	22.8	33.3	81	183.3
May	22.9	32.7	82	144.6
June	21.4	30.4	85	206.5
July	21.3	29.0	88	103.7
August	21.7	28.5	89	10.2
September	20.9	30.0	87.2	56.7
October	21.8	31.8	85	163.6
November	22.1	32.1	85	21.6

Source: Ghana meteorological agency, KNUST agrometeorological station, Kumasi, Ghana.

Appendix 5

Input and output of groundnut, cowpea and soybean varieties production in Kumasi in 2014 major wet season.

Parameter	Land prep	weeding	Thinning	Seeds	planting	Glyphosate/ spraying	Lambda/ spraying	harvesting	Net revenue
Variety Chinese									
	250	333	125	188	250	42	0	250	1904
jenkaar	250	333	125	188	250	42	0	250	2028
Manipinta	250	333	125	188	250	42	0	250	2320
Nkatiesari	250	333	125	188	250	42	0	250	1588
Sumnut-22	250	333	125	188	250	42	0	250	2468
Asetenapa	250	333	125	188	250	42	42	250	1480
Asomdwee	250	333	125	188	250	42	42	250	3270
Asontem	250	333	125	188	250	42	42	250	4332
Hewale	250	333	125	188	250	42	42	250	3039
Videza	250	333	125	188	250	42	42	250	2154
Jenguma	250	333	125	188	250	42	0	250	1644
Quashie	250	333	125	188	250	42	0	250	1654
Salintuya-1	250	333	125	188	250	42	0	250	1698
Songda	250	333	125	188	250	42	0	250	1576
Sonqu-panqu	250	333	125	188	250	42	0	250	2362

Appendix 6

Input and output of maize production in Kumasi in 2014 minor wet season.

Parameter	Haulm equivalent price	weeding	Thinning	Seeds	planting	Glyphosate/ spraying	Lambda/ spraying	harvesting	Net revenue
Haulm Chinese	1604	313	117	64	234	39	39	332	3383
jenkaar	1472	313	117	64	234	39	39	332	34003400
Manipinta	1536	313	117	64	234	39	39	332	30223022
Nkatiesari	1020	313	117	64	234	39	39	332	
Sumnut-22	1516	313	117	64	234	39	39	332	36863686
Asetenapa	528	313	117	64	234	39	39	332	33833383
Asomdwee	726	313	117	64	234	39	39	332	2835
Asontem	640	313	117	64	234	39	39	332	28353516
Hewale	1181	313	117	64	234	39	39	332	35162998
Videza	717	313	117	64	234	39	39	332	
Jenguma	621	313	117	64	234	39	39	332	29983390
Quashie	957	313	117	64	234	39	39	332	33903154
Salintuya-1	777	313	117	64	234	39	39	332	31543135
Songda	1029	313	117	64	234	39	39	332	3724135
Sonqu-panqu	681	313	117	64	234	39	39	332	32703724
	Fertilizer price								32033270

Appendix 7

32813203

3281

Recommended Fertilizer	1235	313	117	64	234	39	39	332	2867

Input and output of soybean production as affected by inoculation and inorganic N in 2015 major rainy season.

Parameter	Land prep	weeding	Thinning	Seed	Inoculant	Fertilizer	planting	Glyphosate/spraying	Lambda/spraying	harvesting	Total revenue

Appendix 8

Treatment											
Quashie +I	416	416	156	188	125	0	156	52	52	78	706
Quashie + 30kg N	416	416	156	188	125	169	156	52	52	78	817
Quashie + 60kg N	416	416	156	188	125	338	156	52	52	78	732
Salintuya + I	416	416	156	188	125	0	156	52	52	78	682
Salintuya + 30kg N	416	416	156	188	125	169	156	52	52	78	449
Salintuya + 60 kg N	416	416	156	188	125	338	156	52	52	78	638
Songda + I	416	416	156	188	125	0	156	52	52	78	546
Songda +30kg N	416	416	156	188	125	169	156	52	52	78	628
Songda +60kg N	416	416	156	188	125	338	156	52	52	78	474
Sonqu-panqu + I	416	416	156	188	125	0	156	52	52	78	1170
Sonqu-panqu + 30kg N	416	416	156	188	125	169	156	52	52	78	1080
Sonqu-panqu + 60kg N	416	416	156	188	125	338	156	52	52	78	1370

Input and output of maize production as affected by haulm and recommended fertilizer in 2015 major rainy season.

Appendix 9

Parameter	Haulm equivalent	Weeding /spraying	Thinning a/sprayi revenue	Seed price	planting ng	Glyphosate	Lambd	harvesting	Total
Treatment									
Quashie +I	885	416	156	64	156	52	52	78	2965
Quashie + 30kg N	1167	416	156	64	156	52	52	78	2814
Quashie + 60kg N	1179	416	156	64	156	52	52	78	2548
Salintuya + I	930	416	156	64	156	52	52	78	1925
Salintuya + 30kg N	870	416	156	64	156	52	52	78	2063
Salintuya + 60 kg N	996	416	156	64	156	52	52	78	2541
Songda + I	921	416	156	64	156	52	52	78	2371
Songda +30kg N	1038	416	156	64	156	52	52	78	2993
Songda +60kg N	831	416	156	64	156	52	52	78	2385
Sonqu-panqu + I	786	416	156	64	156	52	52	78	2788
Sonqu-panqu + 30kg N	708	416	156	64	156	52	52	78	1991
Sonqu-panqu + 60kg N	945	416	156	64	156	52	52	78	1981
	Fertilizer price 1235								
Recommended fertilizer		416	156	64	156	52	52	78	3543

Appendix 10