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BIOLOGICAL NITROGEN FIXATION POTENTIAL OF COWPEA UNDER COMPOSTED MILLET GLUME AND MINERAL FERTILIZER APPLICATION IN SAHELIAN ZONE OF NIGER

BY

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(INGENIEUR AGRONOME)

JULY, 2014

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IN

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DECLARATION

I hereby declare that this submission is my own work towards the MSc degree and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

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ABSTRACT

Cowpea (*vigna unguiculata* L. Walp) is one of the cash crops grown in West Africa, where farming systems are characterized by low soil nutrient contents and limited fertilizer inputs. Therefore, the ability of cowpea to fix atmospheric nitrogen is very important in these farming systems. In this study conducted at N'dounga research station INRAN/ Kollo, the amount of nitrogen fixed by cowpea amended with millet glume compost and mineral fertilizer was assessed using the Total Nitrogen Difference (TND) method. The results showed that the combined application of composted millet glume and mineral fertilizer contributed more to nodulation than mineral fertilizer alone. Furthermore it was observed that 3 t ha^{-1} composted millet glume + 15 kg N ha^{-1} + 26 kg P ha^{-1} produced the highest grain yield (2764 kg ha^{-1}). Grain N and P uptake were significantly higher in the combined compost and mineral fertilizer treatments. The 3 t ha^{-1} composted millet glume + 15 kg N ha^{-1} + 26 kg P ha^{-1} gave the highest nitrogen use efficiency (NUE) and phosphorus use efficiency (PUE). Correlation analysis showed a strong positive relationship (R^2 = 0.84) between grain yield and nodule dry weight. Furthermore, a strong positive correlation (R^2 = 0.98) was observed between grain yield and amount of nitrogen fixed. The proportion of nitrogen derived from atmosphere (Ndfa) in cowpea ranged from 33% to 78%. Combined application of composted millet glume and mineral fertilizer treatments had significant ($P < 0.05$) effect on the proportions of nitrogen derived from the atmosphere and the amounts of N fixed by cowpea. Nitrogen fixed was highest (69.57 kg ha^{-1}) under 3 t ha^{-1} composted millet glume + 15 kg N ha^{-1} + 26 kg P ha^{-1} and represented 262.53% increase over the control (19.19 kg ha^{-1}).

DEDICATION

This thesis is dedicated to my parents and siblings.

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CHAPTER ONE

1.0 INTRODUCTION

Agricultural production over the years has depended on chemical fertilizers, high yielding varieties and pesticides to increase crop yield in order to meet the food supply of the increasing population. The use of chemical fertilizers has therefore become an essential practice to optimize crop production. Regardless of the major role chemical fertilizers play in crop productivity and soil fertility, its increased use in agricultural production has adverse effect on the environment and sustainable agriculture as a whole (Dudal and Byrnes, 1993).

Niger is one of the countries of the Sudano - Sahelian zone where the general decline in soil fertility is one of the major constraints to agricultural production and environmental stability (Kouyate, 1996). At present, soil nutrients continue to be depleted rather than more crop soil productivity. Modern agriculture is now focused on agricultural practices that are inclined towards environmentally sustainable development approaches (Sturz and Howak, 2000) as alternatives to use of chemical fertilizers.

The use of composted millet glume in crop production is gradually gaining popularity among smallholder farmers in Niger. Millet glumes (the residues left after millet threshing) are readily available in most villages of Niger and contain macro and micronutrients (Fatondji *et al.*, 2009). Nonetheless, there is virtually no scientific research on its influence on biological nitrogen fixation and legume grain yield. Biological nitrogen fixation constitutes a very useful resource in agriculture, as leguminous crops are known to contribute as much as 20% of the nitrogen requirement of the world's grain (Herridge *et al.*, 2002).

The ability of cowpea to fix atmospheric nitrogen is not always adequate for yield maximization due to the influence of different factors such as temperature, soil physical, chemical and biological characteristics such as pH of the soil, low phosphorus, presence of inefficient native rhizobia in the soil that are compatible with the legume planted, as well as other biotic agents (Hubbell and Kidder, 2009).

Farmers' practices affect soil productivity (Kiba, 2012) and certainly symbiotic N fixation in cowpea will depend on the fertility status and management methods of soil fertility (Bado *et al*., 2006; Vesterager *et al*., 2008). Composts form an integral part of soil fertility management. Thus, working on the hypothesis that complementary and sole applications of composted millet glume and inorganic fertilizer will enhance the biological nitrogen fixation and yield of cowpea, the specific objectives of this study were to:

i. determine the nodulation and nitrogen fixation potential of cowpea under composted millet glume and mineral fertilizers (N and P).
ii. assess the effect of composted millet glume and mineral fertilizer application on the growth and yield of cowpea.
iii. evaluate N and P use efficiency when used in combination with composted millet glume.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Background of the study

As human populations continue to grow towards an anticipated figure of over eight billion by the year 2020, there is considerable anxiety that the food inequalities prevalent in the word today will worsen over the next twenty years (Pretty *et al.*, 1996). Optimists calculate that, in absolute terms, the planet should be able to sustain this huge population through increases in crop production. It is also predicted that in developing countries, two-thirds (67%) of the increase in food output will in fact come from rising crop yields; 20% will be achieved through expansion of arable area into marginal and degraded lands, and 13% from increased cropping intensity (Alexandrotos, 1995).

However, these advances will have a disappointing impact upon mitigation of the impending crisis if disparity of access to food is not resolved for the poorest households. Amongst strategies for improving access to food is ensuring that local capacity for staple food production is retained or, better still, enhanced (Pretty *et al.*, 1996). This may seem an obvious suggestion but this is becoming increasingly difficult to attain. Rising population densities in rural areas render the average size of agricultural landholdings too small even for subsistence crop production. The risk that rural families will lose access to viable land units providing a year - round food supply is real. This has led to a popular paradigm that rising rural populations place increasing pressure on land through increased cropping intensity and that this threatens the fundamental bio-physical factor underpinning food security and soil fertility (Donovan and Casey, 1998).

The magnitude of nutrient depletion in Africa's agricultural soil is enormous (Smaling, 1993). Nutrient depletion from cultivated land in sub- Saharan Africa indicated annual rates of 4.4, 5 and 3 million tons of N, P and K respectively (Stroosvogel and Smaling, 1990; Sanchez *et al.*, 1997). These rates are several times higher than Africa's annual fertilizer consumption excluding that of South Africa of 0.8, 0.26 and 0.2 million tons of N, P and K, respectively (FAO, 1995). Depletion rates also vary among countries. Intensive crop production without external input may even reveal higher localized depletion values. Assessing nutrient depletion through various output pathways would therefore form an important base for developing sound soil fertility management practices and replenishment strategies. Nutrient depletion rates vary, with soil properties being higher in sandier soils with initial lower levels of nutrient than clay soils with higher nutrient levels. This is largely because soil organic matter particles are less protected from microbial decomposition in sandier soils (Pieri, 1989; Swift *et al.*, 1994).

The removal of produce without replenishing nutrients exported by the crops causes a continued decline in soil fertility and the ability of the land to support any vegetation is impaired (Dudal and Byrnes, 1993). The decline in soil fertility is almost associated with a reduction in soil organic matter which correlates with a loss of structure, lowered water infiltration, leaching and a decrease in nutrient depletion capacity (Greenland *et al.*, 1994). These effects, in addition to less cover to protect, increase runoff and erosion losses which may cause off - site siltation of reservoirs and in some cases eutrophication of rivers and lakes (Sanchez *et al.*, 1997).

The major consequence of soil fertility depletion is a marked decline in crop yield and food security. Food shortages and famine become more acute during drought years. Low crop yields force more farmers to cultivate more land, usually forested areas and marginal which are more susceptible to erosion. A greater strain is put on the limited urban infrastructure which consequently leads to a rise in unemployment, crime and in some cases trigger off political unrest (Bonsu and Quansah, 1992; Homer - Dixon *et al.*, 1993). Soil fertility replenishment could therefore contribute significantly to the resolution of most of the problems of depletion.

A practical goal in the maintenance of soil fertility is to return to the soil most of the nutrients removed from it through harvests, runoff, erosion and other loss pathways (Aune, 1993; Quansah, 1996). The pathways for soil fertility replenishment include mineral fertilizer application, maintenance of soil organic matter (animal manure, plant residue, municipal waste, raw or processed into compost) and accompanying technologies (soil conservation and sound agronomic practices) (Homer - Dixon *et al*., 1993). Mineral fertilizer application is the most obvious way to overcome soil fertility depletion. It has been responsible for a large part of the increases in food production that have occurred in the temperate region, tropical Asia and Latin America and the commercial sector of Africa (Mokwunye and Hammond, 1992; Borlaug, 1996). In spite of its benefits in food production, improper use may cause detrimental environmental effects (FAO, 1972). Within individual nutrient sources, their impact usually depends less on the fertilizer itself than on the amount and the way it is applied. Detrimental effects are usually due to application rates in excess of plant needs or to improper management practices (Dudal and Byrnes, 1993). The main negative effects of higher fertilizer application are occurrences of serious nutrient imbalances and toxicities that affect yields or crop quality and off - site effects from leaching and erosion of nutrients particularly N and P. However, lack of adequate additions of externally derived nutrients severely limits the development of agricultural production on a sustainable basis (Ofori and Fianu, 1996).

2.2 Cowpea and its socio – economic importance in Niger

There are many local and improved varieties of cowpea in Niger. In general, local varieties are crawling, while improved varieties are erect or semi erect, and have characteristics of resistance to diseases and / or insects (Hall, 2004). Cowpea as an atmospheric nitrogen fixing plant enters into symbiosis with several species of rhizobia. Several studies have focused on the fixation of atmospheric nitrogen by cowpea in Africa. Many of them were however made in a controlled environment or at research stations (Belane and Dakora, 2010). Peoples *et al*. (2009) indicate that in Africa, cowpea would take between 15 and 89% of its nitrogen from symbiotic nitrogen fixation, and on average 63 kg N ha^{-1} are recorded by considering only the aerial part of the plant.

By measuring nitrogen fixation of 30 cowpea varieties from various parts of Africa, Belane and Dakora (2010) found Ndfa of 64 - 86%, corresponding to between 49 and 178 kg N ha^{-1} attached to the aerial part of the plants by the method of natural abundance. By the same method, Belane *et al*. (2011) comparing the symbiotic nitrogen fixation of 32 cowpea varieties in southern Africa, found a significant variation in Ndfa among them and the Ndfa ranged from 50 to 81%. That is why cowpea does not require much contribution from nitrogen fertilizer (Christian *et al*., 2005). In a survey of 63 farmers' fields in the north - western region of Ghana, Naab *et al*. (2009), using the natural abundance method found between 12 and 99% of the nitrogen in the aerial part of cowpea originated from the atmosphere. The ability of cowpea to fix atmospheric nitrogen depends on factors such as variety, climate conditions (Nyemba and Dakora, 2010) and soil fertility conditions of the field (Bado *et al*., 2008). Cowpea grows well when the sun is direct (Prota, 2006). Cowpea adapts well to poor sandy soils. However, it is on well-drained soils, (sandy loam) at pH of 6 to 7, that it reaches its highest yields (Prota, 2006).

Cowpea is the most important food legume grown in most parts of tropical Africa (Berthe *et al.,* 2010). It is an important staple in sub-Saharan Africa, particularly in arid savannahs of West Africa. Cowpea is much consumed in Niger due to its organoleptic qualities and the financial benefits it brings to producers (Coulibaly, 2009). This is the most consumed legume and most cultivated in Niger after groundnut. It is grown primarily in Niger for its dry seeds cooked in the most diverse forms. But in some parts of the country, its young leaves fresh or dried, and immature pods are also consumed (Berthe *et al*., 2010). The mature seed contains 23 - 25 % protein, 50 - 67 % starch, B vitamins such as folic acid which is important in the prevention of malformations in the newborn (Pasquet and Baudoin, 1997). Its seeds are a valuable source of vegetable protein, vitamins and income for humans and fodder for animals (Dugje *et al*., 2009). Juvenile leaves and immature pods are eaten as a vegetable. There is a large market for seeds and fodder cowpea in West Africa. According to the results of a study conducted in Nigeria, farmers who harvest and store fodder cowpea for sale in the dry season, increase their income by 25 percent (FAO, 2000). In a system of rotation or association, cowpea also plays an important role as a source of nitrogen for cereal crops (such as maize, millet and sorghum), especially in areas characterized by low soil fertility status. Its nitrogen requirements are low; its roots are equipped with populated nodule bacteria (rhizobia) that contribute to the fixation of atmospheric nitrogen.

In developing countries where access to animal protein is difficult or impossible for some people, cowpea is the only source of protein and most accessible (Capo-Chichi, 2005). In fact, it is referred to as “poor man's meat”. Thus, cowpea is likely to fill the protein deficits in developing countries which form three-quarters of the world's population (Capo-Chichi, 2005). Cowpea plays an important role in the achievement of food security of rural populations in Niger and is consumed throughout the year. It also provides excellent fodder for livestock.

2.2.2 Importance of cowpea cropping systems

Cowpea plays an important role in maintaining the productivity of cultivated soils. It has often been observed that among the commonly used legumes, cowpea has been found to be the best cultural preceding crop (Bado *et al*., 2008). In sub - Saharan Africa, cowpea is usually included in rotations and intercrops to fix atmospheric nitrogen. A preceding cowpea rotation allows a very significant increase in cereal yields, compared to cereals (Bagayoko *et al*., 2000; Bado, 2002). Cowpea has the ability to grow fast and more importantly the spreading type is able to control weeds and erosion (Harrison et *al.*, 2007). Aside being processed into oil, cowpea can be used to prepare a variety of recipes. Cowpea is used in the livestock industry to prepare feeds for livestock. Grain legumes are cheap sources of protein especially to the poor (Ennim et *al.*, 2004). Legumes improve the availability of nitrogen to subsequent crops compared to cereals, due to better mineralization of residues and greater release of mineral nitrogen (Douxchamps *et al*., 2010). Its ability to fix atmospheric nitrogen gives it the important role of preceding crop and the maintenance of soil fertility (Ahounou, 1990).

2.3 Biological nitrogen fixation

Biological Nitrogen Fixation is a process involving the conversion of nitrogen gas (N_2) into ammonia through biological processes; the bacteria involved are able to utilize the molecular N_2 with the help of nitrogenase enzyme to convert atmospheric N to ammonia (FAO, 2006). In agriculture, perhaps, 80% of this biologically fixed N_2 comes from symbiosis involving leguminous plants and α proteobacteria, order Rhizobiales, family *Rhizobiacea*, including species of *Bradyrhizobium*, *Sinorhizobium*, *Azorhizobium* and *Mesorhizobium* (Farrand *et al*., 2003). According to Tahir *et al.* (2009), biological nitrogen fixation of legumes is a vital process for sustaining crop land management and is an effective and efficient source of N supply to plants under favorable atmospheric and environmental conditions. The biological nitrogen fixation symbiosis consists of complex processes of infection of roots by rhizobia, nodule development, nodule function and nodule senescence which is catalyzed by the nitrogenase complex; nitrogenase catalyses the conversion of N_2 to NH_4^+, as represented by:

$N_2 + 10H^+ + 8e^- + n\ Mg\ ATP \rightarrow 2NH_4^+ + H_2 + n\ Mg\ ADP + n\ P_1\ (n \geq 16)$ (Vitousek, 1997).

The process is achieved through a symbiotic relationship through exchange of signals between the legume plant and the rhizobia leading to a mutual recognition and development of symbiotic structures. This process is initiated by adhesion and colonization of the bacteria to the root tips of legume causing deformation. At this stage, the plant perceives the rhizobia signal and initiates a program aimed at formation of symbiotically nitrogen - fixing nodules (Denarie *et al*., 1996). A set of plant genes, initially called nodulins, is specifically activated in response to nodulation factor perception (Ferguson *et al.*, 2010).

A common genetic determinant for rhizobia is the presence of genes encoding nodulation and nitrogen fixation functions (nod, nol, noe, nif and fix genes) involved in production of nodulation signal, the Nod factor, which is a lipo-chitooligosaccharide (Gage, 2004). Along with flavonoids, plant roots secrete a host of compounds, many of which are a ready source of nutrition for the bacteria. Consequently, the rhizobia typically multiply rapidly in the rhizosphere so that a film (called a "biofilm" of bacteria), comprised of the multiplying rhizobia cells embedded in a self-produced slimy matrix of extracellular polysaccharides, anchors itself to the root and importantly to the growing root hairs which are the ultimate points of infection (Downie, 2010).

Root hairs are very thin, hair-like outgrowths from a single epidermal (i.e., surface) cell of the root, and typically are found in the region just behind the growing root tip. These delicate protrusions have very thin walls to facilitate the uptake of water and nutrients. The thin and less cross - linked walls of the root hair also present a less challenging barrier for invading rhizobia (Ferguson *et al*., 2010). While flavonoids attract rhizobia, signaling the nearby presence of a suitable host plant, these same plant-derived compounds also cause the activation of a suite of bacterial genes (called nod genes) which otherwise remain inactive (Freiberg *et al*., 1997; Wang *et al*., 2004).

2.3.1 Quantification of biological nitrogen fixation

The quantification of BNF is the estimation or measurement or the assessment of the amount of nitrogen derived from the atmosphere as a result of the symbiotic association between rhizobia and host legume. There are many methods for quantifying BNF (Danso, 1995) but among the methods the following are commonly used; the nitrogen difference (TND) method, ureide method (xylem-solute), acetylene reduction assay (ARA) technique, and the use of ^{15}N labelled compounds (Danso, 1995; Unkovich *et al*., 2008). Although some of the methods may be more accurate than others, none is perfect as each method has its own disadvantages. The quantification of BNF is necessary for the following reasons: to determine if the selected legume has the ability to fix biological N (Unkovich *et al*., 2008), ascertain the effects of management practices on the amount of biological N fixed and the amount it can fix (Unkovich *et al*., 2008), to determine the effectiveness of the symbiotic association between an introduced strain and a host legume as well as the indigenous strain and a host legume and to determine the contribution of biological N to farming systems (Unkovich *et al*., 2008).

2.3.2 Role and place of nitrogen fixing legumes in the management of soil fertility

Losses of nutrients from the soil occur through leaching, crop removal through harvesting and soil erosion (Stoorvogel, 1993). In as much as these losses are ineviatable, it can be curtailed through the application of inorganic and biofertilizers (Giller and Cadisch, 1995). Legumes have the potential to fix atmospheric nitrogen. We can therefore assume that these species may be sufficient on their own nitrogen requirements, and ensure at least partial nitrogen nutrition associated cultures.

Legumes used for this work of reconstruction of soil must have certain characteristics including: high above ground biomass, the ability to fix atmospheric nitrogen and deeper root development (Young, 1995). Legumes (cowpea) have the opportunity to enrich the soil under certain conditions. The advantage thus created allows us to act positively on the cost of production by minimizing external inputs of nitrogen in a system of crop rotation - rotation (Dommergues and Mangenot, 1970).

2.4 Factors influencing symbiotic fixation of atmospheric nitrogen

2.4.1 Temperature

Excessive temperature in the root system affects root infection by bacteria and symbiotic nitrogen fixation in several legume species. High temperatures delay nodulation, reduce or inhibit the activity of nitrogenase and symbiotic nitrogen fixation (Zahran, 1999). The symbiotic activity in cowpea is therefore expected to have relatively high tolerance to high temperatures. The critical temperature for symbiotic nitrogen fixation in the legume is one of the highest and is somewhere between 35 and 40 ° C (Michiels *et al*., 1995).

2.4.2 Water and water stress

Symbiotic fixation of atmospheric nitrogen by legumes is very sensitive to lack of water. However, the response of the fixation to water stress depends on the stage of plant growth, and is more pronounced during the period of vegetative growth (Zahran, 1999). Concentration and efficiency in the use of P in nodules is increased with soil water content and roots (Zahran, 1999).

2.4.3 Soil pH

Most legumes need a neutral or slightly acidic pH to grow well and produce symbiotically fixed nitrogen. Strains of *Rhizobiaceae* have diversity with respect to the reaction of the soil pH. The majority of them live in a pH between 6 and 7, but few survive and grow in a pH of between 4.5 and 5 (Sadwasky, 2005). Strains of fast growing *Rhizobiaceae* are usually less tolerant to soil acidity than slow growing strains. Indeed, *Bradyrhizobium* strains are generally more tolerant to acidic pH conditions than those of Rhizobium (Sadwasky, 2005). Tolerance of some strains of *Rhizobiaceae* to conditions of soil acidity is linked to their ability to maintain an intracellular pH near neutrality (Sadwasky, 2005).

2.4.4 Senescence of nodules and release of rhizobia into the soil

Nodule death occurs because of plant senescence or other factors like drought, high soil temperatures and nutritional disorders that affect nodule life. The rhizobia then die or are released into the soil, hence completing their life cycle (Vincent, 1970). Since each nodule may contain millions of rhizobia and the number of nodules that may develop on a single plant vary from a few to a thousand or more, decayed nodules release vast numbers of rhizobia into the soil, thus increasing the rhizobia population. Bushby (1981) obtained increased number of soybean rhizobia in soils grown with the crop at 70 days after planting. Where inoculation using effective *Rhizobium* strains has to be done in the tropics, for high yielding cowpea varieties, rhizobia originating from nodule disintegration are likely to form an important component of the rhizobia populations which nodulate subsequent crops (Brockwell *et al*., 1983). Similar effects are also known for micronutrients such as molybdenum and sulphur, which are constituents of the enzyme nitrogenase and are important nutrients for the rhizobia (Munns, 1978). Thus, plants that are dependent on symbiotically fixed nitrogen require greater quantities of macro and micro - nutrients than their non - symbiotic counter - parts (Jonnes and Lutz, 1971).

2.5 Compost

Composting attempts to recreate the conditions, which would occur in an undisturbed ecosystem where organic matter builds on the soil surface and is not regularly incorporated into the soil as in agriculture ecosystem (Lampkin, 1994). The nutrient content of composts, especially those derived from farmyard wastes, varies considerably depending on type of raw materials used, method of composting and maturity. Compost applications can form the foundation of an effective nutrient and SOM management strategy. Nutrients in composts are generally less available compared to manures or leguminous cover crops. The primary reason for reduced nutrient availability in composts is the higher degree of decomposition leading to the production of humic substances resulting in a slower release of nutrients, especially N (Churchill *et al.*, 1996).

The increase in stable SOM and favorable soil properties can be more effectively accomplished with compost than with fresh manure. The main reason for this is that compost is in an advanced state of decay. In the long term, however, the amount of organic matter applied is more important than the type of organic amendments used (Horwath *et al.,* 2002). Increased SOM through compost additions often results in enhanced soil quality. For example, Joyce *et al.* (2002) showed that organic management with composts improved porosity and water retention. Biological soil quality indicators, such as biomass C and N are also improved with compost applications (Horwath *et al.,* 2002).

2.5.1 An overview of the composting process

Composting is the deliberate biological decomposition of organic matter under controlled, aerobic conditions into a humus – like stable product (Epstein, 1997). The compost is an organic matter source and adds humus to soil. It acts to improve soil conditions and plant growth, and reduce the potential for erosion, runoff, and nonsource pollution. The composting process is primarily concerned with the creation of a suitable environment in which aerobic micro – organisms that are responsible for breakdown of organic matter can be optimally active. Composting processes typically have three main stages:

a. A mesophilic growth stage, which is characterized by bacterial growth under temperatures of 25 – 40 ˚C;
b. A thermophilic stage, where bacteria, fungi and actinomycetes (first level consumers) functioning at temperatures of 50 - 60 ˚C, breakdown cellulose, lignin and other resistant materials (this thermophilic stage can go as high as 70 ˚C);
c. A maturation stage, where temperatures stabilize and some fermentation occurs, converting the organic materials to humus (this process commences when the temperature of the composting material reverts to the ambient temperature) (Coyone, 1999).

2.5.2 Output quality and rate determining factors in the composting process

2.5.2.1 Substrate

Organic material is the substrate or food for the decomposing community (bacteria and other organisms). Carbon and N are the two major elements contained in the organic matter and control the activities of the micro – organisms. Carbon is used as a source of energy by the organisms, which oxidize it, generating heat and CO_2. Nitrogen is the main source of protein needed for cell production and population growth (reproduction).

Carbon and N vary with each organic material or feedstock. It is recommended that a blend of organic material be made in such a way that their C: N ratio is < 35 (FAO, 1987), with a range of 20 – 30 being ideal. When C: N ratio rises above this level, heat production drops and the rate of composting slows down due to the limitation of nitrogen, falling short of microbial demand. On the other hand, when the C: N ratio drops below 20, excess nitrogen is lost to the air as ammonia resulting in a rise in pH level. The rate of composting is dependent not only on the environmental factors but also on the nature of the input material (Stentiford, 1993). There is an order of decomposition rate for different fractions of the plant material: carbohydrates, sugars, proteins and fats decompose quickest, followed by hemicelluloses, cellulose and finally lignin.

It is further indicated that composition of organic matter varies with source and consequently the organic constituents in compost also vary with their source (feedstock). During the composting process, the C: N ratio of the initial feedstock typically declines because the C is oxidized and the mineralized by the micro – organisms. A number of researchers have observed a significant reduction in C: N ratios when different sources of organic materials have been composted. For example, Thambirajah *et al.* (1995) observed a substantial reduction in C: N ratio when they composted empty fruit branches (with a relatively high lignin content) with manure added to the substrate. It is clear that C: N ratio is an indicator that the substrate has gone through the biochemical changes of composting, but more importantly is an indicator of compost maturity. A stable product that can be applied to a soil without significant immobilization of soil mineral nitrogen is indicated by the final C: N of the product; for example, mature compost is indicated by a C: N ratio of 10: 1 to 15: 1 when the original material was 30: 1 to 50: 1.

2.5.2.2 Air

The metabolic process used by bacteria to produce energy requires a terminal electron acceptor to enzymatically oxidize the carbon source to carbon dioxide. Different classes of micro – organisms exist based on the carbon and the terminal election acceptor sources they use in metabolic processes. Bacteria that use reduced organic compounds (e.g. naturally occurring organics) as their source of carbon are termed heterotrophic; those that use inorganic carbon compounds (e.g. carbon dioxide) are autotrophic. Bacteria that use free oxygen as their terminal electron acceptor are aerobic; those that use a compound other that free oxygen (e.g. nitrate, sulfate) are anaerobic; and those that can utilize both oxygen and other compounds as terminal electron acceptor are described as facultative (Epstein, 1997).

An aerobic process is the most efficient form of metabolic activity. Hence, oxygen is required for respiration by all aerobic organisms within the composting heap, making proper aeration a crucial factor in aerobic composting. Having sufficient oxygen, aerobic micro – organisms such as bacteria will be active and grow rapidly, consuming more organic material and in the process making nutrients available for plant growth. In the absence of oxygen, aerobic bacteria cannot thrive and anaerobic bacteria take over. These break down the organic material very slowly and often produce volatile compounds with unpleasant odours. This odour comes from sulphur compounds (hydrogen sulphide, dimethyl sulphide, and dimethyl disulfide), ammonia and volatile fatty acids (Epstein, 1997).

2.5.2.3 Temperature

Biological systems typically operate over a limited range of temperature. At low temperature, microbes revert to resting state and at very high temperature, essential proteins are denatured, killing them (Winkler e*t al.*, 1996). Microbes can be classified based to their temperature tolerance. These include psychrophiles that grow at temperatures of less than 20 ˚C, mesophile growing best between 15 and 45 ˚C, and thermophiles growing at temperature greater than 45 ˚C. The compost heap temperature is a function of the accumulation of heat from metabolic processes and at the same time the temperature is a determinant of metabolic activity.

The interaction between heat output and temperature determine the succession of microbial communities and metabolic rates during composting (MacGregor *et al.*, 1981). The temperature phases or composting phases are therefore a result of the amount of heat being produced by microorganisms, balanced by how much is being lost through conduction, convection and radiation (MacGregor *et al.*, 1981). In heat loss by conduction, energy is transferred from atom to atom by direct contact; at the edges of a compost pile, conduction causes heat loss to the air molecules. Loss by convection indicates transfer of heat by movement of a fluid such as air or water. The warm air within compost system rises, creating convection currents which cause a steady but slow movement of heated air upwards through the compost and out to the top. During this process, the energy is transferred in the form of latent heat, the energy required to evaporate water.

Finally, heat is also lost from the compost heap through radiation. The heat generation in the compost pile radiates out into the cooler surrounding air. The smaller the bioreactor or compost pile, the greater is the surface area – to – volume ratio and therefore the larger the degree of heat loss to conduction and radiation (Richard, 2005; Themelis, 2002). Insulation of small compost piles helps to reduce excess heat losses.

The maintenance and residence of the high temperatures within the compost heap as compared to the outside, is controlled by the composting system, the nature of the feedstock, rate of microbial activity and external conditions (temperature and wind). Since there are interactions between the metabolic heat output and temperature, then outside temperature plays a role in controlling the rate of composting. The warmer external temperatures in the warmer regions stimulate microbial activities and speed composting while colder temperatures of the colder regions slow down the composting process.

In general, the optimum temperature range for fast decomposition is between 50 and 60 ˚C, but Epstein (1997) gave a range of 65 – 70 ˚C as the temperature where maximum decomposition takes place for municipal solid wastes. This thermophilic stage is also important for destroying thermo – sensitive pathogens, fly larvae and weed seeds. In outdoor systems, compost invertebrates survive the thermophilic stage by moving to the periphery of the pile or becoming dormant (Coyone, 1999). To achieve a significant reduction of pathogens during composting, the compost should be maintained at a minimum operating temperature of 40 ˚C for five days, and with temperatures exceeding 55 ˚C for at least four hours of this period. Most species of micro – organisms cannot survive at temperatures above 60 – 65 ˚C, demanding cooling of the compost systems when temperatures get too high.

2.5.2.4 Surface area and particle size

Microbial activity mostly occurs on the surface of the organic particles. Smaller particles of organic material provide more surface area for microbes to attack and speed up composting (Haug, 1993). This is achieved by shredding and breaking down the organic materials into smaller pieces in order to expose a greater area for the microbes to work on and allowing ample air spaces thereby increasing the rate of decomposition. Apart from increasing surface area, the cutting of the feedstock also destroys the cell wall protective cover. The absence of the cell wall exposes the organic matrix for microbial attack. On the other hand, very small and compact particles hinder air circulation through the pile. Consequently, this reduces O_2 available to microorganisms within the pile and the microbial activities decreases (Haug, 1993).

2.5.2.5 Volume

Volume is the factor aimed at retaining heat of the compost. The more the compost volume, the more self – insulating it becomes in retaining the heat generated by the microbes (Richard, 2005). Smaller compost piles are associated with greater surface area – to – volume ratios. This exposes the pile to a greater degree of heat loss (Themelis, 2002).

2.6 Summary of literature review

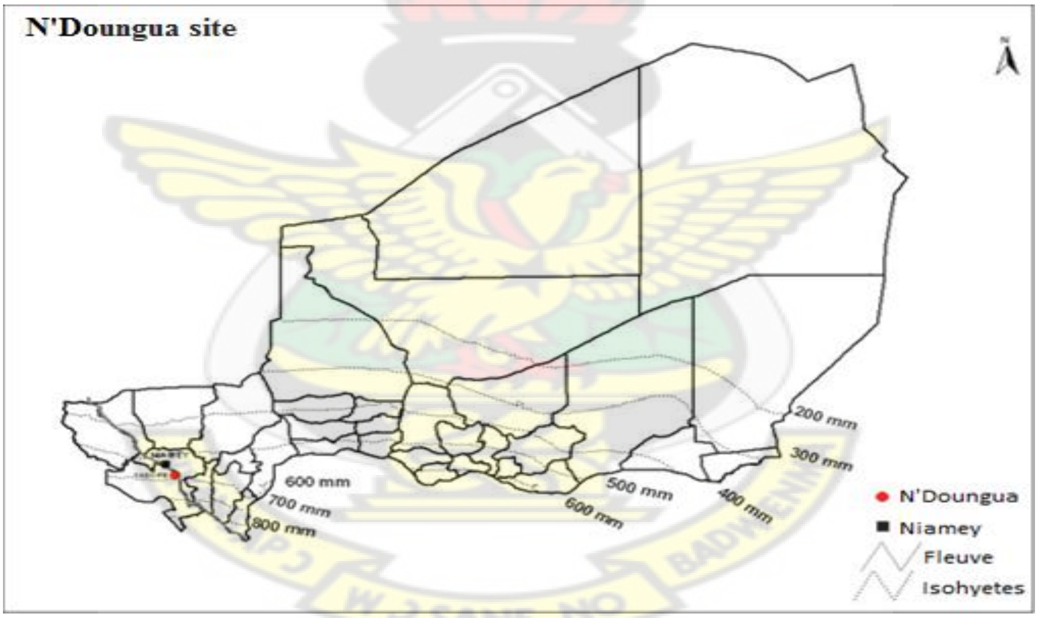
Sub-Saharan Africa is characterized by an area where land degradation is seen as a major limiting factor for agricultural production and food security. Economic and policy constraints limit the use of inorganic fertilizers by smallholder farmers. The use of organic resources to sustain crop yields and build soil fertility will continue to be critical in the tropics. This situation is a consequence of low soil fertility, which is a major constraint to increased food production and has opened a new weave of research to find low - cost solution to improve soil fertility and achieve the ultimate goal of food security. As an important component of agriculture sustainability, there has been a paradigm shift towards the combined application of organic and inorganic fertilizers. Higher soil mineral nitrogen has been reported to inhibit nodulation and N_2 – fixation. Composting attempts to recreate the conditions, which would occur in an undisturbed ecosystem where organic matter builds on the soil surface. The nutrient content of composts, especially those derived from farmyard wastes, varies considerably depending on type of raw materials used, method of composting and maturity period. The increase in stable SOM and favorable soil properties can be more effectively accomplished with compost than with fresh manure. The main reason for this is that compost is in an advanced state of decay. It has been reported that organic management with composts improved porosity and water retention and biological soil quality indicators, such as biomass C and N are also improved with compost applications.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental site

The trial was conducted at Ndounga station / Regional Center for Agricultural Research of Niger (INRAN - CERRA - Kollo, Niger) (Fig. 1). Ndounga is located at longitude 2 ° 18'28" East and latitude 13 ° 25'00" North, at 30 km south - east of Niamey. The average annual rainfall of ten (10) years is 510 mm (INRAN - CERRA - Kollo, 2010).



Source: INRAN, Niger (2010)

Figure 1. Location of the experimental area

3.1.1 Climate of the study site

The climate of the study area is characterized by two distinct seasons: a rainy season from June to October and a dry season for the rest of the months. The rainfall is characterized by storms in which large amounts of water can be saved in a relatively short time. Temperatures vary according to the time of year. The lowest temperature is usually recorded between October and February (23 °C) and the highest between March and June (45 °C).

3.1.2 Soil of study site

The type of soil found in the study area is Arenosol (WRB) (INRAN, 2010), which is highly leached, with low organic matter content, occupies the majority of the zone and are better suited for crops such as millet, cowpea and sesame.

3.2 The planting material

The cowpea variety (IT98K205-8) developed by the International Institute of Tropical Agriculture (IITA) was used. The seeds are white colored and medium in size. Its cycle is between 60 - 70 days with a potential yield of 1.5 to 2.0 t / ha. It is drought resistant and tolerant to *Striga gesnerioides*. It is sensitive to thrips and aphids.

3.3 Field preparation and planting of cowpea

The experimental field was ploughed to a depth of about 15 cm, using a disc plough after which the field layout was done. Plot sizes measuring 6 m × 4.5 m were demarcated. Cowpea was sown at three seeds per hole at a planting distance of 0.75 m × 0.5 m and thinned to two seedlings per hill two weeks after planting. A germination test was undertaken before sowing. Composted millet glumes was applied at the time of planting by micro dosing. Single superphosphate (50% and 100% recommended rate (RR)) was applied before sowing and urea (50% $_{RR}$ and 100% $_{RR}$) at two weeks after sowing. Control plots did not receive compost or chemical fertilizer application.

3.4 Experimental design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three (3) replications. Treatments used were as follows:

T0: 0g compost/ hill, 0%N and 0%P;

T1: 7.5 kg N/ha and 13 kg P/ha

T2: 15 kg N/ha and 26 kg P/ha

T3: 1.5 t/ha compost, 7.5 kg N/ha and 13 kg P/ha

T4: 1.5 t/ha compost, 15 kg N/ha and 26 kg P/ha

T5: 3 t/ha compost, 7.5 kg N/ha and 13 kg P/ha

T6: 3 t/ha compost, 15 kg N/ha and 26 kg P/ha

3.5 Data collection

3.5.1 Nodule count

At 50% flowering, ten consecutive cowpea plants were harvested from the two middle rows of each plot. The plants were cut at about 5 cm above ground. The roots of the plants were carefully dug out, put in polythene bags, together with detached nodules collected from the soil. The roots were then put in a 1 mm mesh sieve and washed under running tap water to remove adhered soil. The nodules were gently removed, washed and counted.

3.5.2 Shoot dry weight

Ten consecutive cowpea plants from the two middle rows of each plot were harvested at 50% podding. The plants were cut at about 5 cm above the ground. The shoots were oven dried for 72 h at 60 ˚C. The dry weights of the shoots were recorded and later milled for laboratory analysis.

3.5.3 Grain yield

Harvesting of cowpea grains was done at physiological maturity, air – dried, threshed and winnowed. The grains were then dried in an oven at 60 ˚C for 72 hours and the dry weights recorded. The grain yield per hectare was then estimated using the dry weight of the grains as described by Okogun *et al*. (2005).

3.6 Composting activity

3.6.1 Composting materials and preparation

The materials used for the composting were millet glume and cattle manure (2 parts of millet glumes: 1 part of cattle manure) and ash. Weights of manure and millet glume used were taken on dry weight basis. Millet glumes were reduced to lengths of 5 – 10 mm, weighed and mixed prior to composting. Using the pit method, compost pits measuring 250 cm × 150 cm × 60 cm were dug filled with the millet glumes and cattle manure and covered with black plastic and soil to minimize water loss. The soil also acted as a bio – filter to minimize odor emission. Temperature and pH of the compost were taken at 0, 1, 2, 4, 6, 8, 10 and 12 weeks of maturation using a mercury thermometer graduated in degree centigrade and a glass electrode pH meter respectively. Composting was done under a shade at the research station (CERRA – Niamey, Niger) and harvested after 90 days maturity.

Triplicate samples of 150 g were collected at the end of the composting process. The compost samples were air-dried and ground. Sub-samples were then taken using a spatula sterilized in 70% alcohol.. The spatula was used to mix the compost slightly and to transfer compost samples into sterile containers and sealed tightly before being taken for laboratory analysis. The remaining compost was then carried to the field for subsequent application.

3.7 Laboratory soil analysis

3.7.1 Soil sampling and sample preparation

Five core samples were taken from each plot of the experimental field at a depth of 20 cm using an augur. The soil samples were then bulked and thoroughly mixed to obtain composite samples from which sub - samples were taken for chemical analysis. The samples were sieved with a 2 mm mesh sieve to remove broken sticks and other debris before physico - chemical analyses were carried out. Properties of the soil were determined in the Soil Science Laboratory of ICRISAT, Niger.

3.7.2 Determination of soil chemical properties

3.7.2.1 Soil pH

The pH of the soil was potentiometrically measured in the supernatant suspension of a 1:2.5 soil: water (w/v) ratio. A 20 g soil sample was weighed into a 100 ml beaker. To this 50 ml distilled water was added and the suspension was thoroughly stirred and allowed to stand for 30 minutes. The pH was then measured using Eutech 510 meter which was calibrated with buffer solutions at pH 4 and 7 by immersing the electrode into the upper part of the suspension.

3.7.2.2 Soil organic carbon

Organic carbon was determined by the modified Walkley and Black method (Nelson and Sommers, 1982). One gram of soil sample was weighed into a conical flask. A blank sample was also included. Ten milliliters of 1 *N* $K_2Cr_2O_7$ solution was added to the soil and the blank. To this, 20 ml of concentrated H_2SO_4 was carefully added from a measuring cylinder. The heat caused by mixing H_2SO_4 and H_2O raises the temperature sufficiently to induce a very substantial oxidation of the organic matter within the first five minutes. Distilled water and 10 ml of concentrated orthophosphoric acid were added and allowed to cool. After 30 minutes, the residual of the $K_2Cr_2O_7$ was titrated against with 0.5 *N* FeSO4 solution using diphenylamine as indicator.

Calculation:

$$\% \text{ Organic C} = \frac{(\text{m.e.}K_2Cr_2O_7 - \text{m.e.}FeSO_4) \times (1.32) \times 0.003}{\text{Weight of dried sample}} \times 100$$

where:

m.e. = normality of solution × ml of solution used

0.003 = m.e. weight of C in grams (12/4000)

1.32 = correction factor

3.7.2.3 Total nitrogen

The total nitrogen of the soil was determined using the Kjeldahl digestion and distillation procedure as described by Bremner and Mulvaney (1982). A 10 g of soil sample was weighed into a digestion tube for the process and 10 lm distilled water added to it. Concentrated sulphuric acid and selenium mixture were added and mixed carefully. The sample was digested on a Kjeldahl apparatus for three hours until a clear and colourless digest was obtained. The volume of the solution was made to 100 ml with distilled water. A 10 ml aliquot of the solution was transferred to the reaction chamber and 10 ml of NaOH solution was added followed by distillation. The distillate was collected in boric acid and titrated with 0.1 *N* HCl solution with bromocresol green as indicator. Traces of nitrogen in the reagents and water used were taken care of by carrying out a blank distillation and titration.

Calculation:

$$\%N = \frac{14 \times (A - B) \times N}{1000 \times W} \times 100$$

where:

N= concentration of HCl used in titration

A= ml HCl used in sample titration

B= ml HCl used in blank titration

14= atomic weight of nitrogen

W= wt. of soil sample in gram

3.7.2.4 Available phosphorus

Available P was determined using the Bray P1 method (Olsen and Sommers, 1982). The method is based on the production of a blue complex of molybdate and orthophosphate ion an acid solution. Phosphorus was extracted by shaking 4 g of air dried soil in 28 ml of 0.025 *M* HCl and 0.03 *M* NH_4F for one minute. Phosphorus was determined in the filtrate by the molybdate - blue method using ascorbic acid as a reductant. Colour development was measured at 882 nm using a spectrophotometer (210 VGP Buck Scientific). The concentration of P in the extract was obtained by comparing of the results with a standard curve.

3.7.2.5 Extraction of exchangeable cations

Calcium, magnesium and potassium in the soil were determined in 1.0 *M* ammonium acetate (NH_4OAc) extract (Black, 1986). A 10 g sample was transferred into a leaching tube and leached with a 250 ml of buffered 1.0 *M* ammonium acetate (NH_4OAc) solution at pH 7. Hydrogen plus aluminum were determined in 1.0 *M* KCI extract as described by Page *et al.* (1982).

3.7.2.6 Determination of calcium and magnesium

A 25 ml portion of the extract was transferred to an Erlenmeyer flash and the volume made to 50 ml with distilled water. Potassium cyanide (1 ml) at 2%, hydroxylamine hydrochloride (1 ml), potassium cyanide (1 ml) at 2% from burette, ethanolamine buffer (10 ml) and 0.2 ml Eriochrome Black T solutions were added. The mixture was titrated with 0.02 *M* ethylene diamine tetraacetic acid (EDTA) to a pure turquoise blue colour. A 20 ml 0.02 *M* EDTA in the presence of 25 ml of 1.0 *M* ammonium acetate solution was added to provide a standard blue colour for titration. The titre value again was recorded. The titre value of calcium was subtracted from this value to get the titre value for magnesium.

Calculation:

$$\mathrm{Ca} + \mathrm{Mg}\ (\mathrm{cmolc/kg\ soil}) = \frac{0.01 \times (\mathrm{Va} - \mathrm{Vb}) \times 1000}{0.1 \times \mathrm{W}}$$

where:

Va = ml of 0.01 M EDTA used in the sample titration

Vb = ml of 0.01 M EDTA used in the blank titration

W = weight in grams of soil extracted

0.01 = concentration of EDTA used

3.7.2.7 Determination of calcium only

A 25 ml portion of the extract was transferred to a 250 ml conical flash and the volume made to 50 ml with distilled water. Hydroxylamine hydrochloride (1 ml), potassium cyanide (1 ml of 2% solution) and potassium ferro cyanide (1 ml of 2%) were added. After a few minutes, 4 ml of 8 *M* potassium hydroxide and a spatula of murexide indicator were added. The solution obtained was titrated with 0.01 *M* EDTA solution to a pure blue colour. Twenty milliliters of 0.01 *M* calcium chloride solution was titrated with 0.01 *M* EDTA in the presence of 25 ml 1.0 *M* ammonium acetate solution to provide a standard pure blue colour. The titre value of calcium was recorded.

3.7.2.8 Determination of exchangeable potassium

Potassium in the soil extract was determined by flame photometry. A standard series of potassium was prepared by diluting 1000 mg/l to 100 mg/l. this was done by taking a 25 mg portion of each into one 250 ml volumetric flask and made to volume with water. Portions of 0, 5, 10, 15 and 20 ml of the 100 mg/l standard solution were put into 200 ml volumetric flasks respectively. 100 ml of 1.0 *M* NH4OAc solution was added to each flask and made to volume with distilled water. The standard series obtained was 0, 2.5, 5.0, 7.5, 10.0 ml/l for potassium. Potassium was measured directly in the percolate by flame photometry at wavelengths of 766.5 mm

Calculation:

$$\text{Exchangeable K (cmolc/kg soil)} = \frac{(a - b) \times 250 \times \text{mcf}}{10 \times 39.1 \times W}$$

where:

a	= mg/l K in the diluted sample
b	= mg/l K in the diluted blank sample
W	= air – dried sample weigh of soil on grams
39.1	= atomic weight of potassium

3.7.3 Determination of soil physical properties

3.7.3.1 Particle size analysis

Fifty – one grams of air dried soil was weighed into a 1L screw lid shaking bottle. Hundred millilitres distilled water was added and swirled thoroughly. Twenty millilitres of 30% H_2O_2 was added, followed by 50 ml of 5% sodium hexametaphosphate and drops of amyl alcohol and swirled gently. It was then shaken on a mechanical shaker for 2 h and the content transferred into a 1L sedimentation cylinder with its content was allowed to stand undisturbed for 3 h and the second hydrometer and temperature readings recorded respectively.

Calculation

$$\%\text{Sand} = 100 - [\text{H1} + 0.2(\text{T1} - 20) - 2] \times 2$$

$$\%\text{Clay} = [\text{H2} + 0.2(\text{T2} - 20) - 2] \times 2$$

$$\%\text{sand} = 100 - (\%\text{sand} + \%\text{Clay})$$

where

H1 = 1st hydrometer reading at 40 seconds

T1 = 1st temperature reading at 3 hours

H2 = 2nd hydrometer reading at 3 hours

-2 = Salt correction to be added to hydrometer reading

0.2 (T-20) = Temperature correction to be added to hydrometer reading

3.7.3.2 Bulk density

The bulk density was determined using the core sampling method (Black, 1986). With the aid of a mallet, a core sampler (5 cm diameter thin – sheet metal tube of known weight and volume) was driven 5 cm into the soil. It was then removed and the soil at both ends trimmed and flushed with a straight edged – knife. It was then transported to the laboratory where it was oven dried at 105 ˚C to a constant weight. The core samplers were removed and allowed to cool before it was weighed and recorded. The volume of the sampler was determined and the dry bulk density.

Calculation:

$$\text{Dry bulk density (g/cm)} = \frac{\text{W1} - \text{W2}}{\text{V}}$$

where:

W1= Weight of core cylinder + oven dried soil

W2= Weight of empty core cylinder

V= Volume of core cylinder

3.8 Laboratory chemical analysis of plant samples

3.8.1 Determination of total nitrogen and total phosphorus

The shoots as well as the seeds of the plants were milled in a miller, after which nitrogen and phosphorus contents were determined.

Total nitrogen was determined by the Kjeldahl distillation and titration method (Constantinides and Fownes, 1994). Total phosphorus was determined by using the spectrophotometric vanadium phosphomolybdate method. One gram of plant sample was weighed into the digestion tube. One millilitres of digestion mixture ($HCIO_4HNO_3$) was added. It was measured into a 50 ml volumetric flask. Ten millilitres of vanadomolybdate was added. Distilled water was added to make the required volume. It was shaken vigorously and kept for 30 minutes. It was read on 430 nm spectrophotometer after a yellow colour had developed. The percentage transmittance was recorded. The absorbance and the P content were determined from a standard curve.

3.8.2 Measurement of biological nitrogen fixation

The amount of nitrogen fixed was assessed using the Total Nitrogen Difference (TND) method. The total amount of nitrogen in cowpea and in the millet (reference crop) were determined and the amount of N fixed was calculated using the modified equations of

Mary *et al.* (1995).

$$\text{N uptake} = \frac{\text{shoot biomass weight} \times \%\ \text{N in shoots}}{100}$$

$$\text{Amount of N Fixed} = \text{N uptake in legume} - \text{N uptake in reference crop}$$

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

where:

Ndfa = nitrogen derived from the atmosphere

3.8.3 Determination of NUE and PUE

Nitrogen and phosphorus use efficiency as well as N and P uptake according to Dobberman (2005) were determined as follows:

$$\text{N uptake (kg/ha)} = \text{\% dry matter N} \times \text{yield}$$

$$\text{P uptake (kg/ha)} = \text{\% dry matter P} \times \text{yield}$$

$$\text{NUE} = \frac{\text{N uptake (fertilizer)} - \text{N uptake (control)}}{\text{Urea fertilizer}} \times 100$$

$$\text{PUE} = \frac{\text{P uptake (fertilized)} - \text{P uptake (control)}}{\text{SSP fertilizer}} \times 100$$

where:

NUE: Nutrient Use Efficiency

PUE: Phosphorus Use Efficiency

3.9 Statistical analysis

All data collected were subjected to Analysis of Variance (ANOVA) using Genstat package (Genstat, 2009) and means separated by the least significant difference (LSD) test at 5% probability level (Steel and Torrie, 1987). All count data were transformed logarithmically (Kihara *et al.*, 2011) before being subjected to ANOVA. Regression analysis was carried out to establish the relationships between measured growth and yield parameters.

CHAPTER FOUR

4.0 RESULTS

4.1 Selected initial chemical physico - properties of soil the experimental field

The soil of the study area was initially characterized to assess its fertility status before crop establishment and application of compost. Data on the initial chemical and physical properties of soil of the study site is presented in Table 1. The results indicated that the soil was predominantly sandy, acidic, very low in total nitrogen, low in phosphorus and medium in organic carbon (Pam and Brian, 2007).

Table 1: Initial chemical and physical properties of study site.

Soil property	Mean	Remark
pH (1: 2.5 H_2O	5.46	*Acidic
Available P (cmolc/kg)	4.85	#Low
Organic C (%)	0.05	#Very low
Total N (%)	0.08	*Very low
Exchabgeable cations		
Ca^{2+} (cmolc/kg)	6.50	*Moderate
Mg^{2+} (cmolc/kg)	0.28	*Low
Na^{2+} (cmolc/kg)	0.06	*Low
K^{+} (cmolc/kg)	0.06	*Low
Sand (%)	95.49	
Silt (%)	2.11	
Clay (%)	2.60	
Texture	Sand	

*Pam and Brian (2007)
#Hills Laboratories, Technical notes (2013)

4.2 Characterization of composted millet glume

The chemical characteristics of materials used for composting and the composted millet glume are shown in Table 2.

Table 2: Chemical properties of composted millet glume and materials used for composting

Property	Organic amendments		
	Millet glume	Manure	Composted millet glume
Total N (%)	0.34	0.80	0.86
Total P (%)	0.13	0.67	0.73
Total K (%)	0.10	0.11	0.20
Org. C (%)	35.51	51.77	35.34
C/N ratio	104.44	69.71	41.09

* Values represent means of triplicate samples

4.3 Nodulation in cowpea

The results of the data collected on nodulation in cowpea are shown in Table 3. The number of nodules formed for all treatments were significantly higher than the control. The highest nodule number was obtained by 3 t compost + 15 kg N + 26 kg P followed by 1.5 t compost + 15 kg N + 26 kg P and 3 t compost + 7.5 kg N + 13 kg P. The lowest nodule number was however obtained by the control followed by 7.5 kg N + 13 kg P and 15 kg N + 26 kg P. The combined application of composted millet glume and mineral fertilizer contributed more to nodule formation than the other treatments.

The mean nodule dry weight assessment revealed that nodule development significantly increased ($P < 0.05$) with the application of 3 t compost + 15 kg N + 26 kg P and 1.5 t compost + 15 kg N + 26 kg P over the control (Table 3). The highest nodule dry weight was produced by 3 t compost + 15 kg N + 26 kg P while the lowest was produced by the control. The application of mineral fertilizer alone (7.5 kg N + 13 kg P and 15 kg N + 26 kg P) gave nodule dry weight which was significantly lower than the combined applications of composted millet glume and mineral fertilizer (3 t compost + 15 kg N + 26 kg P and 1.5 t compost + 15 kg N + 26 kg P).

Table 3: Number of nodules and nodule dry weight as influenced by composted millet glume and mineral fertilizer

Soil amendment rate	Nodule number (plant-^{1})	Nodule dry weight (kg ha^{-1})
Control	9	16.51
7.5 kg N + 13 kg P	13	20.80
15 kg N + 26 kg P	15	24.55
1.5 t *compost + 7.5 kg N ha^{-1} + 13 kg P	18	28.12
1.5 t *compost + 15 kg N + 26 kg P	20	33.05
3 t *compost + 7.5 kg N + 13 kg P	20	30.51
3 t *compost + 15 kg N + 26 kg P	23	36.79

LSD	2.01	2.86
CV (%)	16.7	22.9

***** t ha^{-1}

4.4 Cowpea grain yield, shoot biomass yield and 100 seed weight

Table 4 shows the results of cowpea grain and biomass yields. The lowest grain yield (548.3 kg ha^{-1}) and shoot biomass yield (1340 kg ha^{-1}) were observed in the control. The different treatments influenced grain yield during the study. The 3 t compost + 15 kg N + 26 kg P recorded the highest grain yield followed by 1.5 t compost + 15 kg N + 26 kg P. The highest application of the compost (3 t) produced grain yield relatively higher than the lowest application (1.5 t).

The results of the study showed increased accumulation of shoot biomass (Table 4). Statistical analysis indicated ($P < 0.05$) significant differences among treatments.

The control recorded the lowest shoot biomass yield (1340 kg ha^{-1}) followed by 7.5 kg N + 13 kg P (1397 kg ha^{-1}) and 15 kg N + 26 kg P (1637 kg ha^{-1}). The effect of combined application of composted millet glume and inorganic fertilizer on cowpea shoot biomass was high compared to sole application of inorganic fertilizers. The results further showed that all the treatments were significantly ($P < 0.05$) higher than the control.

The hundred seed weight followed a similar trend as the cowpea grain and shoot biomass yield (Table 4). The 100 seed of all the treatments were significantly higher ($P < 0.05$) than the control. The 3 t compost 15 kg N + 26 kg P application gave the highest hundred seed weights (24.5 g).

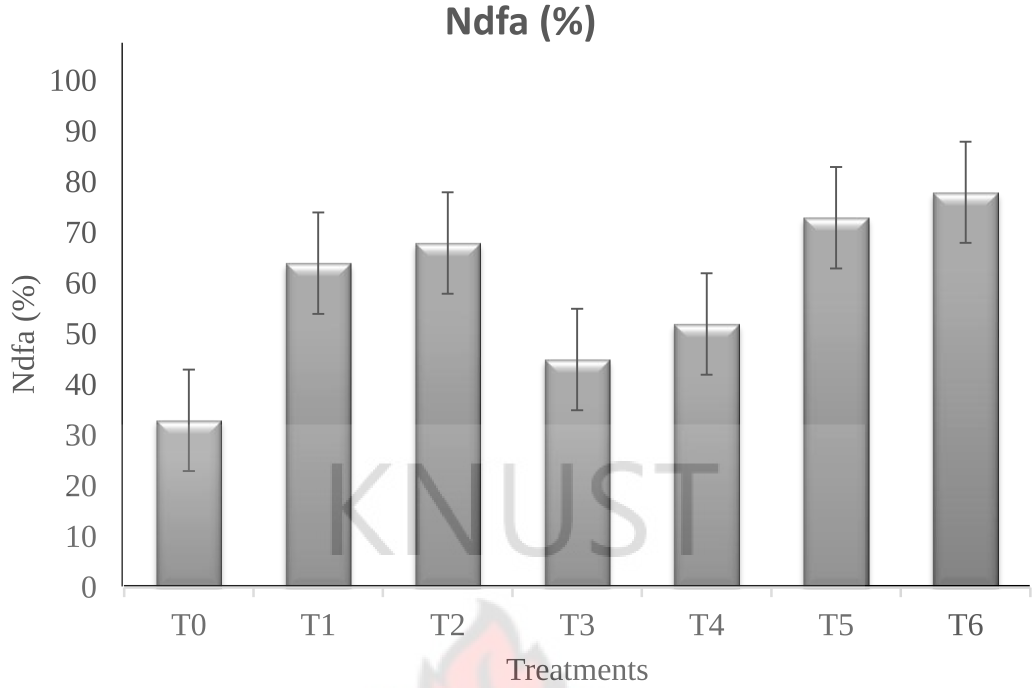
Table 4: Cowpea grain and biomass yields as influenced by composted millet glume and mineral fertilizer

Soil amendment rate	Grain yield ($kg\ ha^{-1}$)	Shoot biomass yield ($kg\ ha^{-1}$)	100 seed weight (g)
Control	548.3	1340.0	17.0
7.5 kg N + 13 kg P	685.0	1397.0	18.0
15 kg N + 26 kg P	787.7	1637.0	21.5
1.5 t *compost + 7.5 kg N + 13 kg P	831.7	1910.0	22.5
1.5 t *compost + 15 kg N + 26 kg P	942.0	2123.0	23.5
3 t *compost + 7.5 kg N + 13 kg P	1168.3	2499.0	23.5
3 t *compost + 15 kg N + 26 kg P	1370.3	2764.0	24.5
LSD	62.5	204.1	0.86
CV (%)	18.9	15.9	12.3

* $t\ ha^{-1}$

4.5 Proportion of nitrogen derived from the atmosphere (Ndfa) and N fixation

The 3 t compost + 15 kg N ha^{-1} + 26 kg P ha^{-1} gave the highest Ndfa (78%) (Fig. 2). The lowest Ndfa was observed in the control which produced 33% of the total nitrogen accumulated. Table 5 shows the amount of atmospheric nitrogen fixed by cowpea under the different treatments. There were significant differences in N fixation ($P < 0.05$) among all the treatments. The amount of N fixed in cowpea varied from 19.19 kg N ha^{-1} in the control to 69.57 kg N ha^{-1} in the 3 t compost + 15 kg N + 26 kg P. The highest application of compost (3 t) resulted in the highest N fixed.



T0 - 0 kg compost + 0 kg N + 0 kg P (control) - **T1** - 1.5 t compost + 7.5 kg N + 13 kg P - **T2** - 1.5 kg compost + 15 kg N + 26 kg P - **T3** - 7.5 kg N + 13 kg P - **T4** - 15 kg N + 26 kg N - **T5** - 3 t compost + 7.5 kg N + 13 kg P/ha - **T6** - 3 t compost + 15 kg N + 26 kg P. Bars represent LSD (50%)

Figure 2. Proportion of nitrogen derived from the atmosphere as influenced by composted millet glume and inorganic fertilizer application

Table 5: **Nitrogen fixed by cowpea as influenced by composted millet glume and inorganic fertilizer application**

Soil amendment rate	Amount of N fixed by cowpea (kg ha^{-1})
Control	19.19
7.5 kg N + 13 kg P	23.33
15 kg N + 26 kg P	29.63
1.5 t *compost + 7.5 kg N + 13 kg P	35.40

1.5 t *compost + 15 kg N + 26 kg P	40.69
3 t *compost + 7.5 kg N + 13 kg P	52.05
3 t *compost + 15 kg N + 26 kg P	69.57
LSD	3.44
CV (%)	15.0

* t ha^{-1}

4.6 Grain nitrogen and phosphorus uptake of cowpea

Amount of grain N uptake following the application of the different treatments are as presented in Table 6. The highest grain N uptake was produced by 3 t compost + 15 kg N + 26 kg P (58.10 kg ha^{-1}). The control recorded the least grain N uptake of 17.49 kg ha^{-1}. Table 7 shows the grain P uptake of cowpea following the application of the different treatments. Grain P uptake was significantly ($P < 0.05$) higher in the combined application of composted millet glume and mineral fertilizer treatments. The lowest grain P uptake (2.43 kg ha^{-1}) was produced by the control while the highest (9.33 kg ha^{-1}) was produced by 3 t compost + 15 kg N + 26 kg P which was 35% more than the control.

Table 6: Grain N uptake of cowpea as influenced by composted millet glume and inorganic fertilizer

Soil amendment rate	Grain N uptake (kg ha^{-1})

Control	17.49
7.5 kg N + 13 kg P	22.48
15 kg N + 26 kg P	26.87
1.5 t *compost + 7.5 kg N + 13 kg P	39.27
1.5 t *compost + 15 kg N + 26 kg P	34.36
3 t *compost + 7.5 kg N + 13 kg P	43.55
3 t *compost + 15 kg N + 26 kg P	58.10
LSD	4.11
CV (%)	17.0

***** t ha^{-1}

Table 7: Grain P uptake of cowpea as influenced by composted millet glume and inorganic fertilizer

Soil amendment rate	Grain phosphorus uptake (kg ha^{-1})
Control	2.43
7.5 kg N + 13 kg P	3.49
15 kg N + 26 kg P	4.21
1.5 t *compost + 7.5 kg N + 13 kg P	4.65
1.5 t *compost + 15 kg N + 26 kg P	5.30
3 t *compost + 7.5 kg N + 13 kg P	6.77
3 t *compost + 15 kg N + 26 kg P	9.33
LSD	0.54

CV (%)	15.2

* t ha^{-1}

4.7 Nitrogen and phosphorus use efficiency of cowpea

Nitrogen use efficiency by cowpea following the application of the different treatments is as shown Table 8. The 3 t compost + 15 kg N + 26 kg P significantly ($P < 0.05$) recorded the highest nitrogen use efficiency (123.51%) while the 7.5 kg N + 13 kg P gave the lowest (55.12%). Nitrogen use efficiency was better in the combined application of composted millet glume and organic fertilizer than with sole inorganic fertilizer.

Phosphorus use efficiency by cowpea after the imposition of treatments is as shown in Table 9. Phosphorus use efficiency in cowpea ranged from 5.66% for 7.5 kg N + 16 kg ha^{-1} to 16.76% for 3 t compost + 15 kg N + 26 kg P. Highest P use efficiencies were obtained by the composted millet glume and inorganic fertilizer than with sole inorganic fertilizer.

Table 8: Nitrogen use efficiency of cowpea as influenced by composted millet glume and inorganic fertilizer

Soil amendment rate	N use efficiency (%)
Control	-
7.5 kg N + 13 kg P	55.12
15 kg N + 26 kg P	70.50
1.5 *t compost + 7.5 kg N + 13 kg P	69.9
1.5 t *compost + 15 kg N + 26 kg P	77.03

3 t *compost + 7.5 kg N + 13 kg P	98.70
3 t *compost + 15 kg N + 26 kg P	123.5
LSD	24.0
CV (%)	19.0

* t ha^{-1}

Table 9: Phosphorus use efficiency of cowpea as influenced by composted millet glume and inorganic fertilizer

Soil amendment rate	P use efficiency (%)
Control	-
7.5 kg N + 13 kg P	5.66
15 kg N + 26 kg P	7.02
1.5 t *compost + 7.5 kg N ha^{-1} + 13 kg P	10.07
1.5 t *compost + 15 kg N + 26 kg P	10.93
3 t *compost + 7.5 kg N + 13 kg P	14.48
3 t *compost + 15 kg N + 26 kg P	16.76
LSD	3.17
CV (%)	22.1

* t ha^{-1}

4.9 Relationships between some measured growth and yield parameters of cowpea

Correlation analyses were used to determine the relationship between measured growth and yield parameters of cowpea. A strong positive relationship (R^2 = 0.8384) was found between nodule dry weight and grain yield (Fig. 3). A similar relationship (R^2 = 0.8682) was observed between nodule dry weight and shoot biomass yield (Fig. 4). Significant positive correlations ($P < 0.05$) were observed among nodule dry weight, grain and shoot biomass yields (Figs. 3 and 4).

A positive relationship (R^2 = 0.8342) was found between amount of nitrogen fixed and nodule dry weight (Fig. 5). There was also a strong positive correlation between amount of nitrogen fixed, cowpea grain yield and cowpea shoot biomass yield with R^2 values of 0.9852 and 0.9656 respectively (Figs. 6 and 7). Amount of nitrogen fixed showed significant coorelation ($P < 0.05$) whith nodule dry weight.

However the correlation coefficients as observed between amount of nitrogen fixed, cowpea grain and biomass yields were not significant ($P > 0.05$).

There was a strong positive correlation (R^2 = 0.9206) between shoot biomass yield and cowpea grain N uptake of cowpea (Fig. 8). Significant correlation ($P < 0.05$) were observed between shoot biomass yield and cowpea grain N uptake of cowpea. Cowpea grain yield positively correlated (R^2 = 0.8924) with grain P uptake (Fig. 9).

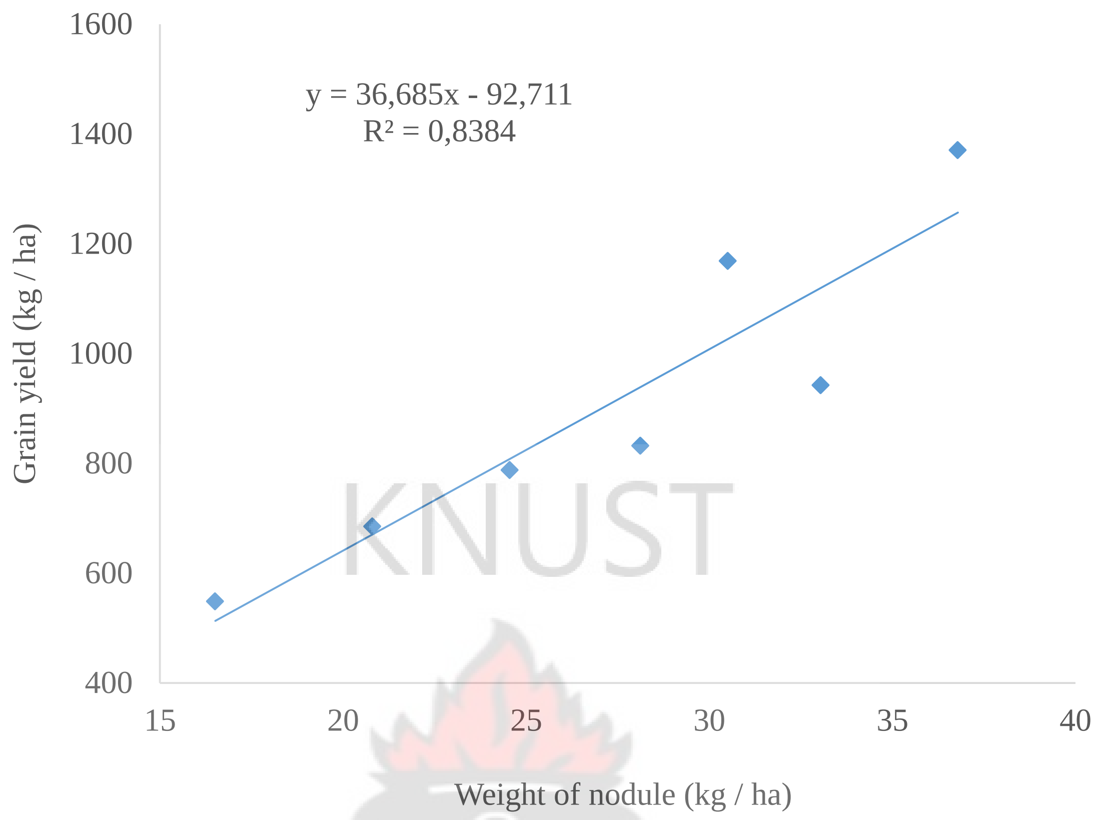


Figure 3. Relationship between grain yield and nodule dry weight of cowpea

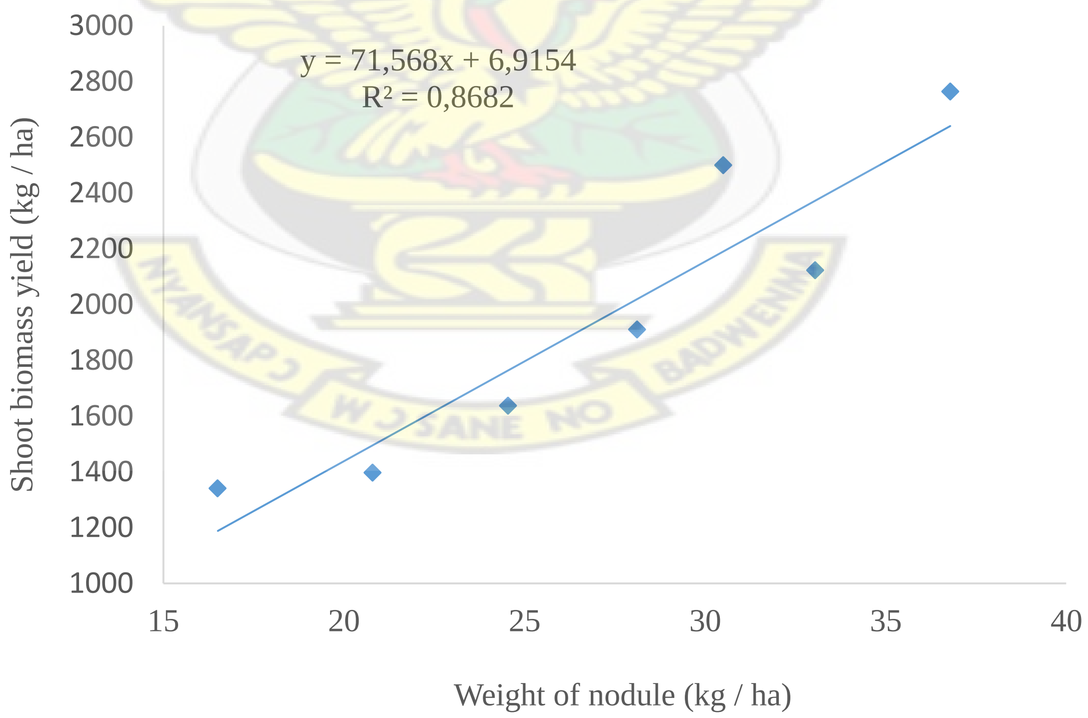


Figure 4. Relationship shoot biomass yield and nodule dry weight of cowpea

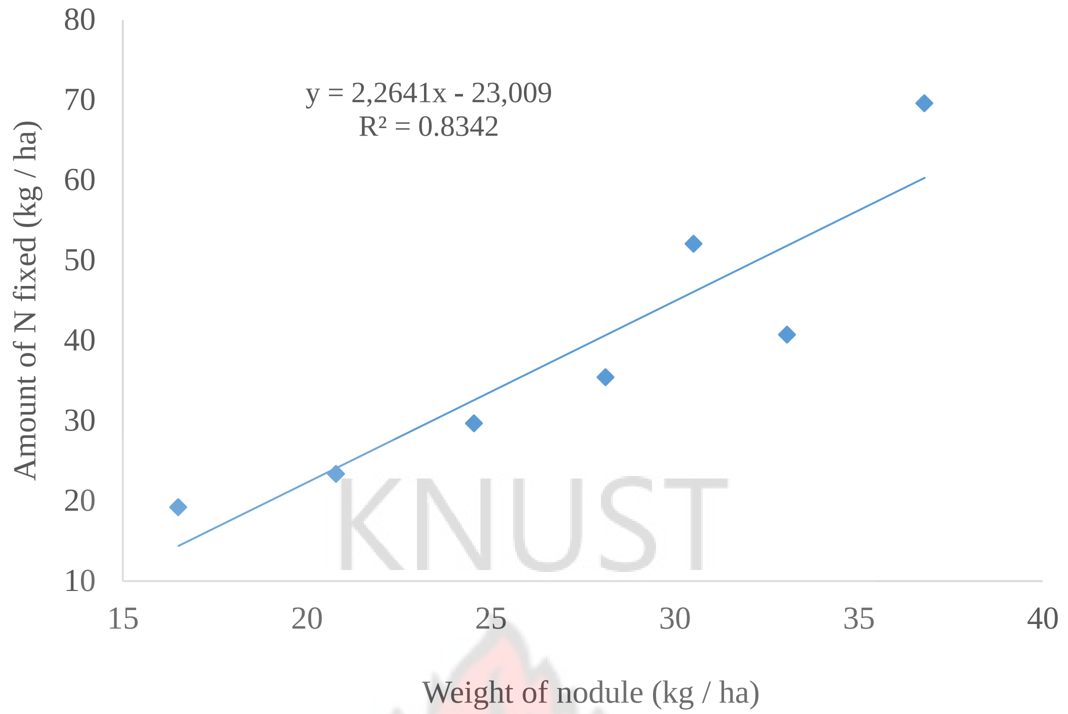


Figure 5. Relationship between amount of nitrogen fixed and nodule dry weight of cowpea

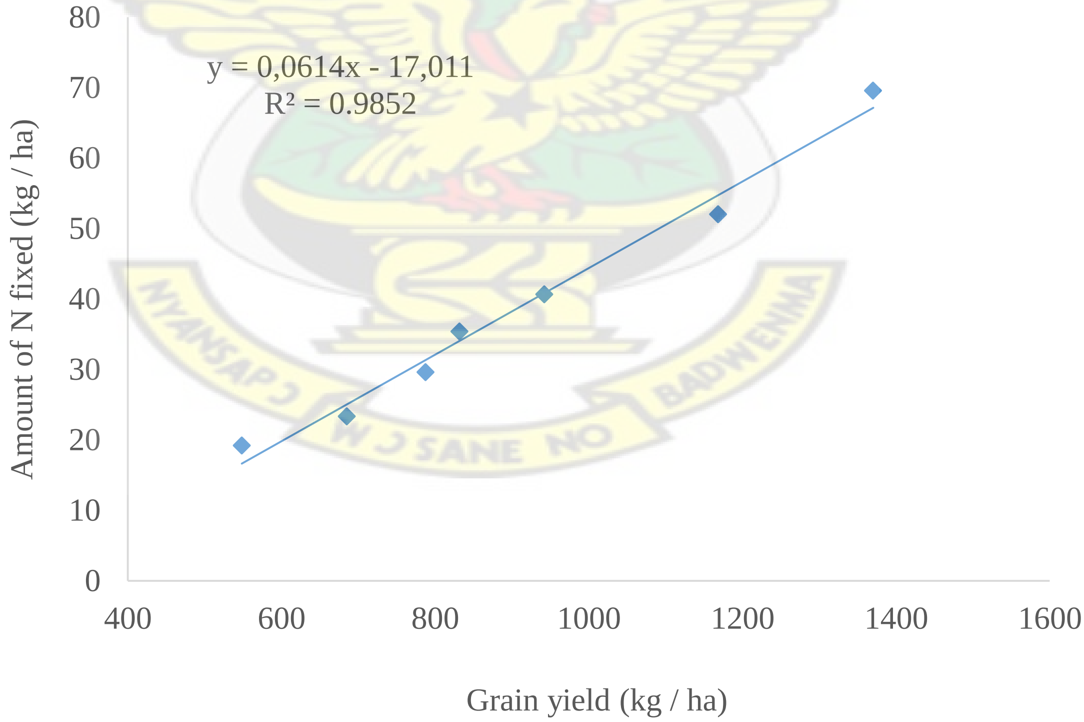


Figure 6. Relationship between grain yield and amount of nitrogen fixed by cowpea

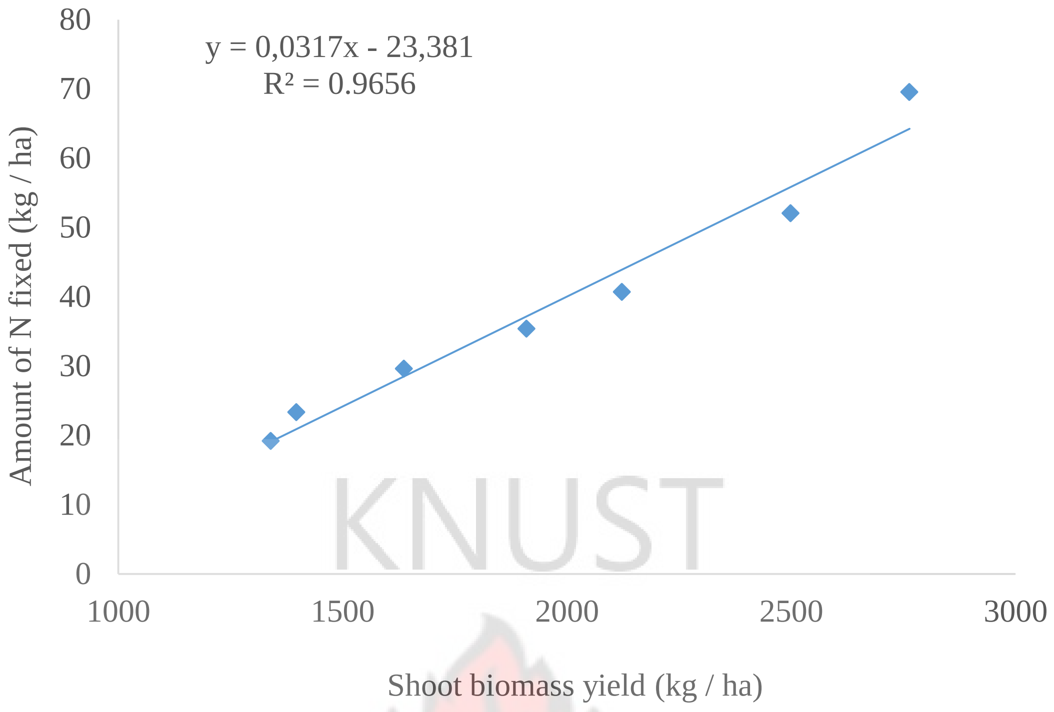


Figure 7. Relationship between shoot biomass yield and amount of nitrogen fixed by cowpea

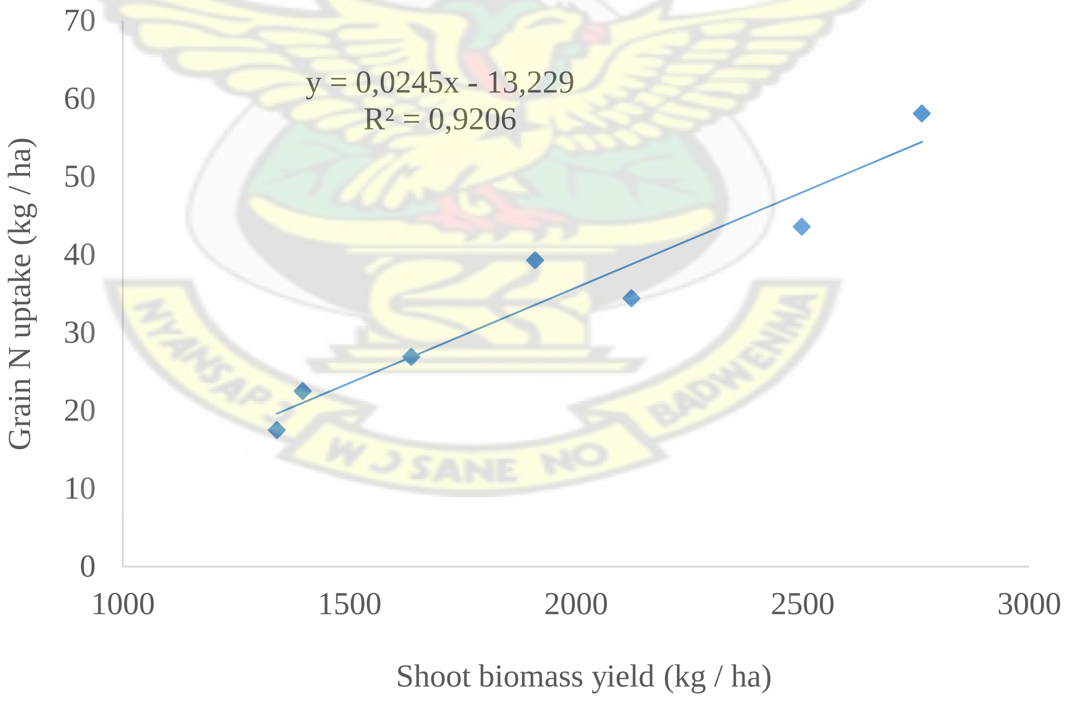


Figure 8. Relationship between shoot biomass yield and grain N uptake of cowpea

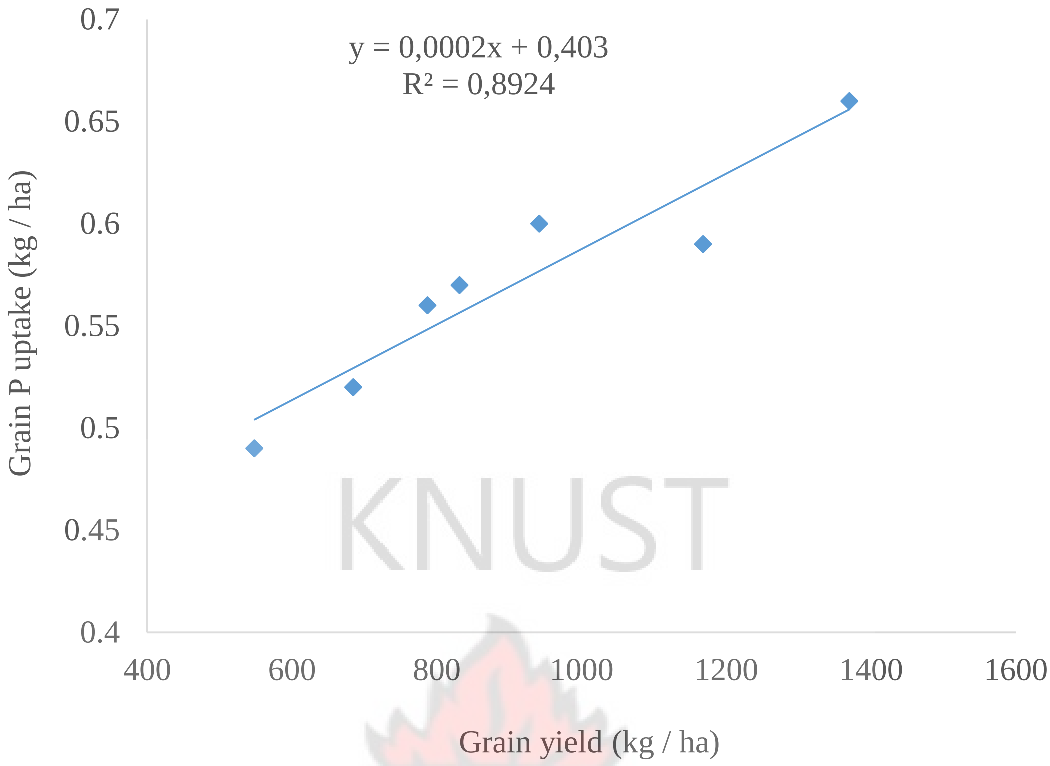


Figure 9. Relationship between grain yield and grain P uptake cowpea

CHAPTER FIVE

5.0 DISCUSSION

5.1 Soil physical and chemical characteristics of the study site

Analysis of the soil collected at the experimental site gave an overview of the soil in terms of its chemical and physical properties and the capacity to support cowpea production (Table 1). The results showed that the pH of the top 15 cm bulk soil sample was slightly acidic and low in the available P. The low soil organic carbon content may be the result of high temperatures resulting in rapid decomposition and the generally low input of organic material. Carbon plays an important role in sandy soil with low clay activity because it acts as substitute for clay CEC build up, protects the soil and it is a mediator of nutrient supply in cropping systems with low chemical fertilizer input (Asadu *et al.,* 1997). The value recorded for total N of the experimental site according to Pam and Brian (2007) was low. Diversity of management practices of soil fertility and cultural practices are the cause of the great diversity of chemical properties of soils (Kiba, 2012). The long-term effects of different modes of fertility management on nitrogen fixation and soil chemical properties have been reported by many authors (Sedogo, 1993; Kambire, 1994; Hien, 2004; Kiba, 2012).

On-farm fertilization practices in Niger are typically characterized by very low use of organic fertilizer, due to their limited availability (Sedogo, 1993). Comparatively, although the quantities supplied are minimal, inorganic fertilization is usually undertaken in cowpea fields especially on improved varieties. The profitable nature of cowpea tends to provide an incentive to invest in inputs for cowpea. However, the amounts of N and P supplied by mineral fertilizers remain low in the major cowpea fields.

5.2 Resource quality of composted millet glume

Composting of millet glume enhanced its fertilizer value (Table 2). At the end of the composting process, all the chemical properties increased appreciably with composting except organic carbon. The quality obtained was further translated into enhanced crop growth and yield since the combined application of the composted millet glume and mineral fertilizer produced relatively higher yields than mineral fertilizer applied alone.

The increased N concentration in the compost following maturation confirms the findings of Dresboll and Throrup – Kristensen (2005) who also observed increased N concentration over time during composting of wheat straw. During the composting process, the C: N ratio of the initial feedstock typically declined while carbon was being oxidized and nitrogen was mineralized by micro – organisms. A number of researchers have observed a significant reduction in C: N ratio when different sources of organic materials were composted. For example, Thambirajah *et al.* (1995) observed a substantial reduction in C: N ratio when they composted empty fruit bunches (with a relatively high lignin content) and manure.

5.3 Cowpea nodulation as influenced by composted millet glume and inorganic fertilizer

Combined application of composted millet glume and inorganic fertilizer treatments produced more nodules than the sole inorganic fertilizer (Table 3). This finding compared favourably with the observation by Naab et *al.* (2009) that plant residues dramatically influenced the formation of cowpea nodules. It can thus be said from the results of this study that combined application of composted millet glumes and inorganic fertilizer has the potential to increase cowpea nodulation. Many workers have demonstrated identical results with combined use of organic and inorganic sources of nutrients (Gitari and Friesen, 2001; Ayoola and Makinde, 2007). Kramer *et al.* (2002) indicated that an organic nutrient source applied in combination with an inorganic source is better utilized than sole organic source. The overall trend of nodule formation in this study indicated that the unamended plots (control) recorded the lowest nodule numbers (Table 3).

A positive relationship was found between nodule dry weight and cowpea grain yield (84%) and shoot biomass yield (87%). The positive relationship (Figs. 2 and 3) between nodule dry weight and cowpea grain and shoot biomass yield showed that the weight of shoot biomass is dependent on nodule dry weight under 3 t compost + 15 kg N + 26 kg P application. Penning and Djiteye (1982) reported that the source of nodules in the presence of organic and inorganic nutrient contribute to increased vegetation growth.

5.4 Cowpea grain and shoot biomass yield as influenced by composted millet glume and inorganic fertilizer

The study showed that the combined application of composted millet glume and mineral fertilizer were significantly effective in promoting cowpea growth and yield (Table 4). Regardless of the quantity of inorganic fertilizer applied, the combined application of composted millet glume and mineral fertilizer resulted in a significant increase in grain yield and biomass yield. The initial low fertility status of the soil coupled with increased yield over the control (Table 1) explains the effectiveness of fertilizers in enhancing crop yields. Abayomi *et al.* (2008) reported a significant increase in dry matter due to the combined use of mineral fertilizer and organic fertilizer.

Providing mineralized nutrients and neutralizing the acidity of the soil, compost influences crop yields in the humid tropics where there is rapid mineralization of organic residues. Ayoola (2006) reported that crop yields were usually least in unfertilized treatments because of the limited nutrients that the soil could supply without any external inputs. The wide gaps established between yields from the control and combined application of composted millet glume and inorganic fertilizer plots could be demonstrated to farmers to help them understand easily the value of composted millet glume in cowpea production. Results obtained further showed that in all cases, the combined application of composted millet glume and mineral fertilizer was favourable in increasing yields than using mineral fertilizer alone (Table 4). Titiloye (1982) similarly reported that the most satisfactory method of increasing cowpea yield was by judicious combination of organic wastes and inorganic fertilizers. Murwira and Kirchman (1993) further reported that nutrient use efficiency of a crop is increased through a combined application of organic matter and inorganic fertilizer. The highest yields therefore obtained from the combined application of compost and mineral fertilizer shows that the cowpea plants benefited more from this combination than sole inorganic fertilizer. There is much evidence that N and P availability act as the mechanical factors limiting crop production in West Africa, but past experiences have shown that their supply to plants should be organically mediated as in this has synergistic effect (Addam *et al*., 2010). Positive relationship was found between the cowpea grain yield and cowpea grain P uptake (90%).

5.6 Proportion of nitrogen derived from the atmosphere (Ndfa) and amount of atmospheric nitrogen fixed by cowpea

The Ndfa was relatively high under the application of 3 t compost +15 kg N + 26 kg P application (Fig. 1). Growth conditions limit Ndfa (Belane and Dakoro, 2009). The amount of nitrogen fixed by cowpea is directly dependent on the growth and yield performance of cowpea (Belane and Dakoro, 2009), which is mainly dependent on soil fertility. Adjei- Nsiah *et al.* (2008) found that Ndfa by cowpea varied between 46 and 68 %. Furthermore, Naab *et al*. (2009) reported Ndfa range from 12 to 78% and N fixation from 1.3 to 42.6 kg N ha^{-1}. Adjei- Nsiah *et al.* (2008) attributed the variability of N fixation to the diversity of farming practices, crop variety and soil fertility. The amount of nitrogen fixed by cowpea in this study ranged from 19.19 to 69.57 kg ha^{-1} (Table 6). The amount of nitrogen fixed is a function of cowpea grain and shoot biomass weight (Keyser and Li, 1992). This was reflected by the strong positive correlation between the amount of nitrogen fixed and cowpea grain yield (90%) and cowpea shoot biomass (90%).

5.7 Grain nitrogen and phosphorus uptake of cowpea as influenced by composted millet glume and inorganic fertilizer

The application of 3 t compost +15 kg N + 26 kg P (Table 6) produced the highest nitrogen uptake followed by application of sole mineral fertilizer. The overall N uptake following the imposition of the various treatments showed that the combined application of organic and inorganic nutrient sources were better utilized by the cowpea plant. All the treatments produced grain N uptake which were significantly higher than the control. These results are in conformity with those of Vanlauwe *et al.* (2001). Palm *et al.* (1997) reported that such an observation might be due to slow but continuous supply of nutrients to cowpea plants due to the influence of chemical fertilizer on organic fertilizer. Positive relationship was found between grain N uptake and grain yield (92%) and shoot biomass yield of cowpea (92%).

The application of 3 t compost +15 kg N + 26 kg P improved P uptake compared with the applications of 15 kg N + 26 kg P and 7.5 kg N + 13 kg P (Table 7). This finding agrees with the results of Okogun *et al.* (2005) who reported a significant increase in seed P due to combined use of organic amendments and inorganic fertilizer. A positive relationship was found between grain P uptake and the cowpea grain N content (86%) and between grain P uptake and cowpea shoot biomass N content (90%).

Belane *et al*. (2011) found that 32 varieties of cowpea which received with high dose of compost produced significantly greater phosphorus and higher nitrogen uptake similar to those measured in this study.

5.8 Nitrogen and phosphorus use efficiency of cowpea as influenced by composted millet glume and inorganic fertilizer

The N use efficiency values indicated that the application of 3 t compost +15 kg N + 26 kg P (Table 8) recorded the highest value. Bationo *et al*. (1989) found a strong and positive correlation between organic amendments and N fertilizer. The values obtained for the combined application of composted millet glume and mineral fertilizer support the null hypothesis of this study that organic fertilizer influence nutrient availability. Higher NUE has been reported in cowpea varieties with high harvest index (Bufogle *et al.*, 1997). The high NUE (123.51%) obtained in this study, means that more N was taken than applied. This may be due to rhizobia that nodulate the roots and receive much food energy from cowpea plants. Rao (1996) reported that when the quantity of nitrogen fixed by rhizobia exceeds that needed by the microbes themselves, it is released for use by the host legume plant. This is why well – nodulated legumes are highly responsive or do not often respond to additions of nitrogen fertilizer. Adaptation of subsurface placement of fertilizers to plants also has the potential to significantly improve N availability to plants and thereby improve NUE (Rao, 1996).

The P use efficiency values also revealed that the application of 3 t compost +15 kg N + 26 kg P recorded the highest value (Table 8). The lowest P use efficiency was associated with the application of the sole inorganic fertilizer (15 kg N + 26 kg P and 7.5 kg N + 13 kg P). Availability and total P levels of soil are very low in sandy Sudano-Sahelian zones of West Africa as compared to other soils in West Africa (Manu *et al.,* 1991). Soils of the Sahelian can have total P values as low as 40 mg P/kg and the value of available P less than 2 mg P/kg. The low content of both total and available P parameters may be related to several factors including parent materials and a high proportion of total P not available to crop (Charreau, 1974).

Among soil fertility factors, phosphorus deficiency is a major constraint to crop production in the Sudano - Sahelian zone. About 80% of the soils in sub-Saharan Africa are short of this critical nutrient element and without the use of phosphorus, other inputs and technologies will not effective. It is now an accepted fact that the replenishment of soil capital phosphorus is not only a crop production issue, but an environmental issue and P application is essential for the conservation of the natural resource base (Charreau, 1974).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

The increasing costs and accessibility of chemical fertilizers to small scale farmers in developing nations coupled with possible environmental pollution make it imperative that research efforts should focus on sustainable soil health and crop productivity while avoiding excessive fertilizer use. The study therefore exploited the integrated application of composted millet glume and mineral fertilizer as an alternative option for enhancing biological nitrogen fixation in cowpea in the Sahelian zone of Niger.

i. The 3 t compost + 15 kg N + 26 kg P application produced the highest nodule number (23) and gave nodule dry weight which was 132% more than the control, suggesting that the complementary application of composted millet glume and mineral fertilizer played a significant role in nodulation as well as in enhancing nitrogen fixation (69.57 kg ha^{-1}) compared to the application of the sole mineral fertilizer. The combined application of composted millet glume and mineral fertilizer had significant effect on the amount of nitrogen supplied through biological nitrogen fixation. This affirmed the null hypothesis that composted millet glume will improve amount of nitrogen through biological nitrogen fixation and consequently increased cowpea yield. This study has shown the importance of combined application of millet glume compost and mineral fertilizer nutrient sources in enhancing soil health and cowpea productivity.

ii. Combined application of composted millet glume and mineral fertilizer led to higher cowpea grain yield than the sole application of mineral fertilizer. It was therefore not surprising when the 3 t compost + 15 kg N + 26 kg P application produced the highest grain (1.37 t ha^{-1}) and biomass yield (2.77 t ha^{-1}). The correlation between the amount of N fixed and grain yield implied that the combined application of composted millet glume and mineral fertilizer contributed to improved nitrogen fixation and increased cowpea yield. This outcome affirms the null hypothesis that composted millet glume will increase cowpea growth and yield.

iii. Nitrogen (58.10 kg N ha^{-1}) and phosphorus (9.33 kg N ha^{-1}) uptake increased significantly with 3 t compost + 5 kg N + 26 kg P application relative to the sole mineral fertilizer application, buttressing the null hypothesis of this study that complementary application of compost and mineral fertilizer enhances nutrient uptake and its use efficiency. The 3 t compost + 15 kg N + 26 kg P application utilized nitrogen and phosphorus in the cowpea plants by 123.5 % for N and 16.76 % for P than the other applications. The various indices for estimating use efficiencies of N and P in cowpea were generally higher in the combined application of composted millet glume and mineral fertilizer than in sole mineral fertilizer application.

The combined application of composted millet glume and mineral fertilizer in an integrated nutrient management strategy promised to be an attractive alternative that small scale farmers could adopt to ensure higher yields. Whilst the return of crop residues is being advocated in Niger, improvements in soil fertility would require equilibrated application of organic matter and inorganic fertilizer. The study has shown that the 3 t compost + 15 kg N + 26 kg P application is potentially ideal for crop growth and soil fertility improvement in Sahelian zone of Niger.

The composting study showed that C: N ratio of millet glume was lowered at the end of the composting process, an indication that soluble C was being degraded coupled with leaching losses of N.

6.2 RECOMMENDATIONS

- To promote the efficient use of composted millet glume in the study area, there is a need to sensitize smallholder farmers regarding the appropriate use of the compost including method(s) and time of application.
- There is the potential to further improve on the quality of composted millet glume produced from the composting method purported in this study. It is also essential the quality of the compost and its fertilizer value are evaluated under long term crop response trials under different agroclimatic conditions.
- Economic analysis regarding the use of composted millet glume is a research study worth considering.

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APPENDICES

Appendices 1: Experimental design

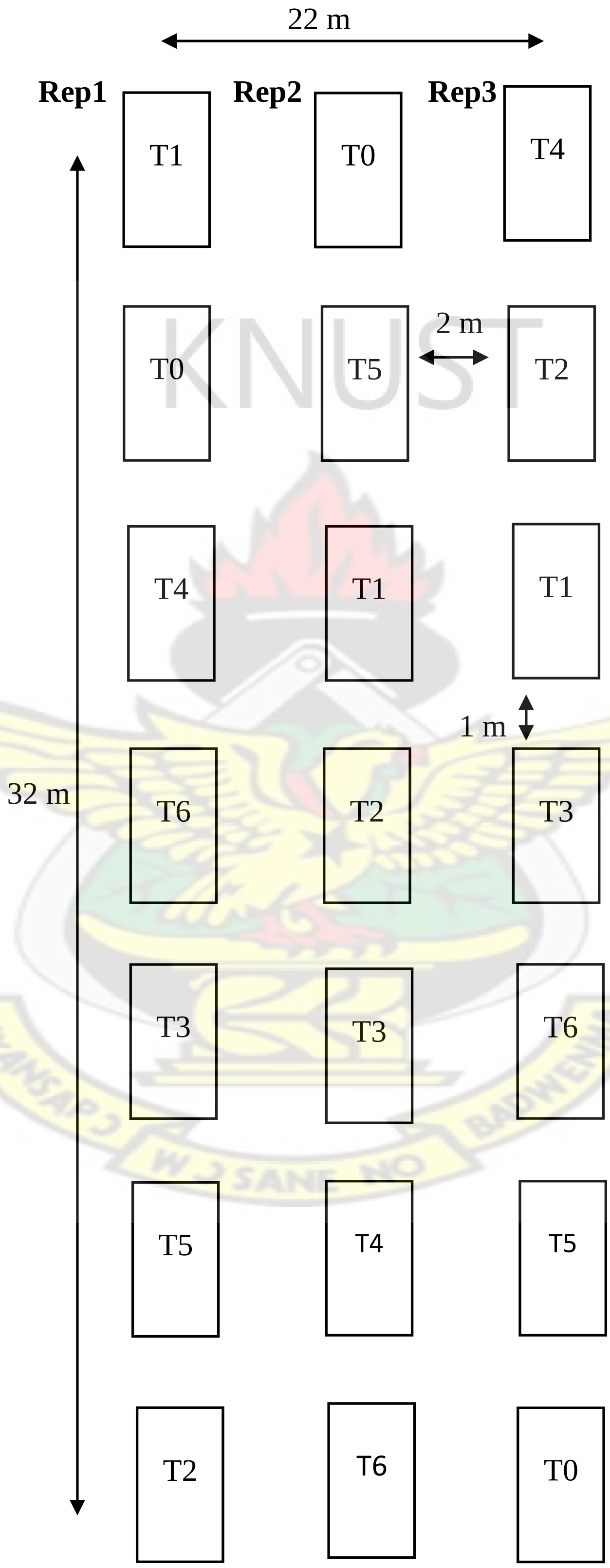

Figure 10. Field layout showing treatment allocations

Appendices 2: plate of millet ears

Source, Mahamadou (2013)

Appendices 3: plate of millet glumes

Source, Mahamadou (2013)