MAIZE RESPONSE TO COWDUNG, NITROGEN AND SULPHUR FERTILIZATION AND EFFECT ON SOIL PROPERTIES IN A NORTHERN GUINEA SAVANNAH ALFISOL OF NIGERIA

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AHMADU BELLO UNIVERSITY,
ZARIA, NIGERIA

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A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF SOIL SCIENCE,
FACULTY OF AGRICULTURE,
AHMADU BELLO UNIVERSITY,
ZARIA, NIGERIA

JANUARY, 2016

DECLARATION

I declare that the work in this thesis entitled "MAIZE RESPONSE TO COWDUNG, NITROGEN AND SULPHUR FERTILIZATION AND EFFECT ON SOIL PROPERTIES IN A NORTHERN GUINEA SAVANNAH ALFISOL OF NIGERIA" has been carried out by me in the Department of Soil Science, Faculty of Agriculture, Ahmadu Bello University, Zaria. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree at this or any other institution.

Ukem, Bassey Okon ______________________ ____________________
Name of Student Signature Date

CERTIFICATION

This thesis entitled, “MAIZE RESPONSE TO COWDUNG, NITROGEN AND SULPHUR FERTILIZATION AND EFFECT ON SOIL PROPERTIES IN A NORTHERN GUINEA SAVANNAH ALFISOL OF NIGERIA” by Bassey Okon UKEM, meets the regulations governing the award of the degree of Doctor of Philosophy of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation**.**

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DEDICATION

To the Glory of God, the Lord Jesus Christ, I am obliged to dedicate this work to my parents: Late Chief Okon U.A. Ukem and Madam Okonanwan Ukem for their guidance, love, care and enormous sacrifices in providing education to the family. My dear wife and our children who at various times were committed to the success of this work and my late brother, Offiong Ukem, for his immense encouragement to me.

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ABSTRACT

A study was conducted in Samaru to investigate maize response to cowdung, nitrogen and sulphur fertilization and effect on soil properties in a northern Guinea savanna Alfisol of Nigeria. The objectives of the study were: to determine effect of complementary application of N, S and cowdung (CD) on growth and yield of maize in a savanna soil; assess the mineralization characteristics of cowdung amendment and to test efficiency of QUEFT model in simulating yield of maize in response to application of the full recommended rates of N, P and K fertilizers in a savanna soil. In order to achieve the stated objectives, a three - phased experimentation was set up, which comprised of a laboratory incubation study, greenhouse study and a field trial. Nitrogen was applied at the rate of 0, 60 and 120 kg N/ha as urea, sulphur was applied at the rate of 0, 15 and 30 kg S/ha as gypsum while cowdung was applied at the rate of 0, 5 and 10 ton/ha, resulting in 27 treatments with 3 replicates. The laboratory incubation and greenhouse studies were conducted in a Completely Randomized Design while the field trial was implemented using the Randomized Complete Block Design. The results showed that there was a significant increase in CO_2 fluxes with 10 ton/ha CD relative to half its rate and manure mineralization rate was higher ($P < 0.01$) with N than sulphur. Also, the amount of NH_4^+ and NO_3^- mineralized at the end of incubation increased ($P < 0.01$) with increase in N, S and CD rates. Growth parameters in both green house and field trials responded significantly ($P < 0.01$) to the amendments, indicating a positive influence on plant vigour. Grain yield, stover and cob weight increased significantly compared to the control and also had a positive correlation with growth parameters. Mean grain yield derived from the QUEFT model in the three years of field experiment was 1896.3 kg/ha from the unfertilized plot and 12,000 kg/ha from the fertilized plot. Soil pH, sulphur, nitrogen and organic carbon increased significantly with increase in CD rates indicating positive effect of manure on soil fertility. The combination of N with S and cowdung significantly increased grain yield by 45% compared to the control, indicating that soil fertility had significantly improved through the amendment. Therefore, sulphur application is required to enhance use efficiency of N in the soil towards increased and sustainable maize production in a northern Guinea savanna soil of Nigeria.

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CHAPTER ONE

1.0 INTRODUCTION

Maize is one of the major cereal crops cultivated extensively in all agro-ecological zones of Nigeria. It ranks second both in total production and utilization after sorghum, followed by millet and rice (National Bureau of Statistics, 2010).

Extensive studies have been conducted in the Nigerian savannas on nitrogen and phosphorus considered as most limiting nutrients for crop production (Ogunlela *et al*., 1988), but not much on S nutrition, especially when in combination with organic manures. Organic manure is a good contributor of N in soils, though the amount of N contained in manure varies with source, quality of the substrate, age, management and ease of mineralization, therefore its co-application with readily soluble inorganic N and S becomes necessary and offers a realistic approach towards sustainable soil productivity, while at the same time improving the soil physical conditions for nutrient retention and uptake by plants.

Fertilizer regime for cereal crops in the savanna of Nigeria emphasises on the continuous application of high rates of N, fairly high rate of P and K, with no attention given to sulphur and micronutrients (Chude *et al*., 2012). In view of this, crop exploitation of soil available nutrients often leads to the deficiency of S and micronutrients, thereby resulting in poor crop yields. Incidental inclusion of sulphur and micronutrients in fertilizers has been effective in masking soil depletions in the past, such that deficiency symptoms were not of any serious concern. But increased cropping intensity, higher crop yields per hectare of cultivated lands, use of high analysis fertilizers such as urea and triple super phosphate (TSP) with no sulphur content, coupled with a low soil organic matter (SOM) content, has contributed to the greater incidence of S deficiency observed in the soils.

Studies on maize response to sulphur fertilizer application in the Northern Guinea savanna of Nigeria revealed that yield was reduced by about 20% due to sulphur deficiency (IITA, 2005) even when the full recommended rates of N-P-K were applied. It is therefore expected that application of S in combination with N and cowdung will enhance availability and efficient use of these essential nutrients and equally increase yield of maize.

Although organic matter provides a retention base for plant major and micronutrients (Sing *et al*., 1995; Syers and Craswell, 1995), the slow rate of mineralization often hinders its short term efficiency relative to long term benefits. Still, many workers have recorded increased and significant yield of crops from organic and inorganic fertilizer application (Adeleye and Ayeni, 2010; Ukem *et al*., 2005). There is therefore the need to incorporate organic residues to boost plant nutrient base while pegging down on excessive mineral fertilizer application in view of its deleterious effect on soil properties.

Studies have shown that nitrogen and sulphur play a vital role in plant nutrition, being components of proteins, nucleic acid, auxins and chlorophyll and promoting a healthy crop performance. Sulphur is also an important element involved in plant biochemistry; being a major constituent of amino acids and in the formation of enzymes and vitamins (Havlin *et al.* 2006; Ceccotti, 1996). Efficient crop response to N fertilization in the savanna of Nigeria especially on cereals is available in literature (Chude *et al*., 2012, Ukem, 2011), but information on the performance of maize to N and S combination amended with cowdung and their effect on soil properties is scarce. Also, the potentials of cowdung, inorganic N and S combinations on maize performance influenced by environmental factors and the resultant impact on soil fertility have not been fully understood in the savanna. Therefore, farmers and other workers need adequate information regarding N availability from organic residues as a guide towards the determination of the optimum inorganic N fertilizer application rate for improved maize yield especially in combination with sulphur.

1.1 Justification of the Work

It is increasingly recognized that maize production in some locations of the world has improved by introduction of sulphur along with the practice of applying nitrogen, phosphorus and potassium (Khan *et al*., 2011; Bharathai and Poongothai, 2008; Ceccotti, 1996; Friesen, 1991). This approach has therefore intensified further research efforts aimed at addressing maize response to sulphur fertilization and equally determining optimum sulphur levels for maize production in combination with nitrogen. However, not much was reported to have been done about nitrogen and sulphur interactions on maize cultivation in the tropical savannas of Nigeria, perhaps due to the dependence on SSP for plant sulphur requirements or on the assumption that the absence of sulphur is not a serious cause for concern by farmers in the area.

Years of crop cultivation and considering the already low soil sulphur status in the savanna soils (Kayode, 1990), in addition to human activities that tend to limit soil fertility, the incidental application of sulphur as SSP cannot be considered sufficient. There is therefore the necessity to incorporate sulphur in fertilizer programme based on actual crop needs, if improvement in maize yield in the savanna is to be achieved.

1.2 Objectives

The objectives of the study are as follows:

1. To determine the effect of complementary role of N, S and cowdung on growth and yield of maize in a savanna soil.
2. To determine the interactive effects of N, S and CD combination on soil chemical properties.
3. To test the efficiency of QUEFTmodel in simulating growth and yield of maize and determine optimum inorganic fertilizer recommendation for maize in the Guinea savanna of Nigeria.

1.3 Statement of the Problem

Due to intensification of agriculture in the savanna zone of Nigeria, available soil nutrients are constantly exploited by crops, leading to deficiency of essential plant nutrients. Also, shortened fallow periods and adverse cultural practices of farmers such as bush burning, crop residue removal and the acute low organic matter content of the soil, contribute to the continuous decline of essential plant nutrients in soils.

Application of inorganic fertilizers as intervention measures benefits mainly N, P and K with a disproportionate amount of sulphur input; though it constitutes 12% of Single Super Phosphate (SSP), and which might not be sufficient to meet crops nutritional needs. In view of this, sulphur deficiency becomes significant, coupled with the already low soil organic matter content.

Workers in the past had erroneously overlooked complementary role of N and S in maize cultivation in the savanna. This has caused nutritional imbalance for the crop and resulted in yield reductions. There is therefore the need to include sulphur along with inorganic N and organic matter for increased maize production.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Soils of the Northern Guinea Savanna

The major soils of the Northern Guinea Savanna agro-ecological zone include Alfisols, Inceptisols/Entisols, Ultisols, and Vertisols (USDA Soil Survey Staff, 1975). It has been reported that soils of the Northern Guinea Savanna which are formed on drift materials overlying basement complex are predominantly coarse textured, generally low in organic matter, poorly structured and generally low in cation exchange capacity (CEC) and the dominant clay type is kaolinite (Ojanuga, 1979).

The dominant soil types are well-drained Alfisols, Entisols and Inceptisols with little profile differentiation and derived primarily from recent aeolian deposits. They are generally yellowish grey or yellowish brown in the first 0-20cm layer and have red or reddish brown B horizons with higher clay content. The Vertisols which constitute about 2% of the country's soil resources occur mainly in the north-eastern flank of the country bound by latitudes 8^0N and 13^0N and longitude 10^0N and 14^0N. They are generally deep, dark coloured, heavy clayey soils with very low water permeability/infiltration capacity and poor internal drainage.

Studies have shown that organic matter content of the savanna soils range from 5.0 g kg^{-1} in Entisols and Inceptisols to about 20.0 g kg^{-1} in Vertisols and hydromorphic soils. The Alfisols are generally shallow, coarse textured, yellowish grey or brown in the surface layer and have red or reddish brown subsurface and lower horizons with higher clay content (Jones and Wild (1975). Organic matter content is generally low; rarely sreaching 2 g kg^{-1} even in the surface soil and total nitrogen content rarely exceeds 1.0 gkg^{-1}. Cation exchange capacity (CEC) values as low as 5 cmol kg^{-1} have been reported for most savanna soils (Jones and Wild, 1975). These soils are moderate to slightly acid in reaction and also have moderate exchangeable bases but very low in total nitrogen and available phosphorus. Soil pH range of between 6.0 - 6.8 has been reported (Jones and Wild, 1975). The fertility of these soils decline rapidly after a few years of continuous cultivation thus requiring heavy application of fertilizers for sustainable crop production (Lombin, 1987).

The use of chemical fertilizers to replace the traditional system of crop rotation and shifting cultivation on these soils had centred largely on nitrogen and phosphorus, considered as most limiting nutrients in the savanna (Uyovbisere and Lombin, 1991). Native soil N is so low that all cereal crops respond to N fertilizers. Jones (1973) reported values varying from 0.08 to 2.90 g kg^{-1} with mean of 0.5 g kg^{-1}. This is closely linked to the generally very low organic carbon content of these soils. Mean value of 4.70 mg kg^{-1} has been reported for phosphorus (Jones, 1973). Total K content of the savanna soils varies from 0.60 to 39.90 g kg^{-1}. Exchangeable K values averaging 0.22cmol kg^{-1} for these soils have been reported (Singh *et al.*, 1983). However, Ca and Mg deficiencies are not common in these soils (Jones and Wild, 1975). Micronutrient levels in these soils are fairly high (Chude *et al.*, 2012).

Urea and calcium ammonium nitrate (CAN) have been the most widely used N sources in the northern guinea savanna. Various compound formulations had equally gained prominence. Comparatively, all nitrogen sources in use are shown to be equally effective in terms of their immediate N supplying power and effects on crop yiel. The only exception is ammonium sulphate where its high soil acidifying effect had made it less popular.

Because of its pronounced deficiency, phosphorus has been recognized as an important yield limiting nutrient in the soils of northern guinea savanna. However, these soils have been found to be of low P-fixing capacity and so most of the P applied is found to be available to crops even if not in the same season (Bationo *et al.*, 1986; Mokwunye, 1977).

Crops commonly grown in the area are sorghum, maize, cowpea, soya beans, sugar cane, groundnut and cotton (Odunze and Ogunwole, 2002).

2.2 Crop responses to nitrogen, phosphorus and potassium fertilizers in the Nigerian savanna

2.2.1 Nitrogen fertilizers

Under continuous and intensive cropping, fertilizers represent the most important source of nitrogen (Jones, 1974). It has been estimated that as much as a third of the energy input (excluding solar radiation) needed to maintain intensive agricultural systems is used to produce nitrogen fertilizers (Jones, 1974). This therefore emphasized the urgent need for the efficient use of nitrogen fertilizers in food production. It has been reported that maize, wheat and sorghum require about 100-120 kg N/ha for optimum yield in the savanna agro-ecological area (Balasubramanian *et al*., 1978).

The N-rate (120 kg N/ha) recommended for cereals in the savanna, according to earlier investigations, can be reduced by half when cereals follow a good crop of N-fixing legume, particularly groundnut in a legume - cereal rotation. This is attributed to the fact that the previous legume crop has been found to leave some of the fixed N for use by the following cereal (IAR, 1976).

Investigations on the effect of continuous use of nitrogen fertilizers on soils have shown that all N-fertilizers are acid forming in the long run, but the intensity of acidification has been found to have differed from one N-source to another. Since the continuous use of ammonium sulphate rapidly acidified the poorly buffered savanna soils, it has been gradually replaced by less acid forming N-sources such as urea and calcium ammonium nitrate (CAN) (Jones, 1976). However, the acidifying effect of N-fertilizers is moderated by the simultaneous addition of organic manures and single superphosphates (Nyongesa *et al*., 2010).

Information in literature has shown that soil acidification was a necessary evil of N-fertilization and also it leads to the loss of Ca and Mg from the top soil (Jones, 1976). Periodic liming has been one of the measures for correcting soil acidification. Fallowing practices and legumes crop management, rather than fertilizers are used in the savanna to correct nitrogen deficiency. Also, it has been established that split nitrogen application helps to ensure an adequate supply of added N at critical stages of crop growth and to reduce N leaching losses due to heavy rainfall, especially in light sandy soils (Enwezor *et al*., 1989).

Benefits of increased fertilizer nitrogen efficiency include, increased crop yield per unit N-applied, less nitrogen leaching and a decreased rate of soil acidification.

2.2.2 Phosphorus Fertilizers

Most savanna soils are deficient in phosphorus which limits crop production to a great extent (Lombin, 1987). In addition to its direct effect on crops, P deficiency retards nitrification in soils and as such leads to low efficiency of applied NH_4^+ - N fertilizers (Purchase, 1974). It has been suggested that phosphorus fertilization should take into consideration not only the crop requirement but also the capacity of soils to fix applied P. Phosphorus fixation is very low in sandy soils but high in clay soils particularly soils with lateritic clay (Charreau, 1974).

The P-fixing capacity of soils was often satisfied by initially applying large amounts of SSP or rock phosphate, which in such cases, annual application of smaller amounts of soluble P-fertilizers like SSP has been found to be effective in maintaining P fertility and crop yield (IAR, 1978). Literature has maintained that since leaching losses and luxury consumption of phosphorus are negligible, the amounts of P required for annual application is roughly equivalent to the crop uptake. Adequate amount of P in any fertilizer programme is found to be helpful in maintaining the soil pH and nutrient status in the long run (Singh and Balasubramanian, 1978). Most crops in the savanna areas require 40-60 kg P_2O_5/ha as being optimum (Balasubramanian and Mokwunye, 1978).

Single super phosphate (SSP) has been reported as the most commonly used phosphatic fertilizer in Nigeria. In addition to P (16 – 20% P_2O_5), it supplies considerable amounts of calcium (18 – 21% Ca) , sulphur (11 – 12% S) and traces of some minor elements (Jones,1987) and the incidental addition of these elements has been found to alleviate their deficiency if any. However, the addition of secondary and trace elements is found to reduce drastically, once SSP is replaced with more concentrated phosphatic fertilizer sources like triple super phosphate (Ahmed, 1975).

Normally, P-fertilizers are applied prior to planting and incorporated into the soil, either by broadcasting before ridging or they are placed in a furrow along the planting row. Broadcasting is found to be good for basal application of rock phosphate while placement is found to be better for the maintenance of the more soluble P fertilizer (Singh and Balasubramanian, 1978).

2.2.3 Efficiency of Fertilizer Use

The intensification of agriculture and the inherent low fertility of most tropical soils (Nyongesa *et al.,* 2010) have led to increase use of chemical fertilizers. Achieving production increases per quantity of fertilizer applied per unit area without emphasis on sustainability of agro – ecological environments has further weakened the resource base and contributes to inefficient fertilizer use. There is therefore the risk of potential environmental pressure arising from inappropriate fertilizer application. In the savanna agro – ecological zone of Nigeria, the most limiting plant nutrients are N, P and K (Lombin, 1987). Therefore, chemical fertilizers are usually formulated for targeted crops on the basis of the availability of the major plant nutrients (Enwezor *et al.,* 1989). But these nutrients alone cannot be the ultimate solution to increase and sustainable crop yield without the integration of other edaphic factors that would promote use efficiency of the applied fertilizers.

According to some studies (Havlin *et al.,* 2006, Jones, 1987 and Cooke, 1982), fertilizers are considered as efficient when maximum economic yield is obtained with minimum possible amount of fertilizer application. The importance of fertilizer use efficiency

(FUE) is to measure the recovery of plant nutrients from mineral fertilizer application in crop husbandry (Cooke, 1982). In agricultural production, it is usually expressed in terms of crop yield per hectare. However, in practice, it is usually difficult to quantify the efficiency of a particular fertilizer due to certain conditions that may lead to the removal of these inputs from the soil (Jones, 1987). Fertilizers applied to enhance crop nutrition may be lost in several ways, especially nitrogen fertilizers, such that, the quantity left in the soil may not be adequate to sustain the crop through its life cycle. Losses due to leaching, losses in gaseous forms, immobilization by chemical precipitation, adsorption on exchange complex, use in microbial cells and negative effect of some soil chemical properties as well as P fixation on soil clay minerals are widely reported (Brady and Weil, 2005).

Records of trials on the efficiency of fertilizer use in Nigeria dates back to the thirties (Falusi, 1981). Fertilizer applied to the soil or crop is often exposed to numerous routes of losses thereby limiting its use efficiency to the crops. In view of the increasing human population in the country and a declining productivity of the soils, it thus became imperative to critically assess the efficiency of applied fertilizers.

Foth (1978) stated that crops grown on most soils particularly in the humid regions respond favourably to the use of well-chosen fertilizers, thus fertilizers should not be expected to make up for every shortcoming of the soil and crop but rather factors such as poor seeds, unadapted varieties of crops, unfavourable weather conditions, poor tillage practices, weeds, poor drainage, bad physical condition of the soil, low organic matter content or even insufficient lime application should be taken into consideration, because all the factors are important and in one way or the other, they affect the efficiency of any fertilizer for any crop grown on any given soil.

It was noted that the most profitable return from fertilizers is nearly always obtained from soils that are in the best physical condition for plant growth but not expected when the fertilizers are used on soils that are either too compact or too loose, too dry or too wet (enwezor *et al*., 1989).

Another factor enhancing efficiency of fertilizer use has been found to be the method of placement and time of application of the fertilizers (Cooke, 1982). Timing and a correct method of application have been found to have positively influenced crop yields.

2.3 Nitrogen availability, nitrogen use efficiency and influence of organic manure

Decomposition of added organic manure to release mainly nitrogen and other essential elements for plant uptake has been the concern of many workers Makinde and Ayeni, 2013). This may be attributed to the different sources of organic materials, their relative nutrient content, the carbon to nitrogen ratio (C: N) in these materials as well as the physical, chemical and biological properties that influence decomposition. It has been reported that the amount of inorganic nitrogen in cattle manure is relatively small (Maskina *et al*., 1988). In some cases, it is either that the organic manure is slowly mineralized or the inorganic N is immobilised by soil organisms which require nitrogen for their metabolism. It is therefore obvious that nitrogen availability from organic inputs might not be sustainable to meet the life cycle of the crop, and its quality is influenced largely by source, nutrient content and prevailing environmental conditions that promote mineralization. Perhaps, it was in view of this, that Van Kessel (2002), documented that the quantity of manure as a N fertilizer is difficult to predict, since manure composition may vary widely according to diet and other management factors. Dairy manure is a complex mixture of materials with varied mineralization kinetics, ranging from relatively resistant lignin to readily available ammonium and volatile acids (Van Kessel *et al*., 2000).

According to some incubation studies, it has been reported that some manures act as net suppliers of N, while others may result in net N immobilization (Calderon *et al*., 2004). Hadas and Portnoy (1994), reported that manures might release up to 29% of their N content as inorganic N during laboratory incubation, but in contrast, Sorensen (1998) found net immobilization of N during manure incubations and the effect was most pronounced with manures rich in volatile fatty acids content. It was this finding that led Calderon *et al* (2004) to suggest that N losses through dentrification as well as N immobilization during laboratory incubations may affect the correlation of incubation data with manure N mineralization in the field as well as preventing a good agreement between manure N pools and mineralizable N.

From the foregoing, it has been shown that the nitrogen supplying ability of organic inputs in soils vary due to the controlling factors of mineralization and immobilization. The dominance of each would greatly influence soil nitrogen availability, uptake and crop performance. It is therefore viewed that plant nitrogen use efficiency needs to be correlated between uptake and initial nitrogen composition of the organic manure or manure nitrogen pools.

Therefore relying solely on organic manure for the supply of nitrogen and other needed nutrients such as P, K, S, Ca and Mg and micronutrients may be sufficient for small holder famers who use organic manure mainly in vegetable farming. But for a cereal crop production like maize in the savanna, where higher rates of fertilizers are recommended (Enwezor *et al*., 1989; Lombin, 1987), co-application of organic manure and inorganic fertilizers for N and S offers a more promising and a balanced nutrient requirement for improved maize production in the savanna than sole application of either organic manure or inorganic fertilizers (Chude *et al*., 2012) Also, the nutrients released from the mineralized organic manure in the soil contributes to soil fertility, leaves residual effect to the succeeding crop and improving spoil physical properties.

2.3.1 Interactive effects of nitrogen, sulphur, and organic manure in crop production

Studies have shown that nitrogen and sulphur play a complementary role in plant nutrition and promote high crop yield and crop quality (Bharathi and Poongothai, 2008). Several workers have reported that S also has a positive influence on the uptake of major nutrients (Dwivedi *et al*., 2002; Chaterjee *et al*., 1998). Sulphur is found to play important roles, in energy transformation, activation of enzymes and in carbohydrate metabolism. Bharathi and Poongothai (2008) reported that sulphur fertilization significantly and positively affected grain and stover yields of maize in a sandy clay loam soil of Tamil Nadu region of India. This significant effect was due to the positive influence of sulphur in combination with optimum levels of N, P and K.

In the savanna region of Nigeria, sulphur fertilization has not been accorded serious priority in comparison to N or P, perhaps due to the incidental inclusion of S in SSP. But results of studies conducted in the recent past suggest that yield of crops is becoming increasingly reduced due to sulphur deficiency not withstanding the application of the full recommended rates of N, P and K (IITA, 2005). Widespread deficiency of sulphur was identified as a major constraint to maize production in the savannas even when N and other major elements were applied (IITA, 2005).

The complementary role of N and S in plant nutrition has been recognised (Bharathi and Poongothai, 2008; Ceccotti, 1996; Friesen, 1991; Brooks, 1979). The availability of both elements in soils is influenced by organic matter content of the soil. Therefore, the amount of plant available nutrients is dependent on the quantity and quality of the applied organic matter and the factors of mineralization.

Soil quality and productivity are closely linked with soil organic matter status (Paul, 2007; Singh *et al*., 1995). Organic amendments play an important role in the improvement of soil structure and soil organic matter content (Singh *et al*., 2004; Meelu *et al*., 1994).

Adequate and sustainable input of organic manure has the benefit of yielding plant nutrients and equally has the potential to reduce or eliminate the need for high rate of N fertilizers for the succeeding crop.

Since maize has a high nutritional requirement, coupled with the already low soil sulphur reserve in the Guinea Savanna (Kayode, 1990), the N, S and organic manure interaction is expected to sustain adequate plant nutrients and increase maize production as the organic manure, on decomposition, contributes to soil fertility and improves the soil physical conditions to enhance nutrient uptake.

2.3.2 Effect of soil organic matter on soil nutrients status and pH

An extensive work has been done already on the effect of application of organic manure on nutrient release patterns, nutrient dynamics, availability and soil pH in the tropics (Mba and Mbagwu, 2003; Zingore *et al*., 2003; Hsieh, 1996; Singh *et al*., 1995). In the tropical savanna of Nigeria, particular attention is paid to soil nutrient replenishments through the use of readily decomposable plant residues and animal remains or the use of life mulch from leguminous cover crops such as mucuna puririens, stylosanthes capitata and centrosema pascuorum (Okpara *et al*., 2005). In addition to these, residues of some herbaceous plants (leaves, bark and seeds) obtained from locust bean, neem, luceana, avocadeo and many others are found to improve soil organic matter (SOM) status and supply essential nutrients such as N, P, K, S, liming elements and micronutrients (Mba and Mbagwu, 2006; Tarfa and Iwuafor, 2002; Olayinka and Ailenubhi, 2001), Also, animal dung, poultry manure, farmyard manure (FYM) and swine slurry are proven to be effective in soil fertility management and increase crop yields in the savanna when applied either alone or in combination with inorganic fertilizers (Ukem, 2009; Ayeni *et al*., 2008; Tarfa *et al*., 2001).

The rapid deterioration and decline of soil properties especially after each year of cultivation coupled with the apparent lack of interest among the farmers to revert to the traditional methods of soil fertility replenishments through crop rotation, extended fallowing and shifting cultivation have continued to diminish SOM credit and accelerates the development of soil acidity due to the continuous application of acid forming chemical fertilizers. Current trends in soil fertility management in the tropics require the use of low input and cost effective technologies such as the continuous application of cheap and easily available organic resources either of plant or animal origin which have the potentials of improving soil quality, serve as soil nutrient stock, increase cation exchange capacity, increase cation and water retention and having a positive residual effect by increasing nutrients reserves without any cumulative adverse effects on soil properties.

Input of organic matter to acid tropical soils was reported to have significantly reduced soil acidity (Ano and Agwu, 2005). Therefore, organic matter possesses liming effect due to their content of Ca and Mg. In a laboratory incubation study to assess the influence of combined application of cowdung and inorganic nitrogen on microbial respiration and nitrogen transformation in an Alfisol, Olayinka and Ailenubhi (2001) reported that cowdung significantly increased soil pH throughout the period of incubation and has a good buffering capacity. Nziguheba *et al*. (1998) reported a decrease in P sorption from the application of organic residue in the Rift Valley Province of Kenya while the application of inorganic P as Triple Super Phosphate (TSP) increased P sorption. Also, Mba and Mbagwu (2006) observed that input of organic manure increased the solubility and availability of phosphorus in the soil by raising the soil pH above 5.0. Therefore, the application of organic residues to the savanna soil was expected to enhance the availability of plant food especially N, P, K and S by reducing leaching losses of N, K and S and P fixation, increase soil organic matter content and also increasing the content of liming elements to reduce high soil acidity.

2.4 Production, Distribution and Economic Importance of Maize in Nigeria

Of the four major cereal crops – sorghum, maize, millet and rice, grown in Nigeria, maize (Zea mays L.) ranks second in importance both in terms of total production and utilization (National Bureau of Statistics, 2010). The estimated annual production of maize in the early 1970s was about 1.6 million metric tonnes of dry grains from about 1.5 million hectares of small peasant holdings (Federal Office of Statistics. 1972). This however, represents a low average yield of about 1000 kg/ha. However, with the use of improved cultivars and other necessary inputs like the fertilizers, pest and disease control measures, production had witnessed a steep increase over the years. In 1988 and 1995, average farmers yield stood at about 2143 kg/ha and 1317 kg/ha respectively while the total annual production for the same period was estimated at about 1500 million metric tonnes and 7240 million metric tons respectively (FAO. 1988 and 1995). Production level in 2010 was estimated at about 7.6 million metric tons of dry grains from a land area of about 4.5 million hectares. Yield obtained from farmers' fields was about 2,653 kg/ha (National Bureau of Statistics, 2010).

2.4.1 Constraints to maize production in the Nigerian savannas

Information in literature shows that an estimated one million hectares of land was planted to maize in the country between 1989 – 1990 and over 50% of this was cultivated in the northern states of Nigeria. From then, production of dry grains has intensified with the benefit of improved cultivars, use of irrigation facilities especially in the drier Sudan and Sahel agro-ecologies and adoption of efficient crop husbandry practices such as timely and correct amount of fertilizer application and management. Ofor *et al*. (2009) reported that within that period, average yield per hectare in the northern savannas on peasant farms was about 0.6 tonnes/ha while that of commercial farms was about 2.0 metric tonnes/ha.With the expansion of maize belts across the varied agro – ecological zones of northern Nigeria and the quest to increase production to meet food sufficiency, the intensification has led to increase in production in the last one decade. For instance, average yield on smallholder farms in 2010 stood at 2500 – 2750 kg/ha while annual production for the same period was 8.9 million metric tonnes of dry grains (National Bureau of Statistics, 2010).

However, inspite of this increase in production, the potential maize grain yield in the Nigerian savannas has remained elusive due to several constraints. These constraints can be categorized as low soil fertility, pest and diseases infestation, rampant menace of competing weeds, unbalanced chemical fertilization, cross boundary climate change such as heat waves, drought and flood, soil acidity/salinity, animal grazing, migratory birds, use of low yielding seed cultivars and other environmental hazards (Kamara, 2013; Ofor *et al.*, 2009).These myriads of constraints have impacted negatively on sustainable maize production in Nigeria and ultimately limits food security. A review of some of these challenges is thus necessary in order to have a basis for adopting a possible remedial measure which could influence the kind of intervention. With respect to the scope and objectives of this study, close attention will be paid to those constraints that have a strong relevance to edaphic factors and their impacts on maize cultivation in the savanna of Nigeria.

Low soil fertility condition of the Nigerian savanna is undoubtedly the most serious constraint confronting the vast majority of subsistent farmers in Nigeria. Studies have shown that soils of the Nigerian savanna are deficient in the major plant nutrients mainly N, P and K (Chude *et al*., 2012). Nitrogen deficiency is by far the most critical of all the major elements followed by phosphorus (Carsky and Iwuafor, 1995). Lack of these nutrients has caused serious yield reductions due to unhealthy growth, leaf chlorosis, poor root development, plant lodging and premature senescence. In response to this, chemical fertilizers are continuously applied in order to improve soil fertility and enhance good plant nutrition and yield. However, the constant application of these fertilizers increases soil acidity and further exposes the soil to degradation due to the removal of Ca and Mg from the soil as the pH decreases. Also, the predominant sandy texture of the savanna soil accelerates soil erosion and run – off, thereby reducing use efficiency when fertilizers are applied.

To avert this, it has been recommended that Integrated Soil Fertility Management (ISFM) should be regularly practiced, where both inorganic and organic fertilizers are applied. Low fertility of the savanna soil is further compounded by acute low organic matter content (Tarfa *et al*., 2001). Results of studies have shown that this kind of combination was effective and has strong potentials for higher crop yield and less harm to the environment (Adeleye and Ayeni, 2010, Idris *et al*., 2010 and Mba, 2006) .Organic fertilization is gradually gaining prominence in crop production among the farming population of Nigeria even though, the problem of unbalanced nutrition is inherent among the different organic materials.

Changes in climatic condition also impacts negatively on sustainable crop production in the savanna zone of Nigeria. The major climatic factors of concern are: the amount of rainfall and its distribution patterns, temperature, humidity and occasional drought (Ofor, *et al*., 2009; Okoli, 2000). In the guinea savanna zone of Nigeria, rainfall distribution has been erratic, causing either flooding in some locations while in other areas, there is less rain but intense heat and drought. Maize is susceptible to drought (Kamara, 2013).Therefore, locations where annual rainfall is less than 700 mm could lead to low yield and crop failure due to high air temperature and drought. Prolonged cases of drought reduce soil moisture and use efficiency of applied fertilizers. Studies have shown that maize requirement for water is quite high (Ofor *et al*., 2009).The shortfall in the amount of rain within the growing season of a crop can be augmented with irrigation in order to sustain production and the use of resistant and early maturing crop varieties in addition to the adoption of good agronomic practices.

2.4.2 Influence of climate on maize response to fertilizer application in the savanna zone of Nigeria

In the generally humid and sub-humid areas of the Nigerian savannas, maize has become the dominant cereal crop extensively grown in these areas. It is gradually replacing sorghum in areas traditionally known to be sorghum dominated. Its adaptation to the guinea savanna in particular (southern and northern guinea) is influenced by the prevailing climatic conditions such as longer periods of rainfall distribution than in the Sudan and Sahel regions (Lombin, 1987). The annual mean rainfall distribution coupled with longer duration of about five to six months and six to eight months of rain in the northern and southern guinea savanna respectively (Kowal and Knabe, 1972) and warmer conditions are among the dominant ecological factors contributing to the expansion of maize production in the guinea savanna agro-ecological zone where the crop can be grown twice in the season especially the early maturing crop cultivars. However, the zone is often prone to water logging and seasonal flooding (Ologe, 1978) due to high clay content of the soil and occasional rise in water level as rainfall intensifies. This occurrence reduces the efficacy of fertilizer application and poor agricultural productivity.

Expectedly, the intensity of maize production in the savanna has equally placed a very high demand for necessary agro inputs especially chemical fertilizers to sustain production capacity and maintain soil fertility. Maize is a high nutrients-requiring crop (Enwezor *et al*., 1989). Its requirements for the major plant nutrients (N, P and K) cannot be met by the native soil resources alone, except through external inputs of inorganic fertilizer application and effective management practices sustained. This is attributed to the increasingly low fertility of the soil, especially the content of N and P considered as the most limiting nutrients in the Nigerian savanna soils (Chude *et al*., 2001; Uyovbisere and Lombin, 1991) for cereal production even under low intensive farming operation. The inherently low soil fertility is inexonerably tied to the acute low organic matter content of most tropical soils. Sanchez *et al*

(1997) had reported that the decline in soil fertility ranks high amongst the factors limiting sustainable food production in sub-Saharan Africa.

Nitrogen requirements of maize and other cereal crops are particularly higher than other nutrients followed by P in the guinea savanna (Lombin, 1987). In view of this limitations posed by acute soil N and P deficiencies, there is always a good response in terms of growth and yield whenever these elements are supplied as inorganic fertilizers. In most cases, fertilizer N recommendation for maize in the savanna doubles that of P and K (Enwezor *et al*., 1989), thereby depicting the serious low levels of N in the savanna soils. But for greater nutritional efficiency, application of both organic and inorganic fertilizers is advocated and current research findings (Ukem, 2011; Nyongesa *et al*., 2010; Ogeh 2010 and Akinrinde, 2006) have proven that this innovation is widely successful without any adverse effect on soil properties and the environment.

Leaching of nitrate and potassium, phosphate fixation, soil erosion, crop removal and denitrification are recognised as the major causes of nutrient losses in tropical soils (Adeoye *et al*., 2008; Sanchez *et al*., 1997). Therefore, there is the risk of low efficient use of these nutrients on crops when added to the soil. However, effective management and cultural practices especially time of fertilizer application and a constant organic matter input have the potentials of enhancing fertilizer use efficiency.

2.5 Work on sulphur requirements of crops

Sulphur is one of the 16 essential elements of plant nutrition (Jones, 1987). Its use as a fertilizer element in the Nigerian savanna has not been as prominent as that of N, P and K which are traditionally supplied as fertilizers to farmers. High incidence of S deficiency was not usually detected and accorded priority in the fertilizer recommendation of major crops grown in the area since crop requirement was generally low, often not exceeding 5 kg S/ha (Kayode, 1990; Kang *et al*., 1981) and this is incidentally met by the supply of SSP (12%S),

NH_4SO_4 (24%S) or K_2SO_4 (18%S), which have the ability to supply both N and S, K and S respectively. But years of intensive agricultural production, coupled with the use of high analysis fertilizers like urea and triple super phosphate (TSP) which are S free and high crop yields removing greater quantities of S from the soil, in addition to acute low organic matter, adverse cultural practices like slash and burn, and crop residue removal from farms at harvest contribute to serious incidence of S deficiency.

Early work on S requirements of crops could not be readily established, but information in literature points to the fact that S deficiency in the savanna zones of West Africa was not entirely new as initial observations were in the production of cash crops such as groundnut, cotton and other major food crops (Friesen, 1991). The principal research work in the 1950s and early 1960s by mainly commodity based organizations and other British research establishments in Nigeria was to identify S deficiencies and determine fertilizer requirements for these crops. This remarkable effort led to the recommendation of 5-10 kg S/ha as a content of either N, P or K fertilizers for these crops (Bolle-Jones, 1964).

Over the years, research interest has shifted to sulphur requirements of major food crops in the Nigerian savanna and other agricultural systems, perhaps due to the positive nutritional role of S to crops in view of its complementary role with N on plant nutrition (Ceccotti, 1996), and also taking into consideration the consequences of its absence in the nutritional needs of crops. In response to this, research bodies such as the International Fertilizer Development Centre (IFDC) initiated a project in the late 1980s to (1) estimate the S requirements of the major cereal crops in the savanna of West Africa, (2) comparing the agronomic efficiency and residual effectiveness of sulphate and the more highly concentrated elemental sulphur and (3) determining the fate of applied S in the soil and crop. It was established that sulphur application enhanced crop performance leading to improved crop yields especially in combination with other major nutrients and its availability is a function of soil, organic matter input, environment and fertilizer source (Friesen, 1991; Fox *et al*, 1977; Bromfield, 1974).

2.5.1 Response of crops to sulphur fertilization

The work of Kayode (1990) and Friesen (1991) recorded significant yield of crops when S was added to the fertilizer materials. In an experiment to determine the response of selected cereal crops, millet, sorghum and maize to S fertilization in the humid tropical conditions of the West African savanna, Friesen (1991) obtained a highly significant increase in maize grain yield followed by sorghum while millet had a non-significant response to S which was in part attributed to varying rainfall distribution. Maize grain yield response was reported as approximately 10% - 65% over the S control, corresponding to actual yield increases of approximately 200 to 2000 kg/ha. In a series of S trials in the moist savannas of Nigeria, Kang and Osiname (1976) obtained significant maize grain yield increases due to rates of S application from 7.5 kg to 30 kg/ha. Kayode (1990) also obtained a significant increase in seed yield of cowpea in the forest zone and southern guinea savanna of Nigeria due to S application.

It was observed by Kang *et al*. (1981) that total and extractable sulphur levels were in the following increasing order: Guinea savanna (Southern and Northern Guinea Savanna) < Derived savanna < Rainforest zone. With this, it implies that sulphur deficiency was found to be most pronounced in soils from Guinea Savanna followed by those from the derived savanna and least deficient in soils from the rainforest zone. It is obvious therefore that maize performance in the Guinea Savanna could be limited by S in view of its low sulphur reserve if appropriate agronomic measures are not enforced in meeting S needs. This should include efficient fertilizer formulation that takes into account S requirements and specific rates to be applied based on crop requirements and environment.

2.5.2 Sources of Sulphur fertilizers and their relative effectiveness.

Sulphur can be applied to the soil using a variety of different products. The most significant fertilizer – S sources are ammonium sulphates [$(NH_4)_2SO_4$], single super phosphate (SSP) and Potassium sulphate (K_2SO_4] (Anon, 1987). Of these, world consumption of S tilts heavily towards ammonium sulphates where it is estimated that approximately 17.0 million tons of ammonium sulphates equivalent to 4.0 million tons of S were used as a fertilizer in 1993 (The Sulphur institute, 1994). Most of this is consumed in temperate agro-ecologies where soil organic matter is a lot higher than in tropical conditions and more so where montmorillonite clays prevail with good soil buffering capacities thus informing the preference for $(NH_4)_2SO_4$. But under tropical soil systems of acute shortages of organic matter, high application of ammonium sulphates has undesirable acidifying effects on the weakly buffered soils (Syers and Craswell, 1995; Sanchez, 1994; Jones and Wild, 1975).

Other sulphur fertilizer sources in use and are equally important include powdered gypsum [$CaSO_4.2H_2O$], elemental sulphur (either as granular or powdered) and sulphur coated triple super phosphate (Friesen, 1991). Studies have shown that elemental sulphur is a highly concentrated material which when incorporated into high analysis fertilizers, provides a means of supplying S to crops without excessively diluting the concentration of other nutrients in the fertilizer. This in effect enables greater nutrient availability from the applied fertilizers and a proportional plant uptake. However, sulphates sources such as ammonium sulphate, gypsum and other sulphate bearing compounds appear to have better and greater efficiency in crop response than the elemental sulphur application in view of the fact that they provide fertilizer sulphur in a readily available forms to crops but elemental S must first undergo oxidation to sulphates before it is available for crop uptake and the oxidation rate itself is a function of particle size, soil moisture content, soil temperature and the presence of S-oxidising micro organisms such as the Thiobacillus thiooxidans (Friesen, 1991). The time lag for this oxidation to be accomplished for eventual plant uptake may result in a decrease availability of this essential nutrient thereby resulting in low efficiency since the other soil factors must be optimum. Also, the time of oxidation may coincide with the active growth phase of the crop requiring the nutrient and deficiency may be ensued resulting in low crop performances. In view of these, use of elemental sulphur forms in fertilizers may not be as nutritionally beneficial as the sulphate sources.

Fox *et al* (1964) and Friesen (1991) have separately observed that the rate of oxidation of sulphur in soils depends inversely on particle size, it therefore implies that in a coarse textured savanna soil of Nigeria, sulphur availability is very likely to be low as a result of low retention characteristics of the soil which makes leaching losses of nutrients inevitable. However, studies have shown that elemental sulphur has a superior residual effect than fertilizer sulphate sources suggesting that its application rate can be reduced by up to half in the following cropping season during crop trials. In the savanna of Nigeria, the bulk of S consumed by plants is incidentally supplied through SSP (Enwezor *et al*., 1989).

2.5.3 Importance of Sulphur in plant nutrition and consequences of its deficiency

Although S has been classified as a secondary element of plant nutrition (Epstein, 1972), its role in enhancing crop growth and yield was as important as that of N, P and K. Enormous research effort has been focussed on nitrogen and phosphorus considered as most limiting nutrients of plant nutrition in the Nigerian savanna (Tarfa and Iwuafor, 2002; Chude *et al*., 2001; Enwezor *et al*., 1989; Lombin, 1987), but much less is known of S. It is therefore not surprising the paucity of information on crop sulphur responses especially in the Nigerian savanna.

Sulphur has a variety of vital roles within the plants biochemistry. It is a major constituent of amino acids which include cysteine and methionine which are the building blocks of proteins. It is also essential in the formation of enzymes, vitamins such as biotin and thiamine and very many other important compounds in the plant like chlorophyll (Epstein, 1972; Ceccotti, 1996). Studies have shown that plants which are S-deficient characteristically are small and spindly. The younger leaves are often light green-yellowish. In the case of legumes, nodulation of the roots is reduced, the oil content of seeds is diminished and delayed fruits maturity when S is omitted from the fertilizer schedule (Buckman and Brady, 1969). Sulphur availability contributes to the overall health of a plant. Previous workers reported that the content of S-containing secondary compounds in plants is not only of importance for nutritive value or flavour, but also for resistance against pests and diseases and this is found to be of great importance for natural resistance of plants in both agricultural and non-agricultural systems where the use of pesticides is prohibited. Fertilization of plants with S is therefore a valuable method of enhancing the natural resistance of plants against diseases and insect damage (Schnug, 1990 and 1991).

Sulphur is also known to have a positive impact on forage production in the temperate climates where the farmers reported significant gains from S additions. This in turn is important in ruminant nutrition and performance. Studies have shown that increased dietary S levels with ruminants have resulted in increased feed uptake, dry matter digestibility and improved N balance which ultimately results in increased meat, milk and wool production (Morris, 1987). Schnug (1992) reported that S deficiencies are the most widespread of all nutrient deficiencies in oil seeds, wheat and other cereal crops in most agricultural zones of Europe. Nitrogen and sulphur are the main constituents of proteins, therefore, a shortage in the S supply of crops also affects the utilization of N within plants for the synthesis of proteins. Thus, S deficiency may cause an enrichment of non-protein N compounds such as nitrite in the plant tissues (Murphy, 1991).

In view of its positive role in the biosynthesis of protein similar to N in plants, the inclusion of S to crops reduces the (N:S) ratio which inhibits the accumulation of non-protein nitrogenous compounds within the plant tissues thereby enhancing the availability of N for uptake.

It is therefore important to maintain an optimal S nutritional status in order to prevent nitrate enrichments within the plant tissues. Also, the vital role of S for agro-ecosystems and especially the importance of S fertilization in optimising crop exploitation of other nutrients particularly N has been recognised (Ceccotti, 1996). Acute S deficiency in agricultural systems poses a serious threat to crop production with strong ecological impacts. An insufficient S supply not only reduces crop yields, but equally reduces quality of food and feedstuffs. In addition to this, efficiency of N fertilizers is reduced causing damaging N losses to the environment which further acidifies the soil solution and pollute ground water. From the foregoing, it is observed that S is as important as N and P in plant nutrition, therefore a reduction or its omission in the fertilizer regime causes serious consequences on growth, yield and quality of arable crops. It is for these reasons that sulphur nutrition of crops should be addressed.

2.5.4 Factors that limit sulphates availability in soils

Studies show that leaching is probably the major loss mechanism of fertilizer S in agricultural systems and this perhaps explains the poor residual value of sulphate fertilizer sources on the highly permeable soils of the West African savanna (Kayode, 1990; Friesen, 1991). The high mobility of sulphate in the soil system is as a result of the predominantly sandy texture of the soil with its attendant high permeability and very low anion retention capacity due to very low organic matter content and this makes the nutrient easily susceptible to leaching losses. In a field experiment with millet in the semi-arid zones of Niger Republic, Friesen (1991) reported that approximately 40% of the residual S had leached below 45cm soil depth where its availability to a subsequent crop may be limited. This underscores the considerable downward mobility of fertilizer S even in semi-arid environments where annual rainfall regime is about 640mm. Kayode (1990) had earlier reported that the sandy nature of the savanna soils of Nigeria coupled with low organic matter and the traditional annual bush burning contribute to the low S reserve hence limiting crop yields. It is therefore expected that input of organic matter either as animal dung or crop residues should improve soil nutrient retention, enhancing its availability for plant uptake, contributing significantly to the total colloidal fraction of the soil, leading to improved soil fertility.

Also, studies have shown that increasing concentrations of phosphorus contribute to sulphate leaching as phosphate is a very strong competitor for sulphate adsorption sites on soil colloid surfaces (Barrow, 1969), due to the rather weak buffering capacity of the soil. However, it is indicated that fertilizer phosphate applied at optimal rates has little effect on sulphate leaching under field conditions.

The increased consumption of S-free, high analysis fertilizers like urea, TSP and other ammoniated phosphates is also one of the causes of S deficiency. Increased cropping intensity, higher crop yields, reduced sulphur dioxide emissions and a shift in major fertilizer sources have led to serious incidences of S deficiencies worldwide (Ceccotti, 1996). With the reduction in SO_2 emissions, it was expected that sulphur additions to the soil would be reduced and invariably contributing to the already low soil S reserve. Bromfield (1974) reported that annual S additions from rainfall in the savanna zone is about 1.14kg/ha suggesting that maize production in the savanna could be limited by S deficiencies.

2.5.5 Factors affecting sulphate adsorption and desorption in soils

A number of factors have been recognized to adsorb and or desorb sulphate in soils. Adsorption decreases availability and plant available SO_4^{2-} for uptake while desorption increases availability and concentration in soil solution for plant use. Such factors as the amount and kind of clay, presence of hydro-oxides of Fe and Al., soil organic matter content, soil pH, soil depth, concentration of SO_4^{2-} in soil solution and the presence of competing anions are found to influence soil sulphur status (Ceccoti, 1996 and Friesen, 1991).

Studies show that sulphate adsorption increases with clay content of soils. Adsorption of sulphate is much higher in kaolinte clays than it is in micas and montmorillonite (Brady and Weil, 2005). Under a low soil pH condition and high Al^{3+} saturation, SO_4^{2-} adsorption by kaolinite clays is found to be approximately equal to that of micas and montimorillonite clays. Increasing soil organic matter content increases SO_4^{2-} adsorption potential thereby declining sulphate availability. Also soil depth influences sulphate adsorption (Barrow 1969). Adsorption capacity of SO_4^{2-} is often greater in subsoils than in the surface soils due to the higher clay content and high Fe and Al oxide content in the subsoil. The soil pH also influences sulphate content of soils. Sulphate adsorption potential decreases with increasing pH, usually negligible at pH > 6.0. It shows that an acidic pH range of 2-4.5 contributes to sulphate adsorption thereby limiting its availability.

2.5.6 Effects of sulphur application on soil pH

Compared to the acidifying effect of N bearing fertilizers on soils, sulphatic fertilizers equally have the capacity to acidify the soil during solubilization in the soil solution or from organic acids released during mineralization of organic sulphur compounds such as sulphated polysaccharides, phenolic sulphates, sulphated lipids and sulphur-containing amino acids (cystine and methionine). In the poorly buffered savanna soils (Jones and Wild, 1975), acidulation due to sulphur fertilizer application will further increase soil acidity with negative impacts on ground water and the environment. However, these harmful effects of sulphur fertilizer application on the environment can be minimised when soil organic matter is judiciously managed. Organic matter is a good contributor of Ca and Mg and as well as other non-acid forming cations to the soil (Ayeni *et al.*, 2008).

Studies show that the application of elemental S as a fertilizer material also contributes to soil acidity (Brady and Weil, 2005). This occurs when the elemental sulphur oxidises in the soil to release sulphate anion (SO_4^{2-}) for plant uptake. Sulphur oxidation is an acidifying process as illustrated in the equation below:

$$2S + 3O_2 + 2H_2O \rightarrow 2H_2SO_4 \rightarrow 4H^+ + SO_4^{2-}$$

The oxidation process of elemental S as illustrated above releases two molecules of sulphuric acid to the soil solution. Since sulphur is a highly mobile element in soils, therefore, effective sulphur fertilizer management is required by applying it as soon as the crops have fully established for effective crop use in order to reduce leaching losses and a consequent acidification of soil and ground water.

However, the acidifying effect of elemental sulphur in particular and other sulphatic fertilizers can be beneficial when applied to highly alkaline and sodic soils of arid and semi-arid regions to reduce the pH of these soils to plant tolerable levels and in disease control.

Sulphate anion concentration in most soils ranges from 3 – 5 ppm and is sufficient for most crops though some soils like the sandy and soils low in organic matter often contain less than 5 ppm SO_4^{2-} (Havlin *et al*., 2006). Since sandy to sandy loam texture and low organic matter content are the dominant features of savanna soils, it therefore makes a sustainable organic matter inputs a precondition for an efficient sulphur fertilizer management and use. Leaching losses of sulphate are greater with monovalent cations than with divalent cations in soil solution (Havlin *et al*., 2006). Also leaching of SO_4^{2-} is least in acid soils saturated with exchangeable Al^{3+} as Al^{3+} has the capacity to adsorb SO_4^{2-} especially in 1:1 clay minerals at low pH.

2.5.7 Effect of loss of sulphur on some soil properties

The removal of sulphur from the soil especially through leaching or crop uptake is usually accompanied by the removal of equivalent quantities of cations like Ca^{2+}, Mg^{2+}, and other non-acid forming cations (Brady and Weil, 2005). In soils with high sulphate adsorption capacity, sulphate leaching is low; therefore the loss of companion cations (Ca and Mg) is also low. But leaching losses from low sulphate adsorption soils are high and usually take with them large quantities of non-acid cations. Therefore sulphur as a secondary macronutrient is seen as an indirect source of conservation of the basic cations in soil solution. This is of great importance especially in soils of forested areas high in soil acidity in view of the liming effects of these bases.

2.5.8 Comparison of the deficiency of sulphur with nitrogen in plants

To a large extent, the deficiency of S in plants often resembles that of N judging from the complementary roles the two elements play in plant nutrition especially as both nutrients are essential constituents of amino acids, proteins, enzymes and vitamins involved in the synthesis of chlorophyll.

Therefore, the visual deficiency symptoms of S are often erroneously likened to that of N deficiency. The uniform chlorotic signs sulphur deficiency manifests in plants differs when compared to that of nitrogen where chlorosis is localised mainly on the foliage. Plants that lack sulphur are usually stunted, thin-stemmed and petioles. Such plants also experience slow growth and delayed maturity, poor fruit and seed quality.

Comparatively, the visual symptoms of sulphur deficiency in plants are noticed mainly on the younger leaves as sulphur is immobile in plants, therefore, the supply of S to the younger leaves from the older leaves gets depleted. In contrast, the visual deficiency symptoms of nitrogen in plants manifest more on the older leaves than the younger leaves as N is highly mobile in plants, theretofore, gets translocated to the younger leaves. In view of the chlorotic signs shown by S and N deficiencies, the supply of S therefore has the potential of boosting plant utilization of both N and S (Brady and Weil, 2005).

2.6 Effect of Organic Matter on Physical, Chemical and Biological Properties of Soils

Organic matter apart from its direct effect on soil nutrient availability and supply also plays important roles on the physical, chemical and biological properties of the soil.

2.6.1 Physical Properties

Organic matter binds soil into aggregates, giving rise to a stable soil structure which are important properties with regards to root growth and proliferation, gaseous exchange, water movement and retention. It has been recognized that a balance between the fine water-retentive pores and coarse transmission pores is required for effective water holding capacity, water and air permeability and root penetration when adequate soil organic matter is maintained (Syers and Craswell, 1995). Papendick (1994) reported that a continuous decrease in soil organic matter levels induced by increased cultivation or a reduction in its input leads to a gradual deterioration of soil structures resulting in difficulties with seedbed preparation, seedling emergence and root growth due to crusting and compaction. Soil organic carbon storage is improved under stable soil aggregates (Jastrow and Miller, 1998).

Crop residues left on the surface of the soil and the subsequent humification of these materials are found to have numerous beneficial effects on the soil physical conditions which reduce soil loss by erosion and equally improve the soil's nutrient status (Hulugalle *et al*., 1987). Other benefits include reduction in soil temperature, splash, slaking, crusting and compaction (Cassel and Lal, 1992). This results in increased soil strength and improved stable pore structure thereby enhancing faunal activities, improvement in water infiltration and reducing runoff and soil loss. Studies have recorded that a major effect of soil structural decline is that of reduced root proliferation and nutrient uptake (Coughlan, 1994). It is therefore imperative considering the low organic matter content of the savanna soils to continuously apply organic residues as this enhances the soil-plant nutrient status and formation of stable aggregates.

2.6.2 Chemical Properties

It is recognised that organic matter probably exerts its greatest impact on chemical properties through direct and indirect effects on nutrient supply (Syers and Craswell, 1995). The chemical composition of soil organic matter with respect to the contents of carbon, nitrogen, phosphorus, sulphur and C: N ratio has been extensively studied (Jenkinson, 1988; Olayinka and Ailenubhi, 2001). The C: N ratio was reported to be relatively constant for most soils ranging from 10-14 while that for C: S is 7-8. However, there appears to be a less relationship between soil organic C and soil organic P than it is with organic N or organic S (Syers and Craswell, 1995). Organic matter therefore yields nutrients directly to the soil on decomposition when optimum conditions in the soil prevail such as moisture content, aeration, microbial activity, pH, temperature and texture.

The humified organic matter plays a very important role in soil exchange processes, chelation and buffering capacity particularly with regards to acid soils of the tropics in view of its high iron and aluminium oxides contents. Input of organic matter is effective in enhancing cation exchange capacity (CEC). This has been found to be very important particularly in sandy soils (Willet, 1994) where organic matter is the dominant contributor to soil CEC rather than being a source of nutrient. Values of CEC for humus ranges from 150 – 300 cmol/kg, while kaolinites, montmorillonites, illites and vermiculites have values of 3 – 15, 80 – 150, 10 – 40 and 100 – 150 cmol/kg^{-1} respectively (Allison, 1973).

The ability of soil organic matter to form complexes with cations resulting in metallic chelates has been documented (Jones, 1987 and Tarfa, 1994). The resulting chelates are water soluble which dissolves in the soil solution thereby releasing cations to the soil medium and contributing to soil fertility especially in micronutrients availability. Lindsay (1974) reported that organic residue deposited on the soil increases the chelation ability of soils. Also added organic matter to soils is found to be effective in reducing exchangeable aluminium by forming Al-complexes thus reducing Al toxicity in acid soils (Bel and Edwards, 1987).

Another important factor of the efficiency of soil organic matter in soil fertility management especially under acidic soil condition such as that of the tropics is that of increasing the efficiency of soil and fertilizer P use by reducing phosphate anion fixation by transforming the inorganic P into organic P compounds thereby protecting it from chemical fixation. This is found to be useful in P deficient acid soils (Tiessen *et al*, 1992). The organic P will then be released to plants on mineralization.

2.6.3 Biological Properties

Soil organic matter provides the substrates for the growth and development of both soil organisms and microbial population. The activities of these organisms lead to the decomposition of organic residues and the synthesis of humufied materials which are relevant to the improvement of the soil's physical and chemical properties. Also, polysaccharides produced by plant roots and micro organisms in the soil stabilise micro aggregates. The formation of humus occurs after the organic matter is decomposed in association with microbial activity and these processes contribute to release nutrients such as nitrogen, phosphorus, potassium and sulphur, as well as many secondary and micronutrients (Phetchawee and Chaitep, 1995). Soil organic matter increases the population of many beneficial soil micro organisms (Hsieh and Hsieh, 1990). However, these benefits are in turn influenced by physical, chemical and environmental conditions such as texture, soil moisture, air supply, temperature and soil reaction (Jones, 1973) which have to be optimised.

The humus content obtained after decomposition is found to be very effective in water retention and contributing significantly to the fine colloidal fraction of the soil which ultimately improves anion retention capacity and soil fertility. The high acidifying condition of tropical soils has been blamed on low organic matter content (Jones and Wild, 1975), which in turn hinders the activities of nitrifying micro organisms of soils and contributing seriously to nitrogen deficiency. This necessitates the continuous application of high rates of inorganic N notwithstanding its harmful effects on faunal and micro organism activities and other soil physical and chemical properties already discussed. A reduction in population of nitrifying bacteria in the savanna soils results in a slow rate of nitrification (Odu, 1967).

One of the important organisms that derive nourishment from the application of organic matter to soils is the earthworm. Through its burrowing activities and feeding on the decomposed organic matter, earthworms redistribute organic materials in the soil and this increases the microbial population leading to increased intensity in the humification processes of the soil and positively affecting water and air movement through the soil and nutrient supply to plant roots. Although input of organic matter stimulates microbial biomass, it is equally of essence to infer that its effect on soil physical, biological and chemical properties are closely related and to a large extent complementary.

2.7 Sources of organic matter and nutrient contents

Organic materials commonly available in the savanna zone of Nigeria can be broadly grouped into crop and animal residues. Residues of plants include the harvested components of plants as cereal straws, stover, grass, legume haulms, harvested components include peels of banana, oranges, plantain, cassava, rice husk, cocoa pods, kola nuts shells, mulch materials such as dry grass/weeds and agro-allied industrial wastes such as brewery waste, waste from beverage industries and disposed food materials from fast food industries and food vendors. Animal sources include dung from cows, horses, donkeys and camels, sheep and goat manure, pig slurry and poultry droppings (Tarfa and Iwuafor 2002; Odunze and Ogunwole, 2002).

Much of these materials abound in the Nigerian savanna and can be directly applied to the field and ploughed in to increase the soil organic matter status, contribute to the soil-carbon credit and also contribute to the soil organic colloid which adsorb basic cations against leaching, act as buffers against pH changes, conserve moisture for plants and creating substrates for soil organisms, but are much less utilised by farmers compared to the use of inorganic fertilizer application due to varied reasons ranging from collection, storage/handling, cost of transportation, slow rate of decomposition and nutrient release to crops and other environmental concerns where these materials are often considered as pollutants and as such burnt away as fuels especially during land clearing operations or used as thatch materials, mat making and for other domestic purposes (Odunze and Ogunwole, 2002; Tarfa, 1994; Balasubramanian and Nnadi, 1980).

Apart from these constraints, reports of efficient crop responses and significant yields from the application of organic residues either as sole application or in combination with inorganic nutrient sources in many tropical agro-ecological zones have been documented (Olayinka *et al*., 1998). A major problem with the use of organic residues as plant nutrients has been that of their slow rate of decomposition (Tarfa *et al*., 2001; Singh *et al*., 1995; Blair *et al*., 1995). Jenkinson (1988) reported that plant and animal tissues vary in their state of decomposition. Many factors have been identified as significantly affecting the decomposition of organic residues in soils. Factors such as sources of plant materials, soil moisture content, aeration, temperature, pH, inorganic fertilizer application and accessibility and their effects have been enumerated (Olayinka and Ailenubhi, 2001; Blair *et al*., 1995; Blair, 1994; Jenkinson and Ladd, 1982).

2.7.1 Composition of the plant material

The diversity in sources of plant derived organic inputs as well as the complexity of these substrates, result in extreme heterogeneity in the microbial reactions involved in their decomposition (Alexander, 1977). Ross (1989) put forward three determinants that affect the quality of organic residues. These include the amount of fibre or wood, the content of C compounds that provide the energy source for the decomposer organisms and nutrients contents such as N and P. Other findings have shown that fleshy organic materials decompose quickly and rapidly, losing water soluble components followed by carbohydrates such as starch, thus accounting for the reduction in dry weight that accompanies their decay (Tate, 1987).

However, the decomposition of woody materials is a lot slower which is informed by its relatively higher carbon to nitrogen (C: N) ratio on account of the high content of lignified materials. Soil microbes working on these substances usually lead to the evolution of carbon dioxide and nutrients release, therefore, substrates having a lower C:N tend to mineralize faster and enhance nutrient availability such as N relative to those with higher C:N ratios.

2.7.2 Effect of moisture

Water is an essential component of soil ecosystems. The overall level of microbial activity and the rate and pathways of decomposition of organic materials are governed by water (Blair *et al.*, 1995; Jones, 1987). Microbial activity is dictated by soil moisture content both directly, by limiting microbial movement and the transport of nutrients in soil solution under drought conditions (Dickson, 1974), or indirectly by the controlling effects of moisture content on soil temperature (Alexander, 1977). Ross (1989) showed that microbial decomposition processes operate over a wide range of soil moisture conditions from wilting point to saturation. Moisture stress causes death of a proportion of the community of soil organisms (Van Gestel *et al.*, 1993) with a resultant decline in microbial population and nutrient dynamics. It is therefore essential for optimum soil moisture conditions to prevail towards effective organic residues decomposition and nutrient mobility.

2.7.3 Oxygen

Studies have shown that the decomposition of organic residues in soils is greatly facilitated by the presence of oxygen in view of the fact that most soil organisms are aerobics thus readily utilising molecular oxygen for respiration and metabolic activities (Singh *et al*., 1995; Epstein, 1972). In the absence of oxygen, anaerobic fermentation results usually by facultative organisms which can thrive either in the presence or absence of oxygen. The consequence of dominance of fermentation processes is the serious decline in decomposition rates (Blair *et al*., 1995). Limited soil aeration often alters the metabolism of organisms which to a large extent renders their population inactive and a consequent reduction in the decomposition of substrates thereby slowing down soil nutrient credit. Also, Jenkinson (1981) reported that the mineralization of added substrates to CO_2 is very much slower under anaerobic than aerobic conditions.

Since savanna soils are predominantly coarse textured (Jones and Wild, 1975) infiltration of materials is therefore unhindered, and easy movement of oxygen into the soil is expected, thereby aiding rapid decomposition of added organic matter and enhancing oxidation processes which in turn yield nutrients to the soil.

2.7.4 Temperature

Tropical environment generally have higher temperature values compared to that obtained in temperate conditions and as such temperatures under a tropical condition are usually higher than in a temperate zone. It is therefore expected that the rate of decomposition of organic residues is a lot higher and faster in a tropical environment than in a temperate zone. In comparing the rate of decomposition of plant materials in a tropical rainforest zone of Nigeria with a mean annual temperature of 26^0C with the rate under cool temperature conditions of southern England, having a mean annual temperature of 8.9^0C, Jenkinson and Ayanaba (1977) found that the decomposition of plant materials in a tropical

Nigerian environment was four times greater than under the temperate conditions. In view of this, the availability of nutrients from the decomposed material will be enhanced with a corresponding plant uptake, however, very high soil temperatures limit microbial population and a consequent decline in their activity and nutrient concentration.

2.7.5 Effects of pH

Savanna soils of Nigeria are noted for their inherent low fertility because of the low organic matter content, low colloidal fraction and weakly buffered (Ogban and Ekerette, 2001; Lombin, 1987; Jones and Wild, 1975). On account of this, changes in soil reaction are expected; pH range between 5.0 – 6.8 has been reported for soils of the Nigerian savanna (Singh *et al.*, 1983). Studies have shown that in acidic soils, decomposition rates are slower than in alkaline soils since microbial activity is restricted under acidic conditions much more than under alkaline conditions (Jenkinson, 1977). Dickinson (1974) also reported that acid and alkaline soils differ in their microbial population and that acidity slows down decomposition by hindering the activities of soil organisms more than in alkaline soils.

A major factor contributing to the acidity of tropical soils is the continuous application of nitrogen fertilizers which which leads to a decrease soil pH, leading to low content of exchangeable bases and increasing the concentration of soluble Al.

2.7.6 Effects of inorganic fertilizers

Previous workers have reported that micro organisms which decompose organic materials added to the soil usually obtain their required inorganic nutrients either from those already present in the soil in available forms or from those in the added plant material itself. The inorganic nutrient element abundantly required by these organisms is N, thereby being the element that often becomes the first and most limiting nutrient to microbial activity in soil (Blair *et al.*, 1995; Epstein, 1972). The previous work of Allison (1965) on the effect of inorganic fertilizer application on soil organic matter decomposition showed that the addition of ammonium nitrate significantly increased the oxidation rate of leaf-pine sawdust than the control. Jenkinson (1981) reported that sometimes large additions of organic matter decompose more slowly than small additions, even when factors such as aeration and moisture content are not limiting, the reason being attributed to nitrogen deficiency. The soil was reported to contain sufficient nitrogen for decomposition of small additions of organic matter but not for large quantities.

Under tropical soil conditions of acute N deficiency (Jones, 1987; Balasubramanian and Nnadi, 1980), the benefit of organic matter application on soil fertility might be elusive if adequate inorganic N application is not sustained since these added inorganic nutrients enhance faunal activity and a subsequent decomposition of organic matter. Therefore, in a situation where large amounts of organic matter are applied but insufficient soil N, there is the risk of microbial N immobilization both from residue and available inorganic forms which further compounds its deficiency.

2.7.7 Nature of the plant material

Finely divided organic matter usually decomposes faster than coarse organic matter (Hsieh, 1996; Olayinka, 1990). In an incubation study to determine the rate of decomposition of different sources of organic materials and CO_2 evolution in soils, Cheshire *et al* (1974) reported that finely ground (<53m) and coarsely ground (<1000m) rye straw had lost 61% of its C and 52% of its C respectively in 448 days. Coarse-textured organic residues tend to be resistant to microbial action much more than the finely-textured organic residues and this is attributed to the accessibility of these materials to microbial activity. Therefore, grinding the residues creates more surface area and equally exposes the substrates to a quicker microbial attack. Since microbial build-up is more rapid on finely ground organic materials, it therefore implies that the N demand for the decomposition will be correspondingly higher. In view of this, the decomposition of organic residues having wide C:N ratios in soil resulted in these fine particles immobilising six times as much inorganic N in the first month as did the coarse particles (Sims and Frederick, 1970).

Environmental factors such as temperature and humidity are identified as factors controlling the rate of decay of organic residues placed on the soil surface rather than when incorporated in the soil. It could be inferred therefore that external environmental conditions of temperature and humidity influence the rate of decomposition of organic residues placed on the surface of the soil but these factors however do not exert so much influence when the residues are placed under the soil surface. Jenkinson (1981) however, maintained that under the condition of uniform moisture and temperature, placement effects are less important. Also, organic residues when left on the surface of the soil as mulch materials often become desiccated and decompose more slowly than when incorporated (Shields and Paul, 1973). It is documented that organic residues generally decompose more rapidly at shallow depths and leave less humus than at lower depths (Schnitzer and Khan, 1972).

2.8 Carbon and Nitrogen Mineralization

It refers to the transformation of organic molecules to inorganic forms typically mediated by biological activity (Sarmiento and Gruber, 2006).During this process, some important elements such as carbon, nitrogen, phosphorus and sulphur are biologically converted by oxidation to carbon dioxide, nitrate, phosphate and sulphate respectively along with some organic and inorganic acids as fatty acid, amino acid, nitric acid and phosphoric acid. The evolution of carbon dioxide is an index of microbial decomposition of organic matter (Haney *et al.,* 2004, Olayinka and Ailenubhi, 2001).The mineralization kinetics itself is a function of the physical, chemical and biological properties of the organic matter, soil properties and the prevailing environmental conditions (White, 2005, Riffaldi *et al.*, 1996).

It has been predicted that the rate of decomposition of organic matter requires that the availability of C in the substrate be measured and the role of controlling factors such as soil temperature and moisture content be quantified under field conditions (Haney *et al.*, 2004). McGill *et al.* (1981) also proposed that the soluble organic C in soils is an immediate source of C for soil microorganisms. Results obtained from several incubation studies have shown that mineralizable C content was directly related to the size of the soluble C and N pools in the soil (Rochette and Gregorich, 1998; Riffaldi *et al.,* 1996; McGill *et al.,* 1981).

Mineralization rates can vary from the easily decomposable simple sugars when added to the soil to the more complex organic polymers such as cellulose, lignin and humic acids which usually undergo a slow decomposition (Riffaldi *et al.*, 1996).The proportion of CO_2 evolved during carbon mineralization gives an indication of the potentials of the organic matter source in contributing organic carbon and plant nutrients when added to the soil and ultimately serves as a criterion for evaluating soil fertility. Therefore, under field conditions, application of organic matter as a soil fertility management strategy may not be of immediate benefit to the soil and crop on account of varied chemical composition of the material. Generally, most of these resources, especially those of plant origin tend to have a high content of wax, resin and lignin constituents, thereby unable to mineralize in time to synchronize with the active growth phase of the crop. However, studies conducted by Franzluebbers and Arshad (1997) showed that when an organic material was ground and rewetted, it resulted in greater flush of CO_2 during incubation than when in a coarse physical state.

Marumoto *et al.* (1982) and Sparling *et al.* (1995) have shown that it may be possible to estimate soil C and N mineralization potential by monitoring the fluxes of CO_2 following the rewetting of dried soil. Other authors have stated that the amount and quality of substrates available for mineralization may be quantified using CO_2 evolution (Sparling and Ross, 1988;

Sorensen, 1974). Anderson and Domsch (1978) suggested that the size of the soil microbial biomass is reflected by the short- term flush of CO_2 after amending labile substrates. In view of these, rewetting a dried soil therefore enhances microbial decomposition which shows the essential role moisture content along with other physical attributes like temperature play in determining organic matter mineralization rates. Haney *et al*. (2004) observed a positive correlation between a rewetted dried soil and the amount of CO_2 evolved after 24 days of incubation.

Nitrogen mineralization involves the biochemical conversion of organic materials to release mainly NH_4-N and NO_3-N to the soil for plant use (Havlin *et al*., 2006). Different organic compounds vary in their content of N. While a large proportion is held under organic forms, a small amount is available as inorganic N fraction (Singh *et al*., 1995).This large organic fraction has to undergo mineralization to facilitate plant access to inorganic nitrogen fractions through the process of nitrification (Haney *et al*., 2004). Nitrification rates in soils could be quantitatively determined in laboratory incubation and screen house studies with some comparable success, but under field conditions, such evaluation seems difficult due to varying environmental conditions and management practices (Haney *et al*., 2004). This imbalance therefore requires a closer attention especially with respect to meeting crop nutritional requirements from the application of organic manures.

The inorganic N fractions obtained are utilized by plants, they could be used by soil microbes especially ammonium ion (Rice and Tiedje, 1989) by immobilization. Still, it could be held tightly in soil clays especially in 1:1 clay minerals (Brady and Weil, 2005), while NO_3- N could be lost by leaching in porous sandy texture soils or converted into gaseous nitrogen forms by denitrification as well as ammonia volatilization (Munoz *et al.,* 2003).The balance between mineralization and immobilization is dictated by nitrogen dynamics and this ultimately influences the soil nitrogen status. The low organic matter content of the savanna soils (Jones and Wild, 1975) and the susceptibility of the soil to nitrate leaching; have raised serious concerns for a more effective plant available nitrogen budget which has the benefit of reducing losses and curbing environmental pollution commonly associated with nitrogenous fertilizers. Therefore, an efficient management of nitrogen either from organic or inorganic fertilizers would enhance a better retention and availability in soil for crop use. For organic N source, this should take into account the quality of the substrate, management and time of application.

2.9 Decomposition Studies

During decomposition, microbes transfer organic matter through compartments of different chemical quality, thereby altering the chemistry and physical accessibility of organic carbon. Conceptual models of decomposition are thus often based on networks of compartments accounting for the chemical heterogeneity of the original substrate and as well as the chemical and physical changes driven by microbial activity and environmental factors (Manzoni *et al*., 2012).

The fluxes of gases released during decomposition can be described mathematically in different ways, but when the goal is to quantify long – term decomposition, linear models are generally appropriate (Manzoni and Porporato, 2009).In a linear model, each pool is considered well- mixed and chemically homogeneous, and the rate of decomposition is assumed to be controlled by the available substrate. The proportion of organic matter decomposed per unit time is therefore constant and equal to the decay constant k(Sierra *et al*., 2012).It is noted that kinetic constants usually account for chemical and climatic conditions and therefore vary across types of organic matter and sites (Manzoni *et al*., 2012).

Soil organic matter decomposition has been found to be a very important process within the earth ecosystem, because it controls the rate of mineralization of carbon and other biogeochemical elements, determining their flux to the atmosphere and the hydrosphere in mineral forms (Sierra *et al*., 2012).The release of these biogeochemical elements is fundamental to other processes in the earth ecosystem, such as the global energy balance (Sierra *et al*., 2012).Manzoni *et al*. (2012) reported that soil organic matter decomposition modelling makes it possible to quantify the turnover of organic carbon (OC) in surface litter and in soil organic matter.

Soil organic matter decomposition is also a basic process for the transformation and availability of mineral elements necessary for plant growth, therefore, it has important consequences for agriculture and humanity since the storage and flux of C in soils have a strong link with ecosystem productivity (Riffaldi *et al*., 1996).According to Six and Jastrow (2002), the amount (stock) of organic matter in a given soil can increase or decrease depending on numerous factors including climate, vegetation type, nutrient availability, disturbance, land use, and management practices. Low SOM content has led to poor soil quality, land degradation and low productivity. Therefore, input of organic matter of good substrate quality along with benign climatic condition could regenerate soil properties and impact positively on crop production.

2.10 Decomposition Models

Given the importance of SOM decomposition in agricultural systems, many models have been developed, describing its dynamics (Manzoni and Porporato, 2009). However, information in literature shows that only a few attempts have been made to synthesize them (Paustian *et al*., 1997). Currently, it was reported that more than 250 different models of SOM decomposition have been proposed since the 1930s, but most of them share common mathematical operations/functions (Manzoni and Porporato, 2009).In view of this, Sierra *et al*. (2012) suggested that it is possible to develop models that can generalize most of the models already proposed.

The basic theory of decomposition kinetics has been well described by several authors (Swift *et al.,* 1979; Bunnell and Tait, 1974).There is a strong correlation between soil respiration and temperature which has been quantified for many soils under different conditions (Kirschbaum, 1995).In many decomposition studies, the temperature coefficient Q_{10} relationship is used to describe the dependence of decomposition on temperature (Katterer *et al*., 1998). Early models of SOM decomposition were put forward by Nikiforoff (1936) and later on by Jenny *et al*.(1949), using the concept of ordinary differential equations as outlined by Manzoni and Porporato (2009).But within the framework of ecosystem science, Olson (1963) presented the first comprehensive treatment of mathematical models of organic matter decomposition.

For most biological or enzymatic mediated processes of soil organic matter decomposition, the kinetic models often employed to describe analytical data either from soil organic C or N mineralization or in nutrient dynamics are mainly the first-order and second-order rate kinetics (Paustian *et al*., 1997; Katterer *et al*., 1998; Jenkinson *et al*., 1991).But other researchers (Seyfried and Rao, 1988) have found that a zero-order equation more adequately describes C mineralization. Other more complex kinetic models used in interpreting chemical kinetic phenomena such as the Elovich equation, Fractional Power equation and Parabolic Diffusion equation have also been tested but to a lesser extent in SOM mineralization in relation to the “Odered” rate models. These kinetic models used in decomposition studies as mentioned can be classified into three groups :(1) Mechanistic model (2) Empirical model and (3) Simulation model (Jones, 1984).

The mechanistic model relates more with the zero – order, first – order and second – order rate equations (Manzoni *et al*., 2012).These models are termed mechanistic because they reveal the mechanisms involved in the reaction and also give an indication of the rate controlling processes (Jenkinson *et al*., 1991). The model describes a particular process in terms of known physical or physiological relations (Smaling, 1993).They are analytical in nature and usually employ mathematical relationships to describe SOM decay processes and nutrient dynamics (Nyongesa *et al*., 2010).Thus, they are of immense importance in ecosystem productivity. The empirical model is more concerned with statistical computations which could be helpful in providing real time prediction capabilities. It estimates a relation between model output and it explanatory variables, without taking into account the underlying processes. It is limited to the range of data with which the model was designed, while the simulation model is a computer created model which enables a situation where a set of conditions could be modified in a way that will not significantly alter the initial conditions but still arrive at the expected outcome. It has the advantage of integrating both the mechanistic and empirical models to achieve its result.

2.10.1 Model description

$$\frac{dX_1}{dt} = L - kX \qquad (1)$$

Where,

X is the energy in organic matter; L is the addition of organic matter and k is decay constant.

Equation (1) treats soil organic matter as one single compartment with an overall decomposition rate representative of all substances within the soil matrix. It has been commonly noted that soil organic matter is heterogeneous, and the single exponential model of decomposition fails to account for this heterogeneity (Swift *et al*., 1979). Earlier, Henin *et al*. (1959) proposed a model to account for the different rates of decomposition of labile and stable material also considering the process of humification, i.e. the transfer of material from the labile to the stable pool. This model can be expressed as

$$\frac{dX_1}{dt} = L - k_1X_1$$

$$\frac{dX_2}{dt} = \alpha k_1 X_1 - k_2 X_2 \qquad (2)$$

Where,

X_1 represents the labile pool and X_2 the stable pool. The parameter α represents the humification or transfer rate. A different version of a two-pool model has been widely used for studies of litter decomposition, in which the system of equations takes the form (Means *et al.*, 1985)

$$\frac{dX_1}{dt} = \gamma k - k_1 X_1$$

$$\frac{dX_2}{dt} = (1 - \gamma)L - k_2 X_2 \qquad (3)$$

In this case, the two pools decompose independently from one another and the amount of litter inputs L is partitioned between the pools according to the parameter y. However, the conventional 'ordered' rate models (Seyfried and Rao, 1988; Smith *et al.*, 1980) are expressed as:

1. Zero – order model

   The linearnised form of this model is expressed as: $q = K_0 t$

   Where,

   q = the amount of material decomposed at time t

   K_0 = zero order rate constant

   The rate constant is completely dependent on the amount of decomposable material thus making this model less effective.

2. First – order model

   The linearnised form of this model is given as: $\ln q = \ln q_0 - K_1 t$

   Where,

   q_0 = the initial amount of the material added at time zero

   q = the amount of material added at time t

K_1= first order rate constant

3. Second – order model

The linear form of the model is given as: $1/q = 1/q_0 + k_2 t$

Where, q_0 and q are the parameters as defined already in the first – order rate model. K_2 is the second - order rate constant.

Regardless of the model used to describe the dynamics of soil organic matter, it is noted that the mineralization rate constant (k) could be influenced by biotic and abiotic factors or both depending on the prevailing conditions. Therefore, rate constant plays an important role in chemical kinetics because, it gives information on rate controlling processes such as temperature effect, moisture effect, nature of the substrates and time in which the organic matter undergoes decomposition.

2.11 Use of Models as Decision Support Tools (DST) in Crop Production

Agriculture remains the major occupation in sub-Saharan Africa, however this cherished occupation is to a large extent subsistent and often exposed to numerous constraints that limit food production. Such problems as low soil fertility and productivity have contributed significantly to lowering production levels in sub-Saharan Africa to the extent that intervention measures such as use of improved crop cultivars and good husbandry practices like timely application of the right type and amount of chemical fertilizers have become necessary. Other factors such as unfavourable weather conditions, pest and diseases, weed infestation, and certain adverse traditional practices, contribute to soil degradation and ultimately to low soil productivity with resultant negative impacts on food production.

Sanchez *et al* (1997) had reported that, soil fertility depletion in small holder farms is the fundamental bio-physical cause of declining per capita food production in sub-Saharan Africa. Breman (1995) also reported that unfavourable climate and low soil fertility create intense pressure on land even at relatively low population densities. Therefore, effective soil fertility management is recognised to play pivotal roles in efforts aimed at improving agricultural productivity. Measures designed to improve soil fertility management should integrate such factors as nutrient – supply capacity of the soil, available soil amendments, and judicious use of mineral fertilizers to achieve balanced nutrient management systems.

2.11.1 The Importance of Models

The numerous constraints faced by farmers in agricultural production therefore requires solutions or necessary interventions so as to minimise the risk of crop failure and achieve good, adequate and sustainable yields for the populations. One of such options is the Decision Support Tools (DSTs) (Bouma and Jones, 2001). DSTs assist in diagnosis and analysis of problems and opportunities related to soil fertility and identify options for improved soil fertility management. The DSTs are computer models designed to utilise factors such as weather, crop variety, prevalent weeds, pests and diseases, crop management (sowing date, fertilizer type and fertilizer application) and socio-economic factors as inputs (Struif-Bontkes and Wopereis, 2003). They are also useful in developing site-specific integrated soil fertility management recommendations that are flexible and respond to the ecosystem diversity and nutrients dynamics.

2.11.2 Types of Models

A number of models have been recognised (Struif-Bontkes *et al*., 2001; Walker, 2000). They include: Decision Support Systems for Agrotechnological Transfer (DSSAT), Quantitative Evaluation of the Fertility of Tropical Soils (QUEFT); Rice Development (RIDEV); Nutrient Management Support System (NuMaSS); Monitoring Nutrient Flows and Economic Performance in Tropical Farming Systems (NUTMON) and many others.

2.11.3 The Application of Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS)

A system which describes the quantitative evaluation of the fertility of tropical soils (QUEFTS) consists of four successive steps as outlined by Janssen *et al*. (1990). These include:

1. The initial soil chemical content
2. Potential supply of N, P and K both from soil and fertilizer application
3. Actual plant uptake of N, P and K
4. Grain yield

The QUEFTS model is designed to achieve balanced fertilizer recommendations for maize under tropical conditions. The model gives a quantitative estimation of fertility level of a soil, using as a yardstick “the expected yield of a crop without use of fertilizer”. It calculates the potential availability of major plant nutrients (N, P and K) and deals with the interactions between them. The model consists of both empirical and calculated relationships (Janssen *et al*., 1990). Empirical relationship of the model was determined on the basis of results obtained from soil chemical properties and crop nutrients uptake, whereas the calculated component deals with output generated from the model from potential nutrient supply and crop yield (Smaling, 1993). The model consists of four major analytical steps, where the outcome of each step is a prerequisite for the next (Janssen *et al*., 1990).

QUEFTS calculates the yield of maize on tropical soils as a function of the availability of soil and fertilizer N, P and K for which organic carbon, available P, exchangeable K and pH (H_2O) act as diagnostic criteria, provided that other growth limiting factors such as moisture deficit, water logging, restricted root penetration and poor crop husbandry practices have been addressed. For the use of QUEFT, a potential maize grain yield of 10000 kg/ha at 12% moisture content is set as a standard but below this level, maize production is limited by the supply of N, P and K (Janssen *et al.*, 1990).

The model considers relationships between yield at maximum dilution (YMD) and yield at maximum accumulation (YMA) of nutrients. For instance, when the amount of a particular nutrient supplied to the plant is low in relation to the other nutrients and growth factors, it is diluted in the plant and its content goes down to a minimum value, therefore, the ratio of yield and nutrient uptake has its maximum value. But, when the amount of nutrient supplied to plant is comparably high, it accumulates in the plant till its content reaches a maximum value, the ratio of yield and nutrient uptake has its minimum value. Under this setting, two kinds of empirical relationships were derived from the use of QUEFTS (Smaling and Janssen, 1993). The relationship between chemical soil properties and potential nutrient supply on one hand and that between nutrient uptake and yield on the other hand. At the early and later growth stages of the crop, the deficiency of any of the major nutrients N, P and K would negatively affect the potential of the others; therefore the QUEFTS system takes into consideration the interactions of these plant macro nutrients and their integrated effect on yield.

The expected output from the use of this model would be validated on data generated during soil analysis, effect of input of the recommended fertilizer rates, plant nutrients concentration and yield. The differences obtained from the calculated yield data from the model and that of empirical data give an indication of the relationship between one nutrient and another, the potential supply of this nutrient by the soil, uptake and their ultimate effect on yield. Crop yield obtained from the unfertilized plot and that obtained from plots that received fertilizers would form the basis for comparison of the fertility status of the soil. Such would help draw useful conclusions on effect of the fertilizer application on crop performance, soil quality and ultimately, influence decisions on site specific fertilizer recommendations for a particular crop, especially when environmental conditions and management practices are optimum.

2.11.4 Conditions for Application of QUEFT Simulation Model

For an effective application of QUEFT, knowledge of the basic soil chemical properties of the experimental site is important. This is because; the soil characteristics serve as diagnostic properties which give useful information on nutrients availability and the need for fertilizer application. Soil chemical properties often employed are, pH (in water), soil organic carbon, available phosphorus, available nitrogen and exchangeable potassium. The values of soil chemical properties should lie within the ranges: pH (H_2O) 4.5 – 7.0; soil organic carbon, less than 70 g/kg; available phosphorus, less than 30 mg/kg and exchangeable potassium, less than 30 mmol/kg respectively (Smaling and Janssen, 1987).

QUEFTS gives a quantitative estimation of the overall fertility level of a soil, using as a yardstick the expected yield of crops without the use of fertilizers. Apart from the use of QUEFTS in estimating crop yield from fertilizer application, the model can also be used to calculate optimal combination of fertilizers from the following considerations (Mulder, 2002).

1. Crop physiological point of view –deals with restoring nutrients imbalance in the soil.
2. Environmental point of view – concerned with minimizing nutrients losses
3. Economic point of view – concerned with fertilizer application which gives the highest net returns.

Since soil fertility serves as a major criterion for testing QUEFT, the maximum quantity of the major nutrients that can be taken up from the soil by the plant needs to be determined which is often referred to as the potential supply of N, P and K (Smaling, 1993). Apart from the interaction effect of N, P and K fertilizer application on crop yield, other inputs such as the plant dry matter, plant harvest index and meteorological data are required (Smaling, 1993).

2.11.5 Constraints to the Use of Simulation Models

There are certain constraints to a successful use of the decision support tools. These range from the failure to capture the complexity of small holder agriculture of the sub-Saharan Africa; some of the tools require data which might not be easily available or are of poor quality and lack of adequate knowledge on the use of a particular model (Mathews and Stephens, 2002). Also, the identification of the appropriate tool to use at a given instance, the problem of data collection, application of the tool, and acceptable conclusions often arrived at (Struif-Bontkes, *et al*., 2001; Walker, 2000).

Although the use of models in agricultural production is entirely new in Nigeria, however, one of the tools has been validated with data generated from maize trials in a Northern Guinea tropical Savanna of Nigeria (Chude *et al*., 2001). Others have been tested or validated elsewhere especially under sub-Saharan tropical conditions (Struif-Bontkes *et al*., 2001). They help proffer solutions to many farmer's experiences and difficulties often encountered in crop production and soil fertility problems. Therefore, the models to be used are to be calibrated and validated with experimental data generated from maize trials using inputs from the changing weather conditions, cultivar choice and other management options.

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Location and Description

The research involved a laboratory incubation study, greenhouse study and field trials were conducted at Samaru, situated in the Northern Guinea Savanna agro-ecological zone of Nigeria.

The laboratory incubation studies were conducted at the Soil Science Departmental Laboratory, Faculty of Agriculture, Ahmadu Bello University, Zaria. The greenhouse study was conducted at the Institute for Agricultural Research (IAR), Samaru, Zaria, while the field trials were established at the Experimental Farms of IAR, Samaru, Zaria, in the Northern Guinea Savanna of Nigeria.

Samaru is located at latitude $11^0$11'N and longitude $7^0$38' and 685m above sea level (Kowal and Knabe, 1972). Annual rainfall regime in the area presents a unimodal pattern, falling from May to October over six months period and usually reaching its peak between July and August with a mean of about 1000mm and average daily temperatures of about 27^0C (Kowal and Knabe, 1972).

3.1.1 Work Plan

The study consisted of three parts namely: (1) laboratory incubation studies (2) green house studies and (3) field studies.

3.1.2 Chemical Analysis of Materials

This involved nutrient composition analysis of the cowdung, soil analysis before and after cropping.

3.2 Laboratory Incubation Studies

Incubation study was set up to determine the dynamics of N in the soil as influenced by the application of organic and inorganic N fertilizers, and to also determine the carbon dioxide flux from mineralization of the organic manure.

3.2.1 Sample collection and preparation

Cowdung (CD) was obtained from the Animal Production Unit of the National Animal Production and Research Institute (NAPRI) Experimental Station, Shika, Zaria, Nigeria. It was mixed and allowed to homogenize for 4 weeks. The soil used for the laboratory incubation study was collected as composites at a depth of 0-20cm from the Institute for Agricultural Research (IAR) Experimental Farms at Samaru – Zaria. The soil was air – dried, crushed and sieved through a 2mm mesh screen. Representative sample was taken for physical and chemical analyses. A similar procedure was also carried out on the cowdung for chemical analysis.

3.2.2 Fertilizer treatments

The cowdung, gypsum (sulphur fertilizer material) and urea were applied to 100g portions of moist soil and mixed thoroughly. Cowdung was applied at the rate of 0, 5 and 10 ton/ha; N as urea fertilizer was applied at the rate of 0,60 and 120 kg N/ha, while sulphur as gypsum was applied at 3 rates (0,15 and 30 kg S/ha).

3.2.3 Experimental Design

The three application rates for N, S and CD gave a total of 27 treatments in a factorial combination. The treatments were arranged in a Completely Randomized Design (CRD) and repeated three times. The treatments structure is shown in Table 3.1.

Table 3.1: Treatments Structure

Trtmt No.	N	S	CD	N	S	CD
1	0	0	0	0	0	0
2	0	0	1	0	0	5
3	0	0	2	0	0	10
4	0	1	0	0	15	0
5	0	1	1	0	15	5
6	0	1	2	0	15	10
7	0	2	0	0	30	0
8	0	2	1	0	30	5
9	0	2	2	0	30	10
10	1	0	0	60	0	0
11	1	0	1	60	0	5
12	1	0	2	60	0	10
13	1	1	0	60	15	0
14	1	1	1	60	15	5
15	1	1	2	60	15	10
16	1	2	0	60	30	0
17	1	2	1	60	30	5
18	1	2	2	60	30	10
19	2	0	0	120	0	0
20	2	0	1	120	0	5
21	2	0	2	120	0	10
22	2	1	0	120	15	0
23	2	1	1	120	15	5
24	2	1	2	120	15	10
25	2	2	0	120	30	0
26	2	2	1	120	30	5
27	2	2	2	120	30	10

N: 0, 1, 2 = 0, 60, 120 kg/ha;

S: 0, 1, 2 = 0, 15, 30 kg/ha;

CD: 0, 1, 2 = 0, 5, 10 ton/ha

3.2.4 Experimental procedure for the incubation studies

Soil samples used for the laboratory incubation studies were collected from the same site used for the field experiment. The actual site was C15 plot, situated at the Institute for Agricultural Research (IAR) Experimental Farms. Prior to planting, soil samples were collected from the experimental field. The samples were mixed thoroughly and bulked. The soil samples were air- dried, ground, sieved through a 2mm sieve and stored in polyethene bags. Representative samples were collected for soil characterization.

From the prepared soil, 100g portions were collected into clean cylindrical plastic jars measuring 12cm depth. The amendments (N, S and CD) were mixed thoroughly with soil at the appropriate rates for the treatments (3.2.2). The mixtures were moistened to about 70% water holding capacity (Olayinka and Ailenubhi, 2001). Thereafter, 20 ml of 1N NaOH solution used for trapping evolved CO_2 was prepared and poured into clean plastic vials (Haney *et al*., 2004).The vials were carefully suspended in the jars through a thread and and the jars were corked tightly to prevent gaseous escape. The jars were arranged in triplicate and incubated at 25^0C in an incubation chamber for 6 weeks. Moisture loss from the microcosms was minimized by adding 2 ml of water to jars at weekly interval to maintain saturated humidity in the headspace (Calderon *et al*., 2004)

At weekly interval, the alkali containing trapped CO_2 was removed and poured into a conical flask. Two drops of phenolphthalein indicator were added and titrated against 0.5 N sulphuric acid solutions to a colourless end-point (Anderson, 1982). After this, 2 drops of bromophenol blue indicator were added and the titration continued to a pink end-point. The procedure was repeated for the 6 weeks of incubation. The amount of CO_2 evolved during the incubation was quantitatively determined using the equation as presented by Makinde and Ayeni (2013).

$$\%\,CO_2 = \frac{Titre\ value\ x\ Normality\ of\ H_2SO_4\ used\ x\ 100}{Weight\ of\ soil\ sample\ x\ 20}$$

Nitrogen mineralization was determined when 5 g portion of the incubated soil mixture was extracted with 2 M KCl by shaking for one hour$^-$ and the extracts analysed for NH_4^+ and NO_3^- by employing the Kjeldahl analytical method (Bremner and Mulvaney, 1982). The determination of CO_2 evolved was conducted at a weekly interval for the 6 weeks of incubation, while nitrogen mineralization (NH_4^+ and NO_3^-) was determined at the end of the incubation period of six weeks. The flasks were opened weekly to allow for aeration. Field capacity was maintained by adding 2ml of water weekly. The amounts of N (NH_4^+ and NO_3^-) mineralized during incubation were calculated from the following equations (Haney *et al.*, 2004).

$$NH_4 - N = TA_2 - TA_1$$

$$NO_3 - N = TN_2 - TN_1$$

Where, TA_1, TA_2, TN_1 and TN_2, represent total concentration of ammonium and nitrate before and after incubation respectively.

In this case, amount of NH_4^+ - N mineralized at the end of the incubation was obtained by the difference between the concentration obtained before and after incubation (Shen *et al.*, 1984). A similar procedure was carried out for NO_3^- - N.

3.2.5 Kinetic Models used during decomposition studies

Several kinetic models have been used to study decomposition rates and dynamics of C and N during soil organic matter mineralization (Olson, 1963; Paustian *et al.*., 1997, Manzoni and Porporato, 2009). These models can be categorized under empirical, mechanistic and simulation models (Riffaldi *et al.*, 1996; Jones, 1984).

The model most frequently used in studying soil organic matter decay characteristics includes the ‘ordered’ (zero – order, first – order, and second – order) rate equations (Six and Jastrow, 2002; Riffaldi *et al.*, 1996). In each case, the choice of a particular model to describe the decay process of an organic matter is influenced by goodness of fit as determined by the coefficient of determination (R^2) and the root mean squared error (RMSE). Therefore, any model that gives a high R^2 value and a corresponding low SE value best fits the choice of model to describe the rate of C or N mineralization and CO_2 flux under the experimental condition. The first – order model often employed in studying the dynamics of C in SOM decomposition is given as:

$$X = X_c \left[1 - \left(\frac{X_c - X_o}{X_c}\right) e^{-kt}\right]$$

(Six and Jastrow, 2002). The linear form of the model can be expressed as:

$$X = X_0 + (X_c - X_0)(1 - e^{-kt}) \qquad (4)$$

Where, t is the time taken for the change to occur, X_c is the C content at equilibrium, and X_0 is the initial C content before the change (t = 0).

For this study, the data generated during laboratory incubation to determine the rate of carbon mineralization and CO_2 flux were tested on each of the mechanistic models and the goodness of fit was computed on the basis of high R^2 and low RMSE values (Katterer *et al.*, 1998).

3.3 Greenhouse Studies

The pot experiment was designed to test effectiveness of various rates of N and S applied as urea and gypsum respectively in combination with rates of cowdung on maize performance. Duration of the experiment was 7 weeks.

3.3.1 Sample collection and preparation for the greenhouse study

Soil used for the greenhouse study was collected from Plot C15 at the Institute for Agricultural Research (IAR). The samples were mixed thoroughly and bulked and preserved in polythene bags. Before planting, the soil was ground, air - dried and sieved through a 2mm mesh screen. The experiment was conducted at the Soil Science Departmental Screen House of IAR, ABU, Zaria.

3.3.2 Greenhouse techniques

Seven kilograms of the prepared soil were weighed out into each of the 27 plastic pots measuring 10 litres and perforated at the bottom to allow for free drainage and adequate root aeration. Cowdung (CD) was applied at the rates of 0, 5 and 10 ton ha^{-1} to the 7 kg soil and mixed, wetted regularly and allowed to equilibrate with the soil for 2 weeks before planting. Three maize grains (Samaz – 14) were sown per pot and thinned to 1 plant per pot at 2 weeks after planting (WAP). All the pots were constantly irrigated to field capacity. Plastic receivers were placed underneath to collect any leachates which were returned to the pots. Weeds were removed from the pots regularly by hand pulling.

3.3.3 Treatments application

Nitrogen fertilizer was applied as urea at the rate of 0, 60 and 120 kg Nha^{-1}; sulphur fertilizer was applied as gypsum at the rate of 0, 15 and 30 kg Sha^{-1}, while cowdung was applied at the rate of 0, 5 and 10 ton ha^{-1}. Nitrogen was applied in two splits, half at 2 WAP and the other half at 6 WAP, while S was applied once at 2 WAP. There was also a basal application of P and K fertilizers, each at the rate of 60 kg/ha P_2O_5 and K_2O at 2 WAP based on the recommendations for maize in the Northern Guinea savanna (Enwezor *et al.*, 1989). All the fertilizer treatments were through band application. The fertilizers were placed in a groove of 5cm deep and about 8cm away from the plant stands and covered. Single Super Phosphate (SSP) and Muriate of Potash (MOP) were the fertilizer materials used for P and K respectively.

3.3.4 Experimental Design

All the 27 treatment combinations were laid out in a Complete Randomized Design (CRD) with three replicates.

3.3.5 Measurements

Plant height, number of leaves, stem girth and leaf area were measusred beginning from 2 WAP at weekly interval up to the time of taselling, the plants were harvested at 7 WAP, by cutting the stem at soil level. The roots were carefully removed from the soil and washed repeatedly with clean water until all the dirts were removed. The plant samples were rinsed with distilled water and oven – dried at 65^0 C for 48 hours for the determination of dry weight. Stem (stover) and root yields were obtained by weighing. Soil samples were also collected from each pot for soil chemical analysis at harvest.

3.4 Field Studies

3.4.1 Study Area

The study was conducted at field C15 of Institute for Agricultural Research, Ahmadu Bello University, Zaria. The climatic and soil class have been presented earlier.

3.4.2 Land Preparation, Field Layout and Fertilizer Application

The study area covering 2598 m^2 or 0.26 ha was ploughed and harrowed. The site was divided into 3 blocks each consisting of 27 plots in a block and each plot measuring 22.5 m^2. There were 6 rows in a plot, each measuring 5 m long with a ridge - spacing of 0.75 m. Cowdung was incorporated at the rate of 0, 5 and 10 tons per hectare by splitting the ridge and mixing with the soil and then allowed to equilibrate for 2 weeks before planting. Nitrogen and S were applied at the rates of 0, 60 and 120 $kgNha^{-1}$ and 0, 15 and 30 kg Sha^{-1} as urea and gypsum respectively. Nitrogen was applied in two equal splits, at two and six weeks after planting (2 and 6WAP), each at half of the recommended rate, while all of S treatments was applied once, at two weeks after planting (2WAP) by band application. The trial was conducted on the same site for three years. There was a basal application of P and K fertilizers at 2WAP at 60 kg/ha as recommended for maize in the zone (Enwezor *et al*., 1989). The P and K fertilizers were applied by banding as described already for N and S.

Single Super Phosphate (SSP) and Muriate of Potash (MOP) were the fertilizer materials used.

3.4.3 Treatment Structure and Experimental Design

Treatment composition for the field studies followed the same pattern as presented already for the greenhouse study. There were three application rates each of N, S and CD (Table 3.1). The treatments were laid out in a Randomized Complete Block Design (RCBD) and replicated 3 times. Quality Protein Maize (QPM) variety (Samaz-14) was planted at 3 seeds per hill at 25cm spacing and thinned to 1 plant per stand after 2 weeks, giving an estimated population of 53,333 stem girth stands/hectare.

3.4.4 Measured Parameters

Weather data for the duration of the trial, such as rainfall distribution, relative humidity (RH), sunshine duration and maximum and minimum temperatures of the experimental site were obtained from the IAR Weather Station, Samaru. Growth parameters routinely monitored included plant height, number of leaves, leaf area and stalk diameter. At harvest, cob yield, grain yield and stover were determined. The procedure was repeated for each year of study.

3.5 Experimental Procedure

3.5.1 Plant height

Plant height was monitored weekly using a metre rule from 5 randomly sampled plant stands per plot beginning from 2WAP up to tasselling stage.

3.5.2 Number of leaves

Leaves per plant per plot were determined by counting the leaves produced from the randomly selected plant stands beginning from 2WAP to tassels emergence.

3.5.3 Stalk diameter

Stalk diameter was determined on the randomly selected plant stands by the use of Vernier callipers and measuring diameter from base of the stalk at a weekly interval from 2WAP up to tasselling stage.

3.5.4 Leaf area

Leaf area was determined by using the method described by Stickler *et al*. (1956). Few leaves per plant were randomly selected. Their average lengths and widths were multiplied and the products were then multiplied by a factor 0.75 beginning from 2WAP to the time tassels emerged.

3.5.5 Harvesting

Harvesting for all the three years was conducted on net plot. The net plot consisted of four inner rows. From the net plot, stover was harvested after the cobs were harvested, by cutting the stover at soil level. Measurements were carried out on the harvested cobs and stover of the net plots. The cobs were shelled and grain yield at about 15% moisture content determined.

However, in order to compare the effects of rates of N, S and CD on grain yield for the three years of study, the following parameters were calculated: relative yield (RY,%), relative yield increase (RYI,%) and relative agronomic effectiveness (RAE,%).These parameters were calculated from their respective formula as shown below:

1. Relative yield at each fertilizer level (RY)

$$RY = \frac{Yield\ of\ each\ treatment}{Yield\ at\ optimum\ fertilizer\ application} x\ 100$$ (Chien *et al*.., 1990)

2. Relative yield increase (RYI)

$$RYI = \frac{Yield\ of\ each\ treatment - Yield\ control}{Yield\ at\ optimum\ fertilizer\ application} x\ 100$$ (Chien *et al*.., 1990)

3. Relative agronomic effectiveness (RAE)

$$RAE = \frac{Yield\ of\ each\ treatment - Yield\ control}{Yield\ at\ optimum\ fertilizer\ application - Yield\ control} x\ 100$$ (Nyongesa *et al*.., 2010)

For the above calculations to be achieved, grain yields at different application levels of N, S and CD were used. This procedure was done fore each year.

3.6 Analytical methods for cowdung and soil characterization

Nutrients compositions of the cowdung and soil physical and chemical properties were determined based on standard analytical procedures as follows:

3.6.1 Organic carbon

Organic carbon was determined by the Walkley-Black Wet Oxidation method (Nelson and Sommers, 1982).

3.6.2 pH

pH was determined potentiometrically in 1:2.5 soil/solution ratio in water and in 0.01M $CaCl_2$ with a PYE Unicam model 190 MK glass electrode pH metre (Mclean, 1965).

3.6.3 Total nitrogen

Total N was determined by the micro Kjeldahl method (Bremner and Mulvaney, 1982).

3.6.4 Available phosphorus

Available P was determined by using Bray-1 extraction method as described by Bray and Kurtz (1945), and the concentration of phosphorus in extract was then determined colorimetrically (molybdo-phosphoric blue colour) using a spectrophotometer, as described by Murphy and Riley (1962).

3.6.5 Exchangeable bases

Exchangeable Ca, Mg, Na, and K were determined by extraction with 1N ammonium acetate (NH_4OAc) saturation method at a pH of 7.0. The amounts of K and Na were determined using the flame photometer, while Ca and Mg were determined by the Perkin Elmer Model 403 Atomic Absorption Spectrophotometer (AAS) (Anderson and Ingram, 1993).

3.6.6 Exchangeable acidity

Exchangeable acidity was determined by shaking the soil with 1 N KCl and titrated with 0.1 N sodium hydroxide (NaOH) (Juo, 1979)

3.6.7 Effective Cation Exchange Capacity (ECEC)

ECEC was determined by summation of total exchangeable bases and exchangeable acidity (Anderson and Ingram, 1993).

3.6.8 Sulphur

Sulphur content was determined by using potassium dihydrogen phosphate (KH_2PO_4) extractant. Suphur was determined in extract as SO_4^{2-} sulphur by the turbidimetric method using Cecil-2000 spectrophometer as described by Udoh and Ogunwale (1986).

3.6.9 Micronutrients

Micronutrients such as Copper (Cu), Zinc (Zn), Iron (Fe) and Manganese (Mn), were extracted using DTPA (diethylene triamine penta ascetic acid) method. The concentration of the micronutrients in the extract was determined by using the Perkin Elmer Model 403 Atomic Absorption Spectrophotometer (AAS) as described by Juo (1979).

3.6.10 Particle size distribution

Particle size distribution was carried out using the standard hydrometer method as described by Bouyocous (1951). During the procedure, 50g of the 2mm sieved soil sample was weighed out into 250 ml plastic beaker, 100 ml of sodium hexametaphosphate (Calgon) used as dispersant was added to the beaker and stirred with a glass rod, 100 ml of distilled water was added to the soil mixture and stirred. The mixture was allowed to stand for 30 minutes with occasional stirring. The mixture was then tranferred into a 1000cm^3 measuring cylinder and the suspension was further mixed thoroughly with a long handle plunger to ensure that no sediment was allowed to form at the bottom of the cylinder. The hydrometer readings for the individual particles were determined at 40 seconds for the silt fraction, 2 hours for the clay fraction and 8 hours for the sand fraction.The results obtained were fitted into the USDA textural triangle in order to determine its correct textural class.

3.7 Simulation Studies

One simulation model was used to compare results obtained from growth and yield of maize in the Northern Guinea savanna agro-ecological zone of Nigeria, based on soil properties, climatic conditions and management practices adopted in the zone. Model used was the Quantitative Evaluation of Fertility of Tropical Soils (QUEFTS).

Input Data: The input data required for the model are organic carbon (OC), plant available P, exchangeable K, total N, P, and as well as soil pH (water), while the expected output from the model (Janssen *et al*, 1990) include, plant nutrient uptake, grain yield at maximum accumulation of N, P and K; grain yield at maximum dilution of N, P and K; grain yield obtained from combination of two nutrients and potential maize grain yield.

3.8 Statistical Analysis

All data collected during the incubation studies, greenhouse and field trials were subjected to statistical analysis of variance (ANOVA) at 0.05 level of probability using the General Linear Model GLM) Procedure of SAS. Least Square Means (LSM) was used to compute treatment means (SAS, 2005). Treatments effects were analysed yearly and pooled over the three years of study. Means were separated using Least Significant Difference (LSD). Regression and linear correlation analyses of the parameters were also determined (SAS, 2005).

CHAPTER FOUR

4.0 RESULTS

4.1 Physical and chemical characterization of the soil

Data pertaining to physical and chemical characteristics of soil of the study site are presented in Table 4.1. Particle size distribution of the soil revealed that texture was dominated mainly by the sand fraction which constituted 66% of the separates, followed by silt (22%) and clay (12%) as expected for most soils of the tropics. The textural class of study area was generally sandy loam (USDA Soil Survey Staff, 1975). The soil was moderately acidic in reaction with a pH ($CaCl_2$) of 5.8. Organic carbon content was low indicating low organic matter content of the Northern Guinea savanna soils. Results obtained for total N, organic carbon and S fell below critical levels of the nutrients and so were deficient (Esu, 1991; Enwezor *et al*., 1989) but the concentration of available phosphorus in the soil was medium (range 0f 10-20 mg/kg). This may be attributed to the residual effect of previous phosphorus fertilizer application in the soil since the field was regularly put into cereal cutivation.

However, contents of exchangeable bases were above the critical limits (Esu, 1991) of their concentration in the soil (Table 4.1), indicating that the soil had low to medium levels of exchangeable bases. Value for effective cation exchange capacity (ECEC) was 5.75 cmol kg^{-1} which was low and characteristic of the savanna soils. But the concentration of Ca and Mg suggests that the soil has moderate liming elements to suppress the development of high soil acidity. Results obtained for Cu and Zn were low (Table 4.1). Also, the contents of Fe (153.87 mg/kg) and Mn (33.60 mg/kg) were high indicating that the parent material of the soil was high in Fe bearing minerals commonly associated with a high kaolinite clay content of the soil. This confirms the findings of Moberg and Esu (1991) that kaolnite and hydro-oxides of iron constitute about 80 – 90% content of clay fraction of the Nigeria savanna soils.

Table 4.1: **Pre-cropping physical and chemical characteristics of soil (0-20cm) of the trial site (2009)**

Properties	Values
Particle size distribution	
Sand (g kg^{-1})	660
Silt (g kg^{-1})	220
Clay (g kg^{-1})	120
Textural class	Sandy loam
pH (1:2.5 w/v H_2O)	6.30
pH (1:2.5 w/v 0.01M $CaCl_2$	5.80
Total Nitrogen (g kg^{-1}))	0.53
Organic carbon (g kg^{-1}))	5.3
C:N	10.0
Sulphur – SO_4^{2-} (mg kg^{-1})	4.83
Available P (Bray-1 mg kg^{-1})	19.25
Exchangeable cations	
Calcium (cmol kg^{-1})	3.40
Magnesium (cmol kg^{-1})	1.37
Potassium (cmol kg^{-1})	0.22
Sodium (cmol kg^{-1})	0.16
Exchangeable acidity (cmol kg^{-1})	0.60
ECEC (cmol kg^{-1})	5.75
Extractable micronutrients	
Iron (mg kg^{-1})	153.87
Zinc (mg kg^{-1})	25.32
Copper (mg kg^{-1})	1.84
Manganese (mg kg^{-1})	33.60

ECEC – Effective cation exchange capacity

Also, a high Fe content of soils revealed that the soil was highly weathered (Brady and Weil, 2005; Jones and Wild, 1975). The low levels of N, P, K and S in soils of Nigerian savanna suggested that supplementary application of these nutrients as fertilizers was essential, especially for a cereal crop production. The result is consistent with findings of Maniyunda and Malgwi (2011); Abdu *et al*., (2008), Uyovbisere and Lombin (1991).

4.2 Chemical composition of the cowdung

The chemical properties of the cowdung used for the trial are presented in Table 4.2. The pH in water was above 8.0. It was moderately high in total N, organic carbon (OC), S and P contents. Also, the contents of basic cations: Ca, Mg, K and Na were low indicating that the cowdung would have low liming effects judging from the values of Ca and Mg content. However, the content of OC in the material indicated that the applied CD had the potentials of improving soil fertility, especially that of tropical savanna soils widely reported for their acute N and P deficiency (Enwezor *et al*., 1989; Abdu *et al*., 2008). Therefore, mineralization of the organic material was expected to increase soil fertility by releasing nutrients for crop use and equally buffering the soil against change in soil pH. The low C: N ratio (11.0) indicated that the cowdung possessed the characteristics of quick mineralization to release nutrients to the soil.

The content of P in the organic matter showed that P released from CD could boost the low P status of the soil. Also, the CD contained low concentrations of micronutrients (Table 4.2). The result is in agreement with the findings from previous studies of Adeleye and Ayeni (2010); Adegbiti and Olayinka (2010); Mba and Mbagwu (2006) on chemical characteristics of organic materials.

Table 4.2: Chemical composition of the cowdung (CD)

Chemical composition	Values
pH (1:2.5 w/v H_2O)	8.50
pH (1:2.5 w/v 0.01M $CaCl_2$	8.20
Total nitrogen (g kg^{-1})	22.0
Organic carbon (g kg^{-1})	242.6
C:N	11.00
Total phosphorus (g kg^{-1})	7.70
Sulphur- SO_4^{2-} (mg/kg)	8.21
Calcium (mg/kg)	0.20
Magnesium (mg/kg)	0.88
Potassium (mg/kg)	1.75
Sodium (mg/kg)	0.44
Zinc (mg/kg)	1.63
Iron (mg/kg)	6.61
Manganese (mg/kg)	0.29

These authors reported that though organic materials vary in their nutrient release characteristics due to source, chemical composition and management, they still have the potentials of improving soil fertility through nutrient release and as such, complements inorganic fertilizer application to crops.

4.3 Climatic conditions of the experimental site during the period of study

Meteorological data of the experimental site during the three years of study are presented in Tables 4.3, 4.4 and 4.5 and Appendix 1 respectively. The data showed that year 2009 was warm with a mean temperature of 33.9^0C, while average minimum temperature for the same period was 18.8^0C. Highest temperature for the year was recorded from April with average temperatures of 38.4^0C. However, this condition was only slightly different in 2010 and 2011 with a mean maximum temperature of 33.7^0C and 33.6^0C respectively (Table 4.4 and 4.5). It was reported that a suitable environmental condition for growth and yield of maize was obtained where mean temperature falls within the range of 30-33^0C during the day, but with cool nights (Downes, 1972). The range of temperatures observed fell within the optimum temperature (30 – 33^0C) required for maize production in the savanna (Okoli, 2000).

Relative humidity was slightly higher in 2010 than 2009 and 2011 with an average of 49.0% compared to 47.5% and 47.2% respectively. Findings revealed that relative humidity provided the cloud condition favourable for pollination and fertilization of crops (Tunde *et al*., 2011). But mean highest sunshine hours recorded in 2009 (7.7hrs) against 6.8hrs and 6.9hrs in 2011 and 2010 respectively (Tables 4.3, 4.4 and 4.5). Also, the year 2010 recorded the longest days of rain averaging 81 days followed by 2009 and 2011 (Appendix 1), though less than the recommended 120 rainy days within the year for optimum maize production. Rainfall distribution was longer in 2010 than in 2009 and 2011.

Table 4.3: Mean monthly maximum and minimum ambient air temperatures, relative humidity (RH %), sunshine duration and days of rainfall monitored during the period of experimentation at Samaru in 2009

Month	**Temperature (^{0}C)**		**RH**	**Sunshine**	**Days of rainfall**
	Max	**Min**	**%**	**(hrs)**	
January	33.8	14.1	14.8	8.6	0
February	36.3	16.9	9.4	8.3	0
March	38.0	19.6	10.0	6.8	0
April	38.4	23.2	48.7	8.2	4
May	35.5	22.2	60.9	8.2	6
June	33.2	21.0	71.2	8.1	11
July	31.3	20.0	73.4	7.4	14
August	29.9	20.4	80.6	5.7	20
September	31.9	20.0	75.5	6.7	14
October	32.8	20.3	71.0	6.6	7
November	32.4	14.8	37.5	8.1	0
December	33.5	13.3	16.5	9.1	0
Mean	**33.9**	**18.8**	**47.5**	**7.7**	**76**

Source: IAR Meteorological Unit, ABU, Zaria

Their differences were 33.2%, 35.4% and 31.5% for 2009, 2010 and 2011 respectively though not significant. Variation in rainfall distribution pattern could impact negatively on crop productivity in the savannah as rainfall is an active climatic factor in agriculture, especially with regards to cereal production.

Table 4.4: Mean monthly maximum and minimum ambient air temperatures, relative humidity (RH %), sunshine duration and days of rainfall monitored during the period of experimentation at Samaru in 2010

Month	Temperature (^{0}C)		RH	Sunshine	Days of Rainfall
	Max	Min	%	(hrs)	
January	33.8	13.4	15.7	9.0	0
February	37.1	17.4	11.1	8.9	0
March	37.2	21.1	18.5	5.8	0
April	38.5	22.8	38.4	6.3	5
May	35.4	22.7	68.2	6.9	7
June	32.6	20.6	73.1	5.3	11
July	30.3	19.4	81.9	4.8	13
August	29.8	20.1	81.9	5.5	19
September	31.2	20.9	78.8	5.2	16
October	32.6	20.7	73.4	6.4	10
November	33.7	16.2	29.1	8.7	0
December	31.8	12.6	17.4	8.7	0
Total/Mean	**33.7**	**19.0**	**49.0**	**6.8**	**81**

Source: IAR Meteorological Unit, ABU, Zaria

Table 4.5: Mean monthly maximum and minimum ambient air temperatures, relative humidity (RH %), sunshine duration and days of rainfall monitored during the period of experimentation at Samaru in 2011

Month	**Temperature (^{0}C)**		**RH**	**Sunshine**	**Days of Rainfall**
	Max	**Min**	**%**	**(hrs)**	
January	30.2	13.1	17.7	7.5	0
February	36.4	18.3	20.4	7.4	0
March	38.6	19.7	13.6	7.1	0
April	38.1	22.3	31.6	6.7	3
May	35.3	22.0	64.5	6.9	11
June	32.3	20.9	76.5	6.2	12
July	30.9	20.0	85.2	6.2	14
August	30.3	19.6	80.1	4.7	16
September	31.9	18.9	76.1	6.4	12
October	34.1	18.1	64.5	6.6	4
November	34.2	11.9	18.0	8.9	0
December	31.4	12.5	16.9	7.6	0
Mean	**33.6**	**18.1**	**47.1**	**6.9**	**72**

Source: IAR Meteorological Unit, ABU, Zaria

4.4 Laboratory Incubation Studies

4.4.1 Main effect of different levels of N, S and CD on CO_2 evolution

Results of six weeks of laboratory incubation for the determination of CO_2 flux are presented in Table 4.6. Carbon dioxide flux increased from the first week of incubation to week 2 across all the levels of N, S and CD application with corresponding means of 5.59 g/kg and 7.85 g/kg respectively. After noticeable increase in the first two weeks of incubation, CO_2 decreased thereafter to six weeks incubation (Table 4.6). The result showed that effects of the treatments on CO_2 evolution significantly ($P < 0.01$) peaked at two weeks of incubation.

It was observed that the various treatment combinations positively and significantly influenced mineralization of the added CD. This could be correlated with situations under field conditions, especially when those physical conditions, such as moisture and temperature, were optimum to stimulate early biological activity. Evolution of CO_2 from the control treatment was lowest for each of N, S and CD levels from the first to the last week of incubation (Table 4.6). This indicated that treatments which received either CD alone or a combination of N and S had minimum amount of substrate supply needed for microbial activity than in the control.

Nitrogen application rate at 120 kg/ha had a better performance in week 2 than half its application rate and the control, suggesting that mineral nitrogen fertilizer input had contributed to the microbial decomposition process of the added CD to release CO_2. This is in agreement with the works of Adeleye and Ayeni (2010); Rochette and Gregorich (1998) and Jenkinson (1981) who found out that nitrogen fertilizer application enhanced microbial decomposition of the added organic matter in the soil, presumably due to the availability of nutrients in the soil for the microbes to utilise. It could be deduced from the result that the amount of available plant nutrients in the soil enhanced microbial decomposition of the added CD.

Table 4.6: Main effect of different levels of N, S and CD on CO_2 evolution in soil of the trial site

	Weeks						
	1	2	3	4	5	6	
N Rates (Kg/ha)	**CO_2 Evolution (g/kg)**						Mean
0	5.35	7.26	4.89	5.33	5.13	4.73	5.45
60	5.56	7.88	5.16	5.64	5.33	4.97	5.76
120	5.88	8.42	5.55	5.56	5.61	4.97	5.99
S Rates (Kg/ha)							
0	5.59	7.59	5.29	5.45	5.28	4.82	5.67
15	5.61	7.62	5.18	5.52	5.42	4.87	5.70
30	5.60	8.34	5.12	5.56	5.37	4.92	5.82
CD Rates (tons/ha)							
0	5.24	6.94	5.01	5.27	5.22	4.75	5.41
5	5.51	8.07	5.5	5.57	5.37	4.87	5.82
10	6.04	8.54	5.08	5.69	5.49	4.99	5.97
Mean	5.59	7.85	5.20	5.51	5.36	4.87	5.73
CV	4.54	5.09	7.97	4.91	4.01	4.17	5.12
R-Square	0.94	0.94	0.84	0.73	0.80	0.79	0.84
LSD	0.05**	0.08**	0.08**	0.05*	0.04**	0.04*	0.06**

** = Significant at P = 0.05, ** = Significant at P = 0.01,*

In addition, CD at 10 ton/ha was superior to either N or S at their peak application levels (Table 4.6). The amount of CO_2 flux after the second week of incubation revealed that the cumulative C mineralization was higher at the initial stage of incubation but declined as the incubation period increased presumably due to decrease in microbial population to carry out any further decomposition.

4.4.2 Interaction effect of different levels of N, S and CD on CO_2 evolution

Interaction effect of different levels of N, S and CD on CO_2 evolution in week 2 is shown in Table 4.7. Two weeks after incubation was used for the interaction of the factors because at this time, the mean amount of CO_2 evolved was highest after which, there was a reduction (Table 4.7).

At each level of N with sulphur kept constant at 30 kg/ha, the result showed that N application at 120 kg/ha was not significantly different ($P > 0.05$) from N at 60 kg/ha. Their corresponding mean values were 9.30 g/kg and 9.35 g/kg respectively. However, there was a significant difference ($P < 0.05$) in amount of CO_2 flux between 60 and 0 kg N/ha application (Figure 4.1). This observation was in agreement with Jenkinson (1981), who reported that a reasonable amount of inorganic N was needed in the soil to stimulate early respiratory activities, leading to the decomposition of organic residues.

The highest amount of CO_2 evolved in week 2 was 9.7 g/kg obtained from the interaction of N at 120 kg/ha with 0 kg S/ha and 5 ton CD/ha, whereas the least was obtained from the control with a mean of 4.6 g/kg (Table 4.7). This represents 97% and 46% respectively of the amount of CO_2 evolved in that order. Also, the amount of CO_2 flux from 120 kg N/ha + 15 kg S/ha + 10 ton CD/ha was less than that of 120 kg N/ha + 0 kg S/ha + 5 ton CD/ha by 10% and the difference was highly significant ($P < 0.01$) (Figure 4.2). This may suggest that the effect of sulphur in the CD decomposition was low, thus the presence or absence of mineral sulphur would not significantly affect organic matter decomposition. Though the content of sulphur in soil at pre-planting was low (4.83 mg kg^{-1}) (Table 4.1), this initial content was adequate for the decomposition reaction to go unhindered.

Table 4.7: Interaction effects of different levels of N, S and CD on CO_2 evolution during the incubation studies

Treatment				Weeks (g/kg)					
Number	N	S	CD	1	2	3	4	5	6
1	0	0	0	3.65^{q}	4.60^{r}	3.95^{m}	4.70^{k}	4.75^{o}	4.35^{o}
2	0	0	5	5.25^{n}	7.60^{k}	5.10^{g}	5.25^{i}	5.15^{l}	4.80^{i}
3	0	0	10	6.15^{b}	7.45^{l}	5.10^{g}	5.30^{hi}	5.25^{j}	4.90^{g}
4	0	15	0	5.40^{lm}	6.25^{q}	4.20^{l}	5.10^{j}	5.05^{n}	4.95^{f}
5	0	15	5	5.65^{gh}	6.75^{o}	5.15^{g}	5.90^{b}	5.10^{m}	4.30^{p}
6	0	15	10	5.40^{lm}	7.95^{i}	5.00^{h}	5.35^{h}	5.40^{h}	5.15^{c}
7	0	30	0	5.70^{fg}	7.60^{k}	5.80^{c}	5.15^{j}	5.15^{l}	4.80^{i}
8	0	30	5	5.45^{kl}	8.10^{h}	5.10^{g}	5.55^{f}	5.20^{k}	4.55^{n}
9	0	30	10	5.55^{ij}	9.00^{d}	4.60^{j}	5.65^{de}	5.15^{l}	4.75^{j}
10	60	0	0	4.85^{p}	7.55^{k}	5.80^{c}	5.25^{i}	5.20^{k}	5.05^{e}
11	60	0	5	5.40^{lm}	7.95^{i}	5.60^{d}	5.45^{g}	5.25^{j}	5.20^{b}
12	60	0	10	5.85^{d}	7.40^{lm}	4.40^{k}	5.95^{b}	5.15^{l}	4.85^{h}
13	60	15	0	5.65^{gh}	7.35^{m}	4.65^{j}	5.55^{f}	5.45^{g}	4.60^{m}
14	60	15	5	6.05^{c}	7.90^{i}	5.85^{c}	5.45^{g}	5.85^{c}	5.05^{e}
15	60	15	10	5.45^{kl}	8.20^{g}	5.30^{f}	5.90^{b}	5.15^{l}	4.90^{g}
16	60	30	0	5.75^{ef}	6.90^{n}	4.75^{i}	5.80^{c}	5.35^{i}	4.60^{m}
17	60	30	5	5.45^{kl}	8.30^{f}	5.45^{e}	5.70^{d}	5.15^{l}	5.05^{e}
18	60	30	10	5.60^{hi}	9.35^{c}	4.60^{j}	5.70^{d}	5.45^{g}	5.45^{a}
19	120	0	0	5.50^{j}	6.60^{p}	5.35^{f}	5.25^{i}	5.25^{j}	4.55^{n}
20	120	0	5	5.35^{m}	9.70^{a}	5.95^{b}	5.70^{d}	5.70^{e}	5.10^{d}
21	120	0	10	8.30^{a}	9.50^{b}	6.35^{a}	6.20^{a}	5.80^{d}	4.60^{m}
22	120	15	0	5.55^{ij}	7.90^{i}	5.50^{e}	5.35^{h}	5.25^{j}	4.65^{l}
23	120	15	5	5.20^{n}	7.55^{k}	5.35^{f}	5.55^{f}	5.40^{h}	5.05^{e}
24	120	15	10	6.10^{bc}	8.70^{e}	5.65^{d}	5.60^{ef}	6.15^{a}	5.15^{c}
25	120	30	0	5.10^{o}	7.75^{j}	5.10^{g}	5.30^{hi}	5.50^{f}	5.20^{b}
26	120	30	5	5.80^{de}	8.75^{e}	5.95^{b}	5.60^{ef}	5.50^{f}	4.70^{k}
27	120	30	10	6.05^{c}	9.30^{c}	4.75^{i}	5.55^{f}	5.90^{b}	5.20^{b}
	Mean			5.59	7.85	5.20	5.51	5.36	4.87
	R-Square			0.94	0.94	0.84	0.73	0.80	0.79
	CV			4.54	5.09	7.97	4.91	4.01	4.17
	LSD			0.05	0.08	0.08	0.05	0.04	0.04
	NxSxCD			**	**	*	NS	NS	**

*NS = Not Significant, * = Significant at P = 0.05, ** = Significant at P = 0.01. Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test*

But mineralization rate showed a positive response to rate of manure application (Figure 4.3). The amount CO_2 evolved increased with rats of CD and mean amount of CO_2 flux with 10 ton/ha (9.5 g kg^{-1}) was significantly different ($P < 0.01$) with the mean amount of 5 ton/ha (8.8 g kg^{-1}). The least effect was obtained at 0 ton/ha CD application (Figure 4.3) and significantly different ($P < 0.01$) with 5 ton/ha CD. The result showed that the presence of mineralizable carbon in the substrate facilitated microbial activity and the higher the amount of C in the substrate, the higher the amount of CO to be released during manure mineralization. Manure addition to the soil is therefore a veritable source of organic matter.

Interaction effect of highest rates of N, S and CD on CO_2 evolution during the six weeks of incubation showed that the peak of organic manure mineralization was obtained at week 2, thereafter, the mineralization rate decreased towards the end of incubation (Figure 4.4). The interaction of the factors particularly, N and CD provided the nutritional requirements for increased microbial activitiy. This is in line with the work of Hsieh (1996); Mba and Mbagwu (2003); Olayinka and Ailenubhi (2001), on the contribution of N and organic residues to soil organic manure decomposition.

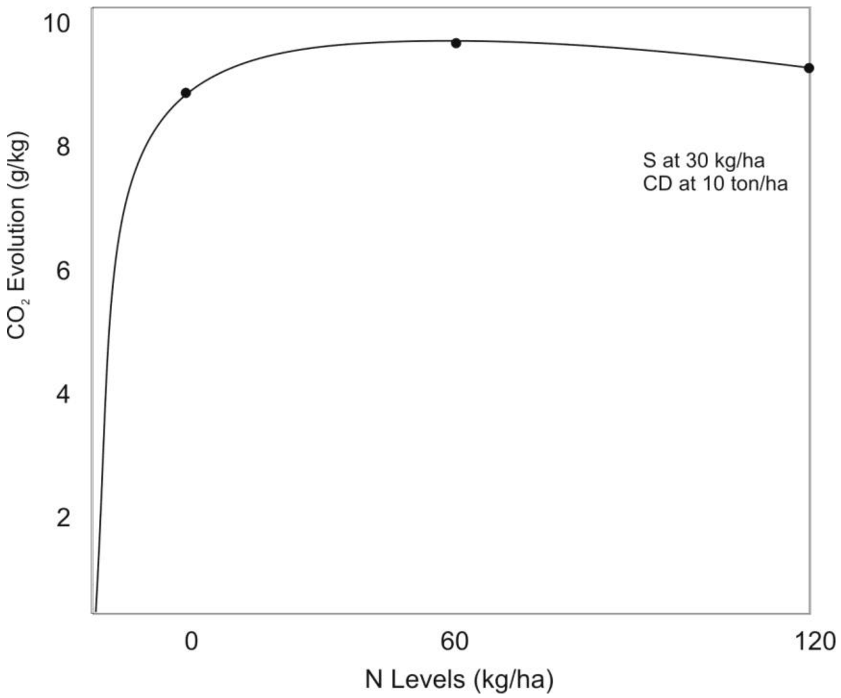


Figure 4.1: **Interaction effect of levels of N on CO_2 evolution in Week 2 at S and CD application rates of 30 kg/ha and 10 ton/ha**

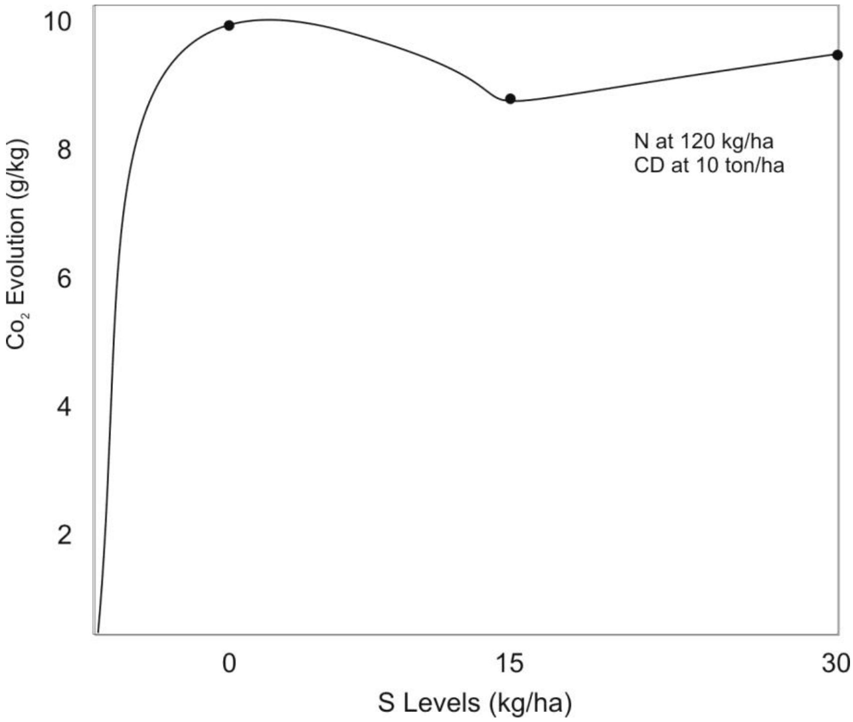


Figure 4.2: **Interaction effect of levels of S on CO_2 evolution in Week 2 at N and CD application rates of 120 kg/ha and 10 ton/ha**

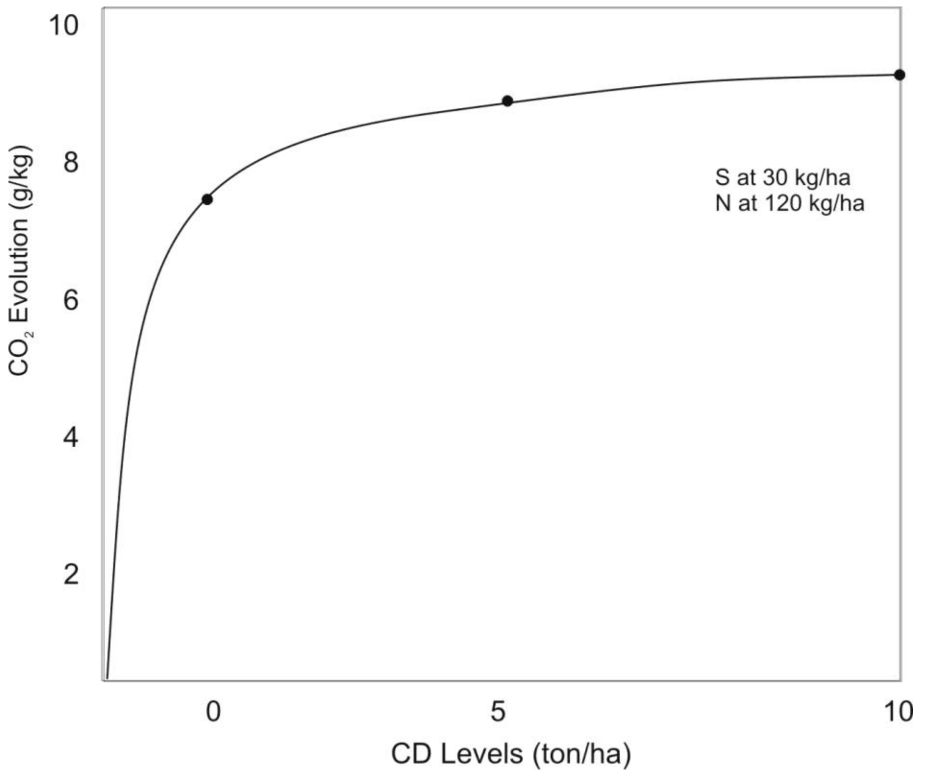


Figure 4.3: **Interaction effect of levels of CD on CO_2 evolution in Week 2 at N and S application rates of 120 kg/ha and 30 kg/ha**

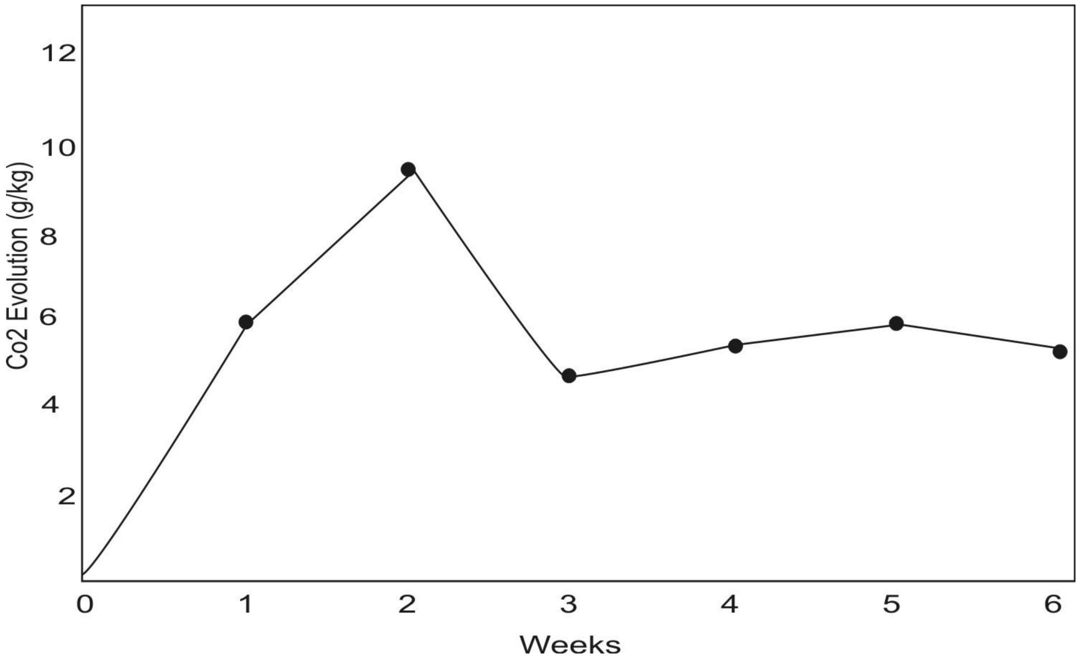


Figure 4.4: **Interaction effects of highest levels of N, S and CD on CO_2 evolution during six weeks of incubation**

4.4.3 Nitrogen mineralization

4.4.3.1 Main effect of the treatments on NH_4^+ - N concentration

Treatments effect on N mineralization (NH_4^+) is shown in Figures 4.4, 4.5 and 4.6 respectively. Ammonium concentration increased from 0.42 g/kg in the control to 0.70 g/kg at 120 kg/ha N level which represented a difference of about 40% increase. Similarly, S and CD levels followed the same trend as observed with N rates, though, the difference between the control and 5 ton/ha CD application was not significant ($P > 0.05$).

The result showed that NH_4^+ concentration increased with increasing levels of N, S and CD application at the end of incubation which peaked at 0.70 g/kg for NH_4^+ – N at 120 kg/ha urea N application. The combination of 120 kg N/ha with 30 kg S/ha and 10 tons CD/ha had the highest interaction effect while the least effect was obtained from 60 kg N/ha + 0 kg S/ha + 0 ton CD/ha (Table 4.9). Their corresponding means were 0.09 g/kg and 0.04 g/kg. The difference in the means was significant ($P < 0.01$).

Comparably least content of ammonium ion within the microcosm of the control further demonstrated the deficiency of biodegradable organic component in the soil. It was observed therefore, that mineral fertilizer application along with manure amendment positively influenced mineralization characteristics of organic matter in the soil resulting in higher levels of NH_4^+ - N compared to the control. Their differences were highly significant ($P < 0.01$).

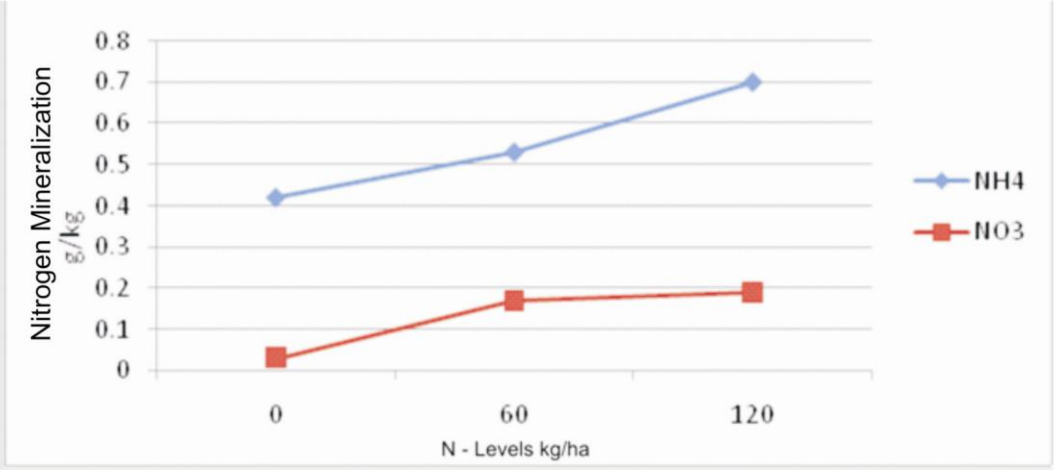


Figure 4.5: Main effect of different levels of N on nitrogen mineralization

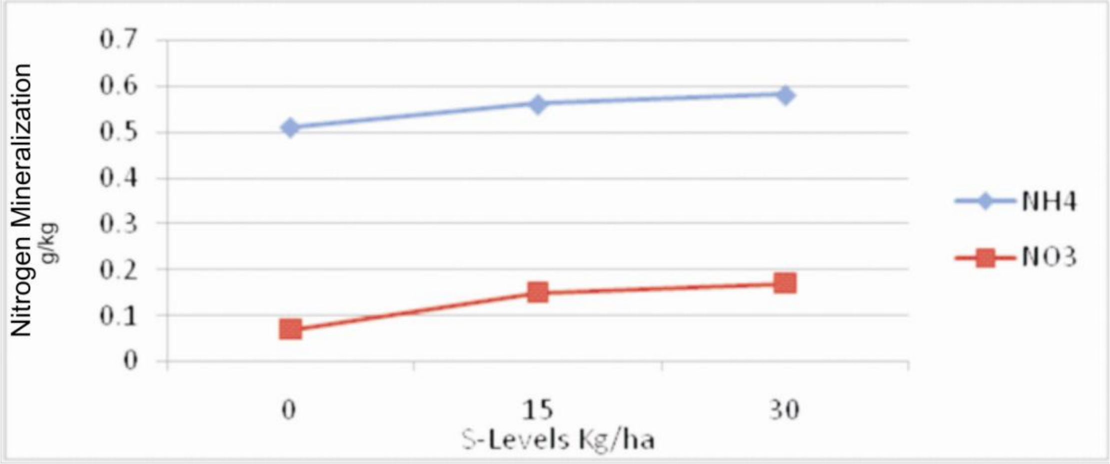


Figure 4.6: Main effect of different levels of S on nitrogen mineralization

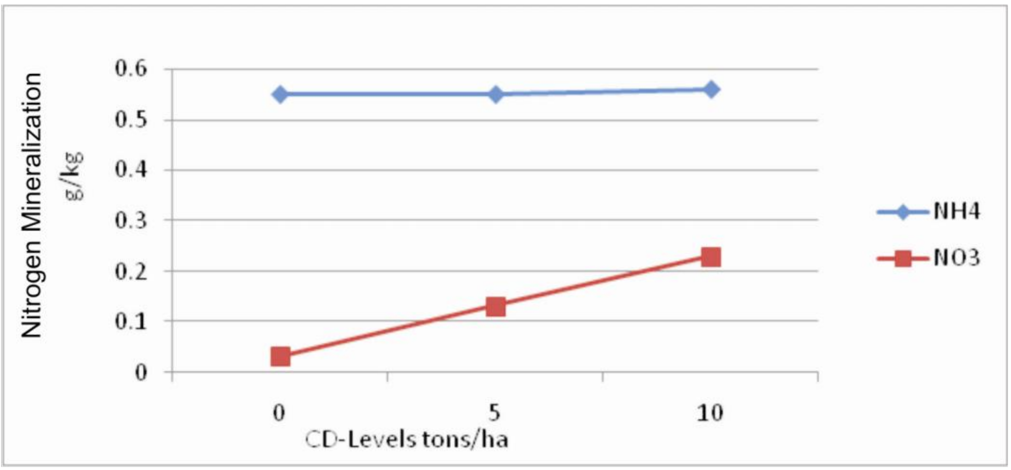


Figure 4.7: Main effect of different levels of CD on nitrogen mineralization

For NH_4^+: Mean = 0.55; CV = 7.54; R-Square = 0.96; LSD (0.05) = 0.01; ** = *Significant at P = 0.01*,
For NO_3^- : Mean = 0.13; CV = 6.97; R-Square = 0.88; LSD (0.05) = 0.02; ** = *Significant at P = 0.01*,

4.4.3.2 Effect 0f treatments on NO_3^- - N concentration

Nitrate concentration in incubated soil mixture also increased exponentially from the control for each of N, S and CD rates with highest concentration of 0.23 g kg^{-1} obtained for 10 ton/ha CD; representing 86.96% amount of nitrate mineralized compared to the control (Figures 4.5, 4.6 and 4.7).

The result revealed that amount of NO_3^- mineralized during incubation was significant ($P < 0.01$) and greater with CD than with mineral N fertilizer application (Figures 4.5). This comparison shows that applied fertilizer N and S were already in their soluble forms, thus readily utilized by soil microbes. The interaction of 60 kg N/ha with 30 kg S/ha and 10 ton/ha had the highest effect on amount of nitrate while the least effect was obtained from the control (Table 4.8).

The greater potential of CD mineralization to release NO_3^- relative to fertilizer N or S was indicative that the activities of nitrifying bacteria were not hindered within the soil, perhaps, due to optimum conditions during the incubation and considering the favourable C/N ratio of the organic compound. Beauchamp and Paul (1989) suggested that manures with C/N ratios below 15 were likely to result in positive N mineralization after application to soil. These observed factors may have led to a greater effect of CD than with mineral N or S fertilizer applications on NO_3^- content of incubated soil.

4.4.3.3 Organic matter decomposition study

Data obtained from CD decomposition during the laboratory incubation study was tested on each of the "ordered" kinetic models (Manzoni and Porporato, 2009, Riffaldi *et al.*, 1996 and smith *et al.*, 1980) in order to quantitatively determine the fitness of the model in describing the mineralization process in the soil applied CD dynamics. The result showed that the goodness of fit was satisfactorily obtained from the second order rate model followed by first order model (Table 4.8). This is an indication of the fact that the decomposition characteristics of the applied organic manure followed the second order kinetic model but the decomposition characteristic was less with the first order decomposition model.

However, the inverse function in the second order decay model implies that as the rate of decomposition decreased with time, there was a cumulative effect of the organic matter decomposition in terms of nutrients release and a subsequent improvement in soil fertility due to nutrient deposition. Therefore, there was a likelihood of organic carbon content in a substrate undergoing decomposition to be exhausted with time and the rate of microbial activity would then decrease. The result is consistent with the findings of Olayinka and Ailenubhi (2001) and Makinde and Ayeni (2013) on microbial decomposition of soil organic matter, CO_2 flux and nutrient release. Also it can be assumed that the amount of biodegradable carbon in a substrate is not inexhaustive but tend to decline with time due to the intensity of microbial action at the initial stage of decomposition and prevailing environmental conditions.

Table 4.8: Values obtained from each kinetic model during carbon mineralization

	1st Order Model	RMSE	2nd Order Model	RMSE
N+S+CD	R^2		R^2	
0 0 10	0.557	0.491	0.576	0.075
0 15 10	0.412	0.395	0.469	0.083
0 30 0	0.452	0.403	0.517	0.085
60 15 0	0.484	0.579	0.509	0.091
60 15 5	0.379	0.502	0.414	0.111
60 30 10	0.376	0.362	0.432	0.158
120 0 0	0.544	0.563	0.581	0.095
120 0 10	0.823	0.282	0.857	0.193

4.4.4 Interaction effects of different levels of N, S and CD on nitrogen mineralization

4.4.4.1 Effect on ammonium concentration

The combination of 120 kg N/ha with 30 kg S/ha and 10 ton/ha CD had the highest interaction effect on ammonium concentration in soil, while the least effect was obtained from 60 kg N/ha in combination with 0 kg S/ha and 0 ton CD/ha. Their corresponding means were 0.089 g/kg and 0.035 g/kg respectively (Table 4.9). The difference in the treatment means was highly significant ($P < 0.01$).

Comparatively, the higher proportion of mineral N in 120 kg/ha and the amount added from CD mineralization could have led to the highest concentration of ammonium obtained from the highest application rates of N, S and CD. However, the lower amount of NH_4^+ obtained from half optimal application rate of N at 60 kg N/ha in combination with 0 kg S/ha + 0 ton CD/ha was consistent with this result, which showed that the higher the amount of mineral N, expectedly, the higher the amount of ammonium mineralized. A similar result was reported by Ayeni (2012).

4.4.4.2 Effect on nitrate concentration

The combination of N, S and CD at 60 kg/ha + 30 kg/ha + 10 ton/ha produced the highest amount of nitrate (0.048 g/kg) during the period of incubation, though, the result was not significantly different ($P > 0.05$) with those of 120 kg/ha + 15 kg/ha + 10 ton/ha and 120 kg/ha + 30 kg/ha + 10 ton/ha. The least effect was from the control plot with a mean amount of 0.002 g/kg of nitrate, but not significantly different with the results of treatments 2 to 14 (Table 4.9).

Table 4.9: Interaction effects of different levels of N, S and CD on nitrogen mineralization during the incubation studies (g/kg)

Treatment Number	N	S	CD	NH_4^+	NO_3^-
1	0	0	0	0.037 ^{jk}	0.002 ^{c}
2	0	0	5	0.046 ^{hij}	0.004 ^{c}
3	0	0	10	0.042 $^{h-k}$	0.003 ^{c}
4	0	15	0	0.041 ^{ijk}	0.005 ^{c}
5	0	15	5	0.040 ^{ijk}	0.003 ^{c}
6	0	15	10	0.044 $^{h-k}$	0.003 ^{c}
7	0	30	0	0.043 $^{h-k}$	0.002 ^{c}
8	0	30	5	0.042 $^{h-k}$	0.004 ^{c}
9	0	30	10	0.047 ^{ghi}	0.005 ^{c}
10	60	0	0	0.035 ^{k}	0.002 ^{c}
11	60	0	5	0.056 ^{fg}	0.013 ^{c}
12	60	0	10	0.051 ^{gh}	0.011 ^{c}
13	60	15	0	0.066 ^{cde}	0.004 ^{c}
14	60	15	5	0.065 ^{def}	0.017 ^{c}
15	60	15	10	0.048 ^{ghi}	0.037 ^{ab}
16	60	30	0	0.062 ^{def}	0.003 ^{c}
17	60	30	5	0.049 ^{ghi}	0.019 ^{c}
18	60	30	10	0.046 ^{hij}	0.048 ^{a}
19	120	0	0	0.061 ^{ef}	0.003 ^{c}
20	120	0	5	0.065 ^{def}	0.019 ^{c}
21	120	0	10	0.067 $^{b-e}$	0.015 ^{c}
22	120	15	0	0.075 ^{bc}	0.003 ^{c}
23	120	15	5	0.061 ^{ef}	0.021 ^{bc}
24	120	15	10	0.068 $^{b-e}$	0.045 ^{a}
25	120	30	0	0.076 ^{b}	0.07 ^{c}
26	120	30	5	0.071 ^{bcd}	0.019 ^{c}
27	120	30	10	0.089 ^{a}	0.046 ^{a}
	Mean			0.055	0.014
	R-Square			0.96	0.88
	CV			7.54	6.97
	LSD			0.01	0.02
	NxSxCD			**	**

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Tes

4.5 Greenhouse Studies

4.5.1 Main effect of rates of N, S and Cowdung on plant height

The effect of different levels of N, S and cowdung on maize plant height from week 2 to week 6 is presented in Figure 4.8 – 4.10, whereas the effects of levels of N, S and CD on week 7 and the mean effects of weeks 2-6 are shown in Table 4.10. The means obtained per week increased from 2 WAP to 6 WAP in response to fertilizer and cowdung application, with mean tallest plant (28.7cm) obtained in week 6.

Plant height response to treatments was not significant ($P \geq 0.05$) at 2, 3, 4 and 7 WAP, but the effect was significant ($P \leq 0.01$) at 5 and 6 WAP and also significant with the mean effect of 6 weeks (Table 4.10) among the CD rates.

The performance of the treatments indicated that both N and S at 120 kg/ha and 30 kg/ha respectively were slightly less effective in relation to half their application rates; especially for N at 60 kg/ha. The observed trend was reversed among cowdung application levels from 0 to 10 ton/ha. As weeks after planting progressed, cowdung application at 10 ton/ha was of greater benefit to crop than at 5 ton/ha but varied with N at 120 kg/ha.

Table 4.10: Main effect of rates of N, S and Cowdung on plant height under greenhouse conditions

	Weeks After Planting (cm)	
N Rates (kg/ha)	**7**	**Mean 2 – 6 weeks**
0	36.40	15.96
60	36.90	16.42
120	35.80	15.66
S Rates (kg/ha)		
0	36.80	12.92
15	36.50	15.86
30	35.80	16.01
CD Rates (tons/ha)		
0	29.80	12.92
5	37.50	16.81
10	41.90	18.3
Mean	36.40	15.65
CV	21.40	20.17
R-Square	0.50	0.52
LSD (0.05)	12.40^{NS}	4.86*

*NS = Not Significant, * = Significant at P = 0.05*

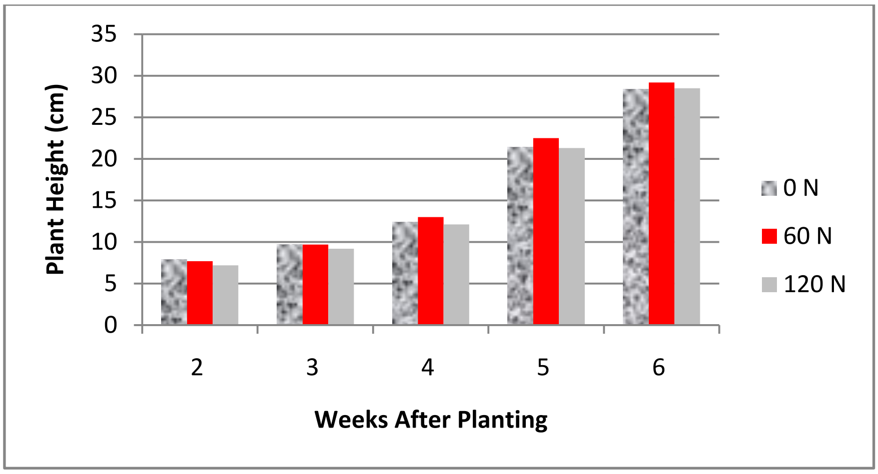


Figure 4.8: Main effect of rates of N on plant height under greenhouse conditions

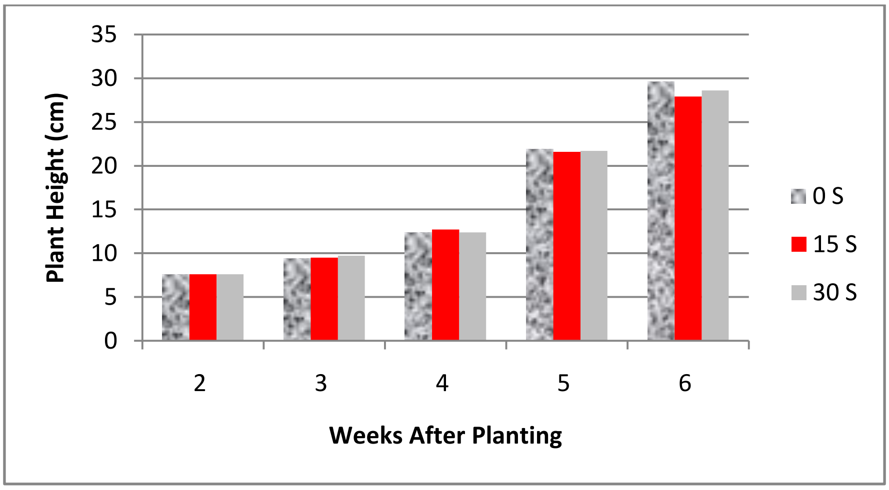
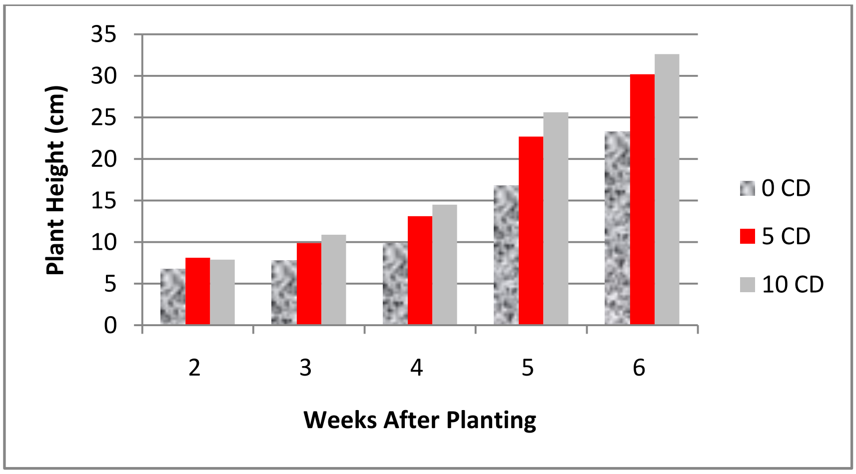


Figure 4.9: Main effect of rates of S on plant height under greenhouse conditions



SE±	2.2	3.4	5.1	5.8	7.8

Figure 4.10: Main effect of rates of CD on plant height under greenhouse conditions

4.5.2 Interaction effect of different levels of N, S and CD on plant height

Results obtained from the interactive combinations of levels of N, S and CD is presented in Table 4.11. The best performance in week 7 was 46.67 cm obtained from the interactive combination of 0 kg N/ha + 0 kg S /ha + 10 ton /ha CD, though the result was not significantly different from 60 kg N /ha +15 kg S /ha + 10 ton /ha CD and 0 kg N / ha + 15 kg S /ha + 10 ton /ha CD with mean plant height of 45.00 cm and 44.67 cm respectively. The least effect (26.40 cm) was obtained from the combination of 0 kg N/ha + 15 kg S /ha + 0 ton/ha CD, though not significantly different from control (Table 4.11).

The combination of N at 60 kg/ha; S at 15 kg/ha and cowdung at 10 ton /ha was more beneficial to the growth of maize than with the higher combination rates. This tends to suggest that there could be a reduction by half of N fertilizer application due to increased organic matter input. The result is in agreement with the previous work of Chude *et al*. (2001) on maize response to nitrogen fertilizer application in the Northern Guinea savanna of Nigeria, where it was reported that under good management, the current recommendation of N for maize (Enwezor *et al*., 1989) can be reduced by half.

Table 4.11: Interaction effects of different levels of N, S and CD on Plant height

	N	S	CD	Plant height (cm) 2	 4	 5	 6	 7
1	0	0	0	7.17^{bcd}	10.00^{cd}	15.33^{f}	22.33^{fgh}	27.00^{b}
2	0	0	5	8.00^{abcd}	14.00^{abcd}	24.83^{abc}	34.00^{abc}	40.67^{ab}
3	0	0	10	7.67^{abcd}	14.00^{abcd}	26.33^{ab}	34.33^{ab}	46.67^{a}
4	0	15	0	5.93^{d}	8.67^{d}	14.71^{f}	20.33^{h}	26.40^{b}
5	0	15	5	7.50^{bcd}	12.67^{abcd}	21.01^{a-f}	25.67^{b-h}	32.67^{ab}
6	0	15	10	10.33^{a}	17.67^{a}	26.50^{ab}	33.50^{a-d}	44.67^{a}
7	0	30	0	6.77^{bcd}	9.00^{cd}	16.17^{def}	23.83^{d-h}	28.33^{b}
8	0	30	5	8.50^{abcd}	12.33^{abcd}	23.17^{abcd}	31.17^{a-g}	39.83^{ab}
9	0	30	10	9.17^{ab}	13.40^{abcd}	24.51^{abc}	30.67^{a-g}	41.00^{ab}
10	60	0	0	8.00^{abcd}	10.17^{cd}	15.67^{f}	21.67^{gh}	27.17^{b}
11	60	0	5	8.83^{abc}	15.33^{abc}	25.83^{abc}	32.50^{a-e}	40.33^{ab}
12	60	0	10	7.27^{bcd}	13.83^{abcd}	24.83^{abc}	33.17^{abcd}	41.00^{ab}
13	60	15	0	6.93^{bcd}	11.90^{abcd}	21.33^{a-f}	26.00^{a-h}	33.20^{ab}
14	60	15	5	8.50^{abcd}	13.33^{abcd}	24.33^{abc}	31.00^{a-g}	38.17^{ab}
15	60	15	10	7.17^{bcd}	13.00^{abcd}	22.83^{a-e}	31.67^{a-f}	45.00^{a}
16	60	30	0	6.33^{cd}	10.50^{cd}	18.83^{c-f}	25.67^{bh}	32.83^{ab}
17	60	30	5	8.17^{abcd}	12.00^{abcd}	21.51^{a-f}	28.67^{a-h}	35.67^{ab}
18	60	30	10	8.00^{abcd}	17.23^{ab}	27.43^{a}	32.33^{a-e}	39.33^{ab}
19	120	0	0	7.00^{bcd}	9.30^{cd}	16.50^{def}	24.50^{c-h}	33.00^{ab}
20	120	0	5	6.83^{bcd}	11.33^{bcd}	19.57^{b-f}	28.33^{a-h}	34.00^{ab}
21	120	0	10	7.67^{abcd}	14.00^{abcd}	28.20^{a}	35.67^{a}	41.53^{ab}
22	120	15	0	6.00^{d}	9.60^{cd}	16.00^{ef}	23.00^{e-h}	33.00^{ab}
23	120	15	5	8.67^{abcd}	13.50^{abcd}	21.33^{a-f}	28.33^{a-h}	35.33^{ab}
24	120	15	10	7.50^{bcd}	14.00^{abcd}	26.00^{abc}	31.83^{a-f}	40.33^{ab}
25	120	30	0	7.33^{bcd}	10.00^{cd}	16.67^{def}	22.33^{fgh}	27.33^{b}
26	120	30	5	7.83^{abcd}	13.33^{abcd}	23.07^{abcd}	32.17^{a-e}	40.41^{ab}
27	120	30	10	6.17^{cd}	13.50^{abcd}	24.11^{abc}	30.53^{a-g}	37.17^{ab}
			Mean	7.60	12.50	21.73	28.71	36.37
			R-Square	0.40	0.40	0.66	0.60	0.45
			CV	18.20	25.30	16.67	16.90	21.38
			LSD	2.20	5.10	5.79	7.80	12.45
			NxSxCD	*	*	*	*	*

** = Significant at P = 0.05*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

4.5.3 Main effect of rates of N, S and Cowdung on number of leaves

Effect of fertilizer application and organic manure amendment on number of leaves per plant is shown in Table 4.12 for week 7 and mean effects of weeks 2 – 6, while effect of the treatments for weeks 2 – 6 is shown in Figures 4.11- 4.13. The treatment effect was not significant at 2, 3 and 4 WAP but the effect was ($P \leq 0.01$) significant at 5, 6 and 7 WAP which is similar to mean effect of the weeks. Foliage production by crops is an index of the level of uptake from the soil by the crop which is influenced by soil fertility and the related environmental conditions or variation in soil fertility as a result of application of fertilizers and management.

Number of leaves increased from an initial mean of 4.8 at 2 WAP to 10.7 at 7 WAP (Figure 4.11 – 4.13) and (Table 4.12) among the N, S and CD application rates, though there was no significant difference in the means obtained from N and S rates, except for CD rates which were significant ($P < 0.01$). The result indicated a good crop response to the application of nutrients and organic manure. The result showed that there was a better response at 60 kg N/ha than with 120 kg N/ha throughout the period of observation but this was not the case with sulphur application at 15 and 30 kg/ha and that of cowdung at 5 and 10 ton/ha respectively, where the higher application levels were nutritionally more effective though not significantly different ($P > 0.05$) with their half application levels.

At the early stages of crop growth (2 – 4 WAP), plant requirement for nutrients was lower than at the later and matured vegetative growth period and treatment effect was not significant, especially among rates of N and S application. A similar result was obtained in Samaru on maize response to combined application of Algifol nutrient solution and N, P, K fertilizers (Ukem, 2011).

Table 4.12: Main effect of rates of N, S and Cowdung on number of leaves

	Weeks After Planting	
N Rates (kg/ha)	**7**	**Mean 2 – 6 weeks**
0	10.30	6.36
60	11.10	7.71
120	10.90	7.41
S Rates (kg/ha)		
0	10.50	7.42
15	10.80	7.52
30	10.90	7.56
CD Rates (tons/ha)		
0	9.10	6.64
5	11.30	7.84
10	11.90	7.98
Mean	10.80	7.38
CV	10.10	12.50
R-Square	0.70	0.89
LSD (0.05)	1.80**	1.56**

*** = Significant at P = 0.01*

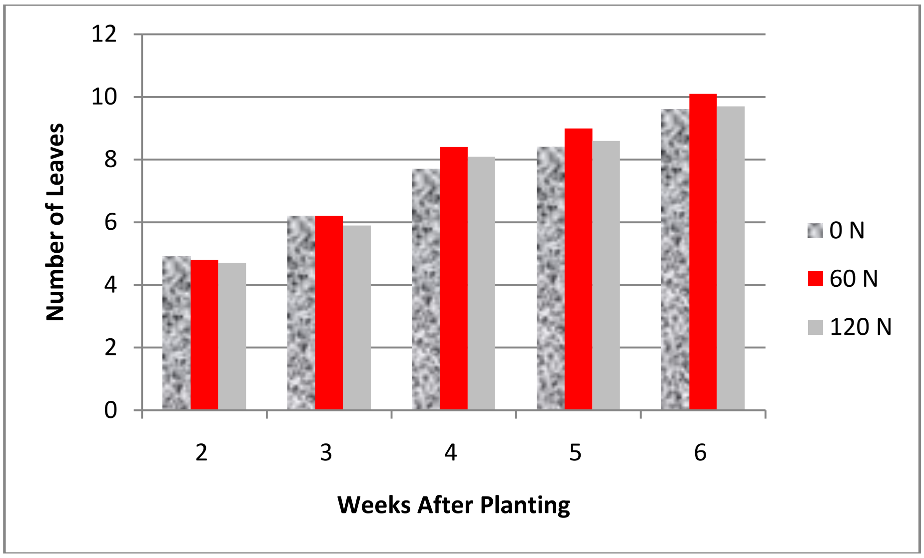


Figure 4.11: Main effect of rates of N on number of leaves

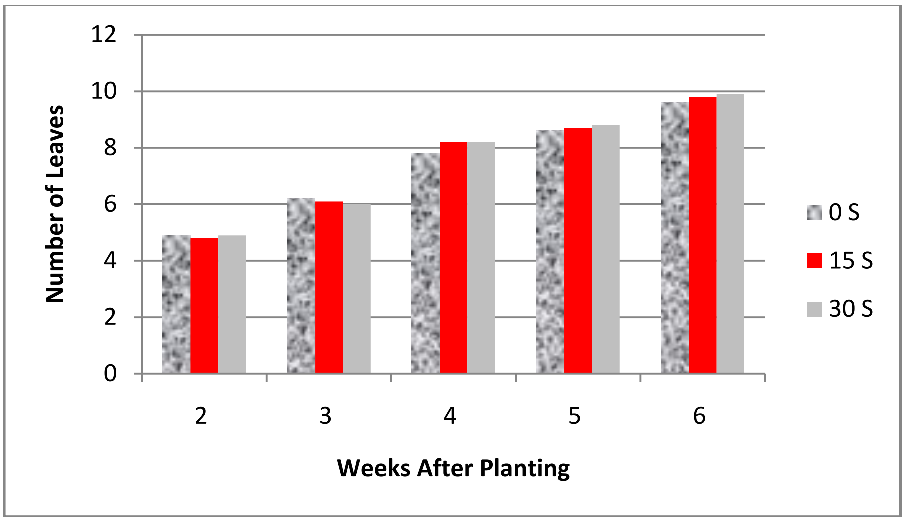
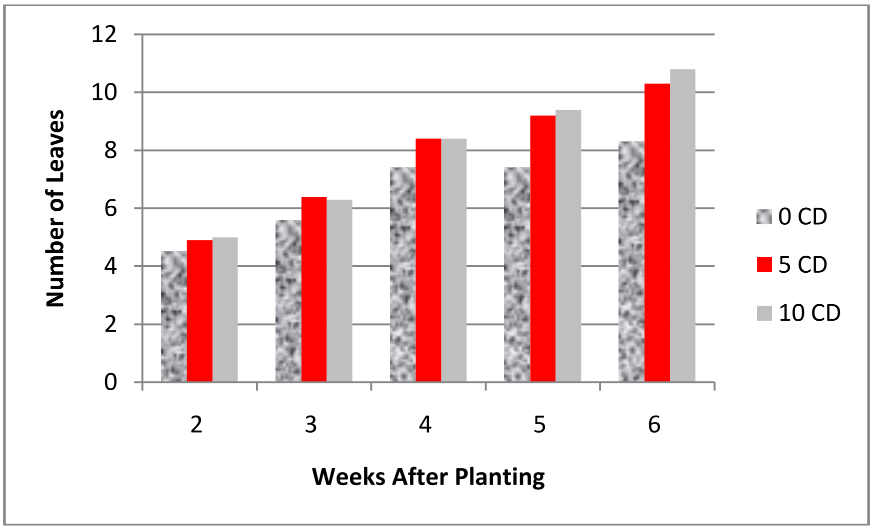


Figure 4.12: Main effect of rates of S on number of leaves



SE± 1.2 1.6 1.6 1.6 1.8

Figure 4.13: Main effect of rates of CD on number of leaves

4.5.3.1 Interaction effect of rates of N, S and Cowdung on number of leaves

The interactive combinations of rates of N, S and CD on number of leaves are presented in Table 4.13. The result showed that the combination of 60 kg N/ha + 15 kg S/ha + 10 ton /ha CD had the highest number of leaves (13) per plant in week 7, though, treatments 18 and 24 also had comparable effects, while the least performance was obtained from 0 kg N/ha + 15 kg S/ha + 0 ton/ha CD with a mean of 8 leaves per plant.

Also, treatment combinations with higher means had the input of sulphur either at 15 kg/ha or 30 kg/ha which were significantly ($P < 0.05$) higher than combinations without sulphur. This indicated that there was a positive interaction effect between sulphur and the other factors (N and CD). However, the mean effect of 0 kg N/ha + 0 kg S/ha + 10 ton CD/ha (12.00) showed that the organic manure alone contributed nutrients to the soil. Soil fertility was therefore improved in response to the application. This enforces the need for organic fertilization of crops in northern Guinea savanna soils.

Table 4.13: Interaction effects of different levels of N, S and Cowdung on number of leaves

				Weeks After Planting				
	N	**S**	**CD**	2	4	5	6	7
1	0	0	0	4.67	7.00^{def}	6.67^{fg}	8.33^{ef}	8.67^{gh}
2	0	0	5	5.00	7.67^{b-f}	9.00^{a-e}	9.67^{a-f}	10.33^{c-g}
3	0	0	10	5.00	8.33^{a-e}	9.67^{abcd}	11.01^{abc}	12.00^{abc}
4	0	15	0	4.33	6.33^{f}	6.33^{g}	7.67^{f}	7.67^{h}
5	0	15	5	4.67	8.33^{a-e}	8.67^{b-f}	10.33^{a-e}	11.00^{a-f}
6	0	15	10	5.67	8.67^{a-d}	9.33^{a-e}	10.33^{a-e}	11.33^{a-e}
7	0	30	0	4.67	7.33^{c-f}	7.67^{defg}	8.33^{ef}	9.00^{fgh}
8	0	30	5	5.67	8.67^{a-d}	9.67^{abcd}	11.33^{ab}	11.67^{abcd}
9	0	30	10	5.00	6.67^{ef}	8.33^{c-g}	9.67^{a-f}	10.67^{b-g}
10	60	0	0	4.67	7.67^{b-f}	7.33^{efg}	8.00^{f}	8.67^{gh}
11	60	0	5	5.33	8.67^{abcd}	10.33^{abc}	10.67^{abcd}	11.33^{a-e}
12	60	0	10	4.67	8.33^{a-e}	9.33^{a-e}	10.67^{abcd}	11.33^{a-e}
13	60	15	0	4.33	8.00^{a-f}	8.00^{d-g}	9.33^{b-f}	9.67^{d-h}
14	60	15	5	5.00	9.00^{abc}	10.33^{abc}	11.33^{ab}	11.67^{abcd}
15	60	15	10	4.67	8.67^{a-d}	8.67^{b-f}	11.00^{abc}	13.00^{a}
16	60	30	0	4.33	7.67^{b-f}	7.67^{d-g}	8.00^{f}	9.00^{fgh}
17	60	30	5	5.00	8.33^{a-e}	8.67^{b-f}	10.33^{a-e}	12.33^{abc}
18	60	30	10	5.33	9.67^{a}	10.67^{ab}	11.33^{ab}	12.67^{ab}
19	120	0	0	4.67	7.33^{c-f}	7.33^{efg}	8.67^{def}	10.33^{c-g}
20	120	0	5	4.67	7.67^{b-f}	8.00^{d-g}	9.00^{c-f}	10.33^{c-g}
21	120	0	10	5.00	7.67^{b-f}	9.33^{a-e}	10.33^{a-e}	11.33^{a-e}
22	120	15	0	4.00	7.33^{c-f}	7.33^{efg}	8.33^{ef}	9.33^{e-h}
23	120	15	5	5.00	8.33^{a-e}	8.33^{c-g}	9.00^{c-f}	10.67^{b-g}
24	120	15	10	5.33	9.00^{abc}	11.00^{a}	11.67^{a}	12.67^{ab}
25	120	30	0	5.00	7.67^{b-f}	8.00^{d-g}	8.33^{ef}	9.67^{d-h}
26	120	30	5	4.33	9.33^{ab}	9.67^{abcd}	11.00^{abc}	12.00^{abc}
27	120	30	10	4.33	8.33^{a-e}	8.67^{b-f}	11.00^{abc}	11.67^{abcd}
			Mean	4.83	8.06	8.67	9.81	10.74
			R-Square	0.32	0.49	0.65	0.67	0.71
			CV	14.92	12.09	12.23	10.99	10.14
			LSD	1.20	1.60	1.69	1.80	1.74
			NxSxCD	NS	*	**	**	**

*NS = Not Significant, * = Significant at P = 0.05, ** = Significant at P = 0.01,*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

4.5.4 Main effect of rates of N, S and Cowdung on stem girth

The treatments effect on stem girth is presented in Table 4.14 for week 7 and the mean effect of weeks 2 - 6, while the treatment effects of different levels of N, S and CD for weeks 2 – 6 are presented in Figures 4.14 – 4.16. The result showed that at the beginning of the trial, there was no significant ($P \geq 0.05$) effect among the fertilizers and cowdung levels at 2 and 3 WAP, but highly ($P \leq 0.01$) significant differences were obtained from 4 to 7 WAP in addition to the mean effects.

As weeks after planting increased, nutrient demand by the crop also increased hence resulting in the crop removing more available nutrients from the soil than before and thereby creating a sink, especially at the initiation of reproductive stage of development and the later grain filling phase. This occurrence might be responsible for the highly significant effect obtained from the highest application rates of both sulphur and cowdung in combination with N application at 60 kg/ha owing to efficient crop physiological benefit derived from S and N combination.

Table 4.14: Main effects of rates of N, S and Cowdung on stem girth (cm)

	Weeks After Planting	
N Rates (kg/ha)	**7**	**Mean 2 – 6 weeks**
0	6.6	3.56
60	6.9	3.74
120	6.6	3.51
S Rates (kg/ha)		
0	6.5	3.5
15	6.7	3.6
30	6.9	3.7
CD Rates (tons/ha)		
0	5.4	2.68
5	7.2	3.92
10	7.6	4.2
Mean	6.7	3.61
CV	13.00	17.02
R-Square	0.70	0.62
LSD (0.05)	1.40**	1.04**

*** = Significant at P = 0.01*

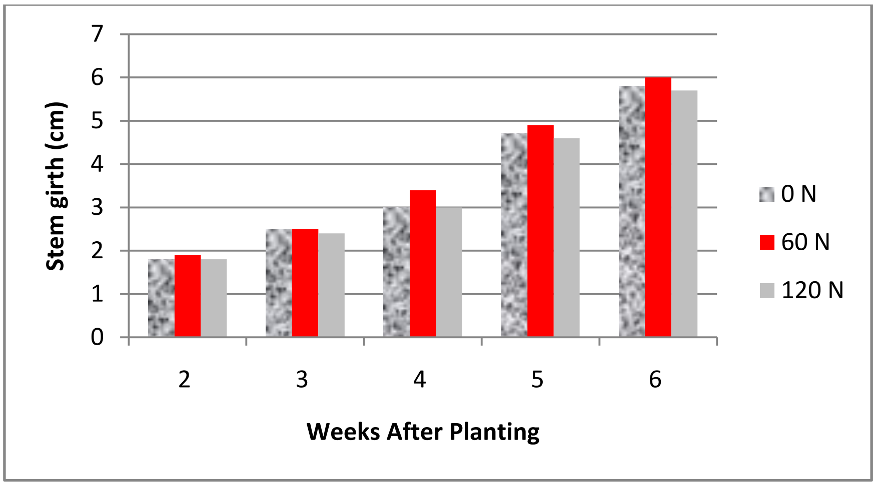


Figure 4.14: Main effect of rates of N on stem girth

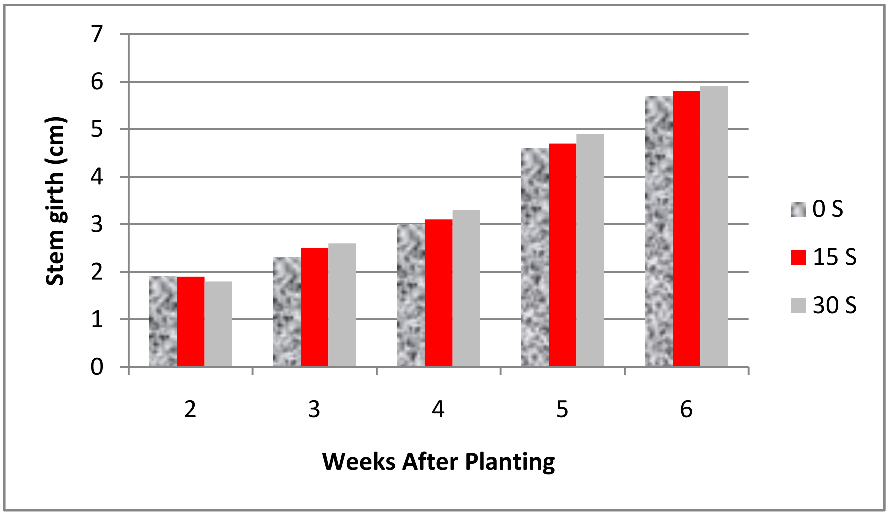
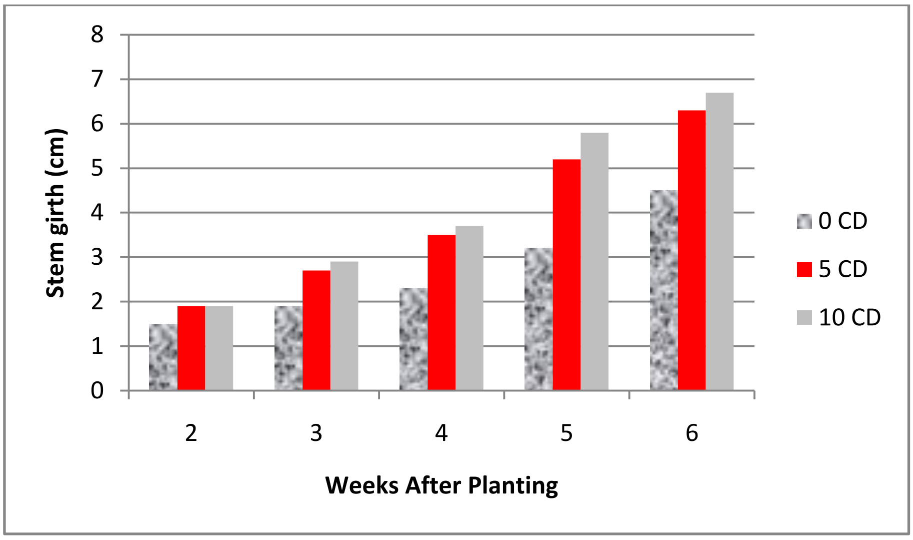


Figure 4.15: Main effect of rates of S on stem girth



SE±	2.6	1.1	1.1	1.2	1.2

Figure 4.16: Main effect of rates of CD on stem girth

4.5.5 Interaction effect of different levels of N, S and CD on plant girth

The interaction effect of different levels of N, S and CD on plant stalk girth was not significant ($P > 0.05$) in weeks 2, 4 and 6; however, there was a progressive increase in stalk girth recorded among the treatments within the same period (Table 4.15). The control treatment had the least effect compared to treatments which received N, S and CD during the same period.

The best interactive combination in week 5 was 6.27 cm obtained from 60 kg/ha + 30 kg/ha + 10 kg/ha but not significantly different ($P > 0.05$) with treatments 6 and 24, while the least effect was obtained from control treatment having 2.90 cm (Table 4.15). In week 7, best interaction was 120 kg/ha + 15 kg/ha + 10 kg/ha (8.07 cm) compared with 4.77 cm got from control plot. The result was significant ($P < 0.01$).

It was observed that treatments having 60 or 120 kg N/ha with half rate of S had a better response with 10 ton/ha CD than with 5 ton/ha CD, indicating a better agronomic efficiency of the higher application rate of organic manure. There was however no significant difference between 60 and 120 kg N/ha during the interaction. Amendment with cowdung at 10 ton/ha in the interaction may have added inorganic N to the soil and as such,impact of higher rate of applied N was same as half its rate.

Table 4.15: Interaction effects of different levels of N, S and CD on plant girth

				Plant girth (cm)				
	N	**S**	**CD**	2	4	5	6	7
1	0	0	0	1.43	1.80	2.90^{e}	3.83	4.77^{h}
2	0	0	5	2.00	3.53	5.37^{ab}	6.00	7.00^{a-f}
3	0	0	10	2.30	3.60	5.90^{ab}	6.76	7.41^{abc}
4	0	15	0	1.30	1.87	2.73^{e}	4.00	4.87^{h}
5	0	15	5	1.67	3.23	5.13^{abc}	6.43	6.57^{a-g}
6	0	15	10	2.20	4.17	6.23^{a}	6.97	7.67^{ab}
7	0	30	0	1.50	2.33	3.47^{de}	5.00	5.80^{c-h}
8	0	30	5	2.17	3.77	5.70^{ab}	6.93	7.77^{a}
9	0	30	10	1.87	3.10	5.40^{ab}	6.13	7.67^{ab}
10	60	0	0	1.77	2.40	3.50^{de}	4.43	5.47^{e-h}
11	60	0	5	2.10	4.30	5.87^{ab}	7.00	7.71^{a}
12	60	0	10	1.87	3.53	5.77^{ab}	6.77	7.17^{a-e}
13	60	15	0	1.50	2.53	3.47^{de}	5.00	5.97^{b-h}
14	60	15	5	2.07	3.60	5.23^{abc}	6.30	6.87^{a-g}
15	60	15	10	1.93	3.63	5.50^{ab}	6.90	7.90^{a}
16	60	30	0	1.60	2.47	3.33^{de}	4.57	5.51^{e-h}
17	60	30	5	2.03	3.53	5.37^{ab}	6.30	7.87^{a}
18	60	30	10	1.93	4.20	6.27^{a}	7.07	8.03^{a}
19	120	0	0	1.63	2.30	2.93^{e}	4.73	5.63^{d-h}
20	120	0	5	1.83	2.67	3.90^{cde}	5.47	6.41^{a-h}
21	120	0	10	1.97	3.10	5.50^{ab}	6.30	7.27^{abcd}
22	120	15	0	1.43	2.23	3.23^{de}	4.00	5.20^{gh}
23	120	15	5	1.87	3.00	4.63^{bcd}	5.50	6.83^{a-g}
24	120	15	10	2.07	4.03	6.23^{a}	4.97	8.07^{a}
25	120	30	0	1.73	2.50	3.43^{de}	4.47	5.33^{fgh}
26	120	30	5	1.80	3.83	5.51^{ab}	6.83	7.47^{abc}
27	120	30	10	1.80	3.63	5.61^{ab}	6.67	7.01^{a-f}
Mean				1.83	3.14	4.74	5.76	6.71
R-Square				0.41	0.68	0.77	0.74	0.69
CV				20.00	10.47	16.49	13.61	13.03
LSD				0.60	1.20	1.25	1.40	1.39
NxSxCD				NS	NS	**	NS	**

*NS = Not Significant, ** = Significant at P = 0.01,*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

4.5.6 Main effects of rates of N, S and Cowdung on leaf area

Results of effect of fertilizer and cowdung application rates on maize leaf area for weeks 2 – 6 are presented in Figures 4.17- 4.19, while the effect on week 7 and mean effect of the treatments for weeks 2 - 6 are shown in Table 4.16.

The largest leaf area of 247.2cm^2 was obtained from the application rate of 10 ton/ha cowdung though not statistically different from the performance of N and S application at 60 and 120 kg/ha, 15 and 30 kg/ha respectively and cowdung at 5 ton/ha (Table 4.16). At 6 WAP, leaf area of 193.6cm^2 was obtained from 10 ton/ha CD application which was 43.0% higher than the control with leaf area of 87.5cm^2. However, result at 6 WAP with 10 ton/ha CD was statistically similar to N levels at 60 and 120 kg/ha and sulphur levels at 15 and 30 kg/ha, indicating a positive contribution from the amendments.

Table 4.16: Main effects of rates of N, S and Cowdung on leaf area

	Weeks After Planting (cm^2)	
N Rates (kg/ha)	**7**	**Mean 2 – 6 weeks**
0	201.10	89.6
60	233.40	98.44
120	221.40	85.8
S Rates (kg/ha)		
0	203.30	82.98
15	203.30	91.82
30	229.30	99.08
CD Rates (tons/ha)		
0	173.10	55.44
5	235.60	99.16
10	247.20	119.26
Mean	216.40	91.29
CV	22.60	32.70
R-Square	0.60	0.85
LSD (0.05)	79.20	51.38*

** = Significant at P = 0.05, ** = Significant at P = 0.01,*

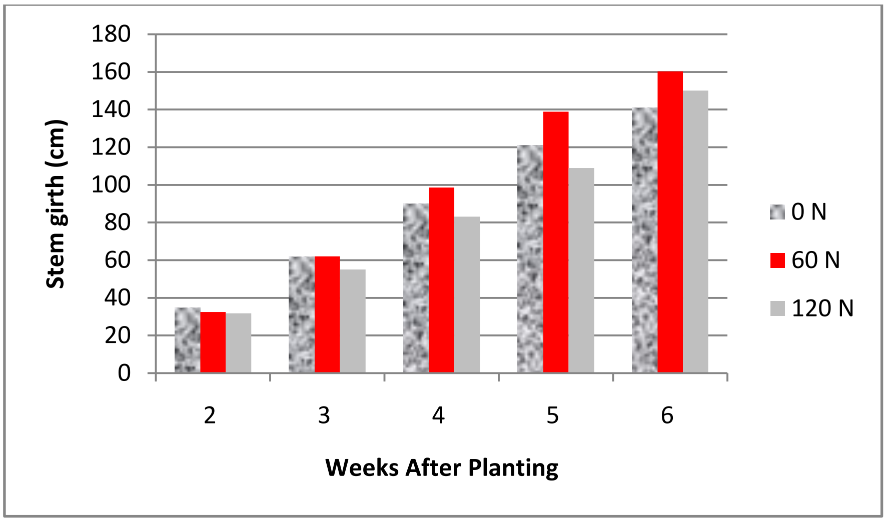


Figure 4.17: **Main effect of rates of N on leaf area**

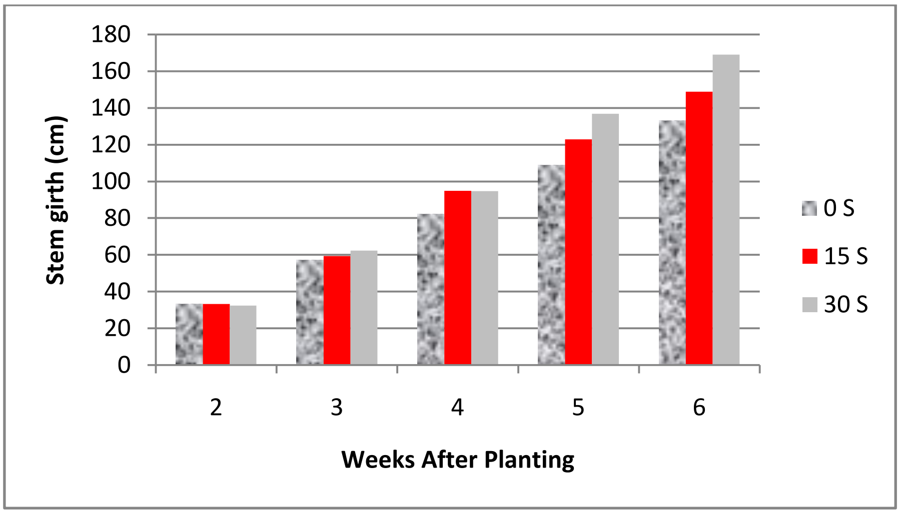
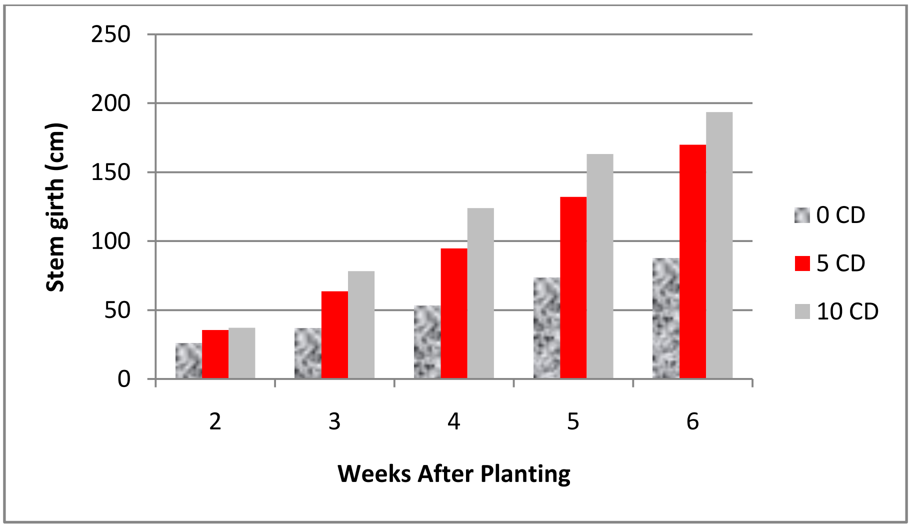


Figure 4.18: Main effect of rates of S on leaf area



SE± 23.4 42.4 65.1 60.7 67.3

Figure 4.19: Main effect of rates of CD on leaf area

4.5.7 Interaction effect of different levels of N, S and CD on plant leaf area

The interactive combination of 120 kg N/ha with 30 kg S/ha and 5 ton/ha CD was the best performing combination in plant leaf area with a mean of 327.87 cm^2 obtained in week 7, while the least effect (128.27 cm^2) was obtained from the combination of 60 kg N/ha + 0 kg S/ha + 0 ton CD/ha (Table 4.17).

The interaction of 0 kg N/ha with 15 kg S/ha and 10 ton/ha CD produced the largest leaf area of 57.43cm^2 in week 2, though the result was not significantly different with 42.40 cm^2 obtained from the combination of 120 kg N/ha with 15 kg S/ha and 10 ton/ha CD. A similar performance was obtained from these interactions in week 4. But at 6 WAP, the highest effect was obtained from the combination of 120 kg N/ha with 30 kg S/ha and 5 ton/ha CD with leaf area of 249.73cm^2 which was statistically at par with 232.47cm^2 obtained from the interaction of 120 kg N/ha with 30 kg S/ha and 10 ton/ha CD (Table 4.17).

As the growth duration advanced, there was a corresponding increase in nutritional requirements of the crop, which led to comparably larger leaf area in weeks 5, 6 and 7 than the preceding weeks. Also, the result obtained in week 6 showed that the higher nutrient combinations, especially N at 120 kg/ha and S at 30 kg/ha were more effective in enhancing physiological growth and development of the crop than half application rates of these nutrients.

Table 4.17: Interaction effects of different levels of N, S and CD on leaf area

				Plant leaf area (cm^2)				
	N	**S**	**CD**	2	4	5	6	7
1	0	0	0	22.63^{bc}	43.20^{ef}	61.33^{hi}	63.97^{i}	145.13^{fg}
2	0	0	5	44.70^{abc}	93.73^{a-f}	127.27^{b-i}	135.10^{e-i}	195.13^{c-g}
3	0	0	10	29.77^{abc}	113.97^{a-f}	146.71^{b-e}	193.03^{a-e}	239.51^{a-f}
4	0	15	0	18.93^{c}	40.73^{f}	66.96^{ghi}	77.00^{i}	152.40^{f-g}
5	0	15	5	27.63^{bc}	81.90^{b-f}	113.21^{d-i}	143.17^{c-i}	226.73^{b-f}
6	0	15	10	57.43^{a}	165.87^{a}	196.73^{ab}	218.37^{abcd}	267.67^{abc}
7	0	30	0	22.97^{bc}	36.87^{f}	67.77^{ghi}	98.63^{fghi}	167.57^{d-g}
8	0	30	5	51.07^{ab}	130.90^{a-d}	165.81^{bcd}	171.03^{a-f}	211.63^{b-g}
9	0	30	10	36.30^{abc}	102.20^{a-f}	143.03^{b-f}	167.07^{b-f}	204.53^{d-g}
10	60	0	0	36.67^{abc}	58.63^{def}	66.77^{ghi}	70.50^{i}	128.27^{g}
11	60	0	5	38.83^{abc}	136.97^{abcd}	193.01^{abc}	220.80^{abc}	259.00^{abcd}
12	60	0	10	34.87^{abc}	106.57^{a-f}	132.26^{b-h}	162.00^{b-g}	226.20^{b-f}
13	60	15	0	25.87^{bc}	61.70^{def}	115.56^{d-i}	122.07^{e-i}	199.80^{b-g}
14	60	15	5	34.10^{abc}	106.33^{a-f}	141.01^{b-g}	185.50^{a-e}	270.73^{abc}
15	60	15	10	31.07^{abc}	121.60^{a-e}	162.26^{bcd}	197.87^{a-e}	276.30^{abc}
16	60	30	0	22.67^{bc}	60.10^{def}	73.47^{e-i}	79.57^{hi}	211.57^{b-g}
17	60	30	5	28.33^{abc}	77.17^{cdef}	119.51^{c-i}	171.07^{a-f}	232.97^{a-f}
18	60	30	10	39.30^{abc}	158.63^{ab}	246.87^{a}	232.60^{ab}	295.83^{ab}
19	120	0	0	30.87^{abc}	44.77^{ef}	63.87^{hi}	74.70^{i}	202.27^{b-g}
20	120	0	5	25.13^{bc}	47.50^{ef}	70.93^{f-i}	116.76^{e-i}	199.67^{b-g}
21	120	0	10	36.77^{abc}	94.93^{a-f}	119.23^{c-i}	160.20^{b-h}	234.73^{a-f}
22	120	15	0	24.70^{bc}	49.73^{ef}	53.83^{i}	81.10^{ghi}	191.51^{c-g}
23	120	15	5	36.53^{abc}	83.27^{b-f}	96.66^{d-i}	136.77^{d-i}	196.90^{c-g}
24	120	15	10	42.40^{abc}	142.07^{abc}	160.31^{bcd}	178.87^{a-f}	227.33^{b-f}
25	120	30	0	29.83^{abc}	81.50^{b-f}	92.73^{d-i}	119.57^{e-i}	158.93^{efg}
26	120	30	5	32.53^{abc}	95.30^{a-f}	161.21^{bcd}	249.73^{a}	327.87^{a}
27	120	30	10	27.23^{bc}	109.87^{a-f}	161.86^{bcd}	232.47^{ab}	253.03^{a-e}
			Mean	32.93	90.59	122.97	150.35	218.64
			R-Square	0.40	0.70	0.71	0.72	0.57
			CV	44.40	43.50	30.95	27.96	22.63
			LSD	23.40	63.10	60.89	67.30	79.17
			NxSxCD	*	*	**	*	*

** = Significant at P = 0.05, ** = Significant at P = 0.01,*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

4.5.8 Main effects of rates of N, S and CD on dry matter

The main effect of rates of N, on stover is presented in Table 4.18. Results showed that response to N application increased marginally among the different levels of N, with the least effect obtained from control with a mean of 12.2 g, while 60 kg N/ha had a mean stover of 15.8 g and application of 120 kg N/ha had stover weight of 16.6 g. Differences in the means were not significant ($P > 0.05$), but there was a noticeable positive effect of N fertilizer application.

Similarly, mean response of stover to sulphur fertilizer rates showed that dry matter increased with rates of applied sulphur (Table 4.18). The least effect was obtained from control with a mean of 13.3 g compared with 15.2 g got from the application of 15 kg S/ha while the highest effect (16.1 g) was obtained from 30 kg S/ha. However, the treatment means were not significantly different ($P > 0.05$).

Also, the effect of rates of CD (0, 5 and 10 ton/ha) followed the same trend of response obtained from N and S application rates, where dry matter increased as the rates of the applied nutrients increased (Table 4.18).However, results obtained with 5 ton/ha CD (18.8 g) and 10 ton/ha CD (19.2 g) were significantly higher ($P < 0.01$) than the mean effect of control.

The result has shown that input of organic manure was effective in enhancing plant dry matter, presumably due to its ability to provide additional nutrients for plant use and recognizing the prime role of organic manure in soil fertility management.

Table 4.18: Main effects of N, S and Cowdung rates on stover and root weight

N Rates (kg/ha)	Stover yield (g)	Root weight (g)
0	12.20	13.20
60	15.80	23.30
120	16.60	19.20
S Rates (kg/ha)		
0	13.30	17.30
15	15.20	17.90
30	16.10	20.50
CD Rates (tons/ha)		
0	6.50	10.90
5	18.80	19.20
10	19.20	25.60
Mean	14.90	18.60
CV	42.10	43.70
R-Square	0.70	0.60
LSD (0.05)	10.00**	13.00**

*** = Significant at P = 0.01*

4.5.9 Main effect of rates of N, S and CD on root weight

Mean effect of rates of N on root weight was higher with 60 kg N/ha than with 120 kg N/ha, while the control treatment had the least root weight (Table 4.18). Their treatment means were 13.2 g; 23.3 g and 19.2 g for control, 60 kg N/ha and 120 kg N/ha respectively. From the results, 60 kg N/ha surpassed control plot by 43.34 % and 120 kg N/ha by 17.61 %, though difference in their treatment means was not significant.

The effects of N and S rates were not significant (*P* > 0.05) on root weight, though higher S rates had marginal increase. The initial soil sulphur content coupled with the contribution of S by applied SSP fertilizer may have reduced the effect of sulphur fertilizer application. However, there was a significant benefit of organic manure application on root weight. The result showed that differences between 0 and 5 ton/ha CD; 0 and 10 ton/ha CD were 15% and 26% respectively (Table 4.18). In view of this, input of organic manure, especially at higher rate (10 ton/ha CD) was of great benefit and played a significant role in root growth and development.

4.5.10 Interactive combinations of N, S and CD on shoot dry matter and root weight

Results presented in Table 4.19 are the effect of interactive combinations of levels of N, S and CD on plant stover and root weight. The combination of 120 kg N/ha with 0 kg S/ha and 10 ton/ha CD had the highest effect on stover with a mean of 26.33 g while the least effect (0.30 g) was received from the control plots of N,S and CD. The difference in their means was 98 %. However, the interaction of 60 kg N/ha + 15 kg S/ha + 5 ton/ha CD had 24.01 g stover yield which could be compared with 26.33 g of the best performing combination (Table 4.19), though their interaction means were not significant.

Availability of nutrients as a result of the application of N, S and CD increased the amount of nutrients in the soil which effectively nourished the growth of maize better than when these nutrients were not applied.

Treatments effect on root weight showed that best performing combination was 120 kg N/ha + 30 kg S/ha + 10 ton/ha CD with a mean of 37.27 g which was significantly ($P < 0.01$) higher than the mean effect of many other treatment combinations, while the control plot had the least effect (3.83 g) (Table 4.19). The difference between these means was 82%, indicating beneficial role of the interaction in soil fertility and in crop nutrition. Also it was observed that root weight responded consistently and significantly ($P < 0.01$) to increasing rates of CD application.Therefore, addition of CD increased soil fertility.

Table 4.19: Interaction effects of different levels of N, S and CD on shoot dry matter and root weight

	N	S	CD		Shoot dry Matter (g)	Root Weight (g)
1	0	0	0		0.30^{g}	3.83^{g}
2	0	0	5		7.67^{def}	14.00^{defg}
3	0	0	10		17.67^{abcd}	13.00^{efg}
4	0	15	0		1.33^{g}	8.73^{fg}
5	0	15	5		15.33^{a-f}	10.00^{efg}
6	0	15	10		21.67^{abcd}	25.00^{a-e}
7	0	30	0		5.07^{efg}	8.33^{fg}
8	0	30	5		21.01^{abc}	13.00^{efg}
9	0	30	10		20.01^{abcd}	22.67^{a-f}
10	60	0	0		3.33^{fg}	8.77^{fg}
11	60	0	5		20.67^{abc}	30.00^{abcd}
12	60	0	10		20.01^{abcd}	31.67^{abc}
13	60	15	0		10.30^{b-g}	15.00^{defg}
14	60	15	5		24.00^{a}	25.33^{a-e}
15	60	15	10		17.00^{a-e}	25.00^{a-e}
16	60	30	0		10.83^{b-g}	16.00^{c-g}
17	60	30	5		15.00^{a-f}	24.00^{a-f}
18	60	30	10		20.00^{abcd}	33.67^{ab}
19	120	0	0		3.67^{fg}	15.23^{defg}
20	120	0	5		20.00^{abcd}	17.21^{c-g}
21	120	0	10		26.33^{a}	21.67^{a-f}
22	120	15	0		9.20^{c-g}	11.67^{efg}
23	120	15	5		22.33^{ab}	20.17^{b-f}
24	120	15	10		15.33^{a-f}	20.21^{b-f}
25	120	30	0		14.00^{a-f}	10.73^{efg}
26	120	30	5		23.00^{ab}	18.67^{b-g}
27	120	30	10		15.00^{a-f}	37.27^{a}
				Mean	14.86	18.55
				R-Square	0.71	0.61
				CV	42.10	43.7
				LSD	10.23	13.28
				NxSxCD	*	*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

4.6 Main effects of different levels of N, S, and CD application on soil chemical properties in the greenhouse

4.6.1 Soil pH

Main effects of treatments on soil pH (H_2O) are presented in Table 4.20. Soil pH decreased consistently and significantly ($P \leq 0.01$) with increasing levels of N fertilizer application. Values ranged from 7.65 to 7.39 from 0 to 120 kg N applied.

Though pH values were slightly alkaline, the acidifying effects of applied mineral fertilizers were shown. However, this trend was the reverse with sulphur application where pH increased slightly with increase in S rates though their treatment means were not significantly ($P > 0.05$) different. With cowdung, application rates increased soil pH significantly and consistently from 6.84 to 8.04 with increasing levels of CD (Table 4.20). This represented increase of 33.98% and 35.67% respectively for 5 ton/ha and 10 ton/ha CD application over the control. From the result, it shows that N fertilizer application tended to acidify the soil more than sulphur and cowdung.

4.6.1.1 Interactive combinations of levels of N, S and CD on soil pH

The interaction of 0 kg N/ha + 30 kg S/ha + 10 ton/ha CD had the highest soil pH (8.21) compared with 120 kg N/ha + 30 kg S/ha + 0 ton/ha CD with a mean soil pH of 6.03. However, treatment combinations 3, 6, 8, 24 and 27 were not significantly different ($P > 0.05$) (Table 4.21). The acidifying effect of mineral nitrogen fertilizer at 120 kg N/ha was shown among the treatment means. Plots which did not receive N but in combination with 15 – 30 kg S/ha and 10 ton/ha CD tend to have relatively higher pH values than those that had higher N rate.

4.6.2 Soil Sulphur Content

The main effects of N, S and CD application rates on soil S content is also shown in Table 4.20. The results indicated that all the factors (N, S and CD) consistently had a positive impact on soil S content.

Soil sulphur content increased with rate of N application, where, zero N plot had the least S content (10.26 mg/kg), while N at 60 kg/ha had 12.47 mg/kg, 120 kg/ha was the highest with 13.44 mg/kg (Table 4.20). The result showed that N fertilizer application increased availability of sulphur in the soil, though differences in the treatment means were not significant ($P > 0.01$). This indicated a positive influence of N on soil sulphur content, which could be attributed to the synergy between the two elements (Friesen, 1991). It could be assumed that in sulphur deficient soils, nitrogen may also be deficient, since the availability of these elements is dictated by similar soil physical properties (particularly, texture and clay minerals), organic matter content and the pH (Brady and Weil, 2005; Khan *et al*., 2011).

Among the sulphur rates, 30 kg S/ha (13.29 mg/kg) was significantly ($P < 0.05$) higher than 0 kg S/ha which had 9.90 mg/kg (Table 4.20). The application therefore had a positive impact. A similar result was obtained among CD rates in which, soil suphur content increased with increase in CD application rates. Best result was got from 10 ton/ha CD (14.22 mg/kg) which was higher ($P < 0.05$) than with 0 ton/ha CD. The results therefore showed a positive response to the amendment and indicating that the soil fertility was initially low.

Table 4.20: Main effects of different levels of N, S and Cowdung application on soil chemical properties under greenhouse conditions

	Soil pH (H_2O)	Organic Carbon (g/kg)	Soil N conc. (g/kg)	Soil S conc. (mg/kg)
N Rates (kg/ha)				
0	7.65	12.90	1.10	10.26
60	7.50	12.90	1.50	12.47
120	7.39	12.90	1.60	13.44
S Rates (kg/ha)				
0	7.47	12.60	1.20	9.90
15	7.49	13.40	1.40	12.99
30	7.58	12.70	1.60	13.29
CD Rates (tons/ha)				
0	6.84	9.70	0.90	9.87
5	7.66	13.30	1.50	12.70
10	8.04	15.70	1.70	14.22
Mean	7.51	12.90	1.40	12.06
CV	6.51	15.15	29.50	20.07
R^2	0.68	0.72	0.71	0.73
LSD (0.05)	0.78**	0.31**	0.07**	3.88**

*** = Significant at P = 0.01*

4.6.2.1 Interactive combinations of levels of N, S and CD on soil sulphur content

The results presented in Table 4.21 are the interactive combinations of levels of N, S and CD on soil sulphur content. The best interactive combination was obtained from 120 kg N/ha + 30 kg S /ha + 10 ton /ha CD (18.11 mg/kg) and a similar performance was obtained from the interaction of 60 kg N/ha + 15 kg S /ha + 10 ton /ha CD, while the least effect was obtained from control with a mean sulphur content of 4.73 mg/kg. The difference between these means was significant ($P < 0.01$).

From the result,there was an evidence of a positive effect of mineral sulphur fertilizer application on soil sulphur content as interactions with zero sulphur rate had significantly ($P < 0.05$) lower soil S content compared to the ones with either 15 or 30 kg S/ha (Table 4.21). However, there was no significant difference among the treatment means consisting of either 15 or 30 kg S/ha. Interactions having CD were significantly higher than the ones without, indicating that the amendment also contributed additional sulphur to the soil other than mineral sulphur fertilizer application.

The combination of sulphur with nitrogen enhanced performance and crop use efficiency of either nutrient. Therefore, their co-application significantly contributed to increase in soil sulphur content after plant uptake. In particular, the presence of cowdung which provided a favourable soil physical condition to enhance retention of SO_4^{2-}. Khan *et al.* (2011) reported that soil characteristics particularly the texture, clay minerals, pH and organic matter influence the content of plant available sulphur by controlling the retention and leaching characteristics of SO_4^{2-} in soils.

4.6.3 Soil Organic Carbon

The effect of CD treatment on soil organic carbon (SOC) content was ($P < 0.01$) significant. Comparatively, cowdung application at 10 ton/ha produced the highest SOC content while the least was obtained from the control plot for S and CD rates (Table 4.20).

Nitrogen application rates did not induce significant differences whereas with sulphur rates, SOC content increased only up to 15 kg/ha S application rate. The performance of sulphur at 30 kg/ha indicated that soil organic matter mineralization may not require higher rates of applied sulphur, probably due to the contribution of sulphur by SSP and the initial soil content.

4.6.3.1 Interactive combinations of levels of N, S and CD on soil organic carbon content

The interactive combinations of rates of N, S and CD on soil organic carbon (SOC) content revealed that the combination of 60 kg N/ha + 30 kg S/ha + 10 ton/ha CD had the highest SOC of 16.4 g/kg and the same effect was obtained with 0 kg N/ha + 15 kg S/ha + 10 ton/ha CD and 0 kg N/ha + 30 kg S/ha + 10 ton/ha CD, while the least effect was obtained with 0 kg N/ha + 30 kg S/ha + 0 ton/ha CD with a mean SOC of 7.9 g/kg (Table 4.21).

All treatment combinations with CD had significantly ($P < 0.01$) higher means than combinations without, indicating that soil quality was better enhanced with input of organic matter than with mineral fertilizer application. The impact of applied N to increasing SOC was less than the contribution of CD and much less with sulphur fertilizer, though availability of N is needed in the soil to stimulate early biological activity (Singh *et al.,* 2004).

4.6.4 Soil nitrogen

Soil nitrogen content at the end of planting is also contained in Table 4.20. The treatment means were positively influenced by the different application levels of N, S and CD. The mean N concentration in the soil was less than the critical level of soil nitrogen status of the savanna soil (Chude *et al*., 2012, Lombin, 1987). It can be deduced that, N obtained from external application of urea and that mineralized from added organic residue was rapidly utilized by the crop for its growth and nutritional needs since the initial concentration was low.

Response to nitrogen rates showed that soil N content increased with increasing rates of N application. The difference between the means of 120 kg N/ha and 0 kg N/ha was 31%. Also, the mean effect of 120 kg N/ha was higher ($P < 0.01$) than with 60 kg N/ha, indicating a high agronomic value of nitrogen fertilizer application in Northern Guinea savanna soil.

Similarly, effect of rates of sulphur fertilizer application on soil N content showed that soil N content increased with rates of S fertilizer application. The application of 0 kg S/ha had the least effect (1.2 g/kg) while 30 kg S/ha had the highest mean of 1.6 g/kg (Table 4.20). The difference among the treatment means was significant ($P < 0.01$).

Effect of CD rates on soil N content followed a similar pattern as shown by N and S rates where, soil N content increased with increase rates of the amendment. The results obtained were 0.9 g/kg; 1.5 g/kg and 1.7 g/kg for 0 ton/ha; 5 ton/ha and 10 ton/ha (Table 4.20). Differences in the treatment means were significant ($P < 0.01$). The trend of response showed that input of CD increased soil N content at the end of cultivation; therefore, there was a positive residual effect of organic manure application on soil chemical properties.

4.6.4.1 Interactive combinations of levels of N, S and CD on soil nitrogen content

The interaction of 60 kg N/ha + 0 kg S/ha + 10 ton/ha CD had the highest soil N content (0.26 g/kg) while, the least effect (0.04 g/kg) was obtained from control plot. However, interaction effect of 120 kg N/ha + 15 kg S/ha + 10 ton/ha CD (0.22 g/kg) compared with the best performing combination (0.26 g/kg) (Table 4.21). Differences between their treatment means were not significant.

Treatment combinations with sulphur had a less impact on soil N content compared to the combination with CD. Also, the combination with rates of N either at 60 or 120 kg/ha with CD at 10 ton/ha was more effective in contributing nitrogen to the soil. In view of this, availability of N in soil was boosted more by mineral N fertilizer application than mineral sulphur fertilizer application. Also, the addition of organic manure further increased the content of soil nitrogen. The result obtained from the control plot was however consistent with the findings of previous workers on acute low nitrogen content of the northern Guinea savanna soil (Malgwi and Kparamwang, 2002); Esu, 1991; Lombin, 1987.

Table 4.21: Interaction effects of different levels of N, S and Cowdung application on soil chemical properties under greenhouse

	N	**S**	**CD**		pH (H_2O)	S (mg/kg)	OC (g/kg)	N (g/kg)
1	0	0	0		7.07^{c-h}	4.73^{i}	9.50^{jk}	0.04^{i}
2	0	0	5		7.23^{b-h}	10.97^{c-h}	12.50^{fg}	0.07^{ghi}
3	0	0	10		8.13^{ab}	9.06^{e-i}	15.30^{c}	0.11^{d-i}
4	0	15	0		6.77^{fghi}	8.03^{ghi}	11.60^{h}	0.06^{hi}
5	0	15	5		8.00^{abc}	12.48^{b-g}	13.50^{e}	0.16^{b-f}
6	0	15	10		8.07^{ab}	11.10^{c-h}	16.40^{a}	0.11^{d-i}
7	0	30	0		7.33^{a-h}	10.46^{d-h}	7.90^{l}	0.08^{fghi}
8	0	30	5		8.07^{ab}	11.07^{c-h}	12.70^{f}	0.15^{b-g}
9	0	30	10		8.21^{a}	14.48^{abcd}	16.40^{a}	0.20^{abc}
10	60	0	0		7.37^{a-h}	6.95^{hi}	9.30^{k}	0.05^{hi}
11	60	0	5		7.43^{a-h}	10.57^{d-h}	12.20^{g}	0.15^{b-g}
12	60	0	10		8.00^{abc}	12.68^{b-g}	16.30^{a}	0.26^{a}
13	60	15	0		6.60^{hi}	8.43^{fghi}	10.70^{i}	0.12^{c-i}
14	60	15	5		7.63^{a-f}	14.19^{abcd}	13.70^{e}	0.13^{c-h}
15	60	15	10		7.90^{abc}	18.11^{a}	14.70^{d}	0.18^{bcde}
16	60	30	0		6.91^{d-i}	12.45^{b-g}	9.80^{j}	0.15^{b-g}
17	60	30	5		7.86^{abcd}	12.28^{b-g}	12.60^{f}	0.17^{bcde}
18	60	30	10		7.80^{a-e}	16.71^{ab}	16.40^{a}	0.15^{b-g}
19	120	0	0		6.87^{e-i}	8.39^{fghi}	9.50^{jk}	0.07^{ghi}
20	120	0	5		7.23^{b-h}	13.48^{bcde}	13.60^{e}	0.19^{abcd}
21	120	0	10		7.90^{abc}	12.28^{b-f}	14.90^{d}	0.13^{c-h}
22	120	15	0		6.67^{a-g}	12.96^{b-g}	9.50^{d}	0.12^{c-h}
23	120	15	5		7.60^{ghi}	16.10^{ab}	14.60^{jk}	0.13^{c-i}
24	120	15	10		8.17^{ab}	15.49^{abc}	15.90^{b}	0.22^{ab}
25	120	30	0		6.03^{i}	10.97^{c-h}	9.60^{jk}	0.19^{abcd}
26	120	30	5		7.83^{abcd}	13.16^{b-f}	13.70^{e}	0.18^{bcde}
27	120	30	10		8.20^{ab}	18.11^{a}	14.90^{d}	0.16^{b-f}
				Mean	7.51	12.06	12.90	0.14
				R-Square	0.68	0.73	0.72	0.72
				CV	6.51	20.07	15.15	29.50
				LSD	0.78	3.88	0.31	0.07
				NxSxCD	*	**	*	**

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

4.7 Field Studies

4.7.1 Main effects of different levels of N, S and CD on plant height

Main effects of rates of N, S and CD on plant height in week 10 for each year of field study is presented in Table 4.22, while results in weeks 2 – 8 for the same period are shown in Figures 4.20 to 4.28. Results presented both in Tables and Figures showed a good response to fertilizer application and input of organic manure.

Significant ($P < 0.01$) increase in maize stalk height was obtained with N rates in the first two years of planting. The best impact in week 10 was got from 120 kg N/ha with a mean stalk height of 70.04 cm in 2009, and 183.77 cm in 2010, the least effect in the same period was got from the plot where N fertilizer was not applied. Further more, N application at 60 kg/ha was significantly ($P < 0.01$) higher than N at zero application, the difference between their means was 9% in 2009 and 39% in 2010. However, there were no significant differences ($P > 0.05$) in stalk height among N fertilizer rates in 2011 (Table 4.22).

Application of sulphur fertilizer enhanced the growth of maize as shown by the result (Table 4.22). Increasing rates of S from 0 to 30 kg S/ha also led to increase in maize stalk height, though the difference in treatment means in week 10 between 15 kg S/ha and 30 kg S/ha in the second and third year of planting was not significant ($P > 0.05$). However, both 15 kg S/ha and 30 kg S/ha were more efficient ($P < 0.01$) than the control in the first two years of planting. Results in 2009 were 52.04 cm and 65.13 cm for 0 kg S/ha and 30 kg S/ha respectively (Table 4.22).

Maize stalk height increased as the rates of CD increased (Table 4.22). Highest effect was obtained from 10 ton/ha CD whereas; the least effect was from the control. Treatment means among the rates were significant ($P < 0.01$).

Table 4.22: Main effects of increasing levels of N, S and CD on plant height (cm) in the field trials

	2009		**2010**		**2011**	
	Week 10	**Mean (wk 2-8)**	**Week 10**	**Mean (wk 2-8)**	**Week 10**	**Mean (wk 2-8)**
0	48.5	22.85	112.3	35.10	200.0	72.38
60	57.9	25.13	151.4	45.53	209.1	81.40
120	70.0	29.13	183.8	53.68	208.9	80.85
S Rates (kg/ha)						
0	52.0	23.58	130.7	38.75	208.0	77.60
15	59.3	25.05	155.3	47.05	208.7	79.55
30	63.5	28.50	161.4	48.55	201.3	77.45
CD Rates (tons/ha)						
0	48.5	23.80	113.5	36.45	190.9	68.30
5	60.6	26.48	154.8	45.38	210.3	80.53
10	67.3	26.88	179.1	52.48	216.8	85.73
Mean	58.8	25.73	149.1	44.78	206.0	78.20
CV	4.44	7.48	11.03	19.82	7.72	14.43
R-Square	0.98	0.87	0.92	0.79	0.57	0.60
LSD (0.05)	4.18**	3.49**	26.32**	16.94**	25.43*	14.66*

*NS = Not Significant, * = Significant at P = 0.05, ** = Significant at P = 0.01,*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

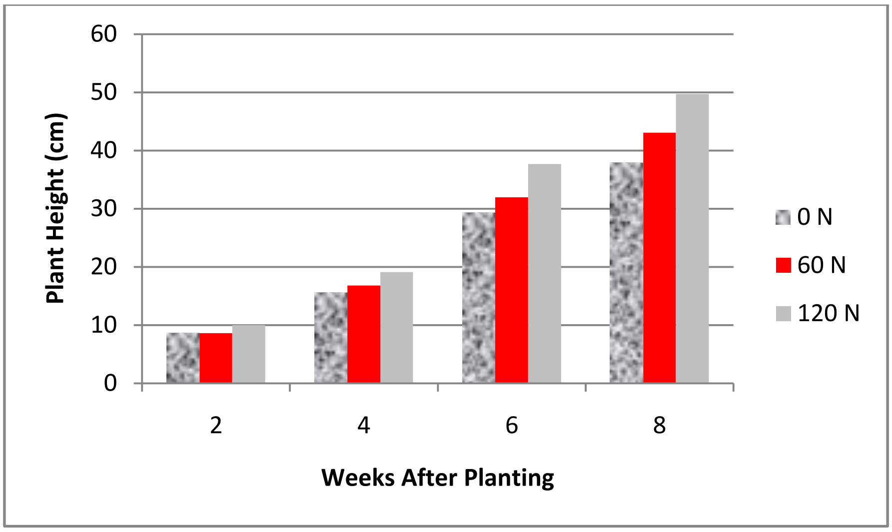


Figure 4.20: Main effect of rates of N on plant height in 2009

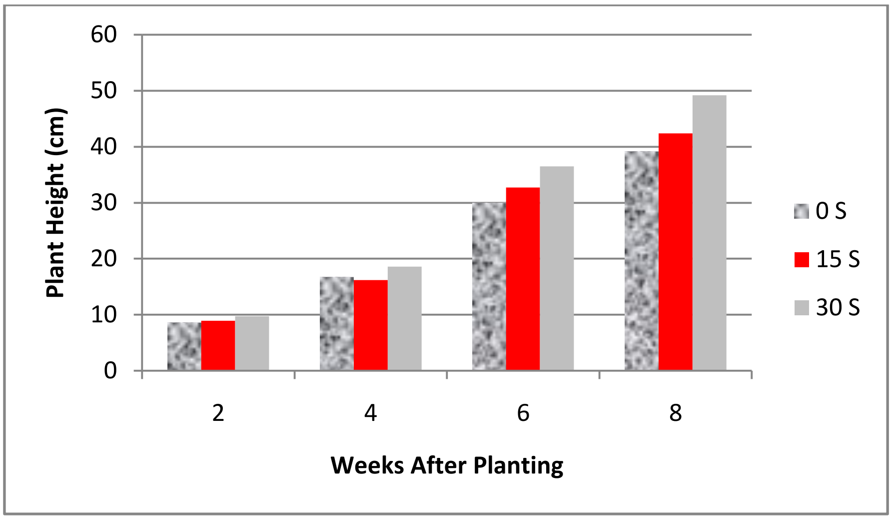
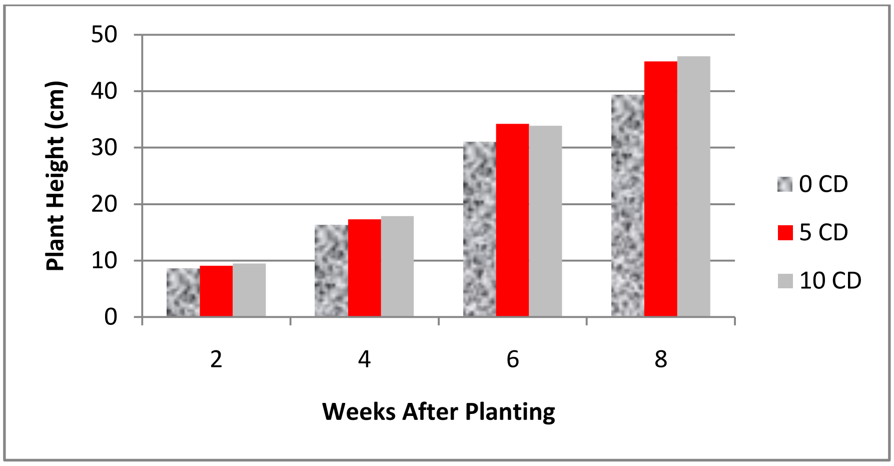


Figure 4.21: Main effect of rates of S on plant height in 2009



SE±	1.03	1.64	1.62	9.68

Figure 4.22: Main effect of rates of CD on plant height in 2009

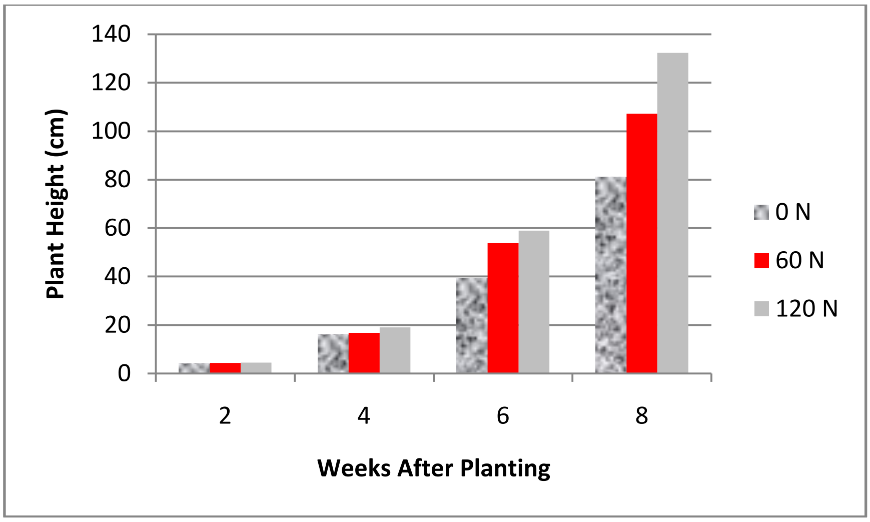


Figure 4.23: Main effect of rates of N on plant height in 2010

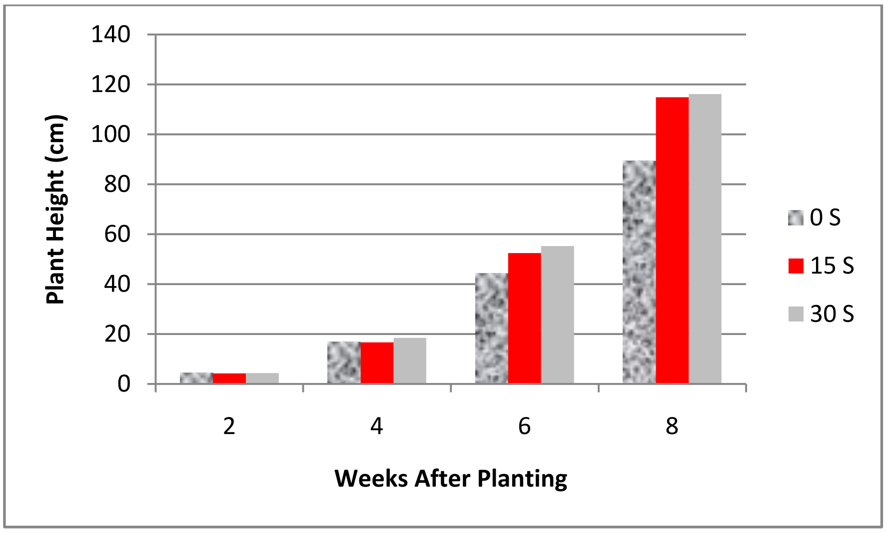
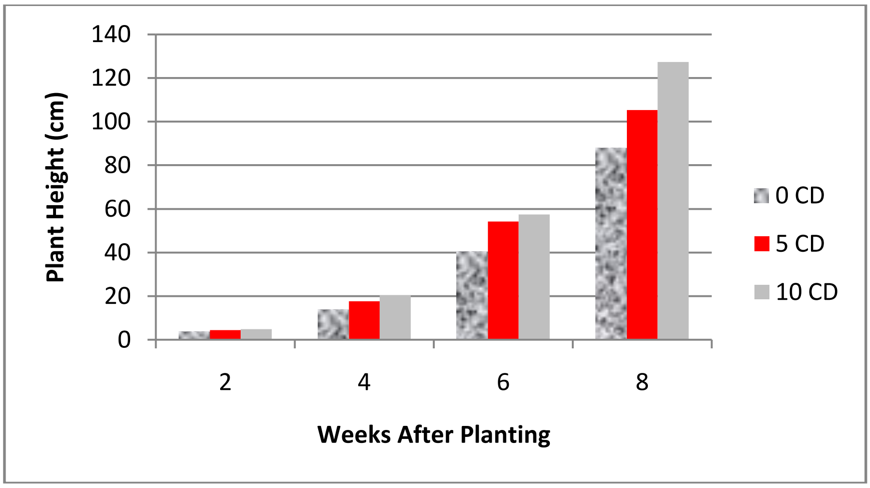


Figure 4.24: Main effect of rates of S on plant height in 2010



SE± 0.86 4.58 21.31 40.99

Figure 4.25: Main effect of rates of CD on plant height in 2010

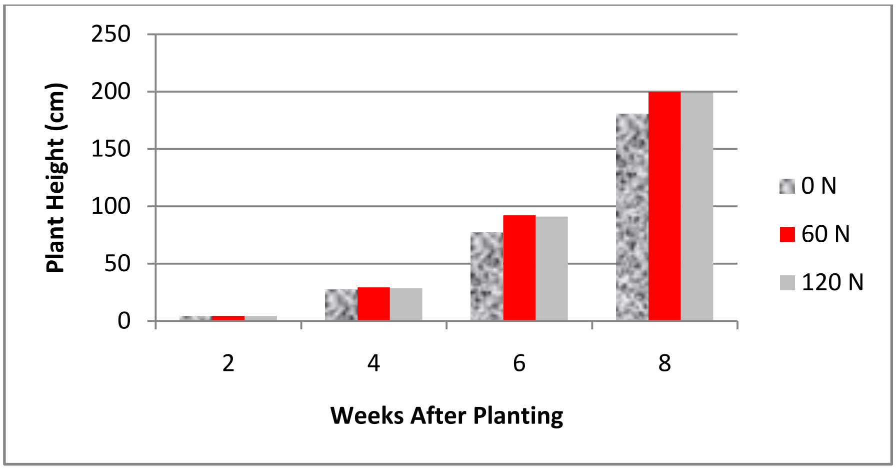


Figure 4.26: Main effect of rates of N on plant height in 2011

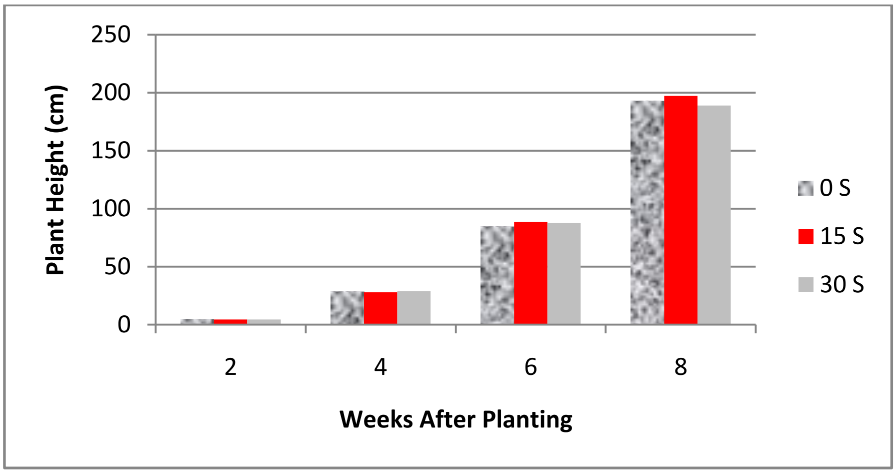
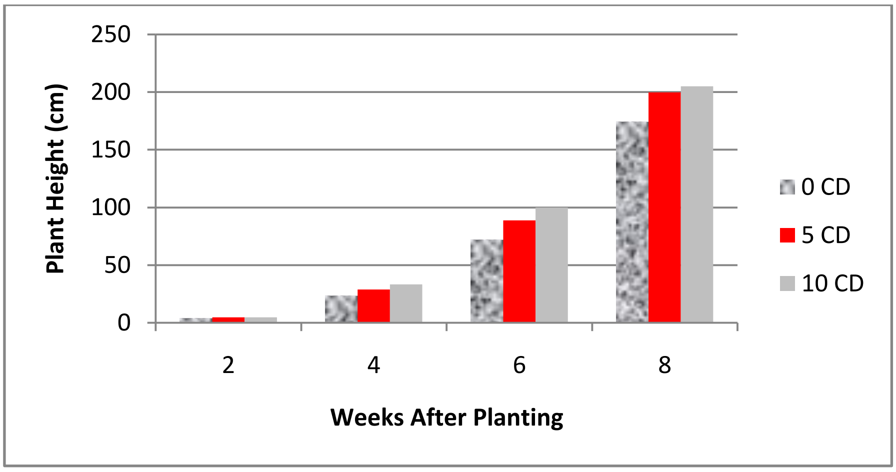


Figure 4.27: Main effect of rates of S on plant height in 2011



SE±	1.00	8.42	23.26	25.95

Figure 4.28: Main effect of rates of CD on plant height in 2011

4.7.1.4 Interaction effect of different levels of N, S and CD on plant height

The results of interaction of different levels of N, S and CD on plant height in 2009, 2010 and 2011 are presented in Tables 4.24; 4.25 and 4.26 respectively. The interaction was significant ($P < 0.01$) in weeks 2, 4 and 6, and also significant ($P < 0.05$) in week 8 (Table 4.23). The highest response in week 8 was obtained from the combination of the highest application rates of the fertilizers with a mean plant height of 59.10 cm in 2009, while the least effect was obtained from the control which had 26.90 cm. The difference was 54.24 % higher than the control and this effect was highly significant.

In 2010, the combination of 120 kg N/ha + 15 kg S/ha + 10 ton/ha CD had the highest response in week 8 with a mean plant height of 165.47 cm as against 51.33 cm obtained from the control (Table 4.24), while the best performance in 2011 was 224.07 cm obtained from 60 kg N/ha + 30 kg S/ha + 10 ton /ha CD and significantly ($P < 0.01$) higher than 147.0 cm obtained from 0 kg N/ha + 30 kg S/ha + 0 ton /ha CD in week 8 (Table 4.25).

The pattern of response showed that each of the factors was effective in boosting vegetative growth of the plant. In 2009, N at 120 kg/ha interacted with the highest rates of S and CD, but in the subsequent years (2010 and 2011), best effect was obtained with 60 kg N/ha (Tables 4.25 and 4.26). This indicated that soil fertility had improved (due to continuous application of the treatments) in the later period of the trial, such that the interaction with highest N rate was not significantly different ($P > 0.05$) with half N rate. The result further revealed that amendment with sulphur and manure increased soil fertility.

Table 4.23: Interaction effects of combinations of N, S and CD on plant height (cm) in 2009 field trial

				Weeks			
	N	**S**	**CD**	2	4	6	8
1	0	0	0	8.37^{f-k}	16.30^{g-j}	20.40^{m}	26.90^{j}
2	0	0	5	7.90^{h-k}	14.47^{j-m}	27.50^{jkL}	34.13^{g-j}
3	0	0	10	9.03^{d-h}	17.67^{e-h}	26.67^{kL}	36.63^{f-j}
4	0	15	0	7.57^{ijk}	14.00^{Lm}	26.10^{L}	31.70^{i-j}
5	0	15	5	7.83^{h-k}	11.13^{n}	33.13^{gh}	43.67^{b-h}
6	0	15	10	10.50^{abc}	19.50^{de}	38.20^{c}	48.80^{a-e}
7	0	30	0	7.27^{k}	13.70^{Lm}	27.57^{L}	37.83^{e-j}
8	0	30	5	9.73^{b-e}	18.20^{efg}	31.73^{hi}	37.30^{f-j}
9	0	30	10	9.20^{d-g}	15.13^{i-L}	32.53^{gh}	44.77^{b-g}
10	60	0	0	7.50^{jk}	12.97^{m}	26.67^{Kl}	32.73^{hij}
11	60	0	5	9.00^{d-h}	21.00^{abc}	36.50^{cd}	45.93^{b-f}
12	60	0	10	8.60^{e-j}	16.00^{h-k}	31.30^{i}	37.83^{e-j}
13	60	15	0	7.77^{h-k}	14.27^{kLm}	28.40^{j}	36.27^{f-j}
14	60	15	5	8.10^{g-k}	15.33^{i-L}	31.50^{hi}	39.33^{d-i}
15	60	15	10	8.43^{f-k}	16.93^{f-i}	27.97^{jk}	37.60^{e-j}
16	60	30	0	10.10^{bcd}	18.67^{ef}	37.40^{c}	57.60^{a}
17	60	30	5	9.20^{d-g}	18.53^{ef}	35.60^{de}	50.73^{abc}
18	60	30	10	8.60^{e-j}	17.80^{e-h}	32.77^{gh}	49.77^{abcd}
19	120	0	0	8.77^{d-i}	17.90^{e-h}	34.60^{ef}	37.60^{e-j}
20	120	0	5	8.40^{f-k}	16.23^{g-j}	31.87^{hi}	49.90^{abcd}
21	120	0	10	9.57^{c-f}	17.77^{e-h}	34.03^{fg}	50.17^{abcd}
22	120	15	0	9.53^{c-f}	17.73^{e-h}	35.83^{de}	40.50^{c-i}
23	120	15	5	10.93^{ab}	19.50^{cde}	38.13^{c}	52.63^{ab}
24	120	15	10	9.83^{b-e}	17.77^{e-h}	34.60^{ef}	51.13^{abc}
25	120	30	0	10.80^{ab}	21.43^{ab}	42.17^{b}	52.13^{abc}
26	120	30	5	10.93^{ab}	20.83^{bcd}	41.37^{b}	53.83^{ab}
27	120	30	10	11.50^{a}	22.67^{a}	47.03^{a}	59.10^{a}
	Mean			9.07	17.16	33.02	43.58
	R-Square			0.84	0.92	0.98	0.75
	CV			7.05	5.95	3.06	13.87
	LSD			1.03	1.64	1.62	9.68
	NxSxCD			**	**	**	*

Significant at P = 0.01

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

Table 4.24: Interaction effects of combinations of N, S and CD on plant height (cm) in 2010 field trial

				Weeks			
	N	**S**	**CD**	2	4	6	8
1	0	0	0	3.57^{e-h}	13.73^{de}	25.80^{g}	51.33^{i}
2	0	0	5	3.70^{d-h}	15.93^{cde}	33.60^{efg}	62.80^{hi}
3	0	0	10	4.73^{abcd}	18.43^{abcd}	43.40^{b-g}	74.80^{fghi}
4	0	15	0	3.27^{gh}	12.20^{e}	28.13^{fg}	61.80^{hi}
5	0	15	5	4.37^{a-f}	15.20^{cde}	39.80^{d-g}	82.20^{e-i}
6	0	15	10	4.80^{abc}	20.50^{ab}	54.47^{a-e}	123.80^{a-f}
7	0	30	0	2.87^{h}	14.77^{cde}	33.87^{efg}	72.17^{ghi}
8	0	30	5	4.33^{b-f}	16.97^{b-e}	45.13^{a-g}	85.87^{e-i}
9	0	30	10	4.50^{a-e}	17.37^{abcd}	49.73^{a-g}	114.57^{b-g}
10	60	0	0	4.33^{b-f}	12.40^{de}	35.53^{efg}	71.80^{ghi}
11	60	0	5	4.77^{abc}	17.53^{abcd}	53.60^{a-f}	92.73^{e-i}
12	60	0	10	5.07^{ab}	17.43^{abcd}	56.73^{a-e}	107.10^{b-h}
13	60	15	0	3.43^{fgh}	12.20^{e}	44.07^{b-g}	84.27^{e-i}
14	60	15	5	4.60^{a-e}	16.50^{b-e}	54.87^{a-e}	116.73^{a-g}
15	60	15	10	4.17^{b-g}	17.73^{abcd}	59.27^{a-e}	144.33^{abcd}
16	60	30	0	3.67^{d-h}	15.70^{be}	46.20^{a-g}	95.77^{d-i}
17	60	30	5	4.37^{a-f}	20.17^{abc}	65.80^{abcd}	102.30^{c-h}
18	60	30	10	4.70^{abcd}	21.20^{ab}	67.67^{ab}	150.03^{abc}
19	120	0	0	3.80^{c-h}	14.40^{cde}	41.07^{c-g}	106.73^{b-h}
20	120	0	5	4.40^{a-f}	19.67^{abc}	60.33^{a-e}	126.67^{a-e}
21	120	0	10	4.77^{abc}	21.27^{ab}	48.73^{a-g}	111.80^{b-h}
22	120	15	0	3.73^{d-h}	15.87^{bcde}	58.53^{a-e}	131.33^{a-e}
23	120	15	5	4.43^{a-f}	16.70^{bcde}	66.57^{abc}	124.43^{a-f}
24	120	15	10	5.40^{a}	23.03^{a}	66.07^{a-d}	165.47^{a}
25	120	30	0	4.20^{b-g}	13.23^{de}	50.00^{a-g}	116.33^{b-g}
26	120	30	5	4.63^{a-e}	20.07^{abc}	68.33^{ab}	154.00^{ab}
27	120	30	10	5.17^{ab}	26.90^{abc}	70.87^{a}	153.53^{ab}
	Mean			4.29	17.30	50.67	106.84
	R-Square			0.67	0.86	0.84	0.78
	CV			12.48	16.55	26.28	23.97
	LSD			0.86	4.58	21.31	40.99
	NxSxCD			*	*	*	*

Significant at 0.05

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

Table 4.25: Interaction effects of combinations of N, S and CD on plant height (cm) in 2011 field trial

				Weeks			
	N	**S**	**CD**	2	4	6	8
1	0	0	0	3.73^{d}	22.73^{def}	60.93^{gh}	154.67^{fg}
2	0	0	5	4.30^{abcd}	23.07^{c-f}	72.47^{d-h}	184.40^{b-f}
3	0	0	10	5.03^{abc}	35.93^{a}	107.87^{ab}	201.20^{abcd}
4	0	15	0	3.60^{bcd}	25.00^{b-f}	75.87^{d-h}	176.87^{c-f}
5	0	15	5	4.67^{abc}	25.47^{b-f}	69.20^{e-h}	189.07^{b-e}
6	0	15	10	5.00^{abc}	33.53^{abc}	94.20^{a-f}	201.40^{abcd}
7	0	30	0	3.67^{bcd}	21.13^{f}	50.80^{h}	147.00^{g}
8	0	30	5	4.47^{abc}	29.13^{a-f}	78.13^{c-h}	178.67^{c-f}
9	0	30	10	4.77^{abcd}	31.27^{a-f}	86.53^{a-g}	189.67^{b-e}
10	60	0	0	4.63^{abcd}	24.67^{c-f}	66.00^{fgh}	186.40^{b-e}
11	60	0	5	4.60^{abcd}	31.87^{a-e}	95.93^{a-e}	208.67^{abc}
12	60	0	10	5.10^{abc}	32.73^{abcd}	106.53^{abc}	202.67^{abcd}
13	60	15	0	3.87^{bcd}	21.73^{ef}	75.07^{d-h}	191.27^{bcde}
14	60	15	5	4.30^{abcd}	30.07^{a-f}	94.40^{a-f}	207.07^{abc}
15	60	15	10	4.43^{abcd}	28.20^{a-f}	95.47^{a-e}	204.47^{abc}
16	60	30	0	3.67^{d}	24.53^{c-f}	80.00^{b-g}	169.00^{efg}
17	60	30	5	4.77^{abcd}	32.53^{abcd}	108.00^{ab}	202.33^{abcd}
18	60	30	10	4.90^{abcd}	36.40^{a}	109.53^{a}	224.07^{a}
19	120	0	0	3.90^{bcd}	20.87^{f}	66.33^{fgh}	171.27^{defg}
20	120	0	5	5.33^{a}	28.73^{a-f}	85.87^{a-g}	212.13^{ab}
21	120	0	10	4.73^{abcd}	35.27^{ab}	97.93^{a-e}	215.67^{ab}
22	120	15	0	4.00^{bcd}	25.13^{b-f}	93.67^{a-f}	177.27^{c-f}
23	120	15	5	4.60^{abcd}	29.27^{a-f}	101.00^{a-d}	214.80^{ab}
24	120	15	10	4.37^{abcd}	32.60^{abcd}	99.13^{a-d}	213.27^{ab}
25	120	30	0	3.83^{cd}	23.20^{c-f}	78.20^{c-h}	194.40^{a-e}
26	120	30	5	4.70^{abcd}	29.20^{a-f}	95.93^{a-e}	201.33^{abcd}
27	120	30	10	5.10^{ab}	32.93^{abcd}	101.13^{a-d}	193.53^{a-e}
	Mean			4.45	28.42	86.89	193.06
	R-Square			0.50	0.58	0.65	0.67
	CV			14.09	18.51	16.73	8.39
	LSD			1.00	8.42	23.26	25.95
	NxSxCD			*	*	*	*

Significant at 0.05

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

4.7.2 Main effects of different levels of N, S and CD on number of leaves

Effect of different levels of fertilizer and cowdung application on number of leaves per plant in week 10 and the mean effects of the weeks are presented in Table 4.26 while the means of weeks 2 – 8 for each year of planting are shown in Figures 4.29 to 4.37. At each week of monitoring, leaves per plant were significant ($P \leq 0.01$) which is attributed to the treatments effect, indicating that application of chemical fertilizers and amendment with CD provided additional benefit needed for the growth of the plant.

In 2009, the treatments means increased from 2 WAP to 10 WAP across the different levels of N, S and CD application with N at 120 kg/ha being the dominant fertilizer level with the highest foliage production followed by S at 30 kg/ha and 10 tons/ha cowdung application, though their treatment means were not significantly ($P \geq 0.05$) different at 10 WAP. The performance in the second year of planting in 2010 was highly consistent with the trend already established in the previous year 2009. However, there was a slight variation in the trend during the third year of cropping in 2011 where N at 60 kg/ha, S at 15 kg/ha and CD at 5 tons/ha were as effective as their full application rates in foliage production resulting in their means not significantly different ($P \geq 0.05$) during the period of observation (Table 4.26).

Table 4.26: Main effects of increasing levels of N, S and CD on number of leaves in the field trials

	2009		2010		2011	
	Week 10	**Mean (wk 2-8)**	**Week 10**	**Mean (wk 2-8)**	**Week 10**	**Mean (wk 2-8)**
0	8.5	6.3	13.1	8.8	14.3	10.2
60	10.2	7.2	14.2	9.3	14.6	10.3
120	11.4	8.4	14.7	9.6	14.3	10.3
S Rates (kg/ha)						
0	8.9	6.7	13.4	9.1	14.4	10.3
15	10.3	7.4	13.9	9.2	14.5	10.3
30	10.7	7.9	14.5	9.4	14.3	10.2
CD Rates (tons/ha)						
0	9.2	6.8	13.3	8.8	13.9	9.9
5	10.2	7.5	13.9	9.3	14.5	10.4
10	10.6	7.7	14.6	9.6	14.8	10.6
Mean	10.0	7.3	14.0	9.2	14.4	10.3
CV	5.03	6.3	4.77	7.5	7.58	7.8
R-Square	0.94	0.9	0.79	0.6	0.31	0.4
LSD (0.05)	0.80**	0.7	1.10**	1.1	1.75	1.3

*NS = Not Significant, * = Significant at P = 0.05, ** = Significant at P = 0.01,*

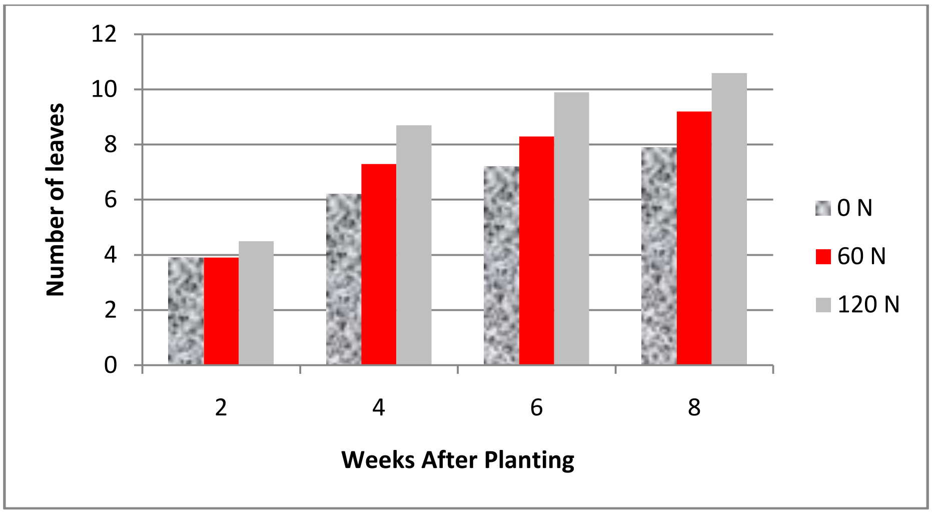


Figure 4.29: Main effect of rates of N on number of leaves in 2009

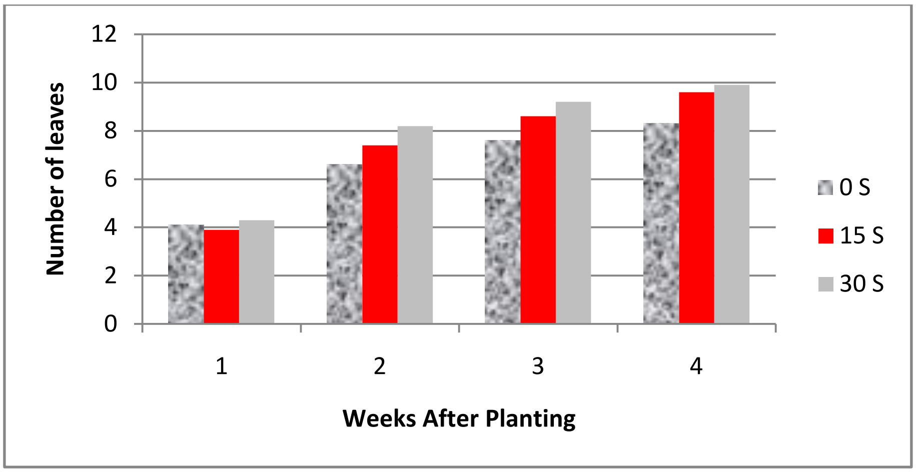
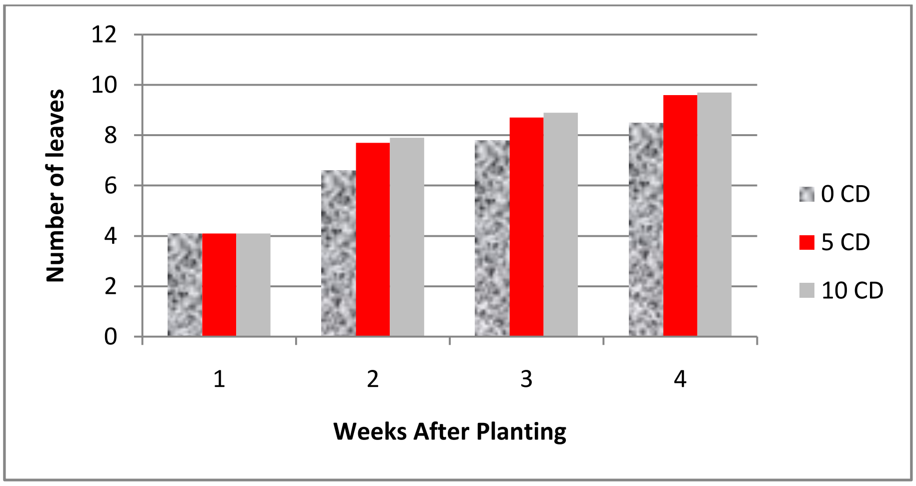


Figure 4.30: Main effect of rates of S on number of leaves in 2009



SE±	0.45	0.94	0.74	0.74

Figure 4.31: Main effect of rates of CD on number of leaves in 2009

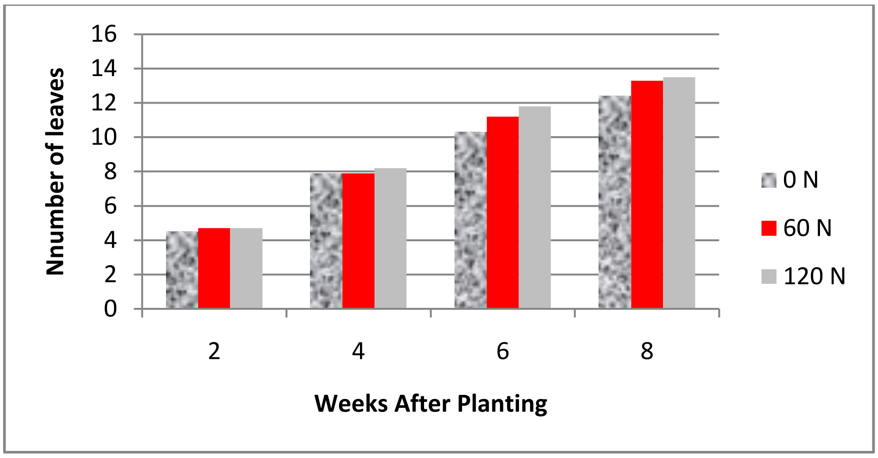


Figure 4.32: Main effect of rates of N on number of leaves in 2010

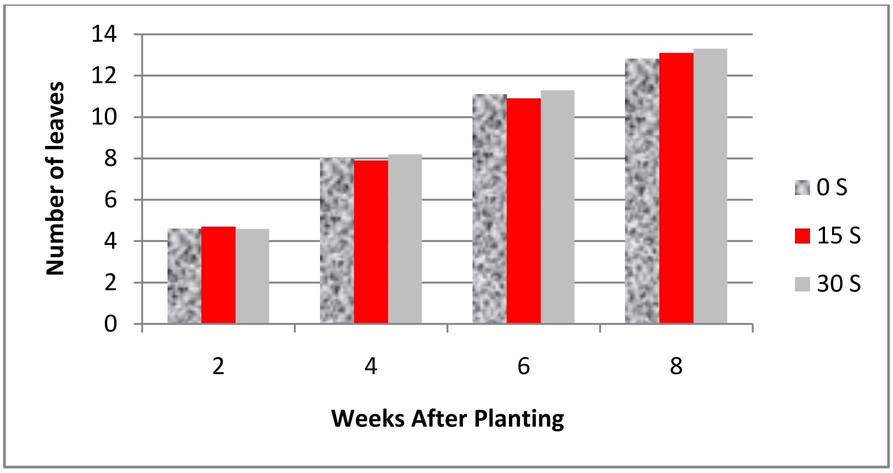
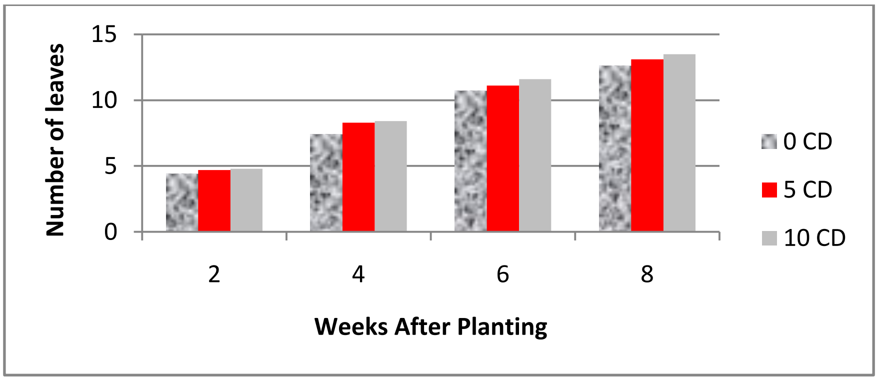


Figure 4.33: Main effect of rates of S on number of leaves in 2010



SE± 0.49 0.96 1.69 1.32

Figure 4.34: Main effect of rates of CD on number of leaves in 2010

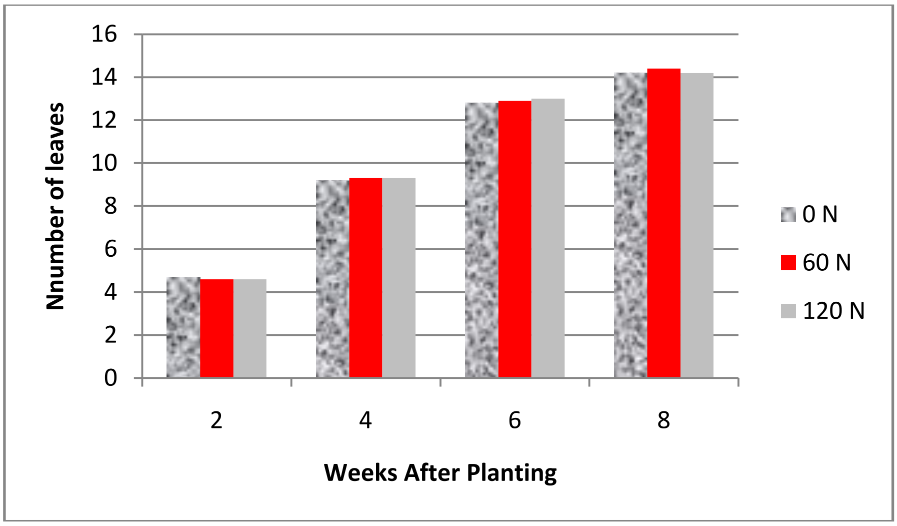


Figure 4.35: Main effect of rates of N on number of leaves in 2011

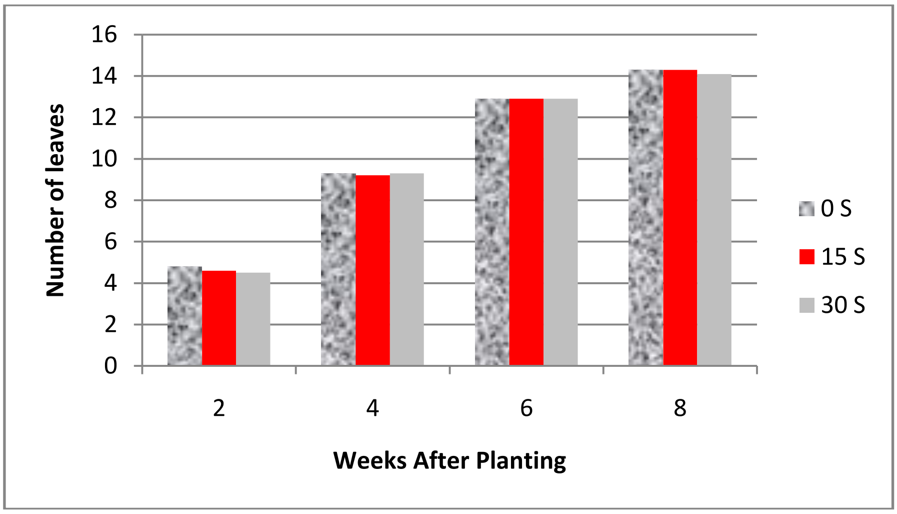
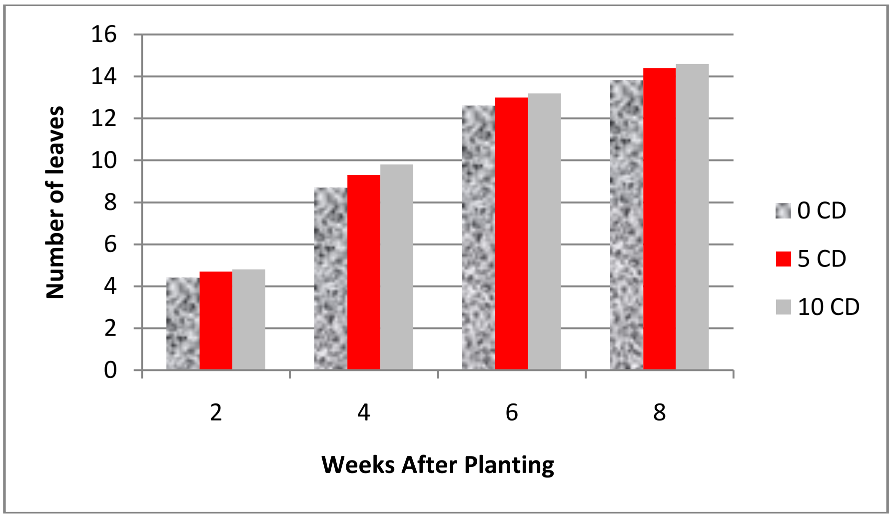


Figure 4.36: Main effect of rates of S on number of leaves in 2011



SE± 0.52 1.41 1.33 1.84

Figure 4.37: Main effect of rates of CD on number of leaves in 2011

4.7.2.1 Interaction effect of different rates of N, S and CD on number of leaves

The interactive combination of N, S and CD on number of leaves per plant during the three years of field study is presented in Tables 4.27, 4.28 and 4.29. The result revealed that the best performance in week 8 was obtained from the interaction of 120 kg N/ha + 30 kg S/ha + 10 ton/ha CD in the first and second year of planting and their corresponding means were 11.80 and 14.40, while the least performance during the same period was from the control and 0 kg N/ha + 0 kg S/ha + 5 ton/ha CD. Their means were 6.4 and 11.10 though not significantly different ($P < 0.05$) with the control in 2010. The performance in 2011 was highest with 0 kg N/ha + 15 kg S/ha + 0 ton/ha CD (15.53), but statistically similar with the rest of the treatment means (Table 4.27).

Table 4.27: Interaction effects of different levels of N, S and CD on number of leaves in 2009 field trial

				Weeks			
	N	**S**	**CD**	2	4	6	8
1	0	0	0	3.97^{e-i}	5.30^{k}	5.80^{k}	6.40^{l}
2	0	0	5	3.40^{j}	5.13^{k}	5.67^{k}	6.57^{l}
3	0	0	10	3.70^{g-j}	5.67^{jk}	6.83^{j}	7.43^{k}
4	0	15	0	3.47^{ij}	5.17^{k}	5.80^{k}	6.53^{l}
5	0	15	5	3.40^{j}	6.60^{ghij}	7.80^{hi}	8.73^{hij}
6	0	15	10	4.40^{c-f}	7.03^{fghi}	8.63^{d-h}	9.27^{ghi}
7	0	30	0	3.73^{g-j}	5.37^{k}	6.83^{j}	7.77^{k}
8	0	30	5	4.60^{bcd}	8.33^{bcde}	8.33^{fghi}	9.40^{ghi}
9	0	30	10	4.77^{bcd}	7.23^{efgh}	8.67^{d-h}	9.27^{ghi}
10	60	0	0	2.83^{k}	5.53^{k}	6.83^{j}	7.70^{k}
11	60	0	5	4.23^{defg}	6.93^{fghi}	8.70^{defg}	9.60^{efgh}
12	60	0	10	3.90^{e-j}	7.63^{defg}	8.00^{ghi}	8.57^{ij}
13	60	15	0	4.37^{cde}	6.00^{ijk}	7.67^{i}	8.60^{ij}
14	60	15	5	3.73^{ghij}	7.37^{efg}	9.07^{cdef}	10.3^{def}
15	60	15	10	3.47^{ij}	7.63^{d-g}	8.30^{fghi}	9.57^{fgh}
16	60	30	0	4.60^{bcd}	8.27^{bcde}	8.40^{e-i}	8.97^{hi}
17	60	30	5	4.03^{efgh}	7.63^{defg}	8.33^{fghi}	9.10^{ghi}
18	60	30	10	3.77^{f-j}	8.50^{bcd}	9.23^{cde}	10.40^{c-f}
19	120	0	0	4.03^{e-h}	6.17^{hijk}	7.73^{i}	8.10^{jk}
20	120	0	5	5.10^{ab}	9.27^{ab}	9.87^{bc}	10.43^{cde}
21	120	0	10	5.33^{ab}	7.97^{c-f}	8.93^{def}	9.93^{efg}
22	120	15	0	4.63^{bcd}	8.70^{bcd}	10.37^{ab}	10.97^{abcd}
23	120	15	5	4.37^{cda}	8.60^{bcd}	9.47^{cd}	10.87^{bcd}
24	120	15	10	3.60^{hij}	9.03^{abc}	10.37^{ab}	11.40^{ab}
25	120	30	0	4.80^{bcd}	8.97^{bc}	10.63^{ab}	11.07^{abcd}
26	120	30	5	4.40^{cde}	9.30^{ab}	10.47^{ab}	11.23^{abc}
27	120	30	10	4.30^{cdef}	10.07^{a}	10.97^{a}	11.80^{a}
	Mean			4.11	7.39	8.43	9.26
	R-Square			0.87	0.91	0.94	0.94
	CV			6.81	7.92	5.48	4.99
	LSD			0.46	0.96	0.76	0.76
	NxSxCD			**	**	**	**

*** = Significant at P = 0.01*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

Table 4.28: Interaction effects of different levels of N, S and CD on number of leaves in 2010 field trial

				Weeks			
	N	**S**	**CD**	2	4	6	8
1	0	0	0	4.41^{b-g}	7.80^{a-f}	9.47^{ef}	11.9^{def}
2	0	0	5	3.87^{g}	7.87^{a-f}	9.20^{f}	11.10^{f}
3	0	0	10	4.60^{a-f}	8.33^{a-f}	10.87^{a-f}	12.67^{cde}
4	0	15	0	4.47^{a-f}	7.40^{ef}	9.67^{def}	11.6^{ef}
5	0	15	5	4.60^{a-f}	7.87^{a-f}	10.53^{a-f}	12.6^{c-f}
6	0	15	10	4.73^{a-f}	8.33^{a-f}	10.47^{a-f}	13.07^{a-e}
7	0	30	0	4.20^{efg}	7.60^{b-f}	10.60^{a-f}	12.77^{a-e}
8	0	30	5	4.67^{a-f}	8.67^{abcd}	10.8^{a-f}	13.4^{abcd}
9	0	30	10	4.87^{abcd}	7.93^{a-f}	10.87^{a-f}	12.53^{cdef}
10	60	0	0	4.80^{a-e}	7.13^{f}	11.07^{a-f}	12.70^{bcde}
11	60	0	5	4.87^{abcd}	8.27^{a-f}	11.67^{abcd}	12.87^{a-e}
12	60	0	10	4.07^{ab}	8.20^{a-f}	12.33^{abcd}	14.33^{ab}
13	60	15	0	4.33^{c-g}	7.33^{ef}	10.27^{b-f}	12.87^{a-e}
14	60	15	5	4.73^{a-f}	8.07^{a-f}	10.00^{c-f}	13.33^{abcd}
15	60	15	10	4.80^{a-e}	7.93^{a-f}	11.40^{a-e}	13.43^{abcd}
16	60	30	0	4.20^{efg}	7.47^{def}	10.93^{a-f}	13.27^{abcd}
17	60	30	5	4.60^{a-f}	8.40^{a-e}	11.53^{a-e}	13.23^{abcd}
18	60	30	10	4.67^{a-f}	8.47^{a-e}	11.73^{abcd}	13.93^{abc}
19	120	0	0	4.17^{fg}	7.47^{def}	11.00^{a-f}	12.60^{cdef}
20	120	0	5	4.87^{abcd}	8.47^{a-e}	12.13^{ab}	13.87^{abc}
21	120	0	10	4.73^{a-f}	8.73^{abc}	12.27^{ab}	13.40^{abcd}
22	120	15	0	4.73^{a-f}	7.53^{cdef}	11.73^{abcd}	13.33^{abcd}
23	120	15	5	5.00^{ab}	8.00^{a-f}	11.93^{abc}	13.63^{abc}
24	120	15	10	4.93^{abc}	8.47^{a-e}	11.93^{abc}	13.70^{abc}
25	120	30	0	4.27^{defg}	7.27^{ef}	12.00^{abc}	12.67^{cde}
26	120	30	5	4.80^{a-e}	8.93^{a}	11.80^{abc}	13.80^{abc}
27	120	30	10	5.07^{a}	8.80^{ab}	12.53^{a}	14.40^{a}
	Mean			4.59	8.03	11.14	13.07
	R-Square			0.59	0.53	0.53	0.61
	CV			6.69	7.51	9.48	6.29
	LSD			0.51	0.98	1.73	1.32
	NxSxCD			*	*	*	*

** = Significant at P = 0.05*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

Table 4.29: Interaction effects of different levels of N, S and CD on number of leaves in 2011field trial

				Weeks			
	N	**S**	**CD**	2	4	6	8
1	0	0	0	4.40^{bcde}	8.80^{abcd}	12.80	14.20^{ab}
2	0	0	5	4.80^{adcd}	8.93^{abcd}	13.00	14.33^{ab}
3	0	0	10	5.33^{a}	9.93^{abcd}	13.40	14.80^{ab}
4	0	15	0	4.53^{bcde}	8.6^{bcd}	12.27	15.53^{a}
5	0	15	5	4.47^{bcde}	9.27^{abcd}	12.67	13.67^{ab}
6	0	15	10	4.87^{abc}	10.07^{abc}	13.20	14.80^{ab}
7	0	30	0	4.33^{cde}	8.33^{cd}	12.00	13.80^{ab}
8	0	30	5	4.60^{bcde}	9.27^{abcd}	12.93	14.00^{ab}
9	0	30	10	4.87^{abc}	9.20^{abcd}	13.07	14.27^{ab}
10	60	0	0	4.87^{abc}	8.93^{abcd}	12.40	14.00^{ab}
11	60	0	5	5.00^{ab}	9.20^{abcd}	13.13	15.27^{ab}
12	60	0	10	4.73^{abcd}	9.27^{abcd}	13.40	14.33^{ab}
13	60	15	0	4.53^{bcde}	8.47^{bcd}	12.73	14.00^{ab}
14	60	15	5	4.47^{bcde}	9.40^{abcd}	13.13	14.67^{ab}
15	60	15	10	4.73^{abcd}	9.20^{abcd}	13.07	14.47^{ab}
16	60	30	0	4.07^{e}	9.33^{abcd}	12.60	14.07^{ab}
17	60	30	5	4.60^{bcde}	9.87^{abcd}	12.93	14.07^{ab}
18	60	30	10	4.47^{bcde}	10.40^{a}	13.20	14.93^{b}
19	120	0	0	4.20^{a-e}	8.20^{d}	12.60	13.00^{ab}
20	120	0	5	4.93^{abc}	9.53^{abcd}	12.60	13.80^{ab}
21	120	0	10	4.53^{bcde}	10.47^{a}	13.53	15.27^{ab}
22	120	15	0	4.67^{bcde}	8.93^{abcd}	13.00	14.20^{ab}
23	120	15	5	4.73^{abcd}	9.33^{abcd}	13.60	15.20^{ab}
24	120	15	10	4.47^{bcde}	9.33^{abcd}	12.87	14.07^{ab}
25	120	30	0	4.20^{de}	8.33^{cd}	12.67	13.07^{b}
26	120	30	5	4.73^{abcd}	9.20^{abcd}	13.07	14.27^{ab}
27	120	30	10	4.80^{abcd}	10.20^{ab}	13.33	14.80^{ab}
	Mean			4.63	9.26	12.93	14.33
	R-Square			0.52	0.42	0.32	0.28
	CV			7.04	9.52	6.41	8.09
	LSD						
	NxSxCD			*	*	NS	*

** = Significant at P = 0.05*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

4.7.3 Main effects of different levels of N, S and CD on stem girth

The main effects of levels of N, S and CD on stem girth for weeks 2-8 in each year of study is presented in Figures 4.38 to 4.46 while the effect in week 10 under the same period is shown on Table 4.30. The result showed a significant ($P < 0.01$) performance across the weeks in the first and second year of planting, but response in the third year of planting was not significant ($P > 0.05$).

Treatment effect in week 10 and the mean effect of the weeks showed that a positive response was obtained from the application rates of N, S and CD. Consistently, maize stalk girth increased with increase in rates of the amendment with control being the least effect in 2009 and 2010. In week 10, mean effects for highest levels of N, S and CD were 6.80 cm; 6.50 cm and 6.50 cm in 2009; 8.10 cm; 7.90 cm and 7.90 cm in 2010 with a slight increase in the third year of planting though treatments effect were not significantly different with the control. The result is consistent with mean effects of the weeks and indicated improvement in soil fertility over the period.

Table 4.30: Main effects of different levels of N, S and CD on stem girth (cm) in the field trials

	2009		2010		2011	
	Week 10	**Mean (wk 2-8)**	**Week 10**	**Mean (wk 2-8)**	**Week 10**	**Mean (wk 2-8)**
0	5.20	3.8	6.10	3.8	9.10	6.3
60	5.90	4.2	7.00	4.4	9.40	6.7
120	6.80	4.8	8.10	4.9	9.40	6.7
S Rates (kg/ha)						
0	5.40	4.0	6.10	3.8	9.30	6.6
15	6.00	4.2	7.20	4.5	9.20	6.6
30	6.50	4.5	7.90	4.8	9.40	6.5
CD Rates (tons/ha)						
0	5.40	4.0	5.90	3.5	9.10	6.2
5	6.00	4.2	7.30	4.6	9.30	6.7
10	6.50	4.5	7.90	4.9	9.60	6.8
Mean	6.00	4.2	7.10	4.3	9.30	6.6
CV	4.39	6.0	4.59	8.4	8.31	11.3
R-Square	0.96	0.90	0.97	0.90	0.42	0.50
LSD (0.05)	0.42**	0.4**	0.52**	0.6**	1.24^{NS}	1.2^{NS}

*NS = Not Significant, * = Significant at P = 0.05, ** = Significant at P = 0.01*

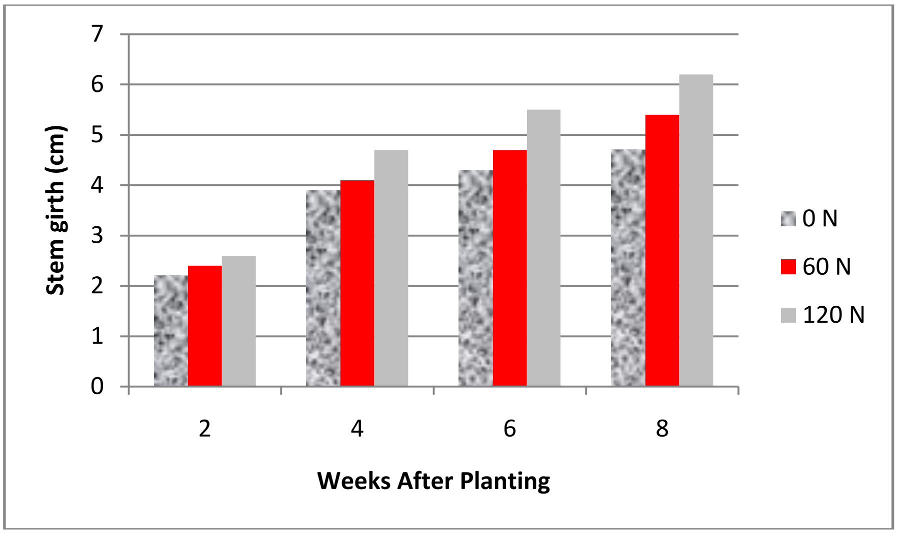


Figure 4.38: Main effect of rates of N on stem girth in 2009

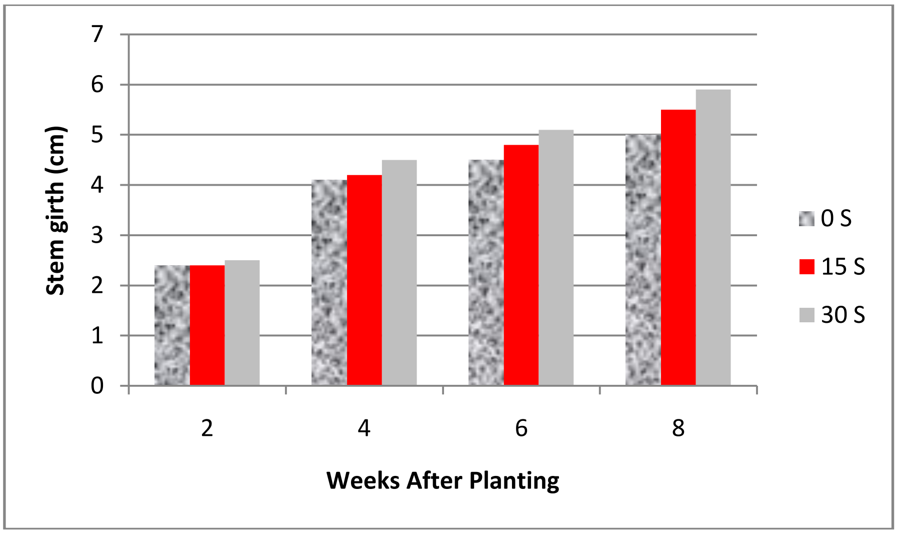
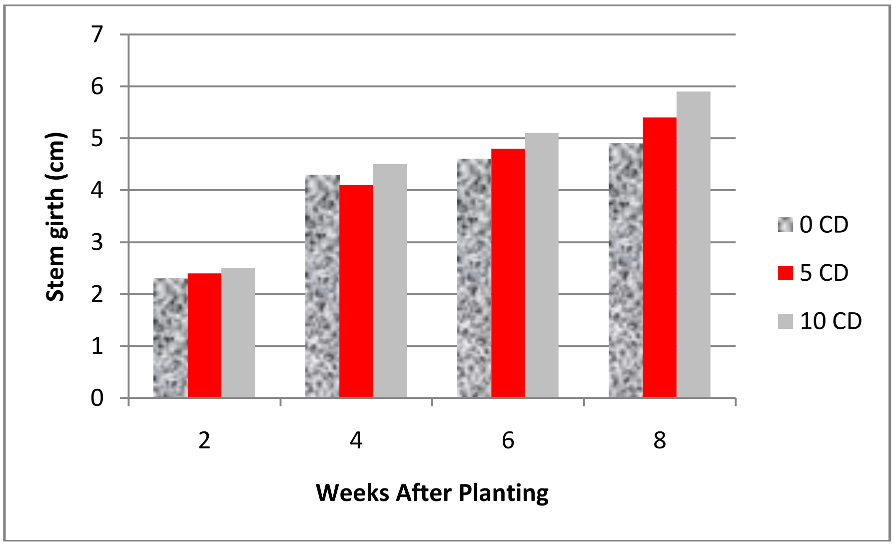


Figure 4.39: Main effect of rates of S on stem girth in 2009



SE± 0.21 0.49 0.39 0.54

Figure 4.40: Main effect of rates of CD on stem girth in 2009

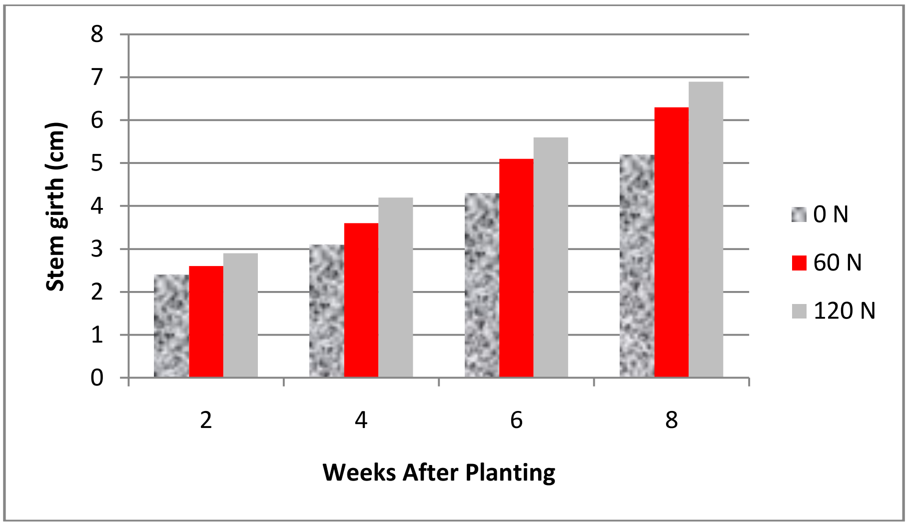


Figure 4.41: Main effect of rates of N on stem girth in 2010

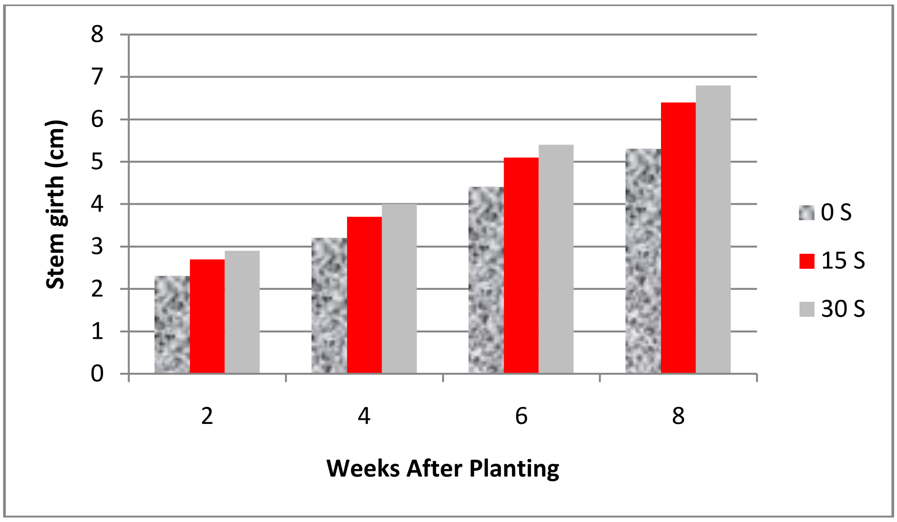
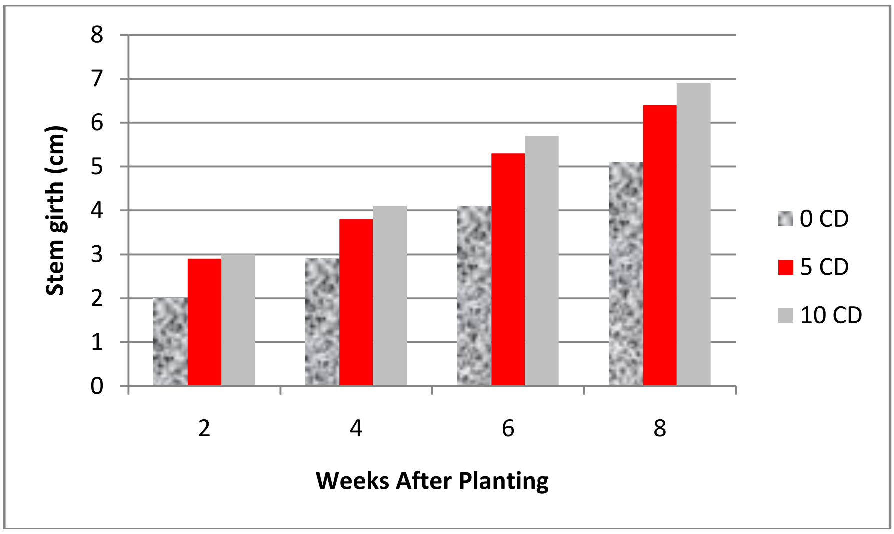


Figure 4.42: Main effect of rates of S on stem girth in 2010



SE± 0.39 0.57 0.66 0.61

Figure 4.43: Main effect of rates of CD on stem girth in 2010

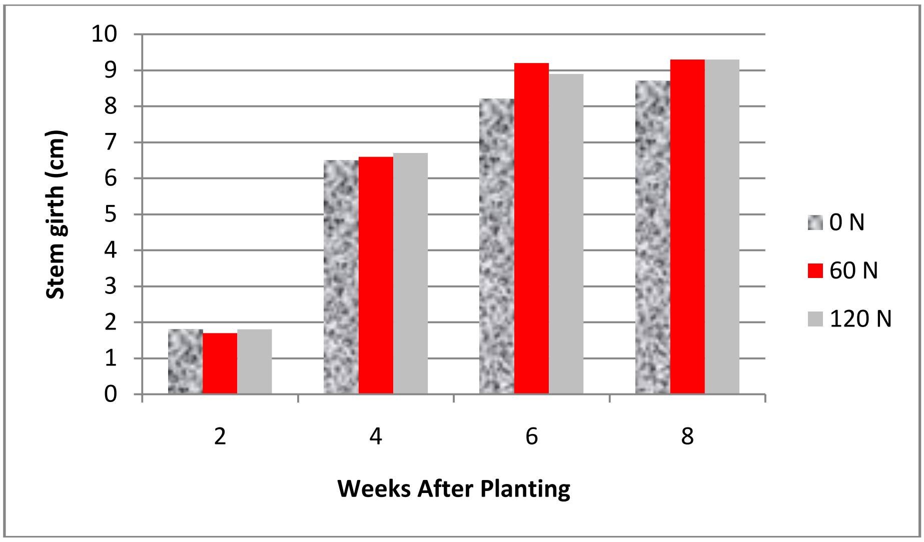


Figure 4.44: Main effect of rates of N on stem girth in 2011

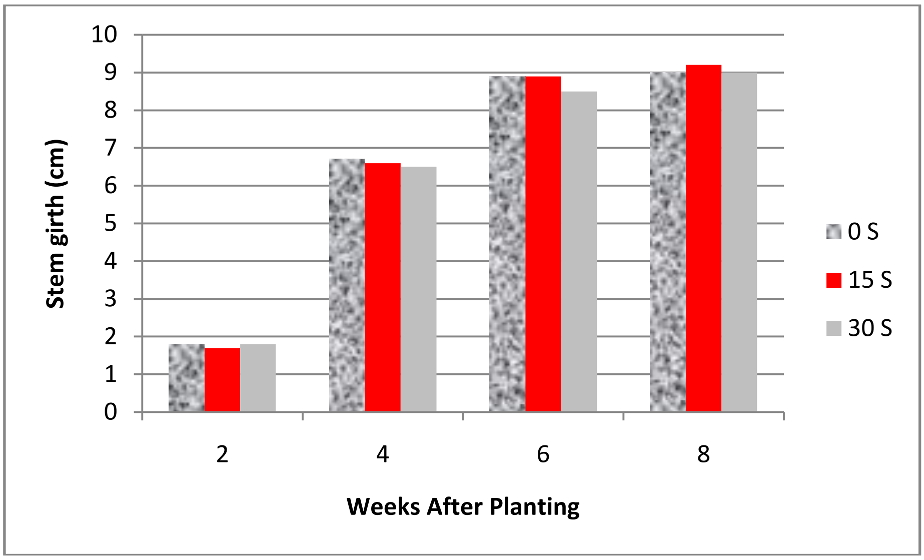
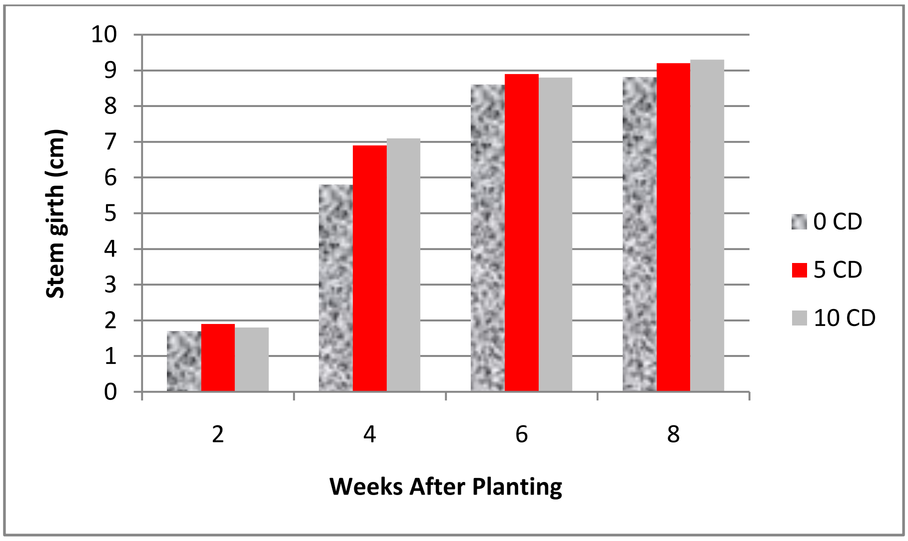


Figure 4.45: Main effect of rates of S on stem girth in 2011



SE± 0.30 1.43 1.56 1.42

Figure 4.46: Main effect of rates of CD on stem girth in 2011

4.7.3.1 Interaction effect of different rates of N, S and CD on stem girth

The interaction effect of levels of N, S and CD on maize stalk girth in week 8 for each year of study showed that best performing combination was obtained with 120 kg N/ha + 30 kg S/ha +10 ton/ha CD in 2009 and 2010 and their corresponding means were 6.87 cm and 8.23 cm which were significantly ($P < 0.01$) higher than the means obtained with control, 0 kg N/ha + 0 kg S/ha + 5 ton/ha CD and other combinations (Table 4.31). However, in 2011, the combination effects of number 15 and 23 had the highest girth (9.83 cm), but not significantly different ($P > 0.05$) with treatment combinations 2, 13 and 22 (Table 4.31).

The result indicated that in the first two years of planting, soil fertility was low, therefore, response from highest combination of the factors was more prominent, but in the later period, lower combination rates also had comparable effects. The results showed that continuous application of mineral fertilizers especially at higher rates may not translate to significant effect on growth.

Table 4.31: Interaction effects of different levels of N, S and CD on stem girth (cm) in 2009 field trial

				Weeks			
	N	**S**	**CD**	2	4	6	8
1	0	0	0	2.13^{jkl}	4.13^{efg}	4.33^{h}	4.53^{kl}
2	0	0	5	2.23^{ijk}	3.67^{gh}	3.70^{ij}	3.97^{lm}
3	0	0	10	2.43^{e-i}	4.07^{fg}	4.40^{gh}	4.57^{jkl}
4	0	15	0	1.93^{l}	3.23^{h}	3.50^{ij}	3.67^{m}
5	0	15	5	2.10^{kl}	3.70^{gh}	4.50^{fgh}	5.27^{ghi}
6	0	15	10	2.13^{jkl}	3.67^{gh}	4.27^{h}	4.80^{h-k}
7	0	30	0	2.20^{ijk}	4.23^{defg}	4.43^{gh}	4.70^{ijk}
8	0	30	5	2.23^{ijk}	4.33^{def}	4.70^{efgh}	5.27^{ghi}
9	0	30	10	2.57^{c-g}	4.60^{a-f}	4.83^{defg}	5.70^{efg}
10	60	0	0	2.13^{jkl}	3.23^{h}	3.33^{j}	4.03^{lm}
11	60	0	5	2.70^{abcd}	3.50^{h}	3.80^{i}	4.33^{kl}
12	60	0	10	2.33^{g-k}	4.13^{efg}	4.60^{efgh}	5.43^{fgh}
13	60	15	0	2.33^{g-k}	4.47^{b-f}	4.93^{cdef}	5.17^{g-j}
14	60	15	5	2.77^{abc}	3.43^{h}	4.47^{fgh}	5.43^{fgh}
15	60	15	10	2.53^{c-h}	4.73^{a-e}	5.33^{abc}	6.30^{a-e}
16	60	30	0	2.37^{f-j}	4.57^{a-f}	4.97^{cde}	5.43^{fgh}
17	60	30	5	2.10^{kl}	4.37^{def}	5.27^{abcd}	5.77^{defg}
18	60	30	10	2.60^{b-f}	4.37^{def}	5.30^{abcd}	6.47^{abc}
19	120	0	0	2.57^{c-g}	4.83^{abcd}	5.27^{abcd}	5.51^{fg}
20	120	0	5	2.37^{f-j}	4.40^{cdef}	5.27^{abcd}	6.03^{b-f}
21	120	0	10	2.30^{hijk}	5.10^{a}	5.67^{a}	6.61^{ab}
22	120	15	0	2.40^{fghi}	5.03^{ab}	5.27^{abcd}	5.71^{efg}
23	120	15	5	2.67^{a-e}	4.73^{a-e}	5.50^{ab}	6.37^{abcd}
24	120	15	10	2.50^{d-h}	4.40^{cdef}	5.67^{a}	6.37^{abcd}
25	120	30	0	2.83^{ab}	4.67^{a-f}	5.16^{bcd}	5.93^{cdef}
26	120	30	5	2.60^{b-f}	4.53^{a-f}	5.70^{a}	6.55^{abc}
27	120	30	10	2.90^{a}	5.00^{abc}	5.57^{ab}	6.87^{a}
	Mean			2.41	4.26	4.81	5.44
	R-Square			0.85	0.82	0.92	0.91
	CV			5.39	7.28	5.17	6.27
	LSD			0.22	0.51	0.41	0.56
	NxSxCD			*	**	**	*

** = Significant at P = 0.05, ** = Significant at P = 0.01*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

Table 4.32: Interaction effects of different levels of N, S and CD on stem girth (cm) in 2010 field trial

				Weeks			
	N	**S**	**CD**	2	4	6	8
1	0	0	0	1.47^{h}	2.27^{k}	3.43^{g}	4.17^{i}
2	0	0	5	2.13^{fg}	2.83^{hijk}	3.60^{g}	4.37^{i}
3	0	0	10	2.67^{cde}	3.33^{e-i}	4.63^{f}	5.20^{gh}
4	0	15	0	1.77^{gh}	2.67^{ijk}	3.33^{g}	4.27^{i}
5	0	15	5	2.60^{de}	3.20^{f-j}	4.70^{ef}	5.67^{efg}
6	0	15	10	2.67^{cde}	3.43^{efgh}	5.20^{def}	6.17^{de}
7	0	30	0	1.73^{gh}	2.57^{jk}	3.60^{g}	4.77^{hi}
8	0	30	5	3.27^{ab}	3.77^{def}	5.17^{def}	6.03^{def}
9	0	30	10	2.93^{abcd}	3.90^{cde}	5.00^{def}	6.53^{d}
10	60	0	0	1.51^{h}	2.23^{k}	3.67^{g}	4.33^{i}
11	60	0	5	2.43^{ef}	3.50^{defg}	4.73^{ef}	5.63^{efg}
12	60	0	10	2.60^{de}	3.30^{e-i}	5.07^{def}	5.73^{efg}
13	60	15	0	1.97^{g}	2.70^{ijk}	3.57^{g}	5.37^{fgh}
14	60	15	5	2.87^{bcde}	3.77^{def}	5.43^{cde}	6.53^{d}
15	60	15	10	3.13^{abc}	4.13^{bcd}	6.10^{abc}	7.30^{bc}
16	60	30	0	2.53^{def}	3.60^{def}	5.07^{def}	6.00^{def}
17	60	30	5	3.11^{abc}	4.60^{b}	5.97^{bc}	7.77^{ab}
18	60	30	10	3.40^{a}	4.70^{b}	6.10^{abc}	7.67^{ab}
19	120	0	0	1.87^{gh}	2.87^{g-k}	3.53^{g}	4.31^{i}
20	120	0	5	2.73^{cde}	3.67^{def}	3.57^{g}	6.71^{cd}
21	120	0	10	3.07^{abc}	4.57^{b}	5.70^{cd}	7.47^{b}
22	120	15	0	2.43^{ef}	3.67^{def}	5.23^{def}	6.63^{d}
23	120	15	5	3.33^{ab}	4.57^{b}	6.07^{abc}	7.43^{b}
24	120	15	10	3.23^{ab}	5.37^{a}	6.57^{ab}	7.93^{ab}
25	120	30	0	3.07^{abc}	3.77^{def}	5.10^{def}	6.43^{d}
26	120	30	5	3.37^{a}	4.67^{b}	6.03^{bc}	7.57^{ab}
27	120	30	10	3.33^{ab}	4.43^{bc}	6.80^{a}	8.23^{a}
	Mean			2.64	3.63	4.93	6.16
	R-Square			0.91	0.91	0.91	0.95
	CV			9.32	9.74	8.24	6.19
	LSD			0.41	0.58	0.68	0.63
	NxSxCD			*	*	**	**

** = Significant at P = 0.05 , ** = Significant at P = 0.01*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

Table 4.33: Interaction effects of different levels of N, S and CD on stem girth (cm) in 2011 field trial

				Weeks			
	N	**S**	**CD**	2	4	6	8
1	0	0	0	1.63^{cd}	6.10^{abcd}	8.67^{abcd}	8.17^{ab}
2	0	0	5	1.83^{abc}	6.67^{abcd}	8.33^{abcd}	9.67^{a}
3	0	0	10	1.93^{abc}	7.43^{ab}	9.17^{abc}	9.33^{ab}
4	0	15	0	1.71^{abc}	6.37^{abcd}	8.17^{abcd}	7.83^{b}
5	0	15	5	1.87^{abc}	6.17^{abcd}	7.83^{bcd}	8.83^{ab}
6	0	15	10	1.70^{abc}	7.33^{ab}	8.33^{abcd}	8.67^{ab}
7	0	30	0	1.70^{abc}	5.30^{d}	7.13^{d}	8.17^{ab}
8	0	30	5	1.87^{abc}	6.57^{abcd}	8.67^{abcd}	8.67^{ab}
9	0	30	10	1.81^{abc}	6.57^{abcd}	7.43^{cd}	8.83^{ab}
10	60	0	0	1.81^{abc}	6.53^{abcd}	8.07^{abcd}	9.01^{ab}
11	60	0	5	1.81^{abc}	7.20^{ab}	9.67^{ab}	8.83^{ab}
12	60	0	10	1.77^{abc}	6.83^{abcd}	9.83^{a}	9.17^{ab}
13	60	15	0	1.60^{cd}	5.67^{bcd}	9.40^{ab}	9.67^{a}
14	60	15	5	1.73^{abc}	6.20^{abcd}	9.50^{ab}	9.17^{ab}
15	60	15	10	1.77^{abc}	6.47^{abcd}	8.67^{abcd}	9.83^{a}
16	60	30	0	1.30^{d}	6.17^{abcd}	9.50^{ab}	9.33^{ab}
17	60	30	5	1.81^{abc}	7.40^{ab}	9.07^{abc}	9.07^{ab}
18	60	30	10	1.70^{abc}	7.20^{ab}	8.67^{abcd}	9.33^{ab}
19	120	0	0	1.67^{bc}	5.10^{d}	8.67^{abcd}	8.51^{ab}
20	120	0	5	1.81^{abc}	7.30^{ab}	9.01^{abcd}	9.01^{ab}
21	120	0	10	1.81^{abc}	7.53^{a}	9.07^{abc}	9.50^{ab}
22	120	15	0	1.60^{cd}	5.90^{abcd}	9.33^{abc}	9.67^{a}
23	120	15	5	1.87^{abc}	7.53^{a}	9.83^{a}	9.83^{a}
24	120	15	10	1.67^{bc}	7.40^{ab}	8.83^{abcd}	9.17^{ab}
25	120	30	0	1.87^{abc}	5.37^{cd}	8.67^{abcd}	9.01^{ab}
26	120	30	5	2.07^{a}	6.67^{abcd}	8.17^{abcd}	9.50^{ab}
27	120	30	10	2.03^{ab}	7.10^{abc}	9.23^{abc}	9.50^{ab}
	Mean			1.77	6.59	8.78	9.09
	R-Square			0.54	0.53	0.49	0.36
	CV			10.66	13.56	11.08	9.75
	LSD			0.31	1.47	1.59	1.45
	NxSxCD			*	*	*	*

** = Significant at P = 0.05*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

4.7.4 Main effects of different levels of N, S and CD on leaf area

The response of plant leaf area to treatments in week 10 is shown in Table 4.34 for 2009, 2010 and 2011, while the results in weeks 2-8 of each year are shown in Figures 4.47 to 4.55 against levels of N, S and CD.

Data presented in Table 4.34 and in Figures 4.47 and 4.50 showed that N fertilizer application had a positive impact on leaf area development in the first two years of planting. Results obtained in week 10 at different levels of N application were significant ($P < 0.01$) in 2009 and significant ($P < 0.05$) in 2010, but not significant in 2011 (Table 4.34).

Sulphur effect in week 10 increased as the rate of sulphur increased during the three years of study. Application of 30 kg S/ha was higher ($P < 0.01$) than S at 15 kg/ha and the control in 2009. Their corresponding means were 487.4 cm^2; 422.9 cm^2 and 346.3 cm^2 (Table 4.34 and Figure 4.48). A similar performance was obtained in 2010, but in 2011, the means were not significantly different ($P > 0.05$) although leaf area increased with levels of sulphur.

Effect of rates of CD on leaf area in week 10 for the three years of study followed the same pattern of N and S, where the highest rate (10 ton/ha CD) was significantly higher ($P < 0.01$) than either 5 ton/ha CD or the control (Table 4.34). The results in week 2-8 also had a similar trend as in week 10 under the same period (Figures 4.49, 4.52 and 4.55), though CD effect on leaf area was not significant ($P > 0.05$) in 2011.

The result revealed that leaf area development was significant ($P < 0.05$) especially with treatment combinations having N, S and CD at their half application levels than in combinations where they were not applied or where only one out of the three factors was applied regardless of the level. For instance, the interaction of 60 kg N/ha +0 kg S/ha + 0 ton/ha CD and 120 kg N/ha + 0 kg S/ha +0 ton /ha CD had leaf area of 263.60 cm^2 and 366.77 cm^2 in week 8, falling behind the mean effects of 60 kg N/ha +15 kg S/ha + 5 ton/ha

CD and 120 kg N/ha + 30 kg S/ha + 10 ton /ha CD, with a mean of 445.57 cm^2 and 635.5 cm^2 respectively (Table 4.35).

In each parameter, the best performance was obtained from the highest level of either N, S or CD which had been the trend already recorded during each year of operation while half of the application rates gave comparative results close to those of full recommendations, but the performance of control was significantly ($P < 0.01$) lower than the half or full recommended doses. This consistency shows that maize production in the savanna was effective during each year of the trial and the marked increase across all the parameters especially for 2009 and 2010 over the control could be attributed to increased nutrient additions through the amendments.

Table 4.34: Main effects of different levels of N, S and CD on plant leaf area in the field trial

	2009		2010		2011	
	Week 10	Mean (wk 2-8)	Week 10	Mean (wk 2-8)	Week 10	Mean (wk 2-8)
0	298.80	160.58	559.60	182.18	646.40	376.45
60	395.60	219.68	702.90	226.53	704.70	423.13
120	562.20	323.70	768.20	244.75	702.20	416.10
S Rates (kg/ha)						
0	346.30	190.38	641.00	204.63	650.40	404.95
15	422.90	230.80	677.10	218.60	692.60	416.13
30	487.40	282.75	712.50	230.18	710.20	395.75
CD Rates (tons/ha)						
0	355.00	206.40	577.70	182.50	634.90	364.30
5	421.20	238.88	687.70	224.28	675.80	418.13
10	480.30	258.68	765.20	246.63	742.50	433.23
Mean	418.90	234.65	676.90	217.78	684.40	405.35
CV	8.49	11.22	12.04	20.72	18.55	19.76
R-Square	0.96	0.95	0.80	0.72	0.47	0.47
LSD (0.05)	56.96**	41.00**	130.47*	59.51*	203.02^{NS}	115.34^{NS}

*NS = Not Significant, * = Significant at P = 0.05, ** = Significant at P = 0.01*

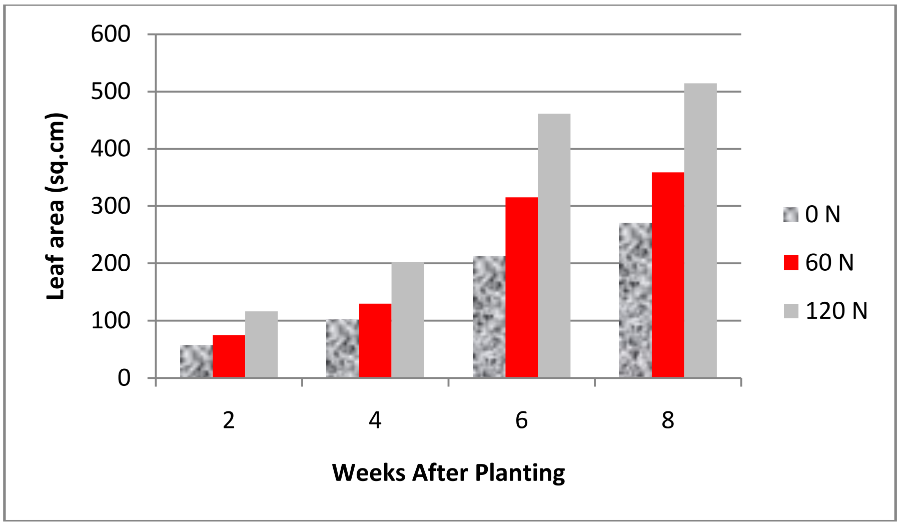


Figure 4.47: **Main effect of rates of N on leaf area (cm^2) in 2009**

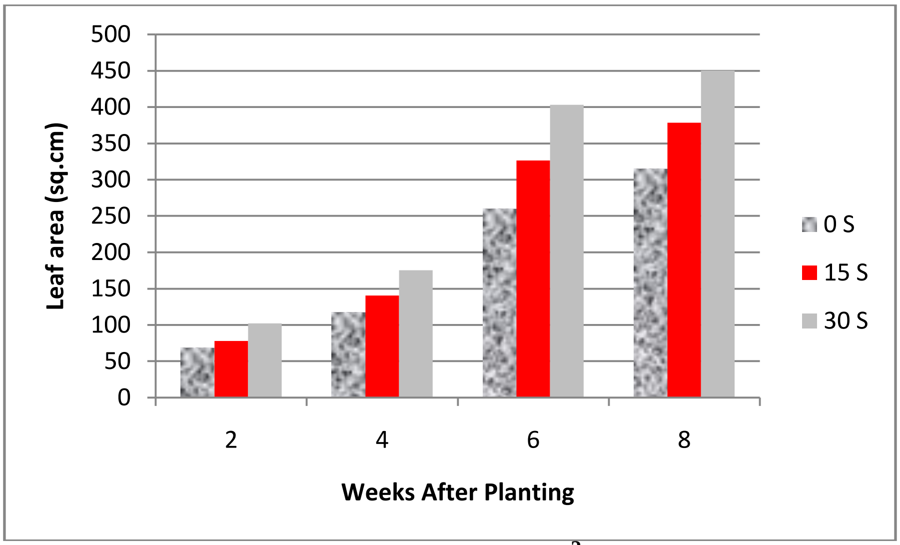
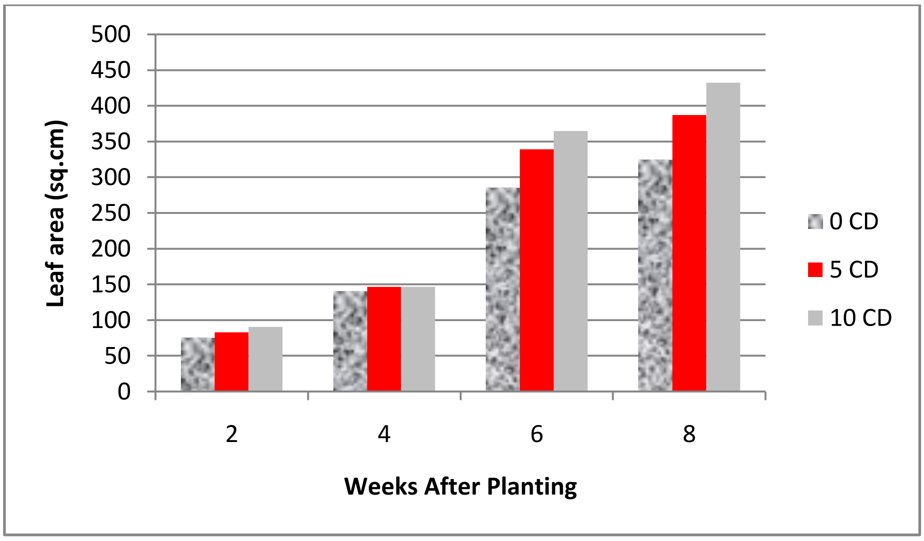


Figure 4.48: **Main effect of rates of S on leaf area (cm^2) in 2009**



SE± 11.82 35.63 58.43 58.10

Figure 4.49: **Main effect of rates of CD on leaf area (cm^2) in 2009**

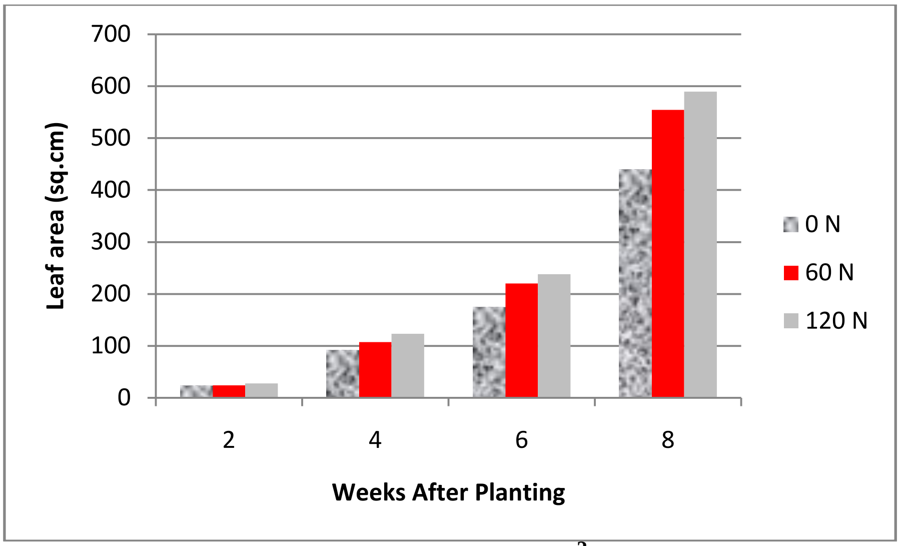


Figure 4.50: Main effect of rates of N on leaf area (cm^2) in 2010

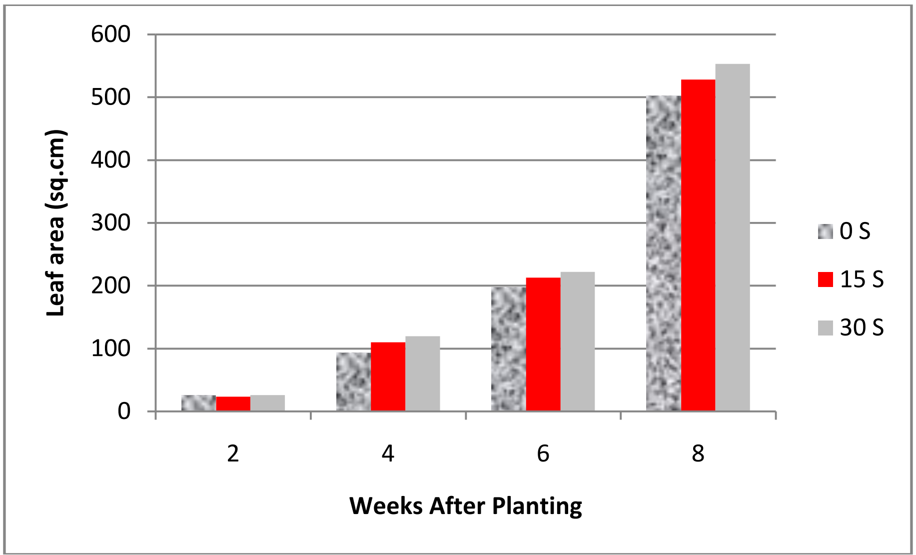
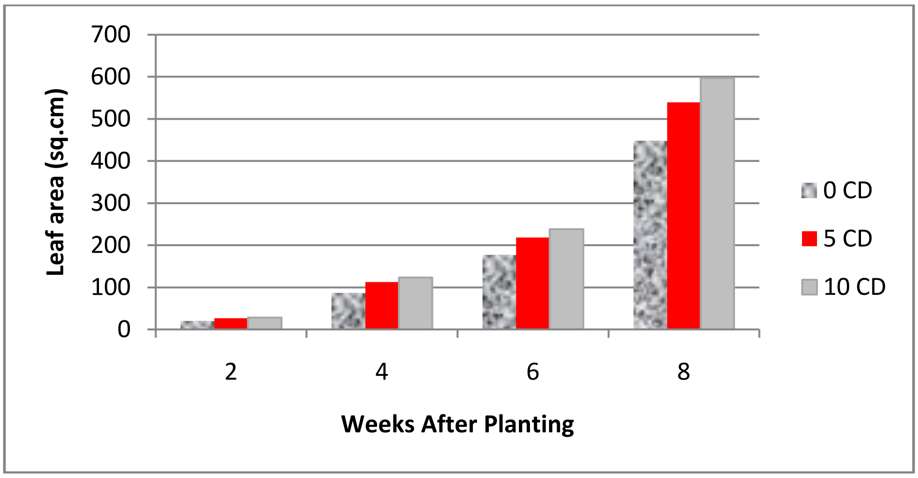


Figure 4.51: Main effect of rates of S on leaf area (cm^2) in 2010



SE± 11.43 35.96 60.32 129.81

Figure 4.52: Main effect of rates of CD on leaf area (cm^2) in 2010

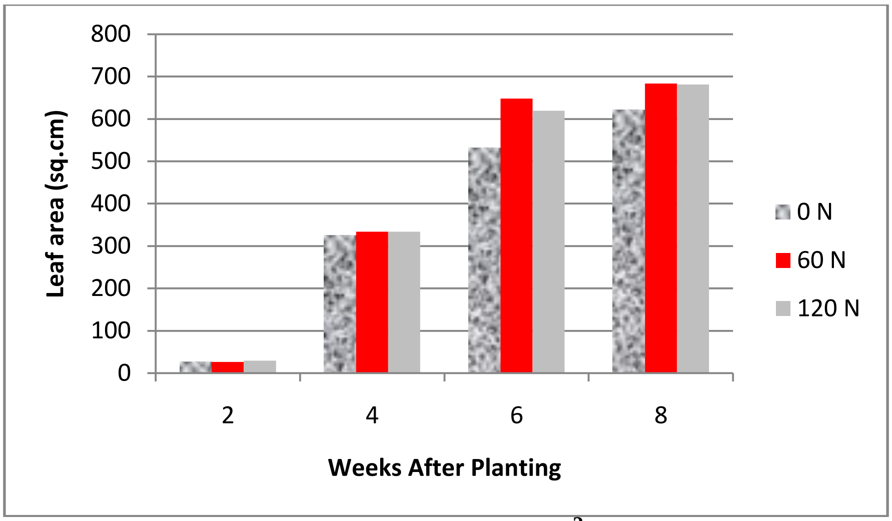


Figure 4.53: **Main effect of rates of N on leaf area (cm^2) in 2011**

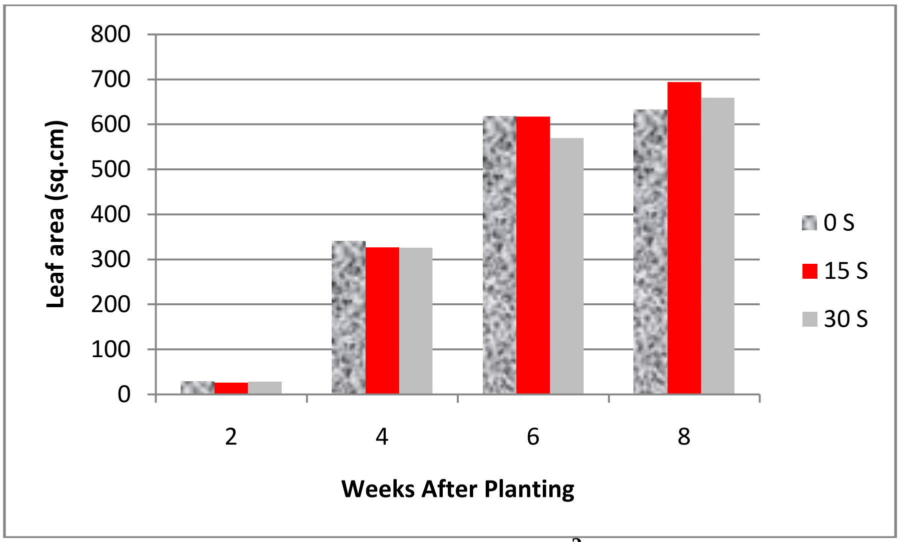
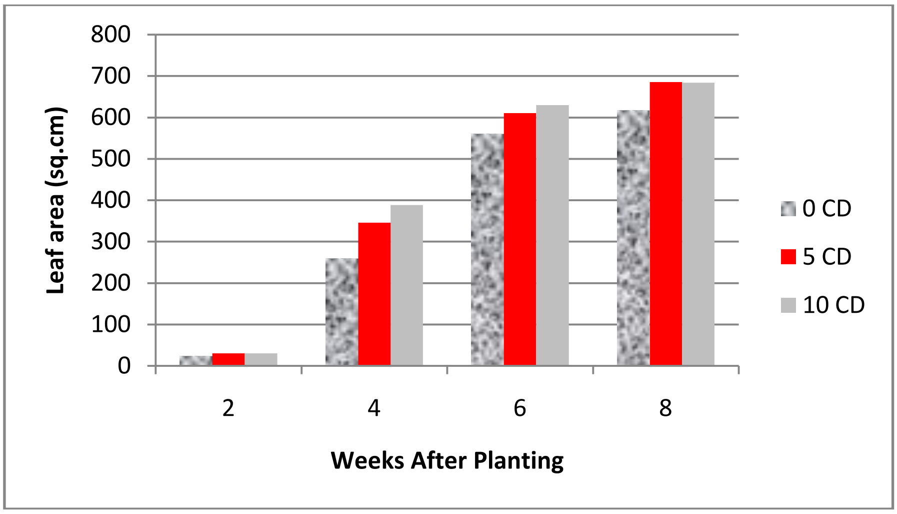


Figure 4.54: **Main effect of rates of S on leaf area (cm^2) in 2011**



SE±	10.79	112.10	158.61	179.86

Figure 4.55: **Main effect of rates of CD on leaf area (cm^2) in 2011**

4.7.4.4 Interaction effect of different levels of N, S and CD on plant leaf area

Interactive effect of different levels of N, S and CD on plants leaf area for weeks 2-8 in 2009, 2010, and 2011 are presented in the Tables 4.35; 4.36 and 4.37 respectively. Effect of the interaction was significant ($P < 0.01$) with the highest mean (635.5 cm^2) obtained from the interaction of highest rates of the factors applied in week 8, while the least response was obtained from the control with a mean of 154.67 cm^2. Also, mean responses from the interaction of N, S and CD on leaf area in 2009 was consistent with the trend of results obtained in 2010 and 2011.

Table 4.35: Interaction effects of different levels of N, S and CD on leaf area in 2009 field trial

				Weeks (cm^{2})			
	N	S	CD	2	4	6	8
1	0	0	0	39.93^{i}	79.30^{ij}	131.00^{kl}	154.67^{k}
2	0	0	5	39.37^{i}	72.90^{j}	164.30^{jkl}	185.73^{jk}
3	0	0	10	47.30^{hi}	73.17^{j}	116.40^{l}	211.03^{ijk}
4	0	15	0	44.73^{hi}	79.67^{ij}	218.20^{hij}	255.90^{hi}
5	0	15	5	44.90^{hi}	84.50^{ij}	158.33^{jkl}	234.23^{hij}
6	0	15	10	47.23^{hi}	85.23^{ij}	201.93^{j}	277.80^{hi}
7	0	30	0	55.20^{h}	95.73^{hij}	206.60^{ij}	292.80^{h}
8	0	30	5	96.43^{cd}	146.20^{efg}	338.40^{ef}	361.87^{g}
9	0	30	10	102.13^{bc}	200.93^{bcd}	379.23^{de}	457.57^{de}
10	60	0	0	45.90^{hi}	92.27^{hij}	199.70^{j}	263.60^{hi}
11	60	0	5	58.10^{h}	85.30^{ij}	190.00^{jk}	243.80^{hij}
12	60	0	10	77.70^{fg}	137.83^{efg}	295.50^{fg}	368.37^{g}
13	60	15	0	87.00^{def}	155.93^{efg}	269.27^{ghi}	284.40^{h}
14	60	15	5	90.33^{c-f}	125.93^{fgh}	411.53^{d}	445.57^{ef}
15	60	15	10	71.40^{g}	118.73^{ghi}	340.97^{ef}	387.80^{fg}
16	60	30	0	78.73^{efg}	162.77^{def}	224.90^{hij}	251.57^{hij}
17	60	30	5	71.33^{g}	141.10^{efg}	416.10^{d}	436.07^{ef}
18	60	30	10	92.13^{cde}	146.27^{efg}	491.60^{bc}	543.93^{bc}
19	120	0	0	77.90^{fg}	138.70^{efg}	325.07^{efg}	366.77^{g}
20	120	0	5	92.53^{cd}	200.83^{bcd}	327.95^{efg}	433.30^{ef}
21	120	0	10	138.23^{a}	180.03^{cde}	591.63^{a}	602.13^{ab}
22	120	15	0	110.77^{b}	221.33^{ab}	514.10^{bc}	540.67^{bc}
23	120	15	5	114.20^{b}	218.00^{abc}	546.60^{ab}	569.83^{bc}
24	120	15	10	91.20^{c-f}	175.07^{de}	277.53^{fgh}	408.07^{efg}
25	120	30	0	137.43^{a}	239.43^{ab}	479.93^{c}	508.40^{cd}
26	120	30	5	137.03^{a}	244.33^{a}	500.57^{bc}	566.27^{bc}
27	120	30	10	148.13^{a}	202.90^{bcd}	589.97^{a}	635.50^{a}
	Mean			82.86	144.61	329.90	381.02
	R-Square			0.97	0.90	0.96	0.95
	CV			8.92	15.39	11.07	9.52
	LSD			11.82	35.63	58.43	58.10
	NxSxCD			**	**	**	**

*** = Significant at P = 0.01*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

Table 4.36: Interaction effects of different levels of N, S and CD on leaf area in 2010 field trial

				Weeks (cm^{2})			
	N	S	CD	2	4	6	8
1	0	0	0	16.92^{c}	63.20^{h}	116.00^{g}	315.83^{g}
2	0	0	5	22.10^{abc}	64.27^{h}	127.33^{fg}	332.40^{fg}
3	0	0	10	26.94^{abc}	98.37^{c-h}	229.63^{abcd}	501.67^{b-e}
4	0	15	0	21.45^{abc}	67.67^{gh}	125.80^{fg}	307.77^{g}
5	0	15	5	26.86^{abc}	110.57^{b-g}	183.43^{c-g}	463.70^{def}
6	0	15	10	21.59^{abc}	102.80^{b-h}	190.67^{b-f}	528.93^{a-e}
7	0	30	0	17.48^{c}	87.63^{efgh}	174.40^{d-g}	436.80^{d-g}
8	0	30	5	32.13^{ab}	126.87^{a-e}	210.43^{a-e}	516.97^{a-e}
9	0	30	10	25.12^{abc}	103.57^{b-h}	211.07^{a-e}	549.30^{abcd}
10	60	0	0	19.26^{bc}	70.20^{fgh}	180.17^{c-g}	493.19^{cde}
11	60	0	5	30.71^{abc}	117.60^{a-e}	238.47^{abcd}	561.97^{abcd}
12	60	0	10	29.38^{abc}	116.20^{a-e}	229.63^{abcd}	636.10^{abc}
13	60	15	0	17.15^{c}	92.40^{d-h}	216.03^{a-e}	497.93^{bcde}
14	60	15	5	20.24^{bc}	118.53^{a-e}	215.60^{a-e}	559.80^{abcd}
15	60	15	10	26.58^{abc}	103.60^{b-h}	226.20^{a-e}	586.97^{abcd}
16	60	30	0	19.35^{bc}	96.20^{c-h}	201.63^{a-e}	510.80^{bcde}
17	60	30	5	24.02^{abc}	107.13^{b-h}	223.00^{a-e}	547.90^{abcd}
18	60	30	10	27.31^{abc}	146.93^{ab}	250.20^{abcd}	597.13^{abcd}
19	120	0	0	24.99^{abc}	65.43^{h}	151.67^{efg}	381.93^{efg}
20	120	0	5	29.83^{abc}	106.67^{b-h}	240.73^{abcd}	658.20^{ab}
21	120	0	10	28.29^{abc}	136.40^{abcd}	265.77^{efg}	638.37^{abc}
22	120	15	0	18.28^{bc}	124.50^{a-e}	231.97^{abcd}	563.80^{abcd}
23	120	15	5	29.78^{abc}	123.60^{a-e}	252.60^{abc}	584.57^{abcd}
24	120	15	10	30.87^{abc}	146.07^{ab}	273.67^{a}	658.67^{ab}
25	120	30	0	24.26^{abc}	112.60^{b-f}	187.57^{c-g}	517.73^{a-e}
26	120	30	5	26.88^{abc}	138.43^{abc}	275.13^{a}	626.07^{abc}
27	120	30	10	35.73^{a}	158.17^{a}	264.23^{ab}	676.70^{a}
	Mean			24.94	107.62	210.85	527.82
	R-Square			0.46	0.84	0.86	0.72
	CV			28.62	20.88	18.02	15.37
	LSD			11.43	35.96	60.82	129.81
	NxSxCD			*	*	*	*

** = Significant at P = 0.05*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

Table 4.37: Interaction effects of different levels of N, S and CD on leaf area in 2011 field trial

				Weeks (cm^2)			
	N	S	CD	2	4	6	8
1	0	0	0	23.57^{bcd}	260.10^{e-i}	562.60^{abcd}	529.10^{c}
2	0	0	5	26.43^{abcd}	287.57^{b-i}	523.03^{bcd}	621.47^{abc}
3	0	0	10	29.83^{abc}	435.13^{a}	645.57^{abc}	635.03^{abc}
4	0	15	0	23.33^{bcd}	281.77^{b-i}	452.23^{cd}	581.37^{bc}
5	0	15	5	28.73^{abc}	310.87^{a-i}	452.23^{bcd}	688.43^{abc}
6	0	15	10	26.60^{abcd}	417.40^{ab}	595.10^{abc}	689.93^{abc}
7	0	30	0	23.57^{bcd}	240.60^{hi}	375.13^{d}	558.47^{bc}
8	0	30	5	34.87^{ab}	358.07^{a-h}	581.17^{abc}	635.30^{abc}
9	0	30	10	26.10^{abcd}	334.87^{a-i}	530.50^{bcd}	633.40^{abc}
10	60	0	0	23.57^{bcd}	305.77^{a-i}	562.23^{abcd}	624.00^{abc}
11	60	0	5	34.07^{ab}	402.50^{abc}	664.30^{ab}	746.37^{abc}
12	60	0	10	32.90^{abc}	396.80^{a-e}	749.93^{a}	690.00^{abc}
13	60	15	0	22.97^{bcd}	256.60^{f-i}	673.40^{ab}	713.37^{abc}
14	60	15	5	25.00^{bcd}	307.50^{a-i}	711.77^{ab}	620.37^{abc}
15	60	15	10	25.30^{bcd}	322.30^{a-i}	601.60^{abc}	782.73^{ab}
16	60	30	0	15.33^{d}	262.30^{d-i}	591.30^{abc}	648.03^{abc}
17	60	30	5	28.17^{a-d}	352.47^{a-h}	627.40^{abc}	644.53^{abc}
18	60	30	10	29.87^{abc}	400.87^{abcd}	652.50^{ab}	683.60^{abc}
19	120	0	0	23.97^{bcd}	205.57^{i}	633.40^{abc}	561.60^{bc}
20	120	0	5	32.20^{abc}	351.50^{a-i}	565.50^{abc}	626.00^{abc}
21	120	0	10	31.13^{abc}	418.90^{ab}	612.03^{abc}	660.03^{abc}
22	120	15	0	20.20^{cd}	269.70^{c-i}	621.73^{abc}	674.43^{abc}
23	120	15	5	31.60^{abc}	392.83^{a-f}	691.13^{ab}	815.30^{a}
24	120	15	10	30.87^{abc}	382.40^{a-g}	685.53^{ab}	682.27^{abc}
25	120	30	0	26.93^{abcd}	243.90^{ghi}	563.17^{abcd}	659.77^{abc}
26	120	30	5	31.20^{abc}	352.07^{a-h}	607.73^{abc}	749.70^{abc}
27	120	30	10	38.80^{a}	386.93^{a-f}	597.73^{abc}	700.87^{abc}
	Mean			27.67	331.01	597.41	661.32
	R-Square			0.48	0.56	0.50	0.35
	CV			24.37	21.16	16.52	16.97
	LSD			10.79	112.10	158.61	179.86
	NxSxCD			**	**	**	*

** = Significant at P = 0.05, ** = Significant at P = 0.01*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

4.7.5 Effects of N, S and Cowdung rates on the combined analysis of plant height, number of leaves, stem girth and leaf area of maize

The data for combined analysis conducted on the growth parameters for the three years of field study is shown in Table 4.38. All the parameters were significant ($P \leq 0.01$) in response to fertilizer application rates.

In each parameter measured, the best performance was obtained from the highest level of N,S and CD which had been the trend already established during each year of operation, while half the application rates had comparable results,but the performance of control was significantly ($P < 0.05$) lower than either half or full application rates.This consistency across all growth parameters, especially in the first two years of planting over the control tended to show that maize production in the Guinea savanna increased due to the amendment.

Table 4.38: Effects of N, S and Cowdung rates on the combined analysis of plant height, number of leaves, stem girth and leaf area of maize

N rates (kg/ha)	Plant height (cm)	No of leaves	Stem girth (cm)	Leaf area (cm^2)
0	60.90	8.40	5.10	300.40
60	71.00	9.30	5.70	361.60
120	77.60	10.10	6.90	410.90
S Rates (kg/ha)				
0	65.70	8.80	5.30	331.10
15	71.20	9.30	5.70	360.90
30	72.60	9.70	5.90	380.70
CD Rates (tons/ha)				
0	59.90	8.70	5.10	313.60
5	71.70	9.40	5.80	364.40
10	77.90	9.70	6.00	394.90
Mean	69.80	9.30	5.70	357.60
CV	13.46	4.80	6.90	11.56
R-Square	0.94	0.94	0.94	0.91
LSD (0.05)	15.04**	0.71**	0.62**	66.18**

*** = Significant at P = 0.01*

4.7.6 Main effect of N, S and Cowdung rates on grain yield in 2009

The response of maize grain yield to application of various levels of N, S and cowdung (CD) was significant ($P < 0.01$). Nitrogen at 120 kg/ha produced the highest grain yield of maize of 1,132 kg/ha while the lowest effect was obtained in the control for either application rates of N, S or CD (Table 4.39). Similarly, sulphur application at 30 kg/ha and cowdung at 10 ton/ha were significant ($P \leq 0.01$) and more effective than sulphur at 15 kg/ha and cowdung at 5 ton/ha respectively (Table 4.39).

The percentage difference of treatment means, revealed that maize grain yield increased with an increase in nitrogen application from 0, 60 to 120 kg/ha (24.5%, 26.4% and 49.1% respectively). Also, application rates of sulphur produced 30.5%, 32.5% and 37% respectively from 0, 15 and 30 kg/ha sulphur rates. Cowdung application at 0, 5 and 10 ton/ha recorded a corresponding increase in grain yield as 20.8%, 33.6% and 45.7% respectively. Differences in their treatment means were significant ($P \leq 0.01$). However, there was no significant ($P > 0.05$) difference in grain yield in the highest rates of N, S and CD (Table 4.39). The result showed that there was a good response obtained from the highest rates of the amendment due to the initial low soil fertility.

4.7.7 Main effect of N, S and Cowdung rates on stover in 2009

Stover increased from 816.4 to 1339.8 kg/ha obtained from 0 to 120 kg/ha, 923.4 to 1204.8 kg/ha from the sulphur rates and 599.1 to 1366.1 kg/ha from the cowdung rates respectively (Table 4.39). There was no statistical difference ($P > 0.05$) between the means obtained from both N at 120 kg/ha and cowdung at 10 ton/ha; though the dry matter yield at 10 ton/ha was slightly better with a 45% higher dry matter yield as against 44% obtained from 120 kg/ha nitrogen application. A similar performance was obtained from nitrogen at 0 kg/ha in relation to cowdung at 0 ton/ha. Increase in stover yield with sulphur application at

30 kg/ha was ($P < 0.05$) compared with sulphur at 15 kg/ha (Table 4.39). The performance showed that stover responded significantly ($P < 0.01$) to the application of N, S and CD.

4.7.8 Main effect of N, S and Cowdung rates on cob yield in 2009

The performance obtained from different application levels of N, S and CD on grain yield and stover was equally obtained on maize cob yield. Nitrogen application at 60 kg/ha and 120 kg/ha had cob yields of 804.9 and 1352.9 kg/ha respectively that were higher than the control (Table 4.39). This represents 28% and 46% respectively in favour of 60 and 120 kg/ha N application over the control. The difference in treatment means was significant ($P < 0.01$), suggesting that soils of northern guinea savanna are inherently low in fertility (Uyovbisere and Lombin, 1991). Therefore requiring an effective management; especially through a constant application of organic matter to rejuvenate and sustain soil fertility as required.

The pattern of effect of nitrogen application, was similar to sulphur and cowdung rates. Their respective results were consistently higher than the control (Table 4.39). The yield difference among sulphur and cowdung rates were 33% and 37% for sulphur at 15 and 30 kg/ha, 34% and 44% for 5 and 10 ton/ha cowdung rates as against 31% and 22% respectively obtained from sulphur at 0 kg/ha and CD at 0 ton/ha. This performance suggests that the nutritional value of sulphur though a secondary macronutrient was essential in boosting crop response to other nutrients.

4.7.9 Main effect of N, S and Cowdung rates on grain yield in 2010

Grain yield in the second cropping in 2010 was significant ($P \leq 0.01$) with respect to fertilizer application (Table 4.39). Expectedly, N at 120 kg/ha was widely superior compared to N at 60 kg/ha. The least performance was obtained from the control with a mean of 511.9 kg/ha which was lower ($P \leq 0.01$) than the mean obtained from N at 60 and 120 kg/ha respectively. Yield differences were 15.3%, 34.7% and 50% respectively in favour of control, N rates at 60 and at 120 kg/ha. Also, a similar response was obtained with cowdung rates with yield differences of 36% and 45% from 5 and 10 ton/ha respectively compared to only 19% from the cowdung control. But sulphur at 0 kg/ha had a higher response than S at 15 kg/ha except for 30 kg/ha where the impact was more noticeable and significantly ($P < 0.01$) different from the control (Table 4.39).

Grain yield appreciated by 32.2%, 33.3% and 30.1% in 2010 for N, S and CD at their highest application levels over that of 2009. Comparatively, there is a significant increase in grain yield in 2010 than in 2009 across all fertilizer levels except that of the control. This increase may be associated with the regenerative effect of the amendments on the soil particularly as modified by the organic resource. Also, nutrient build up due to CD addition further increased soil fertility. There is also the aspect of a favourable climatic condition where relative humidity (Tables 4.3, 4.4 and 4.5) and rainfall distribution (Appendix 1) were better in 2010 than in 2009.

4.8.0 Main effect of N, S and Cowdung rates on stover in 2010

Dry matter yield appreciated significantly ($P < 0.01$) above the control among nitrogen, sulphur and cowdung rates except for sulphur at 0 kg/ha. The trend is consistent with grain and cob yields of the previous year of cropping. Nitrogen level at 120 kg/ha had the highest response followed by cowdung at 10 ton/ha; though there was no significant difference ($P \geq 0.05$) between their means (Table 4.39). Also, sulphur level at 30 kg/ha was significantly ($P \leq 0.01$) better in agronomic efficiency than at 15 kg/ha.

The consistency in dry matter yield increase with a corresponding increase in N and S fertilizer application rates showed that there was short supply of basic plant nutrients in the soils prior to cultivation; thus requiring replenishment for a sustainable agricultural practice. Many workers have reported significant yield increase of maize in the savanna with higher levels of nitrogen application (Idris *et al*., 2010; Musa *et al*., 2009 and Vanlauwe *et al*., 2000); especially when it is applied along with recommended rates of the other major elements, such as P and K fertilizers.

4.8.1 Main effect of N, S and Cowdung rates on cob yield in 2010

Maize cob yield in 2010 was consistent with its performance in 2009 (Table 4.39). Control treatment was the least effective indicating that low soil fertility in the savanna is the limiting factor and indeed a major constraint to a successful crop production programme especially under tropical conditions. Expectedly, cob yield was enhanced when N rates increased from 0 to 120 kg/ha and the same performance replicated among the cowdung rates. However, the overall performance of each of the factors showed that cob yield was significant ($P < 0.01$) in response to the amendment, particularly with N rates (Table 4.39).

Yield responses were 17%, 35% and 49% respectively for nitrogen rates at 0, 60 and 120 kg/ha, 36% and 45% respectively higher than the control for the cowdung rates while sulphur at 30 kg/ha was significant ($P \leq 0.01$) and more effective than S at 15 kg/sha. The yield differentials among the treatment means is an indication that maize production in the savanna thrives much more when optimum levels of soil nutrients are guaranteed along with other management options.

Table 4.39: Main effect of different levels of N, S and CD on grain, stover and cob yields in 2009, 2010 and 2011 field trials

	Grain yield (kg/ha)			**Stover (kg/ha)**			**Cob weight (kg/ha)**		
N rates (kg/ha)	2009	2010	2011	2009	2010	2011	2009	2010	2011
0	566.20	511.90	827.90	816.40	714.30	890.40	758.80	671.60	1,027.10
60	608.90	1,157.10	1,519.20	882.20	1,329.90	1,673.90	804.90	1,308.90	1,871.40
120	1,132.40	1,670.60	2,011.30	1,339.80	1,710.10	2,141.40	1,352.90	1,965.20	2,534.70
S Rates (kg/ha)									
0	702.80	1,104.40	1,453.40	923.40	1,260.80	1,573.50	893.80	1,310.20	1,794.10
15	750.50	954.70	1,385.90	910.20	1,027.10	1,530.70	952.90	1,194.90	1,762.80
30	854.20	1,280.50	1,519.20	1,204.80	1,466.50	1,601.40	1,069.90	1,512.60	1,876.40
CD Rates (tons/ha)									
0	478.90	620.50	1,145.60	599.10	768.70	1,191.70	650.20	758.80	1,466.50
5	775.20	1,211.40	1,412.20	1,073.20	1,326.60	1,581.70	987.60	1,456.70	1,739.80
10	1,053.40	1,507.70	1,800.70	1,366.10	1,659.10	1,932.30	1,278.90	1,802.30	2,226.90
Mean	769.20	1,113.20	1,452.80	1,012.80	1,251.50	1,568.60	972.20	1,339.30	1,811.10
CV	42.80	29.40	35.40	45.40	26.70	31.90	36.70	27.30	37.70
R-Square	0.74	0.87	0.71	0.69	0.85	0.71	0.75	0.86	0.68
LSD (0.05)	539.80**	523.50**	823.90**	735.70**	535.10**	802.40**	570.40**	585.40**	1,091.20**

*** = Significant at P = 0.01*

4.8.2 Main effect of N, S and Cowdung rates on grain yield in 2011

There was no variation in the trend already established in grain yield from the previous years. All the factors (N, S and CD) were effective and significant ($P \leq 0.01$) in enhancing grain yield compared to the control (Table 4.39). Yield differences were 23%, 34% and 44% respectively for each of the three years of cropping.

Grain yield obtained in 2011 at highest N application rate was 2,011.30 kg/ha compared to 827.90 kg/ha and 1,519.20 kg/ha obtained from the control and half N rate respectively. Similarly, grain yield in 2011 at highest S rate was 1,519.20 kg/ha compared to 1,453.40 kg/ha and 1,385.90 kg/ha respectively, obtained from control and 15 kg S/ha. Grain yield with CD rates were 1,145.60 kg/ha; 1,412.20 kg/ha and 1,800.70 kg/ha at 0, 5 and 10 ton/ha respectively. From the results, there was no significant difference ($P > 0.05$) between 60 and 120 kg N/ha, mean effects of S rates were not significant and a similar partern of response was obtained in CD rates. Differences in yield were only marginal especially with S and CD rates. In the third year of cropping, plant nutrients had accumulated over time within the plots and as such, further application did not translate to a significant increase in grain yield.

The different levels of application of N, S and CD were regressed against grain yield (Figures 4.56 – 4.63). It was observed that maize grain yield increased linearly particularly in 2010 with increasing levels of N but later dropped in 2011. Response to S rates was highest with 30 kg S/ha but not significantly ($P > 0.05$) different with 15 kg S/ha, while response to CD rates was linear in 2009.

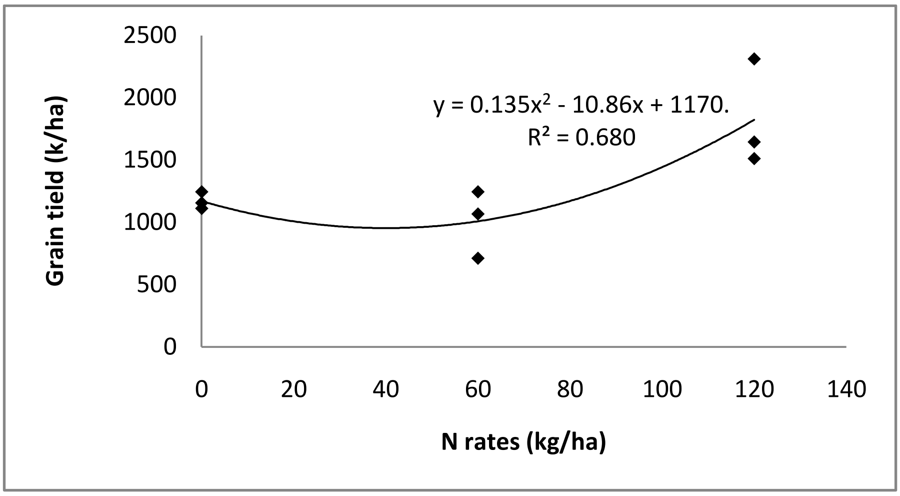


Figure 4.56: Regression analysis of maize grain yield with levels of nutrient application – N rates 2009

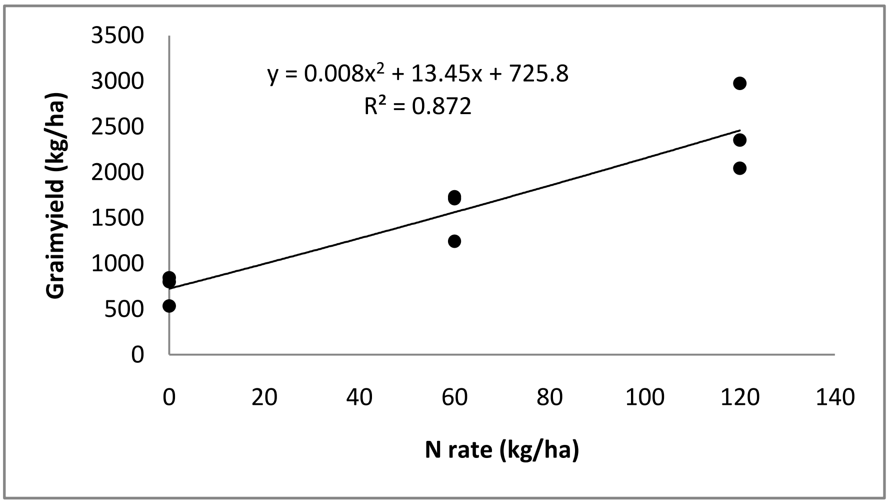


Figure 4.57: Regression analysis of maize grain yield with levels of nutrient application – N rates 2010

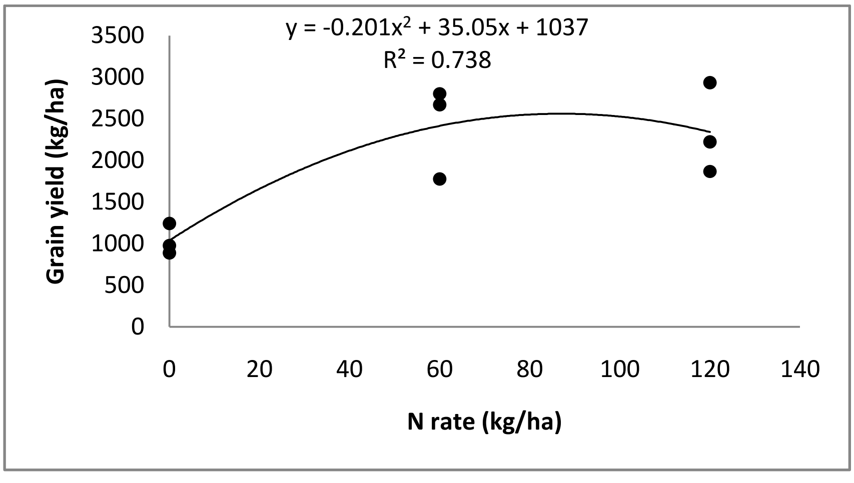


Figure 4.58: Regression analysis of maize grain yield with levels of nutrient application – N rates 2011

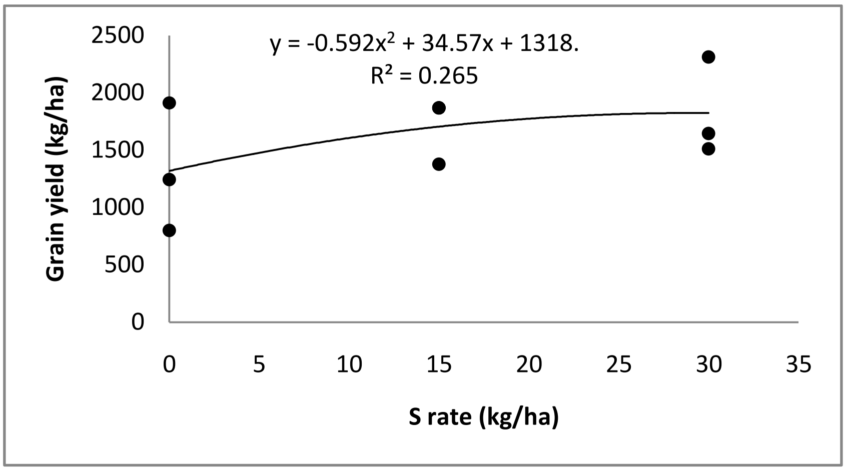


Figure 4.59: Regression analysis of maize grain yield with levels of nutrient application – S rates 2009

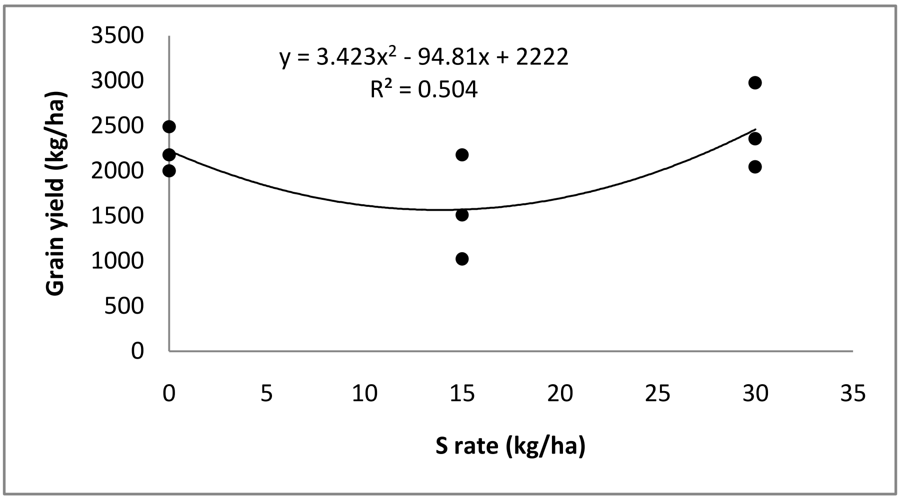


Figure 4.60: Regression analysis of maize grain yield with levels of nutrient application – S rates 2010

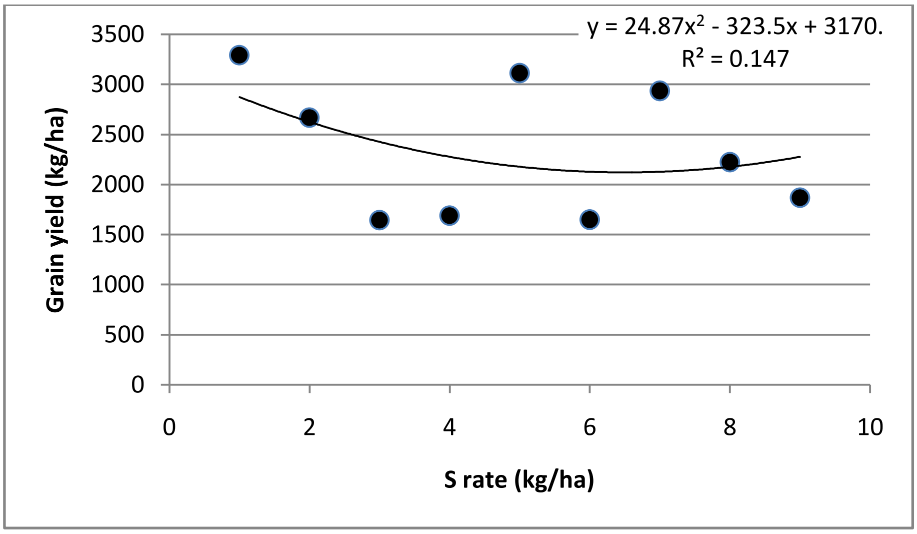


Figure 4.61: Regression analysis of maize grain yield with levels of nutrient application – S rates 2011

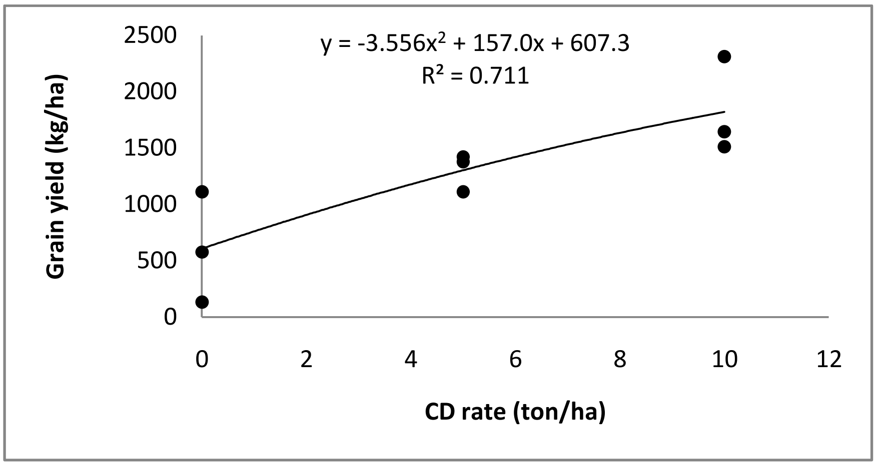


Figure 4.62: Regression analysis of maize grain yield with levels of nutrient application – CD rates 2009

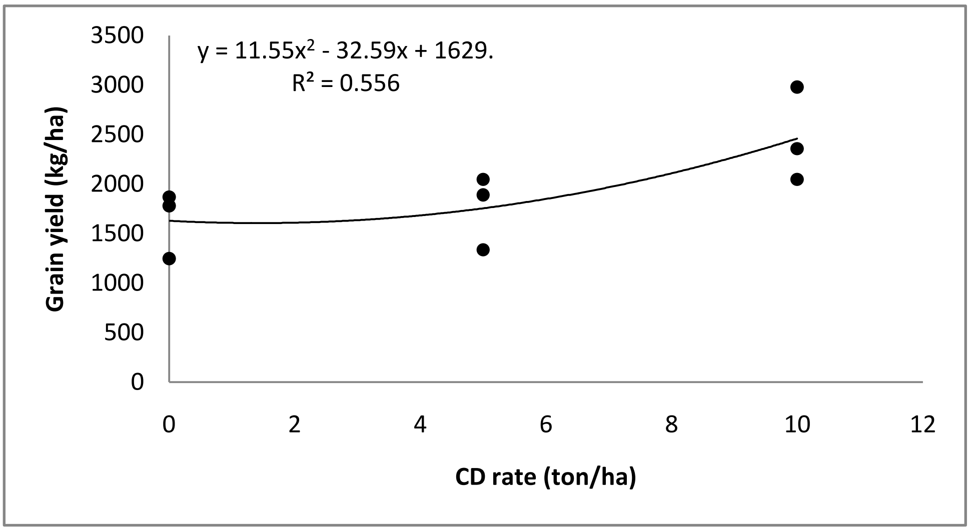


Figure 4.63: Regression analysis of maize grain yield with levels of nutrient application – CD rates 2010

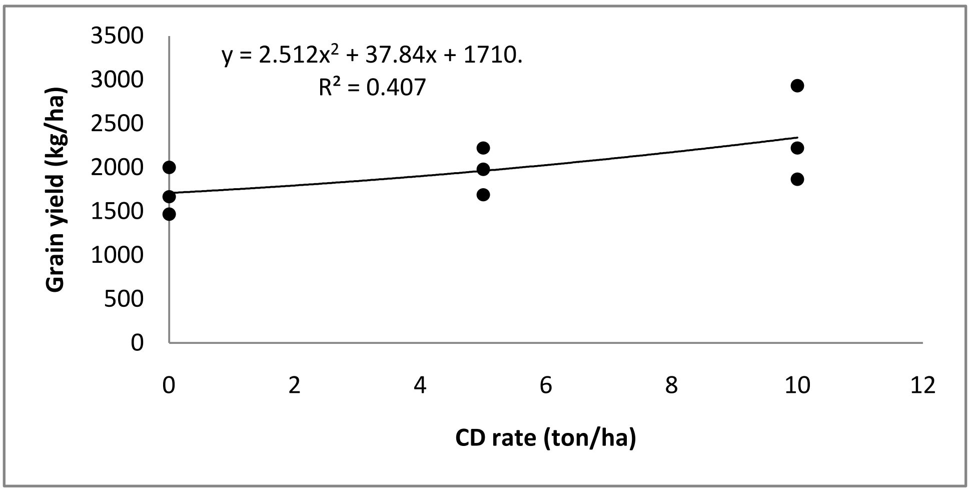


Figure 4.64: Regression analysis of maize grain yield with levels of nutrient application – CD rates 2011

4.8.3 Main effect of N, S and Cowdung rates on stover in 2011

Dry matter yield in the third year of field trial improved tremendously when compared to its performance in the first and second year of cropping. For instance, yield differences between 2010 and 2011 were higher in 2011 across all the fertilizer and cowdung rates. Dry matter yield appreciated by 19.8%, 20.6% and 20.2% in 2011 for N levels at 0, 60 and 120 kg/ha when compared to the performance in 2010.

Sulphur application at 30 kg/ha in 2011 was 397 kg/ha and 135 kg/ha respectively higher compared to 2009 and 2010. Also, stover yield in 2011 with cowdung rate at 10 tons/ha showed a difference of 566 kg/ha and 273 kg/ha higher than in 2009 and 2010 respectively. A similar trend was obtained when half the rates of N, S and CD were applied. The differences in the means were ($P \leq 0.01$) significant (Table 4.39). Similarly, results obtained from cowdung rates in 2011 were consistently higher than those obtained in 2010.

4.8.4 Main effect of N, S and Cowdung rates on cob yield in 2011

Effect of fertilizer application on cob yield in 2011 followed the same trend and nutrients release patterns from cowdung as observed already for the previous two years (Table 4.39). Efficiency of N rates was highest with a mean of 2534.7 kg/ha obtained from the application of 120 kg N/ha. The results for 2010 and 2009 were 1965.2 and 1352.9 kg/ha respectively indicating that cob yield increased through the years of experimentation with respect to increase in N, S and cowdung application. All the fertilizer treatments positively impacted on maize cob weight.

4.8.5 Main effect of N, S and cowdung rates on the combined analysis of grain, stover and cob yields of maize

The combined effects of N. S and cowdung application for the three years of field trial are shown in Table 4.40. As was the trend during each year of the trial, yield responses increased with the application rates of the three factors throughout the period of study. The limiting factor for crop production has been low soil fertility as manifested in the results obtained from the control (Table 4.40). Generally, there was a progressive increase in grain yield, stover and cob weight through the years of study. The pattern of increase was in the order 2011 > 2010 > 2009 for the three yield parameters. This shows that the productive capacity of the soil had greatly improved over the years mainly due to inputs of organic and inorganic source of nutrients.

Table 4.40: Main effect of N, S and cowdung rates on the combined analysis of grain, stover and cob yields of maize

N rates (kg/ha)	Grain yield (kg/ha)	Stover (kg/ha)	Cob weight (kg/ha)
0	635.30	807.10	819.10
60	1,095.10	1,295.40	1,352.40
120	1,604.80	1,730.40	1,950.90
S Rates			
(kg/ha)			
0	1,086.90	1,252.60	1,332.70
15	1,030.40	1,156.00	1,303.60
30	1,217.90	1,424.30	1,486.30
CD Rates			
(ton/ha)			
0	748.40	853.20	958.50
5	1,132.90	1,327.20	1,394.70
10	1,453.90	1,652.50	1,769.40
Mean	1,111.70	1,277.60	1,374.20
CV	35.90	34.60	35.90
R-Square	0.80	0.80	0.80
LSD (0.05)	638.40**	706.80**	790.50**

*** = Significant at P = 0.01*

4.9 Interaction effect of different levels of N, S and CD on grain yield

Interactive combinations of levels of N, S and CD on grain yield in 2009 showed that 120 kg N /ha + 30 kg S/ ha + 10 ton/ ha CD application had the highest interaction with a mean grain yield of 1822.03 kg /ha which was higher than the yield obtained from 120 kg N/ha + 15 kg S/ha + 10 ton/ha CD (1703.57 kg /ha) by 7%, while the least effect was obtained from the plot with no application of N, S and CD (control) with a mean grain yield of 207.43 kg /ha or 87 % less than the performance of full rate of N, S and CD (Table 4.41). The difference among the treatment means was significant ($P < 0.05$). The result was consistent with the performance in 2010 but differed slightly in 2011, where the best performing combination was 120 kg N/ha + 0 kg S/ha + 10 ton /ha CD (2533.10 kg/ha), while 0 kg N/ha + 30 kg S/ha + 0 ton/ha CD had the least effect (222.20 kg /ha).

Table 4.41: Interaction effects of different levels of N, S and CD on grain yield

				Grain Yield			
	N	S	CD	2009 kg/ha	2010 kg/ha	2011 kg/ha	Mean kg/ha
1	0	0	0	207.43^{f}	192.60^{m}	355.53^{kl}	251.85^{k}
2	0	0	5	325.90^{f}	340.70^{lm}	636.97^{i-l}	434.52^{h-j}
3	0	0	10	$1,170.27^{bcd}$	977.67^{f-k}	$1,466.53^{c-i}$	1204.82^{c-h}
4	0	15	0	281.47^{f}	207.40^{m}	444.43^{j-l}	311.1^{jk}
5	0	15	5	562.93^{def}	355.53^{klm}	814.73^{g-l}	577.73^{f-k}
6	0	15	10	429.57^{ef}	903.60^{g-l}	$1,214.73^{e-k}$	849.31^{e-k}
7	0	30	0	666.63^{gef}	207.40^{m}	222.20^{l}	365.41^{ijk}
8	0	30	5	281.47^{f}	696.23^{h-m}	$1,259.17^{d-j}$	745.62^{e-k}
9	0	30	10	$1,170.23^{bcd}$	725.87^{h-m}	$1,036.93^{f-l}$	977.68^{d-k}
10	60	0	0	251.83^{f}	370.33^{j-m}	711.03^{h-l}	444.39^{g-k}
11	60	0	5	$1,169.93^{bcd}$	$1,555.40^{c-f}$	$1,747.97^{a-f}$	1491.11^{a-e}
12	60	0	10	459.20^{ef}	$1,570.23^{c-f}$	$1,555.40^{b-h}$	1194.94^{c-h}
13	60	15	0	577.73^{def}	592.57^{i-m}	$1,199.90^{e-k}$	790.07^{e-k}
14	60	15	5	785.13^{cdef}	$1,362.87^{d-g}$	$1,822.03^{a-f}$	1323.34^{b-f}
15	60	15	10	399.97^{ef}	$1,244.30^{e-h}$	$1,496.17^{c-i}$	1046.84^{c-j}
16	60	30	0	429.60^{ef}	637.00^{h-m}	$1,436.90^{d-i}$	834.5^{e-k}
17	60	30	5	399.97^{ef}	$1,185.07^{e-i}$	$1,288.77^{d-j}$	957.94^{d-k}
18	60	30	10	$1,007.33^{cde}$	$1,896.13^{abcd}$	$2,414.57^{ab}$	1772.68^{abc}
19	120	0	0	429.57^{ef}	755.47^{g-m}	$2,088.67^{a-e}$	1091.24^{c-i}
20	120	0	5	992.47^{cde}	$1,955.37^{abcd}$	$1,985.00^{a-e}$	1644.28^{abcd}
21	120	0	10	$1,318.37^{abc}$	$2,222.03^{ab}$	$2,533.10^{a}$	2024.51^{ab}
22	120	15	0	859.20^{c-f}	992.50^{f-j}	$1,807.23^{a-f}$	1219.64^{c-g}
23	120	15	5	$1,155.47^{bcd}$	$1,362.87^{d-g}$	$1,525.80^{c-h}$	1348.05^{b-f}
24	120	15	10	$1,703.57^{ab}$	$1,570.20^{c-f}$	$2,147.93^{a-d}$	1807.23^{abc}
25	120	30	0	607.33^{def}	$1,629.47^{b-e}$	$2,044.23^{a-e}$	1427.01^{bcde}
26	120	30	5	$1,303.60^{abc}$	$2,088.70^{abc}$	$1,629.47^{b-g}$	1673.92^{abcd}
27	120	30	10	$1,822.03^{a}$	$2,459.03^{a}$	$2,340.53^{a-c}$	2207.19^{a}
	Mean			769.19	1,113.21	1,452.81	1111.74
	R-Square			0.74	0.87	0.71	0.77
	CV			42.83	29.39	35.44	35.89
	LSD			629.90	523.50	823.90	659.1
	NxSxCD			**	**	**	**

*** = Significant at P = 0.01*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

4.9.1 Interaction effect of different levels of N, S and CD on stover

The results of three years of field studies on the interactions of different levels of N, S and CD on plant stover are presented in Table 4.42. The result showed that best performance was obtained from 120 kg N/ha + 30 kg S/ha +10 ton CD/ha in the three consecutive years of study (2,251.63 kg/ha; 2,562.83 kg/ha and 2844.17 kg/ha),while the least performance was obtained with the control in 2009 (414.83kg/ha) and 2010 (340.70 kg/ha) but with 0 kg N/ha +30 kg S/ha + 0 ton/ha CD (325.90 kg/ha) in 2011. The differences in the treatment means were significant ($P < 0.05$) (Table 4.42).

From the results, a better response was obtained with the highest interacting rates of the amendments, indicating that plant tissue development improved significantly on application of these rates of N, S and CD than with half rates, or in combinations where either N or S was not applied. The least effect of the control plot on stover further indicates the low fertility of the Northern Guinea savanna soil.

Table 4.42: Interaction effects of different levels of N, S and CD on stover yield

				Stover			
				2009	2010	2011	Mean
	N	S	CD	kg/ha	kg/ha	kg/ha	kg/ha
1	0	0	0	414.83^{h}	340.70^{j}	474.03^{ij}	409.85^{j}
2	0	0	5	666.63^{e-h}	636.97^{g-j}	903.63^{f-j}	735.74^{e-j}
3	0	0	10	1,407.27^{a-g}	1,096.20^{e-h}	1,377.67^{c-i}	1,293.71^{c-i}
4	0	15	0	325.90^{h}	370.37^{ij}	592.57^{hij}	429.61^{ij}
5	0	15	5	651.80^{fgh}	340.70^{j}	814.77^{g-j}	602.42^{g-j}
6	0	15	10	755.50^{e-h}	1,007.33^{e-i}	1,422.10^{b-i}	1,061.64^{d-j}
7	0	30	0	844.37^{d-h}	459.23^{hij}	325.90^{j}	543.17^{hij}
8	0	30	5	711.03^{e-h}	1,066.57^{e-h}	918.43^{f-j}	898.68^{e-j}
9	0	30	10	1,570.23^{a-e}	1,111.00^{efg}	1,184.00^{d-j}	1,288.41^{b}
10	60	0	0	325.93^{h}	681.43^{g-j}	1,007.30^{e-j}	671.55^{f-j}
11	60	0	5	1,688.73^{abcd}	1,644.30^{bcde}	2,044.23^{abcd}	1,792.42^{bcd}
12	60	0	10	666.60^{efgh}	1,777.60^{bcd}	1,925.73^{a-e}	1,456.64^{b-g}
13	60	15	0	696.27^{efgh}	607.37^{g-j}	1,348.03^{c-i}	883.89^{e-j}
14	60	15	5	829.53^{d-h}	1,629.47^{bcde}	1,718.37^{b-g}	1,392.46^{b-h}
15	60	15	10	888.80^{c-h}	1,555.43^{c-f}	1,703.53^{b-g}	1,382.59^{d-j}
16	60	30	0	622.13^{gh}	859.17^{ghij}	1,555.43^{b-h}	1,012.24^{d-j}
17	60	30	5	681.43^{efgh}	1,244.33^{d-g}	1,362.83^{c-i}	1,096.20^{bc}
18	60	30	10	1,540.60^{a-f}	1,970.17^{abc}	2,399.77^{ab}	1,970.18^{d-j}
19	120	0	0	562.90^{gh}	755.47^{ghij}	1,747.97^{b-g}	1,022.11^{c-i}
20	120	0	5	1,125.83^{a-h}	2,192.37^{abc}	2,340.50^{abc}	1,886.23^{bc}
21	120	0	10	1,451.73^{a-g}	2,222.00^{ab}	2,340.53^{abc}	2,004.75^{c-j}
22	120	15	0	859.17^{d-h}	948.07^{f-j}	1,851.67^{b-f}	1,219.64^{b-e}
23	120	15	5	1,422.10^{a-g}	1,155.47^{d-g}	2,133.13^{abcd}	1,570.23^{bcd}
24	120	15	10	1,762.77^{abc}	1,629.50^{b-e}	2,192.37^{abc}	1,861.55^{b-f}
25	120	30	0	740.67^{e-h}	1,896.10^{bc}	1,822.03^{b-f}	1,486.27^{bc}
26	120	30	5	1,881.30^{ab}	2,029.47^{abc}	1,999.80^{abcd}	1,970.19^{a}
27	120	30	10	2,251.63^{a}	2,562.83^{a}	2,844.17^{a}	2,552.88^{c-j}
	Mean			1,012.80	1,251.47	1,568.56	1341.8
	R-Square			0.69	0.85	0.72	0.75
	CV			45.38	26.72	31.97	34.69
	LSD			735.70	535.10	802.40	691.07
	NxSxCD			**	**	**	**

*** = Significant at P = 0.01*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

4.10 Main effect of N, S and cowdung rates on soil chemical properties

4.10.1 Soil pH

Data on post harvest soil pH at the end of each year of field studies and the three years combined are presented in Table 4.43. For each year of experimentation, the pH was moderately acidic with a mean of 5.7, 5.1 and 5.7 respectively. The result showed that nutrient uptake particularly for N, P, K and S was not hindered as soil reaction was favourable for their availability (Havlin *et al*., 2006; Olayinka and Ailenubhi, 2001).

Soil pH determination is one of the indices of soil fertility rating (Brady and Weil, 2005; Jones, 1987) due to its prime effects on soil properties, nutrients retention, use and use efficiency of applied fertilizers and in nutrient dynamics. The result in 2009 was significant ($P \leq 0.05$) and higher than in 2010, indicating that both N and S rates applied in 2010 and in the previous year might have induced acidity and/or that the mineralization of cowdung was not sufficient enough at that particular time to increase soil organic matter content in order to check soil acidity.

But after the third year of planting, soil pH increased significantly ($P \leq 0.01$) than the results obtained from the previous year in 2010 (Table 4.43). At this time, adequate mineralization had taken place resulting in humus formation with a rise in content of bases.

Table 4.43: Main effect of N, S and cowdung rates on soil soil pH (H_2O)

N rates (kg/ha)	2009	2010	2011	Mean
0	5.90	5.20	5.80	5.60
60	5.60	5.10	5.60	5.40
120	5.70	5.10	5.70	5.50
S Rates (kg/ha)				
0	5.60	5.10	5.70	5.50
15	5.70	5.10	5.60	5.50
30	5.90	5.10	5.70	5.60
CD Rates (tons/ha)				
0	5.70	5.10	5.60	5.50
5	5.70	5.10	5.70	5.50
10	5.80	5.10	5.70	5.50
Mean	5.70	5.10	5.70	5.50
CV	8.20	3.60	3.80	7.60
R-Square	0.70	0.50	0.80	0.60
LSD (0.05)	0.80**	0.30	0.40**	0.70**

*** = Significant at P = 0.01*

4.10.1.1 Interactive combinations of levels of N, S and CD on soil pH

The interaction of different levels of N, S and CD on soil pH in 2009 field studies was not significant ($P > 0.05$), though, highest mean (6.33) was obtained from 0 kg N/ha +30 kg S /ha + 10 ton/ha CD. It indicated that the various treatment combinations did not adversely affect soil pH rather; it was maintained within acceptable pH range for plant growth (Havlin *et al.*, 2006). In the second year of planting (2010), the combination of 0 kg N/ha + 0 kg S /ha + 5 ton/ha CD had the highest soil pH (5.50) and significantly different ($P < 0.05$) with other combinations while the least effect was obtained from 120 kg N/ha + 15 kg S/ha + 0 ton/ha CD (Table 4.44). In 2011, the best performing combination was 6.40, obtained from 120 kg N/ha + 15 kg S /ha + 5 ton CD/ha.

Combinations having N either at 60 kg/ha or 120 kg/ha tended to acdify the soil more than combinations with sulphur rates, though mean effect of their treatments was not significantly ($P > 0.05$) different. Continuous application of nitrogen fertilizers for crop nutrition without combining with organic manure could induce soil acidity.

Table 4.44: Interaction effects of different levels of N, S and CD on soil pH (H_2O) during field studies

				Soil pH			
	N	S	CD	2009	2010	2011	Mean
1	0	0	0	5.43	5.13^{bc}	6.23^{ab}	5.60
2	0	0	5	5.67	5.50^{a}	5.93^{b-e}	5.70
3	0	0	10	5.93	5.30^{ab}	5.53^{e-i}	5.58
4	0	15	0	5.70	5.07^{bc}	5.87^{b-f}	5.54
5	0	15	5	6.23	5.10^{bc}	5.30^{i}	5.54
6	0	15	10	5.77	5.30^{ab}	5.77^{d-h}	5.61
7	0	30	0	6.30	5.23^{abc}	5.53^{e-i}	5.69
8	0	30	5	6.07	5.10^{bc}	5.60^{e-i}	5.59
9	0	30	10	6.33	5.17^{abc}	6.20^{abc}	5.90
10	60	0	0	5.40	5.13^{bc}	5.30^{i}	5.28
11	60	0	5	5.47	4.90^{c}	6.13^{a-d}	5.50
12	60	0	10	5.67	4.93^{bc}	5.80^{c-g}	5.47
13	60	15	0	5.53	5.17^{abc}	5.37^{hi}	5.36
14	60	15	5	5.53	5.03^{bc}	5.37^{hi}	5.32
15	60	15	10	5.60	5.13^{bc}	5.43^{ghi}	5.39
16	60	30	0	5.63	5.13^{bc}	5.47^{f-i}	5.41
17	60	30	5	5.53	5.03^{bc}	5.53^{e-i}	5.37
18	60	30	10	5.67	5.20^{abc}	5.77^{d-h}	5.54
19	120	0	0	5.70	5.00^{bc}	5.60^{e-i}	5.43
20	120	0	5	5.40	4.97^{bc}	5.30^{i}	5.22
21	120	0	10	5.73	5.23^{abc}	5.53^{e-i}	5.50
22	120	15	0	5.70	5.10^{bc}	5.67^{e-i}	5.49
23	120	15	5	5.80	5.07^{bc}	6.40^{a}	5.76
24	120	15	10	5.77	4.87^{c}	5.40^{ghi}	5.34
25	120	30	0	5.83	5.03^{bc}	5.70^{e-i}	5.52
26	120	30	5	5.90	5.07^{bc}	5.93^{b-e}	5.63
27	120	30	10	5.73	5.13^{bc}	5.90^{b-e}	5.59
	Mean			5.74	5.11	5.69	5.52
	R-Square			0.65	0.50	0.79	0.59
	CV			8.15	3.63	3.82	7.59
	LSD			0.80	0.30	0.40	0.70
	NxSxCD			NS	NS	**	NS

*NS = Not Significant, ** = Significant at P = 0.01*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5% level of probability using Duncan Multiple Range Test

4.10.2 Soil organic carbon content

The effects of the application of different levels of N, S and CD on soil organic carbon content (SOC) at the end of each year of field operations and the three years combined are presented in Table 4.45. The response in each year and the combined analysis showed that the effect was ($P < 0.01$) significant. Soil organic carbon increased with increasing levels of fertilizer N, S and cowdung application and also increased significantly across the three years of field experimentation. The trend of increase throughout the period of observation was consistent both in application levels and in duration, thus indicating the beneficial and contributory role of inorganic and organic resource use in soil fertility management.

Table 4.45: Main effect of N, S and cowdung rates on soil organic carbon

N rates (kg/ha)	Soil Organic Carbon			
	2009	**2010**	**2011**	**Mean**
	g/kg	g/kg	g/kg	g/kg
0	5.30	5.90	6.00	5.70
60	6.90	7.10	8.10	7.40
120	7.10	7.60	9.00	7.90
S Rates (kg/ha)				
0	5.60	5.80	6.40	5.90
15	6.70	7.20	8.10	7.30
30	7.00	7.60	8.70	7.70
CD Rates (ton/ha)				
0	5.10	4.80	5.70	5.20
5	6.60	7.20	7.90	7.30
10	7.60	8.60	9.50	8.60
Mean	6.40	6.90	7.70	6.90
CV	24.36	20.22	18.49	20.74
R-Square	0.66	0.79	0.82	0.77
LSD (0.05)	0.25**	0.22**	0.23**	0.23**

*** = Significant at P = 0.01*

4.10.2.1 Interactive combinations of levels of N, S and CD on soil organic carbon

The interaction effects of rates of N, S and CD on soil organic carbon content showed that best performing combination in 2009 (9.5 g/kg) was obtained from 120 kg N/ha + 15 kg S/ha + 5 ton/ha CD while the least effect was from the control plot (3.8 g/kg) though not significantly different with treatment 2 (Table 4.46). In 2010, best interaction effect (11.7 g/kg) was obtained from 120 kg N/ha + 30 kg S/ha + 10 ton/ha CD while the least effect was the control (2.8 g/kg). A similar performance as reported for 2010 was obtained in 2011 and mean effects of the three years of study. The interaction effects were significant ($P < 0.01$) (Table 4.46).

Table 4.46: Interaction effects of different levels of N, S and CD on soil organic carbon during field studies

				Soil Organic Carbon			
				2009	2010	2011	Mean
	N	S	CD	g/kg	g/kg	g/kg	g/kg
1	0	0	0	3.8^{g}	2.8^{j}	3.1^{j}	3.2^{j}
2	0	0	5	3.8^{g}	$4.8^{g\text{-}i}$	4.7^{hij}	4.4^{ij}
3	0	0	10	$6.9^{a\text{-}g}$	$6.7^{e\text{-}i}$	$7.2^{d\text{-}h}$	$6.9^{e\text{-}i}$
4	0	15	0	4.9^{efg}	$4.9^{g\text{-}j}$	4^{ij}	4.6^{ij}
5	0	15	5	4.9^{efg}	$8.2^{b\text{-}e}$	$8.3^{b\text{-}f}$	$7.2^{d\text{-}i}$
6	0	15	10	$6.3^{b\text{-}g}$	$6.5^{e\text{-}i}$	$8.1^{b\text{-}f}$	$6.9^{e\text{-}i}$
7	0	30	0	4.4^{fg}	$5.4^{f\text{-}j}$	$5.3^{g\text{-}j}$	$5^{g\text{-}j}$
8	0	30	5	$6.4^{b\text{-}g}$	$6.5^{e\text{-}i}$	$6.9^{d\text{-}h}$	$6.6^{e\text{-}i}$
9	0	30	10	$5.8^{c\text{-}g}$	$7.1^{d\text{-}h}$	$6.6^{e\text{-}i}$	$6.5^{e\text{-}i}$
10	60	0	0	$5.6^{d\text{-}g}$	4^{ij}	$5.1^{g\text{-}j}$	4.9^{hij}
11	60	0	5	$5.8^{d\text{-}g}$	$6.1^{e\text{-}i}$	$7.4^{c\text{-}h}$	$6.4^{e\text{-}i}$
12	60	0	10	$8.5^{a\text{-}d}$	$7.7^{c\text{-}f}$	$8.5^{b\text{-}f}$	$8.2^{b\text{-}f}$
13	60	15	0	4.9^{efg}	$5.9^{e\text{-}i}$	$6.3^{f\text{-}i}$	$5.7^{f\text{-}j}$
14	60	15	5	$6.7^{a\text{-}g}$	$8.1^{b\text{-}f}$	$9.3^{b\text{-}e}$	$8^{b\text{-}f}$
15	60	15	10	$7.3^{a\text{-}f}$	9.8^{abc}	9.5^{bcd}	$8.9^{a\text{-}e}$
16	60	30	0	$6.3^{b\text{-}g}$	$5.4^{f\text{-}j}$	$6.6^{e\text{-}i}$	$6.1^{e\text{-}i}$
17	60	30	5	$7.7^{a\text{-}e}$	$6.5^{e\text{-}i}$	10^{bc}	$8.1^{b\text{-}f}$
18	60	30	10	9.4^{ab}	10.6^{ab}	10.3^{b}	10.1^{abc}
19	120	0	0	3.8^{g}	4.7^{hij}	4.7^{hij}	4.4^{ij}
20	120	0	5	$5.7^{d\text{-}g}$	$7.8^{c\text{-}f}$	$7.8^{b\text{-}g}$	$7.1^{d\text{-}i}$
21	120	0	10	$6.4^{b\text{-}g}$	$7.5^{c\text{-}g}$	$9.2^{b\text{-}e}$	$7.7^{c\text{-}h}$
22	120	15	0	$6.7^{a\text{-}g}$	$5.7^{e\text{-}i}$	$6.8^{d\text{-}h}$	$6.4^{e\text{-}i}$
23	120	15	5	9.5^{a}	$6.6^{e\text{-}i}$	$7.4^{c\text{-}h}$	$7.8^{b\text{-}g}$
24	120	15	10	9^{abc}	$9.5^{a\text{-}d}$	12.9^{a}	10.5^{ab}
25	120	30	0	5^{efg}	4.3^{ij}	$9.1^{b\text{-}e}$	$6.2^{e\text{-}i}$
26	120	30	5	$8.5^{a\text{-}d}$	10.4^{ab}	10.1^{bc}	$9.7^{a\text{-}d}$
27	120	30	10	9.1^{ab}	11.7^{a}	13.1^{a}	11.3^{a}
	Mean			0.64	0.69	0.77	0.69
	R-Square			0.66	0.79	0.82	0.78
	CV			24.36	20.22	18.49	20.74
	LSD			0.25	0.22	0.23	0.23
	NxSxCD			NS	**	NS	*

*NS = Not Significant, * = Significant at P = 0.05, ** = Significant at P = 0.01*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

4.10.3 Soil nitrogen content

The effect of fertilizer N, S and cowdung application rates on soil nitrogen content is shown in Table 4.47. The pattern of results showed a gradual build up of soil N from 2009 to 2011 as all the treatment levels in 2011 were ($P \leq 0.01$) significant and their corresponding means were twice as high as those of either 2009 or 2010.

Soil N content obtained from the control for N, S and CD levels was consistent with the initial soil N status (Table 4.1). Therefore, the content of soil N for the control plot in 2009 and 2010 respectively was not unexpected. The effect of the application was ($P \leq 0.01$) significant in 2009 and 2011 but not significant ($P > 0.05$) in 2010.

In 2010, the contribution of nitrogen to the soil across all the levels of fertilizer N, S and CD application did not show any clear pattern of response though N fertilizer application at 120 kg/ha had only a slight edge over that of N at 60 kg/ha. But among the S fertilizer rates, 15 kg/ha had a higher soil N content than with 30 kg/ha sulphur application. A similar trend was observed between 5 ton/ha and 10 ton/ha CD application. Plant utilization and fixation by microorganisms as well as inadequate release of N into the soil during mineralization or a combination of any of the avenues through which nitrogen is lost from the soil may have contributed to the low soil nitrogen recovery.

The content of soil N in 2011 followed a sequence of response where nitrogen content increased as the application levels of N, S and cowdung increased (Table 4.47). From the result obtained, the control plot had the lowest soil nitrogen content across N, S and CD rates indicating the low residual content of nitrogen even when mineral fertilizer nitrogen was applied in previous experiments in the field.

Table 4.47: Main effect of N, S and cowdung rates on soil nitrogen content

N rates (kg/ha)	Nitrogen 2009	2010	2011	Mean
	g/kg	g/kg	g/kg	g/kg
0	0.50	0.80	1.50	0.90
60	0.80	0.80	1.70	1.10
120	0.80	0.90	2.40	1.40
S Rates (kg/ha)				
0	0.50	0.80	1.20	0.80
15	0.70	0.90	2.20	1.30
30	0.80	0.80	2.30	1.30
CD Rates (tons/ha)				
0	0.50	0.80	1.10	0.80
5	0.70	0.80	1.80	1.10
10	0.80	0.80	2.70	1.40
Mean	**0.70**	**0.80**	**1.90**	**1.10**
CV	31.73	30.13	57.77	39.88
R-Square	0.72	0.42	0.63	0.87
LSD (0.05)	0.04**	0.40	0.17**	0.27

4.10.3.1 Interactive combinations of levels of N, S and CD on soil nitrogen content

Interaction effects of the amendments on soil nitrogen content are shown in Table 4.48. The best effect in 2009 was obtained from the combination of 120 kg N/ha + 15 kg S/ha + 10 ton/ha CD with a mean of 0.14 g/kg, in 2010, the combination of 60 kg N/ha + 15 kg S/ha + 0 ton/ha CD had the highest soil N content of 2.74 g/kg which was significantly higher than other combinations, whereas, in 2011, the best performing combination was 0.62 g/kg obtained from 120 kg N/ha + 30 kg S/ha + 10 ton/ha CD, while the least effect in the same period was 0.06 g/kg obtained from the control,though not significantly different with treatments 2, 4 and 10 (Table 4.48).

The result showed a gradual build up of N in the soil particularly after the second year of planting which was higher ($P < 0.01$) than the mean effect in 2009. The mean effect of soil N in 2011 showed that combinations with N and CD had higher N content than other treatments. Organic manure and inorganic N fertilizer therefore contributed to the increase in soil N content.

Table 4.48: Interaction effects of different levels of N, S and CD on soil total nitrogen during field studies

				Soil Total Nitrogen			
				2009	2010	2011	Mean
	N	S	CD	g/kg	g/kg	g/kg	g/kg
1	0	0	0	0.02^{ef}	0.82^{b}	0.06^{d}	0.3
2	0	0	5	0.03^{def}	0.82^{b}	0.07^{d}	0.31
3	0	0	10	0.06^{b-f}	0.76^{b}	0.13^{bcd}	0.32
4	0	15	0	0.05^{b-f}	0.88^{b}	0.06^{d}	0.33
5	0	15	5	0.05^{b-f}	1.11^{b}	0.14^{bcd}	0.44
6	0	15	10	0.05^{b-f}	0.70^{b}	0.33^{b}	0.36
7	0	30	0	0.05^{b-f}	1.05^{b}	0.12^{bcd}	0.41
8	0	30	5	0.04^{def}	0.82^{b}	0.21^{bcd}	0.36
9	0	30	10	0.08^{b-e}	0.07^{b}	0.22^{bcd}	0.33
10	60	0	0	0.05^{b-f}	0.76^{b}	0.06^{d}	0.29
11	60	0	5	0.08^{b-e}	0.75^{b}	0.09^{cd}	0.31
12	60	0	10	0.05^{b-f}	0.59^{b}	0.19^{bcd}	0.28
13	60	15	0	0.06^{b-f}	2.74^{a}	0.22^{bcd}	1.05
14	60	15	5	0.11^{ab}	0.88^{b}	0.19^{bcd}	0.39
15	60	15	10	0.08^{a-d}	0.99^{b}	0.29^{bc}	0.46
16	60	30	0	0.09^{a-d}	0.94^{b}	0.16^{bcd}	0.39
17	60	30	5	0.08^{b-e}	0.59^{b}	0.14^{bcd}	0.27
18	60	30	10	0.11^{abc}	0.94^{b}	0.22^{bcd}	0.42
19	120	0	0	0.04^{c-f}	0.76^{b}	0.08^{cd}	0.29
20	120	0	5	0.08^{b-e}	0.99^{b}	0.19^{bcd}	0.42
21	120	0	10	0.09^{a-d}	0.82^{b}	0.2^{bcd}	0.36
22	120	15	0	0.06^{b-f}	0.81^{b}	0.14^{bcd}	0.34
23	120	15	5	0.09^{a-d}	0.70^{b}	0.32^{b}	0.37
24	120	15	10	0.14^{a}	0.89^{b}	0.25^{bcd}	0.43
25	120	30	0	0.07^{b-f}	0.76^{b}	0.12^{bcd}	0.32
26	120	30	5	0.08^{a-d}	0.82^{b}	0.25^{bcd}	0.39
27	120	30	10	0.01^{f}	0.82^{b}	0.62^{a}	0.49
	Mean			0.07	0.87	.017	0.39
	R-Square			0.72	0.42	0.63	0.87
	CV			31.73	30.13	57.77	39.88
	LSD			0.04	0.40	0.17	0.27
	NxSxCD			**	*	**	NS

*NS = Not Significant, * = Significant at P = 0.05, ** = Significant at P = 0.01*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

4.10.4 Soil sulphur content

Effect of application of different levels of fertilizer N, S and CD on soil sulphur content at the end of each year of planting is as shown in Table 4.49. After each year of planting, soil sulphur content increased along with the levels of treatments particularly for gypsum-S rates and CD rates. The only exception was urea-N application where N at 60 kg/ha had a slightly higher mean than 120 kg/ha in 2010 but in 2009 and 2011, the reverse was the case. The effect of these treatments on soil sulphur content was ($P < 0.01$) significant in each year of operation. The treatment means for 2009, 2010 and 2011 were 13.77 mg/kg, 17.28 mg/kg and 24.54 mg/kg respectively with a mean of 18.53 mg/kg in the combined analysis. This represents a percentage difference of 24.58%, 30.84% and 43.79% for 2009, 2010 and 2011 respectively (Table 4.49).This result shows that soil sulphur content increased both in terms of variation in treatment levels and years of continuous fertilizer application. In view of this, it appears that soil S content had a cumulative effect mainly due to continuous sulphur fertilizer application and a positive impact of organic matter input due to mineralization.

Table 4.49: Main effect of N, S and cowdung rates on soil sulphur

N rates (kg/ha)	Sulphur			Mean
	2009	2010	2011	
	mg/kg	mg/kg	mg/kg	mg/kg
0	11.17	14.64	19.77	15.19
60	13.25	19.32	25.13	19.23
120	16.89	17.89	28.71	21.16
S Rates (kg/ha)				
0	8.61	12.52	19.95	13.69
15	13.44	17.11	25.51	18.65
30	19.27	22.22	28.26	23.25
CD Rates (tons/ha)				
0	11.34	14.65	21.41	15.79
5	14.09	17.81	23.86	18.59
10	15.87	19.39	28.34	21.20
Mean	**13.77**	**17.28**	**24.54**	**18.63**
CV	13.14	6.60	7.61	9.85
R-Square	0.95	0.98	0.97	0.97
LSD (0.05)	3.55**	2.24**	3.66**	3.57**

*** = Significant at P = 0.01*

4.10.4.1 Interactive combinations of levels of N, S and CD on soil sulphur content

The interaction effect of rates of N,S and CD on soil sulphur content after cultivation (Table 4.50) revealed that best performing combination was consistently obtained from 120 kg N/ha + 30 kg S/ha + 10 ton/ha CD in the three years of study and the mean of the three years. The results obtained in 2009, 2010, 2011 and mean of the three were, 18.09 mg/kg; 18.29 mg/kg; 25.18 mg/kg and 20.52 mg/kg respectively, while the least effect in 2009 was 5.09 mg/kg obtained from 0 kg N/ha + 0 kg S/ha + 5 ton/ha CD. But from 2010 to 2011 and the mean of the three years duration, the least effect of the interaction was obtained from control treatment, their corresponding means were 4.62 mg/kg; 5.01 mg/kg and 5.09 mg/kg respectively. The differences in the treatment means were significant (*$P < 0.01$*).

Table 4.50: Interaction effects of different levels of N, S and CD on soil sulphur content during field studies

				Soil Sulphur			
	N	S	CD	2009 mg/kg	2010 mg/kg	2011 mg/kg	Mean mg/kg
1	0	0	0	5.65^{op}	4.62^{o}	5.01^{k}	5.09^{k}
2	0	0	5	5.09^{p}	10.39^{lm}	17.69^{i}	11.06^{ij}
3	0	0	10	8.98^{k-o}	9.12^{m}	26.55^{d-g}	14.88^{gh}
4	0	15	0	6.17^{nop}	17.23^{fg}	20.02^{hi}	14.47^{gh}
5	0	15	5	10.75^{j-m}	14.52^{ij}	16.99^{i}	14.09^{ghi}
6	0	15	10	15.88^{e-h}	17.64^{fg}	23.2^{fgh}	18.91^{ef}
7	0	30	0	20.42^{cd}	26.17^{b}	28.24^{cde}	24.94^{b}
8	0	30	5	11.06^{jkl}	11.06^{kl}	17.21^{i}	13.29^{ghi}
9	0	30	10	16.49^{efg}	20.5^{de}	23.05^{gh}	20.01^{de}
10	60	0	0	7.63^{mnop}	7.01^{n}	10.73^{j}	8.45^{j}
11	60	0	5	7.92^{l-p}	20.51^{de}	21.21^{hi}	16.55^{fg}
12	60	0	10	13.14^{hij}	20.98^{d}	27.61^{de}	20.58^{cde}
13	60	15	0	7.14^{nop}	16.66^{gh}	25.07^{efg}	16.28^{fg}
14	60	15	5	22.67^{bc}	25.68^{b}	26.44^{d-g}	24.93^{b}
15	60	15	10	10.65^{j-m}	18.86^{ef}	28.81^{bcd}	19.44^{def}
16	60	30	0	13.98^{g-j}	15.17^{hi}	31.64^{b}	20.26^{cde}
17	60	30	5	14.56^{f-i}	25.37^{bc}	28.05^{cde}	22.66^{bcd}
18	60	30	10	21.58^{bc}	23.62^{c}	26.63^{def}	23.94^{b}
19	120	0	0	9.14^{k-n}	11.39^{kl}	17.25^{i}	12.59^{hi}
20	120	0	5	13.39^{g-j}	13.89^{ij}	16.96^{i}	14.75^{gh}
21	120	0	10	6.51^{p}	14.77^{hi}	36.53^{a}	19.27^{def}
22	120	15	0	12.04^{ijk}	12.59^{jk}	31.35^{bcd}	18.66^{ef}
23	120	15	5	17.54^{def}	12.54^{jk}	31.62^{b}	20.56^{cde}
24	120	15	10	18.09^{de}	18.29^{fg}	25.18^{efg}	20.52^{cde}
25	120	30	0	19.89^{cd}	20.99^{d}	23.41^{fgh}	21.43^{bcd}
26	120	30	5	23.89^{b}	25.75^{b}	38.59^{a}	29.41^{a}
27	120	30	10	31.55^{a}	30.8^{a}	37.49^{a}	33.28^{a}
	Mean			13.77	17.28	24.54	18.63
	R-Square			0.95	0.98	0.97	0.97
	CV			13.14	6.60	7.61	9.85
	LSD			3.55	2.24	3.66	6.57
	NxSxCD			**	**	**	**

*** = Significant at P = 0.01*

Means followed by the same letter(s) within the same column and treatments are not significantly different at 5 % level of probability using Duncan Multiple Range Test

4.11 Correlation Studies

4.11.1 Greenhouse Studies

The matrix of coefficients of correlation between agronomic parameters and some soil chemical properties obtained during the greenhouse study is as shown in Table 4.51. Except for the correlation between plant height and soil pH, dry stalk weight and soil pH, root weight and soil nitrogen concentration and soil pH with soil N concentration which were significantly ($P < 0.05$) correlated, all the other agronomic and soil chemical properties were highly ($P < 0.01$) significantly correlated. Plant height, number of leaves per plant, stalk diameter and leaf area were positively and significantly ($P < 0.01$) correlated with each other and also having high coefficients of correlation (Table 4.51).

Table 4.51: Matrix of coefficient of correlation (r) between agronomic parameters, soil pH soil organic carbon and soil nitrogen concentration in the greenhouse

	Plant height	No of Leaves	Stalk diameter	Leaf Area	Fresh stalk weight	Dry stalk weight	Root weight	Soil pH	Organic carbon	N conc.
Plant height	1.00									
No of Leaves	0.48**	1.00								
Stalk diameter	0.83**	0.89**	1.00							
Leaf Area	0.82**	0.84**	0.90**	1.00						
Fresh stalk weight	0.85**	0.77**	0.79**	0.79**	1.00					
Dry stalk weight	0.65**	0.65**	0.63**	0.64**	0.64**	1.00				
Root weight	0.47**	0.48**	0.49**	0.49**	0.34**	0.42**	1.00			
Soil pH	0.37**	0.45**	0.54--	0.44**	0.42**	0.34*	0.33*	1.00		
Organic carbon	0.46**	0.42**	0.55**	0.49**	0.42**	0.46**	0.36**	0.63**	1.00	
N conc.	0.25*	0.36**	0.40**	0.36**	0.37**	0.51**	0.29*	0.31*	0.43**	1.00

* = Significant at P = 0.05, ** = Significant at P = 0.01

4.11.2 Field Studies

Results presented in Tables 4.52 - 4.55 show the matrix of coefficients of correlation between growth and yield parameters in 2009, 2010, 2011 and mean effect of the three years combined. Grain yield positively and significantly ($P \leq 0.01$) correlated with stover, cob weight, plant height, number of leaves, stem girth and leaf area and their corresponding correlation coefficients were r = ± 0.89**, 0.98**, 0.59**, 0.56**, 0.57**, 0.57** respectively in the three years combined. Similarly, there was a highly significant correlation between stover against grain yield and growth parameters. A similar performance was recorded from cob weight versus grain yield and growth parameters (Tables 4.52 – 4.55). Correlation coefficient between stem girth and plant height was 0.87**; leaf area and plant height was 0.77**, while leaf area and stem girth was 0.88**. Soil pH also correlated positively with grain yield, stover, cob weight and all the growth parameters, its effect on cob weight was significant ($P \leq 0.05$).

The matrix of correlation indicated that each of the growth parameters impacted positively on grain yield, stover and cob weight. Therefore, the treatments effect, improvement in soil fertility and effective crop husbandry practices created the synergy which resulted in a positive impact.

Table 4.52: Matrix of coefficient of correlation (r) between agronomic parameters and soil pH in 2009

	Grain yield	Stover	Cob weight	Plant height	No of Leaves	Stem girth	Leaf Area	Soil pH (H_2O)
Grain yield	1.00							
Stover	0.87**	1.00						
Cob	0.97**	0.90**	1.00					
Plant height	0.63**	0.62**	0.63**	1.00				
No of Leaves	0.54**	0.49**	0.55**	0.89**	1.00			
Stem girth	0.54**	0.48**	0.52**	0.84**	0.84**	1.00		
Leaf Area	0.53**	0.48**	0.54**	0.81**	0.84**	0.86**	1.00	
Soil pH (H_2O)	0.14	0.29	0.25*	0.02	0.01	0.01	0.09	1.00

* = Significant at P = 0.05, ** = Significant at P = 0.01

Table 4.53: Matrix of coefficient of correlation (r) between agronomic parameters, soil pH and soil N in 2010

	Grain yield	Stover	Cob weight	Plant height	No of Leaves	Stem girth	Leaf Area	Soil pH (H_2O)	Soil N
Grain yield	1.00								
Stover	0.93**	1.00							
Cob	0.97**	0.94**	1.00						
Plant height	0.61**	0.69**	0.64**	1.00					
No of Leaves	0.64**	0.63**	0.64**	0.62**	1.00				
Stem girth	0.68**	0.66**	0.70**	0.85**	0.65**	1.00			
Leaf Area	0.68**	0.69**	0.70**	0.78**	0.77**	0.82**	1.00		
Soil pH (H_2O)	-0.13	-0.13	-0.17	-0.31	-0.27*	-0.22*	-0.31*	1.00	
Soil N	-0.08	-0.13	-0.08	-0.12	-0.24*	-0.12	-0.09	0.05	1.0

* = Significant at P = 0.05, ** = Significant at P = 0.01

Table 4.54: Matrix of coefficient of correlation (r) between agronomic parameters and soil pH in 2011

	Grain yield	**Stover**	**Cob weight**	**Plant height**	**No. of Leaves**	**Stem girth**	**Leaf area**	**Soil pH (H_2O)**
Grain yield	1.00							
Stover	0.85**	1.00						
Cob	0.99**	0.84**	1.00					
Plant height	0.56**	0.66**	0.54**	1.00				
No of leaves	0.23*	0.40**	0.21	0.67**	1.00			
Stem girth	0.40**	0.54**	0.39**	0.64**	0.63**	1.00		
Leaf area	0.41**	0.55**	0.41**	0.69**	0.59**	0.82**	1.00	
Soil pH (H_2O)	(0.14)	(0.06)	(0.15)	0.03	0.11	0.13	0.13	1.00

* = Significant at P = 0.05, ** = Significant at P = 0.01

Table 4.55: Matrix of coefficient of correlation (r) between agronomic parameters, soil pH and leaf N content for the three years combined

	Grain yield	**Stover Yield**	**Cob weight**	**Plant height**	**No of Leaves**	**Stem girth**	**Leaf area**	**Soil pH (H_2O)**	**N conc. Leaves**
Grain yield	1.00								
Stover	0.89**	1.00							
Cob	0.98**	0.89**	1.00						
Plant height	0.59**	0.54**	0.59**	1.00					
No of Leaves	0.56**	0.51**	0.56**	0.73**	1.00				
Stem girth	0.57**	0.54**	0.58**	0.87**	0.52**	1.00			
Leaf area	0.57**	0.57**	0.58**	0.77**	0.66**	0.88**	1.00		
Soil pH (H_2O)	-0.03	0.07	-0.04	-0.01	-0.37**	0.18*	0.17*	1.00	
N conc, Leaves	0.32**	0.28**	0.35**	0.77**	-0.35**	0.79**	0.68**	0.26**	1.00

* = Significant at P = 0.05, ** = Significant at P = 0.01

4.12 Simulation Studies

The results obtained from field trials of maize at Samaru in the Northern Guinea savanna (NGS) agro – ecological zone of Nigeria were compared with computed data using the QUEFTS Simulation Model (Janssen *et al.*, 1990). This was to assess the relationship among chemical soil data, potential supply of N, P and K from the soil and fertilizer input, actual crop nutrients uptake in terms of N, P and K, maize grain yield, as well as the interaction among these major plant nutrients. The model recognized that crop yield is a function of availability of the three major nutrients; especially when all other yield limiting factors are optimum. The results obtained from the simulation model are presented in Tables 4.56, 4.57 and 4.58 for each year of field experiment.

For this study, grain yield at 120 kg N/ha application was used as a reference because the grain yield obtained at this rate was significantly ($P < 0.01$) higher than the corresponding yield at 60 kg/ha throughout the three years of field study (Table 4.39). Stover yield and cob weight also had a much better response at 120 kg N/ha fertilizer application than at half rate. Therefore, 120 kg N/ha became the optimum benchmark for this calibration, while P and K were fixed at 60kg/ha P_2O_5 and K_2O respectively. Also, soil test data with which the model was calibrated in this study fell within the acceptable ranges as recommended by Janssen *et al.*, 1990.

The simulated yield at fertilizer application was much higher (12, 000 kg/ha) than when fertilizers were not applied (1,852 kg/ha). Also, the amount of N, P and K taken up by the plant (Tables 4.56, 4.57 and 4.58) was much greater during fertilizer application than at baseline condition. It shows that maize response to chemical fertilization was effective and such yield limiting factors as water deficit, weed infestation, pest and disease attacks and micronutrient deficiency were not apparent, however, availability of P and N in particular is still a major constraint for a sustainable maize production in the savanna of Nigeria.

Table 4.56: Simulated output of maize grain yield from unfertilized and fertilized soils in Northern Guinea savanna for 2009

	Baseline nutrients supplied to maize by UNFS (kg/ha)	Actual nutrient uptake for N, P and K (kg/ha)	Yield at max. accum. of N,P, K (kg/ha)	Yield at max. dilution of N,P, K (kg/ha)	Yield calc. For combination of 2 nutrients (kg/ha)	Potential Maize grain yield (kg/ha)
N	29.38	29.16	YNA = 771.0	YND = 1991	YNP = 1624	1,852
P	11.76	10.56	YPA = 961.0	YPD = 4886	YNK = 1951	
K	79.38	52.80	YKA = 1901.0	YKD = 7319	YPK = 1954	
Fertilized Soil (120:60:60 N, P & K)						
N	2,316.58	2,164.21	63,068	162,857	12,000	12,000
P	626.76	581.92	55,596	282,545	12,000	
K	1,092.18	1,066.89	41,411	159,433	12,000	

Key:
YNA = Yield at max. accumulation of N
YPA = Yield at max. accumulation of P
YKA = Yield at max. accumulation of K
YND = Yield at max. dilution of N
YPD = Yield at max. dilution of P
YKD = Yield at max. dilution of K

Table 4.57: Simulated output of maize grain yield from unfertilized and fertilized soils in Northern Guinea savanna for 2010

	Baseline nutrients supplied to maize by UNFS (kg/ha)	Actual nutrient uptake for N, P and K (kg/ha)	Yield at max. accum. of N,P, K (kg/ha)	Yield at max. dilution of N,P, K (kg/ha)	Yield calc. For combination of 2 nutrients (kg/ha)	Potential Maize grain yield (kg/ha)
N	24.63	24.54	YNA = 636.0	YND = 1643	YNP = 1387	1561
P	14.47	10.01	YPA = 909.0	YPD = 4617	YNK = 1643	
K	127.14	46.35	YKA = 1650.0	YKD = 6353	YPK = 1643	
	Fertilized Soil (120:60:60 N, P & K)					
N	2743.83	2535.91	73893	190809	12,000	12,000
P	709.27	655.46	62628	318280	12,000	
K	1181.94	1160.14	45044	173421	12,000	

Table 4.58: Simulated output of maize grain yield from unfertilized and fertilized soils in Northern Guinea savanna for 2011

	Baseline nutrients supplied to maize by UNFS (kg/ha)	Actual nutrient uptake for N, P and K (kg/ha)	Yield at max. accum. of N,P, K (kg/ha)	Yield at max. dilution of N,P, K (kg/ha)	Yield calc. For combination of 2 nutrients (kg/ha)	Potential Maize grain yield (kg/ha)
N	35.34	35.05	YNA = 943.0	YND = 2435	YNP = 1974	2276
P	13.87	12.50	YPA = 1147.0	YPD = 5828	YNK = 2433	
K	111.31	66.38	YKA = 2430.0	YKD = 9357	YPK = 2433	
	Fertilized Soil (120:60:60 N, P & K)					
N	3185.34	2937.74	85638	221139	12,000	12,000
P	833.47	768.04	73394	372993	12,000	
K	1352.71	1328.67	51610	198700	12,000	

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Laboratory Incubation Studies

5.1.1 Main effect of different levels of N, S and CD on CO_2 evolution

At the initial stage of incubation (weeks 1 and 2), there was a flush of microbial activity within the microcosms which led to comparatively higher amounts of CO_2 fluxes than at the later weeks of incubation. This was attributed to the presence of relatively larger C pools within the substrate, particularly in week 2, where the mean volume of CO_2 evolution (7.85 g/kg) was highest (Table 4.6) thereby stimulating higher rates of respiratory activity by microbes within the soil system. However, as period of incubation increased to week 3, there was a reduction in microbial activity perhaps due to resistance of organic manure to decomposition with time. The mean volume of CO_2 obtained was 5.20 g/kg was significantly ($P < 0.01$) lower than in week 2. Initial flush phase had significantly reduced the available C pool in the substrate for microbial activity. These findings agree with those of Makinde and Ayeni (2013), Nyongesa *et al*., (2010), Calderon *et al*., (2004), Olayinka and Ailenubhi (2001), who reported a drop in CO_2 evolution at the later stages of soil and organic matter incubation due to the decrease in the proportion of biodegradable organic matter.

The eventual decrease in the amount of CO_2 flux in week 6 with a mean of 4.87 g/kg indicated that, the available substrate within the soil had been exhausted, thereby manifesting comparable lower CO_2 fluxes across application levels of N, S and CD. This indicates that nutrients have now been added to soil due to decomposition (Ayeni, 2011).

The low level of CO_2 flux from control treatment could be representative of the reactions in soils of the Nigerian savanna known to be characteristically low in organic matter (Chude *et al*., 2012). Also, micro organisms in the soil could have utilized the residual organic matter in the soil which led to the low amount of carbon dioxide evolved from the control as observed by others (Calderon *et al*., 2004; Olayinka and Ailenubhi, 2001).

5.1.2 Interaction effect of different levels of N, S and CD on CO_2 evolution

The low amount of CO_2 flux from 0 kg/ha CD even at 120 kg/ha N showed that the presence of mineral N was not enough to stimulate microbial decomposition of soil organic matter in the absence of mineralizable substrates . Also, the mineral N supplied to the soil might have been immobilized by soil microbes, thereby reducing the intensity of microbial decomposition of organic matter. This result was supported by the previous work of Hadas and Portnoy (1994) and Mary *et al*., 1996 on effect of mineral N application on decomposition and dynamics of soil organic matter.

Consistently, the evolution of carbon dioxide as a result of the combination of N at 120 kg/ha and S at 30 kg/ha showed that as the rate of cowdung increased, there was a corresponding significant ($P < 0.05$) increase in amount of CO_2 released from the interaction (Figure 4.3), thus indicating that higher levels of organic materials have the potentials of contributing to higher concentrations of CO_2 than smaller quantities on interaction with nitrogen and sulphur.

The trend showed that the relative importance of the external input to the decomposition of organic matter was in the decreasing order of CD > N >S. This therefore suggests that the contribution of S to the decomposition was lower than N, while the added organic manure had an overriding influence, which may be attributed to the content of carbon in the amendment.

The cumulative effect of highest rates of N, S and CD on CO_2 evolution in the six weeks of incubation (Figure 4.4) is consistent with the results obtained with other treatment combinations, where the peak period of CO_2 evolution was in week 2.

5.1.3 Nitrogen mineralization

5.1.3.1 Main effect on NH_4^+ - N concentration

The difference in treatment means at the highest levels of N, S and CD was highest with N followed by S while CD was least. This suggests that mineral nitrogen fertilizer contributed relatively more inorganic forms of N as ammonium during mineralization than with either S or CD at the time of sampling. Organic carbon fraction within the substrate (CD) may have been immobilized by micro organisms, which led to the comparable lower concentration of NH_4^+. In a study conducted by Ayeni (2012) in south western Nigeria to determine effect of single and combined application of cattle dung and urea fertilizer on carbon and nitrogen mineralization, it was reported that urea – N released highest amount of NH_4^+ - N than cattle dung after 60 days of incubation. This was attributed to minimum fixation of urea – N by soil microbes, denitrification or volatilization. This finding was therefore consistent with result of the present study.

5.1.3.2 Effect on NO_3^- - N concentration

A comparison of means obtained for NH_4^+ - N and NO_3^- - N at the end of incubation study revealed that concentration of NH_4^+ - N was much higher than that of NO_3^- - N though the two were subjected to the same conditions during sampling for analysis. This may be due to the presence of a positive electrical charge in ammonium ions to enable its retention on soil colloid, usually having a net negative charge (Brady and Weil, 2005). Biologically, the NH_4^+ - N in the soil may have been fixed by soil micro biota than was the case for NO_3^-. It has been reported that soil microbes have a preference for NH_4^+ rather than NO_3^- as a mineral nitrogen source (Rice and Tiedje, 1989). Furthermore, Calderon *et al.* (2004) reported that nitrifying bacteria were important sinks for NH_4^+ in soil.

5.1.4 Organic matter decomposition study

Availability of readily decomposable carbon in a substrate is an essential requirement for increase microbial activity in soil organic matter decomposition, especially for organic materials with lower C: N ratios and low lignin content, the amount of carbon dioxide evolved during the incubation declined at a later stage of the incubation, thus indicating a reduced rate of biological activity. By the end of the second week (14 days of incubation), about 94% of the active biodegradable carbon content in the substrate had mineralized as CO_2 and dropped suddenly to about 43% in week 3 (21 days of incubation) (Figure 4.1). This resulted in a mass loss of about 51% between weeks 1 to week 3. It shows that after 21 days of incubation, the half life (Six and Jastrow, 2002) of the minieralizable carbon in the organic manure has mineralized as evident in the proportion of CO_2 evolved during the period of incubation. The gradual decline in the amount of CO_2 flux from week 4 and finally to week 6 showed that the smaller population of micro-organisms in the soil might have utilised the remaining 49% of the biodegradable carbon in the substrate. This might have been the reason for the fitness of the second order rate model in describing the decay pattern of the added organic matter in the study.

5.1.5 Interaction effects of different levels of N, S and CD on nitrogen mineralization

5.1.5.1 Effect on ammonium concentration

The contribution of sulphur in the interaction was collaboratory, because findings by Bharathai and Poongothai (2008), Friesen (1991) have shown that the nutritional efficiency of applied N was positively influenced by availability of S. Also, it was observed that, lowering the amount of added CD in the interaction led to lower amounts of ammonium especially in the absence of sulphur. Inclusion of organic material in the combination therefore enhanced mineralization.

5.1.5.2 Effect on nitrate concentration

The results showed that application of nitrogen fertilizer at the rate of 120 kg/ha did not translate to increase in NO_3^- - N at incubation; rather, half this rate was more effective. This is a reverse of the result previously reported for ammonium. The result further showed that, all combinations having CD at the highest application rate (10 ton/ha) with 30 kg S/ha were significant ($P < 0.01$) and had more nitrate than with those having 5 ton/ha CD. In view of this, higher amount of organic manure could increase the concentration of plant available nitrate in the soil and ultimately improves soil fertility.

5.1.5.3 Deductions from the laboratory incubation studies

The rate of decomposition of the organic manure decreased with time (week 2 to 6). This shows that the benefit of organic manure input to crops tend to favour long – term effect more than immediate nutritional needs.

Microbial activity for the decomposition of organic manure was highest at the initial stage of the incubation period than at the later stages due to the abundance of readily biodegradable carbon in the organic material.

The mean amount of CO_2 flux in week two was 7.85 g/kg while the amount of CO_2 flux in week six was 4.87 g/kg. This shows that the activity of micro-organisms in soils during manure decomposition is influenced by the amount of carbon present in the substrate.

Mineral nitrogen fertilizer was found to have positively influenced microbial decomposition of soil organanic manure whereas; mineral sulphur fertilizer application did not. Thus, use of mineral sulphur in soil manure decomposition would not have the expected result compared to nitrogen fertilizer application. This could be due to the influence of initial soil sulphur content.

Also, the pattern of organic manure decomposition showed a time–dependent decay process and that organic manure mineralization was not continuous, rather, it has a time limit, which was influenced by the availability of carbon, being an active factor in microbial activities.

The concentration of NH_4^+ - N at the end of the incubation was highest with mineral fertilizer N application than with either S or CD. This showed that comparatively, more NH_4^+- N production was induced by the application of inorganic nitrogen fertilizer, a similar effect was obtained with CD and sulphur application. Ammonification was therefore more effective with urea fertilizer application than with S or CD.

5.2.0 Greenhouse Studies

5.2.1 Main effect of rates of N, S and Cowdung on plant height

5.2.1.1 Main effect of N levels

From the result, there was no significant difference among the N fertilizer application rates (Table 4.10 and Figure 4.7). Under greenhouse conditions, 60 kg/ha N application had a better effect on maize stalk height than at 120 kg/ha. This may be considered in excess of crop requirements, though the soil exhibited very low nitrogen status at the initial stage.

5.2.1.2 Main effect of S levels

Also, there was no significant difference ($P > 0.05$) among the levels of sulphur fertilizer application on maize stalk height (Table 4.10 and Figure 4.7). It was observed that each level of the applied nutrient was comparable effect in enhancing maize growth.

5.2. 1.3 Main effect of CD levels

Significant differences ($P < 0.01$) were obtained with the application of different levels of CD. The result showed that as the rate of CD increased, there was a corresponding increase in stalk height (Table 4.10 and Figure 4.7). Mean effects of 0, 5 10 ton/ha CD on plant height in week 7 were 29.8 cm; 35.5 cm and 41.9 cm (Table 4.10). Some studies, Makinde *et al*. (2010) and Law-Ogbomo and Osaigbovo (2011) reported comparatively higher crop growth and yield from application of organic materials either as decomposed crop residues or cattle manure with lower rates of inorganic N fertilizers in Nigeria.

Organic manure application was of immense benefit to the growth of maize in the Northern Guinea savanna soil, judging from the significant result. Therefore, its inclusion as a source of plant nutrient in a savanna soil is required.

5.2.1.4 Interaction effect of different levels of N, S and CD on plant height

Results obtained from the interactive combinations of levels of N, S and CD is presented in Table 4.11. The best performance in week 7 was 46.67 cm which was obtained from the interactive combination of 0 kg N/ha + 0 kg S /ha + 10 ton /ha CD, though the result was not significantly different with 60 kg N /ha +15 kg S /ha + 10 ton /ha CD and 0 kg N / ha + 15 kg S /ha + 10 ton /ha CD with mean plant height of 45.00 cm and 44.67 cm respectively. The least effect (26.40 cm) was obtained from the combination of 0 kg N/ha + 15 kg S /ha + 0 ton/ha CD, though not significantly different with control (Table 4.11).

The result showed that maize growth significantly benefitted from the combination of half rates of N and S along with the input of highest rate of cowdung than with full application rates of N and S. This could be attributed to the additional nutrients mineralized from the cowdung.

5.3.0 Main effect of rates of N, S and Cowdung on number of leaves

5.3.1 Mean response to N rates

Rates of applied nitrogen fertilizer did not significantly ($P > 0.05$) affect foliage production. The result indicated that response to N was only up to 60 kg/ha and mean number of leaves obtained in week 7 was 11.1 as against 10.9 got from the application of 120 kg N/ha. It shows that the application of 60 kg N/ha was just sufficient for foliage production and as such, any further application did not translate to improved performance.

5.3.1.2 Mean response to S rates

Effect of rates of sulphur application was similar to that of N as earlier reported (Table 4.12) and (Figure 4.12). There was no significant difference ($P > 0.05$) among sulphur application rates on foliage production. The result showed that increasing rates of S only had a slight increase in number of leaves but no significant increase.

5.3.1.3 Mean response to CD rates

However, significant differences ($P < 0.01$) were obtained among CD application rates on maize foliage production (Table 4.12) and (Figure 4.12). From the result, it was observed that, number of leaves increased as the rate of CD increased, in view of this, 10 ton/ha CD application had the highest number of leaves (11.9) in week 7, though, it treatment mean was not significantly different ($P > 0.05$) with mean of 5 ton/ha CD (11.3).The least effect was got from control which had 9.1.

The performance of CD is an indication of improved soil fertility derived from the amendment. Also, the significant response obtained from CD compared to inorganic N or S shows that good quality manure is an important natural resource required for managing soil fertility by enhancing nutrient retention use by plants.

5.3.4 Interaction effect of rates of N, S and CD on number of leaves

The results (Table 4.13) have shown that treatment combinations having half the rates of N and S fertilizer (60 kg N/ha and 15 kg S/ha), especially with 10 ton/ha CD application provided a better synergy for the growth of maize than with higher rates of N and S. The amount of sulphur supplied by gypsum in the trial other than it content in SSP fertilizer enhanced nutritional efficiency of the applied N at the reduced rate, though the content of inorganic sulphur was initially low in the soil. Also, the added organic manure at 10 ton/ha was sufficient and provided good nutrition to the crop. This may be attributed to increase in soil organic matter content. The interaction therefore had a positive effect on foliage production.

5.4.0 Main effect of rates of N, S and Cowdung on stem girth

Stem girth response to fertilizer and cowdung application in the study followed the same pattern of response as in plant height and number of leaves. The result presented in Table 4.14 shows effect of the treatments on stem girth in week 7 and mean effects of weeks 2 – 6, while, treatments effects of different rates of N, S and CD from week 2 to week 6 are presented in Figure 4.14.

5.4.1 Mean response to N rates

There was no significant difference ($P > 0.05$) among the N application rates on maize stem girth in week 7 (Table 4.14) and (Figure 4.14), though, 60 kg N/ha was only slightly better than 120 kg N/ha. Therefore, increasing N rate beyond 60 kg/ha did not impact positively on the plant stem girth.

5.4.1.2 Mean response to S rates

The result showed that effect of S application rate was not significant ($P > 0.05$) across the duration of study, even though, stem girth increased along the weeks. Increase in stem girth with increasing levels of sulphur fertilizer application was only marginal (Table 4.14).This may be attributed to the initial soil sulphur content, which was slightly less than the critical limit of soil sulphur concentration (4.83 mg/kg) (Table 4.1), according to the rating by Esu (1991).

Since each plots other than the control, received SSP fertilizer at 60 kg/ha as recommended for maize in the Guinea savanna (Chude *et al.*., 2012), this may also add to the soil sulphur content and as such, a higher application rate not having a significant impact.

5.4.1.3 Mean response to CD rates

Along the period of observation, maize stem girth increased as the rate of CD increased (Table 4.14 and Figure 4.14). Mean effect at 0 ton/ha CD in week 7 was 5.4 cm as against 7.2 cm and 7.6 cm respectively, obtained from 5 ton/ha and 10 ton/ha CD application. This resulted to 25% and 29% increase over the control, from half and full rates of CD.

The result showed that, comparably, input of organic material improved soil fertility by adding more nutrients to the soil, thereby enhancing crop uptake and growth.

5.4.1.4 Interaction effect of different levels of N, S and CD on plant girth

The combination of 120 kg N /ha + 15 kg S/ha + 10 ton/ha CD produced the highest stalk girth of 8.07 cm in week 7, but, this result was not significantly different with interactive combinations of number 8, 17 and 18 (Table 4.15). Also, it was noticed that treatment combinations without the organic manure input had the lowest stalk girth compared to those containing either 5 or 10 ton/ha CD application. Therefore, organic manure input may have improved soil fertility, especially in combination with half the application rates of N and S fertilizers.

It was observed that treatment combinations involving nitrogen application either at 60 or 120 kg/ha with 30 kg/ha S application were more effective compared with 15 kg/ha S fertilizer input. This shows the nutritional benefit of N and S interaction in maize production in the Nigerian savanna. The result is consistent with the earlier result obtained by IITA (2005) on maize production in the savanna zone of Nigeria.

5.5.0 Main effects of rates of N, S and cowdung on leaf area

5.5.1 Response to N rates

Increasing rates of N did not have a corresponding effect on maize leaf area, rather, N application at 60 kg/ha had a better response, but its mean was not significantly different (*P*

> 0.05) with the mean obtained from the application of 120 kg N/ha. The results in week 7 for 60 kg N/ha and 120 kg N/ha were 233.4 cm^2 and 221.4 cm^2 (Table 4.16), which translated to 5% difference, higher than with 120 kg N/ha.

From the results, the higher application rate of N did not have a superior impact on the plant’s leaf area, suggesting that, though the pre – planting soil analysis revealed a serious deficiency of N (Table 4.1), but application of half the recommendation was satisfactory.

5.5.1.2 Response to S rates

There was an increase in maize leaf area with increasing levels of S fertilizer, as the largest leaf area in week 7 (229.3 cm^2) was obtained from the application of 30 kg S/ha, though not significantly different with that of 15 kg S/ha (203.3 cm^2) (Table 4.16). However, significant differences in leaf area were obtained in weeks 5 and 6 among sulphur rates (Figure 4.18).

The results have shown that maize leaf development required relatively higher amount of S, since its initial content was low, a better response was obtained with this rate. The application of sulphur fertilizer could therefore enhance the performance of maize in the nsorthern Guinea savanna of Nigeria.

5.5.1.3 Response to CD rates

Consistently, manure application at 5 ton/ha had a lower leaf area compared to 10 ton/ha and the same trend was obtained from the means of 7 weeks of cropping (Table 4.16 and Figure 4.19).

Results obtained in week 7 with 5 ton/ha CD was 235.6 cm^2 as against 247.2 cm^2 got from the input of 10 ton/ha CD. However, the difference in their means was not significant ($P > 0.05$). The application of either 5 ton/ha CD or 10 ton/ha CD was superior to the control which had a mean leaf area of 173.1 cm^2 (Table 4.16).

Influence of CD application on leaf area manifested differences among the CD rates, indicating that, the application was beneficial to the growth of maize, considering its positive role in maintaining soil fertility (Olatunji and Ayuba, 2011; Nyongesa *et al*., 2010; Odunze and Ogunwole, 2002). Also, the result has shown that it is not inorganic fertilizer application alone that was capable of providing the required nourishment for the growth of a crop, though, it has the characteristics of a quick nutrient release compared to organic manure (Havlin *et al*., 2006), rather, input of organic matter was an added advantage.

Leaf development was influenced by factors such as soil fertility, prevailing climatic conditions, crop variety and genetic characteristics of the plant, as well as ecology. Apart from its prime role in photosynthetic activity in plants for food manufacturing, maintaining a balance between carbon dioxide and oxygen in the environment, transpiration and contributing to the removal of toxic constituents as exudates (Jones, 1987). Plant leaves also play a very important role in foliar nutrition of crops (Ukem, 2011; Effiong *et al*., 2006; Xu *et al*., 1999 and Cooke, 1982). Achieving these functions would require optimum and balanced plant nutrition. Therefore, application of fertilizer rates along with organic manure amendments expectedly furnished the crop with the needed plant food for growth and tissue development.

5.5.1.4 Interaction effect of different levels of N, S and CD on plant leaf area

The result (327.87 cm^2) (Table 4.17) revealed that the largest leaf area was produced from the interaction of N and S in their highest application levels in combination with 5 ton/ha CD, though the difference with 120 kg N/ha + 30 kg S/ha + 10 ton/ ha CD (253.03 cm^2) was not significant ($P > 0.05$). The significant effect obtained from the highest rates of the amendments suggests that, being an active vegetative growth factor (Effiong *et al*., 2006; Jones, 1987), comparably, higher amount of nutrients would be required and also considering the initial low soil deficiency of these essential plant nutrients. Also, the overriding effect of

N and S rates further indicated that these two elements have a complementary role in plant nutrition (Ceccotti, 1996; Misra, 2003). Therefore, their presence may have stimulated cellular activities within the plant resulting in more nutrients demand.

5.6.0 Main effects of rates of N, S and CD on dry matter

There was no significant difference among the rates of N and S in maize stover, however, a significant ($P < 0.01$) effect was obtained with rates of CD application (Table 4.18). It shows that soil fertility was initially low and a positive response was therefore obtained due to the application.There was however no significant difference in the means between half and full rates of CD amendment, indicating that half rates also had a comparable effect. The performance indicated that soil fertility was rejuvenated due to the application of organic manure. Studies have shown that soil quality and productivity are enhanced when the presence of organic matter is guaranteed (Ano and Agwu, 2005; Adeleye and Ayeni, 2010; Nyongesa et al., 2010). Therefore, manure input enhanced soil productivity.

5.7.0 Main effect of rates of N, S and CD on root weight

The superior performance of 60 kg N/ha over 120 kg N/ha suggested that its contribution to root growth and weight was sufficient under greenhouse conditions, especially in collaboration with other nutrients.

Mean effect of rates of sulphur on root weight is presented in Table 4.18. Root weight increased with increase in rates of applied sulphur, where, 30 kg S/ha had root weight of 20.5 g over the control with 17.3 g, while 15 kg S/ha had root weight of 19.2 g (Table 4.18). However, there was no significant difference in the treatment means. But the performance of 30 kg S/ha showed that the application was beneficial to the plant.

The greatest effect of the factors (N, S and CD) on root growth and weight was obtained with CD application, where a significant difference ($P < 0.01$) was obtained with 10 ton/ha CD over the control. Their corresponding results were 25.6 g and 10.9 g. Also, mean effect of 5 ton/ha CD was higher than the control by about 27.67 %, though, their means were not significantly different (Table 4.18).

The overriding influence of organic manure at the highest application rate has revealed the acute low organic matter content of the soil (Malgwi and Kparamwang, 2002), as such, a good response was obtained from the application. Also, it showed that the added organic manure had mineralized early (Mba, 2006; Tarfa and Iwuafor, 2002) and increased soil fertility, thereby enhancing plant access to nutrients.

5.8.0 Interactive combinations of N, S and CD on plant dry matter and root weight

It was observed from the results (4.19) 120 kg N/ha + 0 kg S/ha + 10 ton/ha CD was the best performing combination with stover yield of 26.33g, but the result was statiscally similar with 60 kg N/ha + 15 kg S/ha + 5 ton/ha CD (24.00 g). Apart from such combinations without N or S or where CD was omitted, stover yield significantly responded to treatments, indicating that the combinationpositivel impacted on maize dry matter in the northern Guinea savanna soil. The inclusion of CD in the interaction also added nutrients particularly sulphur to the soil, which may have reduced high responses from inorganic sulphur application.

Effect of treatment combinations on root weight showed that full application of 120 kg N/ha + 30 kg S/ha + 10 ton/ha CD significantly ($P < 0.01$) performed more than other treatment combinations (Table 4.19) with a mean root weight of 37.27 g, whereas, the plot with no application of fertilizer and organic manure had the lowest root weight with a mean of 3.83 g, representing a difference of about 82 % between their means. Nutrients availability in a balanced proportion influenced greater root weight than other combinations.

5.9.0 Main effects of different levels of N, S, and CD application on soil chemical properties in the greenhouse

5.9.1 Soil pH

The impact of fertilizer N application on soil reaction is an indication that soil acidity would be induced by mineral nitrogenous fertilizers, judging from the progressive downward trend obtained with increase in N fertilizer application levels, especially on long term basis where fertilizer N is continuously applied to support intensive agricultural production. However, with sulphur, the effect was not as much as it was for N, and soil pH was not significantly reduced (7.0 - 7.8) and the contribution of S to the development of soil acidity was relatively lower than that of mineral N fertilizers.

The positive contributions of organic matter to soil properties especially to tropical soils are well known (Adeleye and Ayeni, 2010; Brady and Weil, 2005; Singh *et al.,* 2004; Olayinka and Ailenubhi, 2001; Hsieh and Hsieh, 1990). The significant effect of organic matter with respect to improvements in soil chemical properties was expected and this falls in line with results of previous workers (Odunze and Ogunwole, 2002; Tarfa, *et al*., 2001) on the use of organic residues as a strategy for soil fertility management in the tropical savanna.

Judging from the treatment means, sustainable application of quality organic compounds offers a great opportunity to increase soil organic matter content and rejuvenate soil resources for greater productivity through plant adaptation within the acceptable pH range. Increase in soil pH as a result of organic manure amendment might be due to enrichment of soil with calcium and magnesium from the organic residue (Mba and Mbagwu, 2006; Idris *et al.,* 2010).

5.9.1.1 Interactive combinations of levels of N, S and CD on soil pH

The result showed a progressive increase in soil pH as the amount of CD increased, also, interactions where CD was at zero application had lower soil pH compared with the ones with CD. Organic manure input in the treatment combination mineralized to add more organic carbon to the soil, thereby increasing the soil pH towards alkaline pH values. Many workers, (Odunze and Ogunwole (2002); Hseih, (1996); Olayinka and Ailenubhi (2001); Singh *et al.* (2004) have reported a significant reduction in soil acidity as a result of effect of organic manure application. Therefore, the good response obtained with CD combination with rates of N and S was an indication that application of organic manure to the soil contributed to addressing soil acidity and ultimately improving soil fertility in the long run.

5.9.2 Soil Sulphur Content

There was a positive effect of rates of sulphur fertilizer application on soil sulphur content (Table 4.20). The result showed that soil sulphur content increased by 25.51% over the control from the application of 30 kg S/ha. Therefore, application of sulphur fertilizer increased soil sulphur content at the end of the trial. Application of fertilizers such as gypsum (19.05 % sulphur content) has the potentials of increasing the content of sulphur in the soil. In locations where soil sulphur content is low, application of sulphatic fertilizers would be beneficial to plant nutrition.

Results of effect of CD application on soil sulphur content indicated that 10 ton/ha CD application was significantly ($P < 0.01$) higher than the control. The difference in their means was about 30.59 %, but, there was no significant difference between the means of 5 and 10 ton /ha CD (Table 4.20).

The efficient performance of CD at the highest level of application to soil available sulphur indicated that input of organic manure was relevant in improving soil fertility, especially that of the Nigerian savanna, where organic matter content is inherently low (Chude *et al*., 2012; Lombin, 1987; Malgwi and Kparamwang, 2002).

5.9.2.1 Interactive combinations of levels of N, S and CD on soil sulphur content

The result revealed a pattern of response in which combinations having 0 kg S/ha and 15 kg S/ha had lower amount s of sulphur compared with combinations with 30 kg S/ha. A similar trend was obtained with CD amendment where, interactions with 10 ton CD/ha was significantly ($P < 0.05$) different when compared with half its rate.

Therefore, the application of S as fertilizer and organic manure caused sulphur enrichments in the soil, thereby indicating that the element was initially deficient in the soil (IITA, 2005). Also, judging from the threshold soil sulphur content of 4.83 mg/kg (Table 4.1) and the result obtained from either 60 kg N/ha + 15 kg S /ha + 10 ton /ha CD or 120 kg N/ha + 30 kg S /ha + 10 ton /ha CD (18.11 mg/kg), the interaction was effective and beneficial.

5.9.3 Soil Organic Carbon

Savanna soils are inherently low in organic matter content (Musa *et al*., 2009, Chude *et al*., 2001, Jones and Wild, 1975) and methods aimed at increasing their productive potentials for a wide range of crops through sustainable organic matter input are documented in literature (Adeoye *et al*., 2008; Akinrinde, 2006; Odunze and Ogunwole, 2002). Judging from the initial low SOC (Table 4.1) and result obtained at the end of trial (7 WAP), it could be inferred that there is increased benefit from the use of organic manure as amendment.

At 7 WAP, the difference obtained as means for soil organic carbon content was 59% higher than the content at pre cropping. This was attributed to the ease of mineralization of added substrate in contributing organic carbon and nutrients to the soil and less of immobilization by soil organisms. Furthermore, the high OC content in the CD amended plot suggested that the value of organic wastes as bio-fertilizers is cumulative (Adeleye and Ayeni, 2010; Singh *et al.*, 2004) and extend beyond the period of application.

Result obtained showed the cumulative benefit of organic manure in sustainable soil fertility management, through the gradual build up of plant nutrients (N, P, K, and S) as a result of mineralization.

5.9.3.1 Interactive combinations of levels of N, S and CD on soil organic carbon content

Consistently, the application of CD at 5 ton /ha had lower SOC content compared with 10 ton/ha CD on interaction with N and S. This suggested that, soil amendment with organic manure along with rates of N and S was an important factor in boosting soil organic carbon content and ultimately improving soil fertility. This may be due to acute low organic matter content of the soil (Tarfa and Iwuafor, 2002). Previous studies have reported significant crop responses to combinations of organic and mineral fertilizers in the Nigerian savanna (Adeoye *et al*., 2008; Tarfa *et al*., 2001; Ukem, 2011).

The added organic manure increased soil SOC content at the end of the study by adding new organic carbon to the soil. However, the low SOC content obtained with 0 kg N/ha + 30 kg S/ha + 0 ton/ha CD showed that sulphur alone could not contribute organic carbon to the soil, especially in the absence of organic manure, therefore, input of organic manure was crucial.

5.9.4 Soil nitrogen

The comparably low soil N content obtained from zero N plot against plots amended with mineral N fertilizer was attributed to low soil fertility which has been widely reported (Chude *et al*., 2012; Abdu, *et al*., 2008, Uyovbisere and Lombin, 1991). In view of this, application of nitrogen fertilizer is required for sustainable maize production in the savanna. The result further showed that a significant amount of N was left in the soil after crop uptake either from 60 or 120 kg N/ha, indicating increased benefit of the application.

The result indicated that application of sulphur fertilizer had a positive impact on soil N content as mean effect showed a progression from 0 – 30 kg S/ha. This may be attributed to the relationship between the two nutrients especially in crop nutrition (Havlin *et al.*, 2006), source and availability in soil. Friesen (1991); Fox *et al*. (1977) and Ceccotti (1996) reported that availability of sulphur in soil enhanced use efficiency of N.

The result also showed that a good amount of N can be obtained from organic residues and rate of application was an important factor in quantifying the amount of N released. Application of 10 ton/ha CD was of greater benefit to the soil compared to the lower rates. The savanna soils of Nigeria have very low N content (Chude *et al.,* 2012; Uyovbisere and Lombin, 1991); therefore, effective use of organic materials has great potentials towards addressing this deficiency.

5.9.4.1 Interactive combinations of levels of N, S and CD on soil nitrogen content

There was a positive impact of N fertilizer and CD application especially at 10 ton/ha on soil N content, whereas, the contribution of S to soil N content was minimal and effect was only up to 15 kg S/ha. However, sulphur effect may have been masked by other alternative sources of sulphur, such as SSP, the added organic manure and soil.

Also, results got from interactions having 0 ton/ha CD and 5 ton/ha CD with either 60 or 120 kg N/ha were much lower than in combinations where CD was at its highest application rate. Input of organic manure was therefore an important component in the interaction along with rates of N. In view of this, there is need to integrate mineral and organic fertilizers for a more effective soil fertility management in the savanna.

5.9.5 Deductions from the greenhouse study

The following deductions were made from the greenhouse study.

Among the agronomic parameters measured, half the application rates of N and S were statistically similar with their full application rates. However, organic manure input at 10 ton/ha was much more effective in all the agronomic parameters throughout the duration of study.

Plant height, number of leaves, stalk girth and leaf area were significantly higher with organic manure amendment than with either N or S rates. This occurrence validates the quest for integrated soil fertility management in the savanna where use of good quality organic manure is an important component.

Soil chemical properties benefited significantly from the application of CD as there was an increase in their concentration beginning from 5 – 10 ton/ha CD input. Soil pH, OC, N and soil sulphur content were highest at 10 ton/ha CD relative to the optimum levels of N and S. It can be deduced that organic manure has the potentials of improving the fertility status of savanna soil.

5.10 Field Studies

5.10.1 Main effects of different levels of N, S and CD on plant height

5.10.1.1 Response to N rates

Nitrogen fertilizer application was effective in promoting a good response of maize in view of the significant differences obtained with its rates. Also, the deficiency of N in the soil was manifested in the comparably lowest mean obtained in the control plot (48.49 cm) in 2009 and 112.26 cm in 2010, which indicated the acute low nitrogen content of soils of the Guinea savanna of Nigeria (Chude *et al*., 2001; Lombin, 1987; Musa *et al*., 2009). As such, its relevance is emphasized for a good nutrition (Havlin *et al*., 2006; Jones, 1987) and a sustainable crop production in the savanna.

The result in 2011 indicated that, increased availability of N in soil might have been obtained due to residual effects of previous application, as mean differences with respect to N rates were statistically similar. Therefore, continuous N fertilizer application over a period of time for the nutrition of a crop did not result in higher productivity in the long run but could increase soil nitrogen content.

5.10.1.2 Response to S rates

The result revealed that sulphur was initially deficient in the soil and its application therefore alleviated this deficiency. In addition, it showed that the applied sulphur improved nutrition of the crop much better than it was in zero sulphur plot (Bharathi and Poongothai, 2008), and maize performance in the savanna could benefit greatly from additional source of sulphur application, rather than sole dependent on SSP fertilizer (Kang and Osiname, 1976) for crop sulphur requirements. Under intensive cultivation as currently practiced in the savanna of Nigeria (Chude *et al*., 2012), additional input of sulphur to complement that of SSP is of advantage.

5.10.1.3 Response to CD rates

The consistent lowest performance of control in stalk height is an indication of acute low soil fertility, but a significant improvement was obtained when cowdung was added. The result suggests the need for its application. However, there was no significant difference ($P < 0.05$) in the means between 5 ton/ha and 10 ton/ha CD application in 2011, indicating that fertility condition in the soil may have improved over time and as such, further addition, especially at close interval, may not make any significant difference in the results due to accumulation from previous application. This result is consistent with the previous work of Adeleye and Ayeni (2010).

5.10.1.4 Interaction effect of different levels of N, S and CD on plant height

The result showed a positive impact of the applied N, S and CD combination either at half or full application rates. The interaction effect obtained from the highest levels of N, S and CD was significantly ($P < 0.05$) better than with half application rates.

The combination of 0 kg N/ha + 15 kg S/ha + 0 ton /ha CD; 0 kg N/ha + 30 kg S/ha + 0 ton /ha CD and 60 kg N/ha + 0 kg S/ha + 0 ton /ha CD or where one of the three factors was not supplied were ineffective and as such, their interaction means were the lowest, presumably due to inadequate and unbalanced nutrition.

It was observed that N rate was the major determinant in the interaction as means obtained increased with increasing levels of N while the presence of S and CD was complementary. However, the efficacy of S in the interaction was mainly influenced by its application rates. This observation was obvious as the rate of S interacting with N increased; there was also an increase in plant height. It thus suggests that, the nutritional role of S in combination with N would be more effective when sulphur was available and sufficient especially in soils where the initial concentration of the nutrient was low.

It could be recalled that the concentration of sulphur in soil of the trial site before planting was lower than the critical level. (Kang and Osiname, 1976; Isitekhale *et al*.., 2013), therefore the application of S at 30 kg/ha with CD alleviated the initial deficiency.

5.11.0 Main effects of different levels of N, S and CD on number of leaves

The incorporation of fertilizers and the amendments with an organic substance led to more leaves being produced on the plant than the control in 2009 and 2010 respectively. A greater response was obtained because the applied nutrients, especially the optimum levels of N and S increased availability and use efficiency which may have facilitated cellular activities within the plants protoplasm, tissue development and growth. These activities enhanced comparatively more foliage production on the fertilized plots relative to the control.

Therefore, a healthy and effective growth of yield parameters ultimately influences greater yield outputs. The contributions of N and S in particular showed that their co-application stimulated both their individual and collaboratory nutritional roles especially during the active vegetative growth period preparatory to the initiation of reproductive growth and a later grain filling stage. The attainment of these growth phases was achieved through a balanced nutrition from the application of fertilizers and organic matter inputs.

In the third year of cropping, the accumulation of nutrients from the two previous years in addition to the ones supplied in the current year did not make any significant difference in number of leaves produced. This may be due to sufficiency of the applied nutrients coupled with the residual effect of previously applied nutrients.

5.11.1 Interaction effect of different rates of N, S and CD on number of leaves

The superior performance of full application levels of the treatments over the other interactive combinations showed that additional amount of plant nutrients was received from the interaction, which resulted to a significant ($P < 0.01$) effect in 2009. The consistent performance in 2010 with 120 kg N/ha + 30 kg S/ha + 10 ton/ha CD showed that the initial soil fertility was low and could not support plant growth without mineral fertilizer and CD application. The result is consistent with the previous work of Tarfa *et al*. (2001) in Samaru, northern Guinea savanna of Nigeria.

5.12.0 Main effects of different levels of N, S and CD on stem girth

5.12.1 Response to N levels

The impact of application levels of N on maize stalk girth in week 10 showed that girth increased as the levels of N application increased, where, N at 120 kg N/ha surpassed half its rate and control by 13.24 % and 23.53 % respectively in 2009, suggesting that there was a good response from nitrogen fertilizer application. The performance in the second and third year of planting reflected a similar pattern of response as in the first year (Table 4.30). The lowest response obtained from control further showed the acute N deficiency in Northern Guinea savanna soil (Lombin, 1987). Therefore, maize production in the savanna would require optimum levels of N for a successful growth cycle.

5.12.2 Response to S levels

Sulphur application effect on maize stalk girth showed a positive impact (Table 4.30). Girth increased along with increasing levels of S, where the highest response was obtained from 30 kg S/ha, with a mean of 6.5 cm and lowest in the control (5.4 cm). The difference between the means was significant ($P < 0.01$). The same trend of response was obtained in 2010 and 2011, though treatment means in 2011 were not significantly different.

The high response to S application in the first two years of planting showed that the initial soil sulphur content was low, and was boosted as a result of the application. But, the amount increased during the period of planting due to continuous application, such that further input in the third year had no significant effect. The performance indicated that the initial low S content of the soil was addressed through external input of mineral S, but continuous application, especially in a non-intensive cultivation would not make much impact.

5.12.3 Response to CD levels

Effect of levels of CD on stalk girth had a similar pattern with those of N and S levels (Table 4.30). In each year, stalk girth in week 10 was highest (6.5 cm) with the highest level of CD (10 ton/ha CD), while the least effect (5.4 cm) was obtained from control. In 2010, the results were 7.9 cm as against 5.9 cm for CD application at 10 ton/ha and control, while in 2011, the mean effects at the same levels of CD, were 9.6 cm and 9.1 cm. Mean responses between 0 and 10 ton/ha CD in 2009 and 2010 were significant ($P < 0.01$), but differences in 2011 were not significant.

It showed that a better response was obtained with higher application rate of CD compared with the lower rates, due to initial low soil fertility. From this performance, availability of plant nutrient and in good condition is required for growth and development of plant tissues.

5.12.4 Interaction effect of different rates of N, S and CD on stem girth

The superiority of N, S and CD at their highest application levels over other combinations indicate the high nutrient demand by the crop, coupled with the low fertility of soil of the study area (Abdu *et al.*, 2008). Therefore, application of these elements and organic manure increased soil fertility in a proportion which was beneficial to the plant. The result also showed a positive collaboration between nitrogen and sulphur in plant nutrition as reported by Bharathai and Poongothai (2008) and the benefit of organic manure input.

5.13.0 Main effects of different levels of N, S and CD on leaf area

5.13.1 Response to N level

There was a significant benefit derived from application of N fertilizer during leaf area development, as 120 kg N/ha had much larger leaf area than 60 kg N/ha. The least effect was from control in 2009. Differences in means at 10 WAP were 19.87%, 37.21% and 42.99% for the control, N at 60 and 120 kg/ha respectively in 2009. The means for 2010 were 27.56%, 34.61% and 37.81% in favour of control, N at 60 and 120 kg/ha respectively. There was no statistical difference among the means of N at 120 kg/ha, S at 30 kg/ha and CD at 10 tons/ha within the same period in 2010. This indicated that optimum application levels of these nutrients complemented each other and leaf area increased much more in the second year of planting than in the first year.

But leaf area obtained from 60 and 120 kg N/ha in 2011 was not significant ($P > 0.05$). This tends to suggest that continuous application of N for the growth of a crop overtime would not result to a positive effect due to availability of the nutrient from residual content in the soil. This observation was also reported by Effiong *et al*. (2006).

At the initial growth period, soil fertility was low (Table 4.1), therefore, application of N at the highest rate was superior to half its rate, indicating that optimum condition was reached at this level. Between 2009 and 2010, N effect on leaf area development was in the order 120 kg/ha > 60 kg/ha > 0 kg/ha.

5.13.2 Response to S level

The overriding effect of S at its highest level of application compared to 15 kg/ha and the control showed the importance of sulphur in plant nutrition (Havlin *et al.*, 2006; Jones, 1987), and also indicated that the element was initially lacking in the soil. Therefore, supplemental application was necessary. However, the non significant effect in 2011 among the treatments indicated that soil fertility had improved over time from previous application; therefore, treatment means from different level of S were statistically similar.

5.13.3 Response to CD levels

The result showed that CD contributed additional nutrients to the soil other than the ones supplied directly by urea and gypsum. Also the added organic manure improved soil fertility, judging from the least effect of the control. In areas such as Northern Guinea savanna, where acute organic matter deficiency has been reported (Chude *et al.*, 2012; Odunze and Ogunwole, 2002), input of readily mineralizable organic manure is an important step in soil fertility management.

Leaf area development is a yield attribute of crops influenced by physiological changes within crop biochemistry in response to nutrition, soil moisture, solar radiation, ambient air temperature and other environmental conditions. It plays a very important role in plant photosynthetic process, manufacture of carbohydrate and in respiration (Epstein, 1972). David and Maxico (1995) noted that the determinant of leaf development is leaf area index which is influenced by rate of formation of leaves, size and life of leaves, leaf area duration, production and partitioning of assimilates. Therefore, effective development of these attributes ultimately influences the physiological function of leaves in food production and respiratory activities. Availability of plant nutrients in optimum conditions is critical to these functions; hence the superior performance of the highest levels of N, S and CD in the trial.

5.13.4 Interaction effect of different levels of N, S and CD on plant leaf area

Since interactive combination of N, S and CD at their full application rates had leaf area which was significant ($P < 0.05$) than with half the rate of N, S, CD and also, the half rates being superior to the combinations where any of N, S or CD was not applied and the control. Therefore, improvement in nutrition as a result of increased levels of N, S and CD was the major factor that influenced plant leaf area in this study. Each nutrient in the interaction was important for the growth of the plant, especially, the presence of sulphur in the combination enhanced plant utilization of the other nutrients as stated by Bharathi and Poongothai (2008); Havlin *et al*. (2006); Misra, 2003). The same pattern of response was obtained in 2010 and 2011.

5.14.0 Main effects of N, S and cowdung rates on the combined analysis of plant height, number of leaves, stem girth and leaf area of maize

This trend of response where maize growth potentials were positively influenced by the amendments shows that improvements in soil fertility played a dominant role in maize plant nutrition and a major determinant for increased, qualitative and sustainable yield of crops in the Nigerian savannas aside from the positive contributions of climatic factors. In view of this observation, the continuous cultivation of maize in the savanna without an adequate soil fertility plan where organic resources are integrated along with inorganic sources of plant nutrients could lead to disappointing results. Effective management of crop residues and other organic materials to improve soil organic matter content in combination with inorganic fertilizers has offered a better and realistic agronomic approach and also environmentally sound agricultural practice where availability of plant food is more secure than with sole application of either (Adeleye and Ayeni,2010; Tarfa *et al*., 2001).

Though the performance of plant height, leaves per plant, stem girth and leaf area peaked at 120 kg/ha, the means obtained at this level were not significantly ($P \geq 0.05$) different from similar levels of S and CD reflecting the synergy and husbandry of the crop through the applied nutrients. It implies that nitrogen deficiency is still a serious cause for concern in the savanna soils and at the same time, soil sulphur availability should not be overlooked since its inclusion in specified rates has proven its nutritional relevance in the study and its role can no longer be fulfilled through application of Single Super Phosphate (SSP) alone which had been the practice (Enwezor *et al*., 1989; Kang and Osiname, 1976). This innovation has added value to maize performance in the savanna thus becoming a suitable alternative approach for improved soil productivity.

In view of this nutritional benefit to the crop due to the amendments, the threat of soil acidity through N and S fertilizer application is reduced considering the co-application of an organic material in the study.

5.15.0 Main effect of N, S and cowdung rates on grain yield in 2009

The cumulative effect of the treatments on grain yield as computed by Munoz *et al*., (2003) method showed that mean grain yield was 66.7% for nitrogen, sulphur and cowdung rates respectively. This uniformity in result indicates that applied nutrients interacted positively and their effect was largely complementary. The effective performance of treatments over the control and the incremental yields obtained as treatment rates increased shows improvement in soil fertility due to quick release of nutrients from both organic and inorganic fertilizers (Adeleye and Ayeni, 2010). Therefore, a cereal crop production in the savanna still requires input of either mineral fertilizers or a combination of both mineral and organic manure for greater outputs. The application of organic manure along with mineral fertilizers provided additional benefits to maize yield in Kenya than sole applied mineral fertilizer (Nyongesa *et al*., 2010).

Sanchez *et al*. (1997) had identified low soil fertility as the major constraint to sustainable crop production in sub-saharan Africa. A combination of mineral fertilizers and organic manure application is one of such strategies adopted to improve soil fertility and ultimately increase crop yield in the savanna. The impact of N and cowdung application peaked at 120 kg/ha and 10 ton/ha respectively. This suggests that growth and yield conditions were satisfied due to soil enrichments as sulphur provided needed stimulating effect for the efficiency of added materials. Increased productivity of savanna soil as a result of amendments with soil enriching organic manure and inorganic fertilizers guarantees greater crop yields and improvements in soil properties.

5.16.0 Main effect of N, S and cowdung rates on stover in 2009

The highly significant result obtained with increasing nitrogen rates indicated that initial low N content of the soil improved with increasing levels of N. Chude *et al* (2001) and Tarfa *et al*. (2001) reported increase in stover of maize in the guinea savanna soil with increase in N levels. Therefore, effective plant dry matter accumulation is a function of a balanced nutrition apart from other variables such as adequate soil moisture content, soil air and soil pH in addition to other factors influencing nutrients mobility in soils which have to be optimised.

The result is consistent with S application at 15 and 30 kg Sha^{-1} and cowdung from 0 to 10 ton/ha. N fertilizer application and N mineralized from CD and increase in soil organic carbon; due to mineralization of organic material, enhanced soil available N for plant uptake which was utilised for growth and tissue development to impact positively on plant dry matter accumulation. Sulphur facilitated the optimal utilization of N and the other applied nutrients by boosting crop use efficiency of major nutrients (Bharathi and Poongothai, 2008; Havlin *et al*., 2006).

Fertilizer N application and S are therefore important synergistic and/or complementary nutritional elements in view of their beneficial role in crop production especially in areas of acute deficiency (Table 4.1). Also, cowdung apart from mineralizing to release plant available food improved physical condition of the soil for retention and efficient use of both nitrogen and sulphur.

5.17.0 Main effect of N, S and Cowdung rates on cob yield in 2009

The progressive increase in cob yield with increasing levels of N, S and CD application indicates that a good yield of maize in the guinea savanna can be obtained when full recommendation of fertilizers is applied. Also organic manure inputs to increase use efficiency of the added mineral fertilizers through improvements in physical and chemical properties of the soil would be required. Efficient crop performance in the savanna is expected when all required conditions are optimum. However, differences among means of S at 0, 15 and 30 kg/ha were only marginal, suggesting that this nutrient might have been leached, under utilised by the crop or a higher rate might be optimal. The result further shows that application of N fertilizers to maize at 120 kg/ha will require a higher S rate than 10-20 kg/ha for a proper nutritional benefits and synergy.

5.18.0 Main effect of N, S and cowdung rates on grain yield in 2010

The variation in sulphur performance shows that 15 kg/ha is considered inadequate to meet maize sulphur needs in northern guinea savanna soils but a recommendation of 30 kg/ha or higher appears more promising. Nutrients demand by crops is greater in soils which are exhaustively cultivated in order to meet crop requirements and equally meet near target yield expectancy, which is the case in soils of the northern guinea savanna. Also, the less efficiency of 15 kg S/ha relative to the sulphur control could be attributed to lack of synchrony between the application and uptake. This is in agreement with the findings of Ogeh *et al.* (2001) who opined that the native capacity of the soil to retain applied fertilizers in a form available to the crop throughout the growing season varies in time and location.

The application of organic wanure to the soil enhanced maize performance when compared to the control. Generally, savanna soils have a marked organic matter deficiency (Duyilemi *et al.*, 2010; Adeleye and Ayeni, 2010; Adeoye *et al.*, 2008). The significant effect obtained with cowdung at 5 and 10 ton/ha over the control is an indication that the added organic manure improved bio-availability of nutrients in the soil for plant uptake and that it possesses a good substrate quality in view of its low C:N (Table 4.2) for increased microbial population and action of mineralization. A sustainable application of organic wanure therefore has the potentials of increasing the productivity of agricultural lands in the savanna. However, due to its slow release patterns of nutrients for plant use, co-application with mineral fertilizers especially in the savanna soils and in humid environmental conditions is still a viable option due to their quicker nutrient release characteristics and a balanced nutrition. Many workers have reported comparatively higher crop yields with less harm to the environment from the use of organic nutrient sources combining with reduced levels of inorganic fertilizers (Mba, 2006; Ukem *et al.*, 2005; Adediran *et al.*, 2003; Tarfa *et al.*, 2001).

5.19.0 Main effect of N, S and cowdung rates on stover in 2010

The continued positive crop response to nitrogen fertilization in particular, and other major nutrients in the savanna, revealed that soil fertility was very low to support optimum crop production; thus suggesting integrated soil fertility management where use of organic residues is accorded top priority.

Organic fertilizers input to the savanna soils is of a high agronomic value judging from their comparative effect with mineral fertilizers; in terms of crop nutrition and yield output. There is a gradual build up of soil resources in the long run from organic fertilizer application with the capacity to reduce the negative effects of inorganic fertilizers; particularly acidification and the increased removal of nutrients other than the ones supplied by the fertilizers (Isitekhale and Osemwota, 2010).

A higher soil pH, greater soil moisture retention, increased microbial activity, increase in organic carbon content, improvement in total N and P contents and increased proportion of non-acid forming cations are closely associated with organic matter content of soils. Therefore, there is the need for their constant input. However, the gain made by urea N at 120 kg/ha over CD rate at 10 ton/ha on stover shows that organic fertilizer source as sole application has not yet replaced mineral fertilizers especially in their nitrogen supplying ability for crop nutrition in the Nigerian savannas, but their combination is evidently superior to their sole application as also reported in many studies (Isitekhale and Osemwota, 2010; Ogeh, 2010 and Ukem, 2009).

5.20.0 Main effect of N, S and cowdung rates on cob yield in 2010

Growth and a good quality yield of crops is often distorted when there is an imbalance in soil nutrient status (Havlin *et al*., 2006; Epstein, 1972). The wide superiority of N at 120 kg/ha over sulphur and cowdung at 30 kg/ha and 10 tons/ha respectively shows the comparative advantage of mineral N fertilization in crop nutrition in relation to other major elements specially with respect to a cereal crop production in a savanna soil. Although N fertilizer application accelerates soil acidity and a reduction in soil microbial biomass (Calderon *et al*., 2004; Singh *et al*., 2004; Kumar and Goh, 2000), its overwhelming positive effects on crop utilization and yield of many staples in the savanna are among the compelling necessities of the frequency and high rate of N consumption by plants. But the adoption of integrated soil fertility management where renewable biological plant materials are used have the potentials of reducing high N fertilizer application down to half its recommendation with a capacity to reduce high soil acidity in the long run.

5.21.0 Main effect of N, S and cowdung rates on grain yield in 2011

The progressive increase in grain yield over the three years shows that there was a positive cumulative effect of N, S and cowdung application through increase in soil organic matter from the cowdung on the soil and crop by increasing the build up of plant available nutrients over time. Also, the application of fertilizers and cowdung during the third year of cropping equally resulted in more nutrients being available for maize coupled with mineralization of the organic material from the previous years. This is in agreement with the findings of Adeleye and Ayeni (2010); Mba and Mbagwu (2006) and Zingore *et al*. (2003) who reported a significant increase in maize yield due to residual concentration of plant available nutrients from organic matter application. The soil bio-remediation process as a result of organic matter enrichments also prevented nutrients losses mainly leaching of N, K and sulphur thereby contributing to their availability and use efficiency.

There is also the likelihood that availability and use efficiency of the basal applied P was enhanced because of a reduction in P sorption due to increase in soil organic matter content as Nziguheba *et al*. (1998) found a decrease in P sorption from application of organic residue. In addition to this, the decomposition of the added organic material could have released organic acids to solubilise P, thereby overcoming its deficiency and increasing its uptake and crop yield. Abdu *et al*. (2008) and Agbenin (2003) have reported that savanna soils have a high P-fixation capacity due to the preponderance of Al and Fe hydroxides.

An improvement in the soil physical, chemical and biological conditions as a result of application of organic manures and other crop residues has a net positive effect on soil productivity and crop performance (Okpara *et al*., 2005; Hulugalle *et al*., 1987). Since each plot per replicate was retained for the three consecutive years of field experiment, nutrients stock accumulated over time both from added mineral fertilizers and organic amendments, their residual effects therefore manifested in yield increase in the third year of planting relative to the previous two years.

5.22.0 Main effect of N, S and cowdung rates on stover in 2011

Greater availability of nutrients from the three years of incorporation of urea N, sulphur and cowdung led to positive residual effects and increased soil organic matter content through the period which could have enhanced a higher concentration, uptake and a quick utilization of plant nutrients in the third year. This is because, the productive potentials of the soil were satisfied and the crop was able to easily access nutrients in a more available form than was the case previously due to favourable soil chemical properties. Crop trials in the savanna always have a good response to fertilizer application even if half the recommendation is applied (Ukem *et al*., 2006; Chude *et al*., 2001 and Enwezor *et al*., 1989)

The contributory nature of the added nutrients in sustaining an effective growth and dry matter accumulation of the maize plant especially for N and S interaction in plant nutrition shows that there was an active photosynthetic process during the growth phase with a concomitant increase in soil organic carbon content from the decomposition of cowdung and a subsequent uptake and assimilation of carbon and other major nutrients resulting in increased dry matter yield. Sulphur and nitrogen are the essential constituents of amino acids, the building blocks of plant proteins; hence they are actively involved in chlorophyll synthesis and in many enzymes and vitamins required for protein metabolism (Bharathi and Poongothai, 2008; Havlin *et al*., 2006 and Brooks, 1979). An active photosynthetic process due to N and S interactions thus initiated high carbohydrate synthesis resulting in increased dry matter accumulation.

5.23.0 Main effect of N, S and cowdung rates on cob yield in 2011

The high efficiency of the added nutrients shows that the performance of the nutrient was maximised considering the fact that the fertility of the savanna soil was initially low (Table 4.1) to sustain crop production without fertilizer application. Agricultural lands in the Nigerian savanna are constantly put into cultivation and as such, nutrient depletion due to crop uptake is common (Musa *et al*., 2009; Tarfa and Iwuafor, 2002; Malgwi and Kparmwang, 2002). Therefore, a good response was obtained when these nutrients were supplied in fertilizers and from organic manure amendment.

The impact of N application in the trial shows that its use efficiency was at the peak when the other nutrients are also supplied especially during the active vegetative growth phase, taselling and grain filling stages. Consistently, sulphur inclusion stimulated the optimum role of these major nutrients in enhancing cob yields which were much higher than the control. Such critical periods of growth and tissue development of the crop leading to early and healthy reproductive growth stages cannot be fulfilled if one or two of these nutrients were omitted which would have resulted in an unbalanced nutrition and a consequent yield reduction. These growth phases usually place a high demand on plant food and water to avoid hunger and water stress and enable the plant attain the required growth and yield standards. This is often the problem with the low-input small holder farmers who may not even apply fertilizers at all. The significant impact of sulphur application in the trial shows that relying only on single superphosphate (SSP) for crop sulphur needs in the savanna is no longer sustainable, specific recommendation is therefore desirable.

5.24.0 Main effect of N, S and cowdung rates on the combined analysis of grain, stover and cob yields of maize

Nitrogen use efficiency was optimum at 120 kg/ha similar to sulphur at 30 kg/ha and nutrients released from cowdung mineralization. The superior performance of N and cowdung over the control is an indication that improved soil properties and a balanced nutrition form a vital component of maize growth and yield requirements in the guinea savanna of Nigeria as the deficiency of any of these basic nutrients will manifest poor growth, yield reductions and poor seed/grain quality or even premature senescence.

Both dry matter yield and cob weight are the yield components of grain yield of crops (Bharathi and Poongothai, 2008; Tarfa *et al*., 2001; Abubakar, 1999), therefore, an increase in grain yield of maize owing to S additions could be attributed to increased yield of yield components like cob weight and stover. Studies have shown that in the presence of sulphur, the efficiency of added N fertilizer is enhanced (Dwivedi *et al*., 2002). In view of this, efficient use of N in particular and those elements mineralized from the added organic material had a positive interaction on maize grain, stover and cob yields whereas an omission of S would have significantly reduced yields. These findings are consistent with those of IITA (2005); Friesen (1991); Kang and Osiname (1976) who observed that sulphur deficiency has a debilitating effect on crop production but that crop yields were significantly ($P \leq 0.05$) increased when sulphur was added.

In this study, it can be deduced that cowdung, N and S application had a positive collaborative effect by causing nutrients enrichments in the soil for maize uptake since these major elements were initially deficient (Table 4.1). The stimulatory effect of the applied S in facilitating N, P and K plant utilization led to the increased grain, dry matter and cob yields due to increase in metabolic activities within the plant biochemistry, synthesis of chloroplast and the activation of ferredoxin photosynthetic process (Misra, 2003; Sakal *et al*., 2000).

Both N and S are the essential constituents of amino acids and important enzymes involved in chlorophyll and protein synthesis (Havlin *et al.*, 2006). Their co-application is therefore found to be complementary and beneficial in plant nutrition especially in the savanna area where they are deficient and coupled with the fact that cereal sulphur requirements were not given any serious attention compared to the situation on legumes.

Owing to these high yields obtained from the optimum recommendation of N in particular and 30 kg/ha sulphur application, and considering the regularly practiced soil fertility depleting farming methods, it is necessary to opine that higher recommendations of N above this threshold could still give relatively better results in the savanna in view of the intensity of farming activities and use of high yielding crop varieties taking up more nutrients than expected from the soil, as a result of variation in soil properties due to land use, or negative environmental impacts. These observations should therefore influence decisions on future fertilizer N and S maize requirements and recommendations in the Nigerian savannas.

In addition to the beneficial role of fertilizers and organic manure input in rejuvenating soil fertility which led to higher yield and higher agronomic efficiency, there is need to mention that these yield increase and agronomic efficiency of the adapted technology could have been unrealistic without the contribution of the seed variety (Samaz – 14),which adapted easily to the agro – ecology, tolerable climatic conditions to support the growth of maize and efficient management practices. Also, the menace of pests and diseases during the field trial was minimal. These attributes other than fertilizer application alone coordinated to enhance maize performance in the Northern Guinea Savanna. Even though RY, RYI and RAE had 100% success in response to the application of the full recommended rate of N at 120 kg/ha and lowest for the control, the support and collaboration of a good crop variety and favourable weather condition coupled with good crop husbandry practices are important growth and yield requirements which should not be overlooked.

5.25.0 Interaction effect of different levels of N, S and CD on grain yield

The result has shown that grain yield increased with combinations having either half or full application rates of N, S and CD, but interactive combinations without any of N,S or CD was significantly (*P < 0.05*). In view of this, the application of N and S fertilizers in addition to organic manure improved soil fertility which was good for the growth and yield of maize. Also, the combination of N and S in particular provided nutritional benefits to the crop (Bharathai and Poongothai, 2008), while the organic manure in the combination added more nutrients to the soil through mineralization (Makinde and Ayeni, 2013). Therefore, availability of the required plant nutrients and in their correct proportion was essential for a good crop performance.

The interactions of N and S at their full application rates with CD at 10 ton/ha were significantly (*P* < 0.05) higher than those with 5 ton/ha CD and least with 0 ton/ha CD, indicating that maize production in the Northern Guinea savannah benefitted from the amendments due to improvement in soil fertility where manure additions also released additional nutrients to the soil.

Therefore, there is still need for manure application to complement and enhance use efficiency of the applied mineral fertilizers, by boosting nutrients retention and also contributing plant food to the soil during mineralization. Studies have shown that integrating mineral fertilizers with organic residues improves soil fertility and ultimately increases crop productivity (Adeleye and Ayeni, 2010; Nyongesa *et al.,* 2010).

But a reversal of this trend in 2011 where 120 kg N/ha combining with 0 kg S/ha and 10 ton/ha CD had the highest interaction rather than with 15 or 30 kg S/ha suggested that addition of S from CD and residual effect of previous sulphur application in the first two years of planting was able to meet crop requirement, therefore, further application did not increase maize grain yield. This observation should be taken into consideration when making recommendations for maize sulphur requirements in the Nigerian Savanna.

5.25.1 Interaction effect of different levels of N, S and CD on stover

As it was the trend in grain yield, a significant and better response was obtained in combinations which had N, S and CD at either at half or full application rates compared with combinations without these inorganic fertilizers and CD. Also, combinations where one or two of the factors were lacking had lower interaction means in relation to those that had complete (Table 4.41).

Therefore, improvement in soil fertility as a result of the application had a positive impact on maize dry matter accumulation because of nutrient availability and synergy among the applied nutrients. Addressing soil nutrients deficiency in a savanna soil through fertilizer application and organic manure input has the potentials of improving soil fertility condition, increasing plant access to nutrients and ultimately increasing crop growth and yield.

The superior performance of the full application rates of N, S and CD on maize dry matter over the other treatments showed that soil fertility had improved through the application. Tarfa *et al*. (2001) and Nyongesa *et al* (2010) respectively obtained a better and significant result on maize performance from the combination of inorganic and organic fertilizers in northern Guinea savanna soil of Nigeria and in the Rift Valley region of Kenya, which was attributed to the abundance of plant food from the combination.

5.26.0 Main effect of N, S and cowdung rates on relative yield (RY), relative yield increase (RYI) and relative agronomic effectiveness (RAE) of maize

Differences in grain yield were obtained from the application levels of N, S and CD from 2009 to 2011. In each year, N application rate at 120 kg/ha was superior in RY followed by half its rate, while the control was the lowest. The same pattern of response was obtained from the CD rates. However, impact of S application levels on RY varied between the control and 15kg/ha (1/2 the application rate), where relatively, higher means were obtained from the control in 2010, though there was no statistical difference between their means. The full application rate of 30 kg/ha was most effective in RY compared to either its half dose or the control.

Comparatively, RYI obtained from 60 and 120 kg/ha respectively was much more favoured by the application of the higher N rate for maize production in the Northern Guinea Savanna. The trend was consistent in the three years of study. The performance of S and CD on RYI of maize was similar to that of N, where 30 kg/ha S and 10 ton/ha CD input out yielded their half application rates. Similarly, the RAE revealed a pattern of overwhelming effect of the highest application levels of N, S and CD throughout the duration of the field study. In each year, the RAE was much less with 60 kg/ha N compared with 120kg/ha N, sulphur and cowdung at 30 kg/ha and 10 tons/ha respectively were more effective and had much higher yields than their half doses.

The behaviour of these nutrients in maize nutrition and yield revealed the benefit of applying the correct fertilizer ratios especially for N and S for maize cultivation in the Nigerian savanna, where these nutrients show a marked deficiency and a good response has always been obtained when fertilizers are adequately supplied (Chude *et al*., 2012). N applied at 120 kg/ha and S at 30 kg/ha were complementary in agronomic efficiency, balanced by organic manure input. It shows that soils of the Northern Guinea Savanna cannot support an effective and sustainable maize crop production even at half application levels of fertilizers rather; application of the full recommended rates is more beneficial. In this study, 5 ton/ha CD input was lower in RY, RYI and RAE compared with 10 ton/ha CD. This further reveals the need for a continuous organic matter input to the savanna soils, due to its ability to improve soil fertility, retain soil moisture (Adeleye and Ayeni, 2010), and reduce leaching of nitrogen (Mba and Mbagwu, 2006) and also reduces phosphorus sorption (Nziguheba *et al*., 1998). As the fertilizer levels increased from the control to the optimum, there was a proportional increase in yield due to nutrients addition to the soil and plant uptake.

This kind of collaboration among N, S and CD especially at the optimum application levels proved much more effective in crop husbandry, leading to higher yields compared to their lower rates. This is attributed to nutrients abundance sourced from the optimum rates of N, S and CD and their ability to synergize in order to meet maize nutritional requirements better than the reduced fertilizer levels in a savanna soil. Also, it shows that sole application of any of these amendments is not enough to satisfy crop nutritional needs, rather, integrating them provides the opportunity for a balanced nutrition, enhance efficient and quick nutrients delivery to the growing crop.

5.27.0 Main effect of N, S and cowdung rates on soil chemical properties

5.27.1 Soil pH

In the northern Guinea savanna soil of Nigeria, a low soil pH (H_2O) averaging 4.5 – 4.9 has been reported (Tarfa *et al*., 2001; Singh *et al*., 1983) which was attributed to the negative effects of continuous application of acid forming nitrogen fertilizers and acute low soil organic matter content (Adeoye *et al*., 2008; Akinrinde, 2006; Malgwi and Kparmwang, 2002; Uyovbisere and Lombin, 1991).

There is the observation that the effectiveness of organic manure inputs to soils is influenced by time for which decomposition is achieved so as to make nutrients available for plant uptake. Although the cowdung was of a high quality substrate in view of its C/N ratio, its ability to release the needed organic carbon at that particular time was not obtained. Therefore, longer periods for mineralization seem more effective and reliable.

Also, there is the possibility that micro organisms may have utilised the nutrients in the substrate for their tissue growth, cell enlargement and metabolism thereby reducing the capacity of the organic matter to address any development of soil acidity. The factors determining decomposition and nutrient release patterns of organic materials in soils are well known (Singh *et al*., 2004; Sanchez *et al*., 1997 and Haynes, 1986), yet there is growing need to correlate time required for organic matter decomposition with nutrient release and availability for plant uptake. Such correlation would enable a quantitative evaluation of mineralization kinetics of the various organic residues and their efficiency as nutrients suppliers.

Increase in organic matter content over the years might have increased the soil pH levels indicating a positive residual effect of the applied organic substance on the soil. This is because organic materials are reported to have liming effects on acid soils in view of their content and supply of basic cations such as Ca, Mg and K (Adeleye and Ayeni, 2010; Ayeni *et al*., 2008). Also, increase in soil pH over the years from the application of cowdung even when varying rates of N and S fertilizers were applied in combination suggests that both physical and chemical properties of the savanna soil can be greatly improved due to a gradual build up of soil organic matter with a capacity to buffer the soil against changes in soil pH in favour of low acidity. The incorporation of organic amendments was significantly beneficial in terms of improvements in soil resources.

5.27.1.1 Interactive combinations of levels of N, S and CD on soil pH

The interaction means in 2011 were significant ($P < 0.01$) with best performance (6.49) obtained from 120 kg N/ha + 15 kg S/ha + 5 ton/ha CD, while the least effect was obtained from treatment combinations 0 kg N/ha + 15 kg S/ha + 5 ton/ha CD; 60 kg N/ha + 0 kg S/ha + 0 ton/ha CD and 120 kg N/ha + 0 kg S/ha + 5 ton/ha CD (Table 4.44). However, the mean effects of interactions in the three years of study were not significant.

The build-up of nutrients over the period, especially carbon enrichments from organic manure and the content of bases in gypsum stabilized soil pH even when mineral N and S fertilizers were applied. The positive effects of organic matter on soil properties have been documented (Mba and Mbagwu, 2006; Olayinka and Ailenubhi, 2001; Malgwi and Kparamwang, 2002).

5.27.2 Soil organic carbon content

Consistently, cowdung application rate at 10 ton/ha had the highest soil organic carbon content of 7.6 g/kg, 8.6 g/kg and 9.5 g/kg for 2009, 2010 and 2011 respectively followed by nitrogen application at 120 kg/ha with a mean soil organic carbon content of 7.1 g/kg, 7.6 g/kg and 9.0 g/kg for the same period while sulphur fertilizer application rate of 30 kg/ha had the lowest SOC content though not significantly ($P > 0.05$) different from that of N at 120 kg/ha. A similar trend was observed in the combined analysis of the three years results (Table 4.45).

As the control treatment had the lowest soil organic carbon content across the N, S and CD application levels with a mean of 5.3 g/kg, it indicates that the northern Guinea savanna soil is inherently low in soil organic matter content as earlier reported by Uyovbisere and Lombin (1991) and Chude *et al*. (2001). According to Esu (1991), the soil organic carbon content obtained from the control plot falls within the low level of soil fertility rating. But the amendment of the soil with a good quality substrate and application of nitrogenous and sulphatic fertilizers increased soil organic carbon content as shown in Table 4.45. Mineralization of the applied manure released carbon to the soil which increased the amount of soil organic carbon coupled with the beneficial role of inorganic nitrogen fertilizer application on soil organic carbon content. This interplay of soil fertility enrichments by the different factors encouraged microbial activities within the biosphere resulting in the decomposition of the organic manure.

It was further observed that the significantly low levels of soil organic carbon recorded from the control plots may be attributed to the low soil nitrogen and sulphur contents compared with the plots that received either 60 or 120 kg N/ha and 15 or 30 kg S/ha respectively. This indicates the close association particularly that of N and S with CD to facilitate the mineralization activity which was lacking in the control treatment due to the deficiency of nitrogen and sulphur. This observation is in agreement with the findings of Singh *et al*. (2004), Blair *et al*. (1995) and Jenkinson (1981) for the availability of native soil nitrogen content sufficient to stimulate microbial decomposition of the added organic resource. In the light of this, the application of organic residues alone would not be sufficient to meet soil and crop requirements for N since its decomposition to release plant nutrients requires an appreciable amount of soil available nitrogen. Therefore, the application of mineral N fertilizer even at half the recommendation is needed to complement any soil reserves of N for a quick and efficient mineralization of the applied organic manure.

5.27.2.1 Interactive combinations of levels of N, S and CD on soil organic carbon

There was a positive impact of the amendments on soil organic carbon content, such that progressively, organic carbon increased with rates of amendment and with period of experimentation. The mean effects of the three years were 11.3 g/kg and significantly ($P < 0.01$) higher than the content at pre-planting (5.3 g/kg). This indicated a positive cumulative effect of the application on soil properties which was also reported by Adeleye and Ayeni (2010) and Tarfa *et al.* (2001) in the forest zone and northern Guinea savanna zone of Nigeria respectively, especially, the input of organic manure.

5.27.3 Soil nitrogen content

Nitrogen fertilizer application at 120 kg/ha, S at 30 kg/ha and CD at 10 ton/ha recorded significantly higher results than their half application rates. Comparatively, cowdung application at 10 ton/ha was widely superior in soil nitrogen credit than N at 120 kg/ha and the rest of the treatments. Continuous application of manure over the years and the fact that N immobilization by microbes in the soil was low may have contributed to the comparative results obtained from CD. This relative efficiency of the organic manure amendment over that of mineral fertilizer N or S shows the important role of soil organic manures in promoting bioavailability and as a nutrient contributor which is capable of nourishing the soil for a sustainable productivity. However, it was observed that the greater efficiency of the applied organic matter in boosting soil fertility was achieved through the complementary effect of the applied nitrogen and sulphur fertilizer rates.

Nitrogen availability in tropical soils for plant use has been a major concern for agriculturists because of its low soil content (Nyongesa *et al*., 2010). It is also one element which has attracted so much of research attention due mainly to its enormous contributions to the growth, nutrition and yield of crops (Havlin *et al*., 2006; Epstein, 1972). Its deficiency in tropical soils is attributed primarily to acute low soil organic matter content (Jauro *et al*., 2006; Akinrinde, 2006). Also, the negative impacts of denitrification, nitrate leaching, ammonia volatilization and immobilization in microbial tissues control the dynamics cum availability of soil nitrogen. Effective management of crop residues, animal dung, life mulch with leguminous crops and use of other organic materials therefore guarantees higher soil organic matter content and ultimately increasing soil nitrogen status.

5.27.3.1 Interactive combinations of levels of N, S and CD on soil nitrogen content

The contribution of N in fertilizer in addition to the amount obtained from CD increased the content of N in the soil at the end of planting. Nitrogen is a major yield limiting nutrient in the Nigerian savanna (Chude *et al.,* 2012; Lombin, 1987), its content in soil is often reduced after cultivation (Jones, 1987). There is the need for its application through chemical fertilizers to increase soil fertility and support crop production. The combination of nitrogen and sulphur fertilizers with organic manure was therefore beneficial, since the interaction contributed N to the soil. After three years of field experiment, the result obtained in 2011from N, S, and CD at their highest rates significantly ($P < 0.01$) increased soil nitrogen content compared to half this combination. This indicated that maize production in a northern Guinea savanna soil would have a good response from mineral N fertilizer application.

5.27.4 Soil sulphur content

From the initial concentration of 4.83 mg/kg of soil available sulphur prior to planting (Table 4.1) to 13.77 mg/kg after planting in 2009 (Table 4.49), higher than the critical level of 5 mg/kg (Fox *et al*., 1977) of soil sulphur availability in the savanna, the concentration increased by about 64.92%. Therefore, improvement in soil sulphur content due to application of gypsum in collaboration with SSP beginning from 2009 to 2011 reflects the increase agronomic value and resource benefit of the technology for crop sulphur nutrition, particularly in the Nigerian savanna, where sulphur deficiency has been reported (Raji, 2008; Kayode, 1990; Kang *et al*., 1981). Depending on SSP alone for crop sulphur needs is therefore no longer sustainable judging from the significant differences obtained between the fertilized or CD treated plots and the control.

Leaching is one of the most important ways through which sulphate is lost from the soil (Havlin *et al*., 2006; Brady and Weil, 2005) especially in humid and or sub-humid conditions where annual rainfall is high and soil texture is predominantly sandy. Therefore, soil sulphur concentration at the end of each planting season ranging from 13.77 mg/kg in 2009 to 24.54 mg/kg in 2011 is significantly higher than at the threshold (Table 4.1) where its content was less than the critical level (4.83 mg/kg). The reason for this increase may be attributed to improved soil physical properties through organic matter amendment which enhanced greater sulphate retention in addition to the quantity added to the soil through organic matter mineralization. Also, it revealed that soil sulphur stocks and or dynamics must consider input from inorganic fertilizers, annual returns from organic matter mineralization and leaching losses. A reduction in leaching losses through input of organic matter would ensure availability of inorganic sulphate for plant uptake.

In 2011, the mean sulphate -S concentration was 28.71 mg/kg; 28.26 mg/kg and 28.34 mg/kg respectively for N, S and CD at their highest application levels (Table 4.49), indicating that there was an accumulation of plant available sulphur over the years. These values were higher than those of the previous results in 2010 and almost doubled that of 2009 despite the easy susceptibility of the nutrient to leaching, especially in a sandy loam texture of soil of the area. The treatment means were not significantly ($P > 0.05$) different and as such, reflects the collaboration particularly between N and S on one hand, S and CD on the other hand. Studies have shown that both S and N exist in soils as a constituent of organic compounds such as sulphur containing amino acids, proteins and enzymes (Khan *et al*., 2011; Havlin *et al*., 2006), therefore this relationship considering their treatment means is understandable.

The decline in total and extractable sulphur in the savanna soils can therefore be attributed to increase farming intensity often without sulphur fertilizer application, poor management practices such as sustained burning of crop residues and low soil organic matter content which need to be addressed so that crops can easily access soil available sulphur for their nutritional requirements. The concentration of sulphate -S in the soil at the end of field experimentation is consistent with the results obtained by Aghimien and Osemwota (2012).

5.27.4.1 Interactive combinations of levels of N, S and CD on soil sulphur content

The results showed that higher combination rates of the amendments were superior to half the rates or in combinations where either S or CD was omitted (Table 4.50). The consistency of the highest application rates of N, S and CD in the interaction showed that the element was initially lacking in the soil, therefore, application of both mineral fertilizers (particularly sulphur) and the amount mineralized from organic manure synergized to increase soil sulphur content, through effective collaboration of N.

5.27.5 Deductions from the field studies

In the three years of field operations, plant height, leaves per plant, stalk girth and leaf area peaked at the highest application levels of N, S and CD. In the combined analysis, the following results were obtained, 77.6 cm, 10.1, 6.9 cm, 410.9 cm^2; 72.6 cm, 9.7, 5.9 cm and 380.7 cm^2; 77.9 cm, 9.7, 6.0 cm and 394.9 cm^2 as against 60.9 cm, 8.4, 5.1 cm and 300.4 cm^2; 65.7 cm, 8.8, 5.3 cm and 331.1 cm^2; 59.9 cm, 8.7, 5.1 cm and 313.6 cm^2 obtained from the control.

The application of N, S and CD in the study at varying rates showed that yield of maize improved significantly compared to the control and the same trend was obtained on stover and cob weight. This combination greatly benefited maize performance in the savanna soil by increasing their availability in the soil and use efficiency.

Sulphur addition facilitated N use efficiency due to their effective relationship in plant nutrition, thus resulting in their dual purpose resource use both in terms of enhancing photosynthetic activity as both elements are the essential components of chlorophyll and in plant nutrition as manifested in increase in grain yield. Cowdung application provided the improved soil physical condition in addition to its positive impact on the chemical properties of the soil leading to improvements in soil organic matter content and a reduction of leaching of N and S in particular and as well as a reduction in P fixation.

In all the parameters measured, N application at 120 kg/ha was superlative both in agronomic parameters, grain yield, stover and cob weight, thus emphasizing the acute nitrogen deficiency in the savanna soil. In the combined analysis, maize grain yield was 1.6 tons/ha, 1.5 tons/ha and 1.2 tons/ha respectively for N at 120 kg/ha; CD at 10 tons/ha and S at 30 kg/ha. The trend was the same for cob weight and stover. The efficacy of fertilizer and manure application on grain yield, stover and cob weight was in the order N > CD >S. In view of this, managing the soil to supply adequate plant nutrients is a basic necessity for sustainable crop production.

5.28.0 CorrelationAnalysis

5.28.1 Greenhouse Studies

The positive contribution of the organic matter amendment along with the combination of mineral fertilizer N and sulphur significantly improved soil fertility such that the productive capacity of the soil was increased and the output in terms of growth and yield parameters did not suffer any physiological damage rather, the intervention was widely successful owing to soil nutrients enrichments, since soil biophysical and chemical properties were enhanced to facilitate soil delivery of nutrients in good quality to the growing crop. The comparatively higher coefficients of correlation particularly among all the growth parameters and stover have revealed the dependence and or functional nature of these parameters on a balanced nutrition. This assertion is premised on the fact that each growth parameter measured closely influenced the performance of the other apart from the influence of climatic conditions and soil properties which have to be optimum. However, it is not out of place to opine that crop variety may have contributed to the efficient performance of the crop in a northern guinea savanna soil but the improvement in soil fertility had a superior effect as shown in the crop performance.

Enhancing a sustainable and a good quality yield of crops in a savanna soil therefore requires an effective soil fertility management particularly where the use of organic resources is prioritised. Nyongesa *et al*. (2010), Makinde *et al*. (2010), Singh *et al*. (2004) and Sanchez *et al*. (1997) had investigated and documented the benefits of integrated soil fertility management in the tropics in terms of improvements in soil resources and increase in crop yield. The exceptionally high correlation coefficients between leaf area and plant height, number of leaves and stalk diameter shows that the photosynthetic process of the plant was active as light energy, water and carbon dioxide were effectively utilized during the vegetative growth phase. This is influenced by the collaboration of nitrogen and sulphur since both nutrients are essentially required in chlorophyll synthesis (Bharathi and Poongothai, 2008; Havlin *et al*., 2006).

However, the low correlation coefficient of soil N concentration suggests that the element was removed from the soil for plant uptake .Therefore; nitrogen availability in the soil for crop use is of paramount importance especially for a cereal crop production in the Nigerian savanna. Also, the correlation between organic carbon with soil pH and soil N content respectively ($r = \pm 0.63^{**}, 0.43^{**}$) indicates that the addition of this substrate was of high value and increased benefit to soil properties because as the soil organic carbon content increased, expectedly, soil pH and soil nitrogen concentration also increased. In view of this, application of organic manure is an essential requirement for soil fertility replenishment in the savanna.

5.28.2 Field Studies

The uniformity in the results obtained indicates that soil nutritional levels were significantly improved on application of various fertilizer and cowdung rates. As growth factors (plant height, number of leaves, leaf area and stalk girth) increased as the fertilizer application rates increased, there was therefore a positive impact on the yield parameters which further demonstrates that the inherently low fertility of the soil at the initial stage had improved markedly. It was observed that improvements in soil fertility and plant nutrition owing to external input of soil nourishing materials generally facilitated the close association among the growth and yield attributes. Therefore, increase in soil productivity became the dominant factor influencing the positive and highly significant correlation between growth and yield parameters much more than the contributions of plant genetic and varietal factors in the three years of study.

However, the impact of soil pH on the growth and yield parameters was minimal judging from their rather low correlation coefficients. The result is largely consistent with the performance in 2010, 2011 and the combined analysis of the three yeas respectively (Tables 4.25, 4.26 and 4.27), apart from soil pH in 2010 which negatively correlated with the other parameters, presumably, due to increase in soil acidity (decrease in soil pH) in 2010. High soil acidity is detrimental to nutrients pool, microbial activity and biomass and ultimately a detriment to plant nutrient uptake. The application of an organic residue in the study stabilised soil resources for effective plant utilization. Therefore, the adapted technology is of great benefit both in terms of soil fertility restoration and improvement in crop yields.

5.29.0 Simulation Studies

Simulated baseline data revealed that NGS soil where the trial was conducted, potentially supplied 29.38, 11.76 and 79.38 kg/ha N, P and K respectively prior to planting. Apart from K, the other two more essential nutrients were much lower than the recommended rates for maize in the savanna (Chude *et al*., 2012). Therefore, input of these plant nutrients stimulated quick plant utilization and a subsequent yield increase. The proportion of K supplied by the soil was higher than that recommended for maize in the savanna. This shows that under a low input farming activity, potassium deficiency may not be a serious yield limiting factor relative to the requirements for N and P. The reason for this comparable high potential supply of K by the savanna soil might be attributed to soil parent material which contains relatively moderate to high K content due to the presence of K-bearing minerals.

However, the frequency with which the soil is put into cultivation, coupled with the risk of nutrients depletion due to crop removal at harvest and leaching losses of K, in addition to luxury consumption, reinforces the need for a supplemental K input in order to enhance use efficiency of the applied N and P fertilizers, and a balanced nutrition, as K is an integral component of the major plant nutrients (Havlin *et al*., 2006),and also maintain soil fertility to a reasonable level to sustain crop production.

The low potential supply of N and P by the soil revealed that these two elements are inherently deficient in the savanna soil thus mitigating their deficiency would require chemical fertilizer application in addition to a sustained organic matter input.

The pivot of QUEFTS is formed on the relationship between nutrients uptake and crop yield (Janssen et el., 1990). Therefore, the amount of P withdrawn by the plant was comparably lower than that of N by about 20%. This occurrence is not surprising considering the problem of P fixation in tropical soils (Nyongesa *et al*., 2010) which accounts for the inefficient use of applied P fertilizers in crop nutrition. The simulated data (Tables 4.56, 4.57 and 4.58) revealed that P deficiency in the soil was the major factor of inefficient plant utilization of applied N and K. The interaction among these major elements in the soil enhanced their use efficiency which is the focal point of the QUEFTS system (Smaling and Janssen, 1993). The amount of N taken up at the end of the field experiment in 2011 was about four times that of P and two times that of K which reflects the overriding importance of N in cereal cultivation in the Nigerian savanna. This also justifies the high rate of N requirements for maize in the savanna.

The QUEFTS model assumes that apart from the limitation of N, P and K in the soil, all other yield limiting factors should be optimum (Janssen *et al*., 1990). The simulated data (Tables 4.56, 4.57 and 4.58), showed that when conditions are optimum and fertilizers are supplied in good time and in their correct nutrient ratios, maize grain yield as high as 12,000 kg/ha could be realized in NGS of Nigeria. This is about 33.33% higher than what Chude *et al*. (2012) suggested. Finding of this present study is that improvement in soil fertility through application of full recommended fertilizer rates (N, P and K) could increase and sustain maize production in the savanna soil of Nigeria, especially when all other yield limiting factors have been addressed.

The model therefore validated results obtained and was found consistent with data generated and tested on maize trials in Kenya using QUEFTS system (Janssen *et al*., 1990). Therefore, the current fertilizer recommendation for maize peaked at 120-60-60 kg/ha N, P_2O_5 and K_2O respectively was adequate for maize in the Northern Guinea savanna if P deficiency is effectively managed to enhance optimal P fertilizer use efficiency. In areas of acute P deficiency, higher rate might be more effective in order to enhance greater nitrogen use efficiency. It can be inferred that optimum proportions of N, P and K in the soil would enhance increased maize yield in the Nigerian savanna; provided all other yield limiting conditions are sufficiently addressed.

CHAPTER SIX

6.0 SUMMARY AND CONCLUSION

6.1 Summary

The study was set up to investigate response of maize to cowdung, nitrogen and sulphur fertilizer application and effect on soil properties in a northern Guinea savanna Alfisol of Nigeria. To achieve these, a laboratory incubation, greenhouse and field studies were conducted at the Institute for Agricultural Research Experimental Station Samaru.

Organic material used for the study was cowdung (CD).It was obtained from the National Animal Production and Research Institute (NAPRI), Shika – Zaria and characterized for its chemical composition. The results obtained showed that organic material contained comparable high organic carbon (OC) and moderately high total nitrogen and phosphorus. The C: N ratio of the compound was low, indicating positive potentials for improving soil fertility and ability to mineralize quickly to release soil nutrients to the plant.

During the first phase, the potentials of CD as a source of plant nutrients were investigated in a laboratory incubation study. The contribution of N and S to carbon mineralization was also evaluated. The treatments consisted of three application rates each for N, S and CD. Results obtained showed that within two weeks (14 days) of incubation, about 94% of applied organic material had decomposed, leading to the evolution of CO_2,but dropped sharply to about 43% in the third week (or 21 days) of incubation. There was a gradual decrease in amount of CO_2 fluxed from week 4 to the end of the incubation in week 6. This suggests that at advanced mineralization stage, further incubation may not yield any significant amount of nutrients. This shows that added organic material has a good quality substrate; having the characteristics of a quick mineralization to contribute nutrients to the soil, especially to synchronize with the period of vigorous vegetative growth phase.

The sharp drop in amount of CO_2 flux in week 3 shows that at this time, about half of the active carbon content in the organic material had mineralized. It suggests that half-life of the organic matter undergoing decomposition was reached within three weeks of incubation. These decay characteristics corresponded more to the second – order than to the first – order rate kinetic models. The decrease in amount of CO_2 flux from weeks 4 – 6 shows that microbial activity had significantly reduced due to lack of carbon in the substrate for microbes to work on. Perhaps, the polymeric groups in the substrate were left behind after the easily mineralized components were mineralized, thus resisting further decomposition. Cowdung application at 10 ton/ha significantly ($P < 0.05$) contributed more CO_2 during decomposition than either N or S; perhaps due to its carbon content. Therefore, its addition to the soil contributed to a higher amount of soil organic carbon content and ultimately to soil organic matter.

In the second phase, a pot experiment was set up to test the effect of complementary application of varying rates of N, S and CD on growth and yield of maize and to monitor in particular, the interaction among these factors on growth parameters under a controlled condition. It was also set up to investigate variation in growth trends between half and full application rates of the fertilizers and CD and as well as their impact on soil chemical properties. Findings showed that growth parameters such as plant height, number of leaves per plant, stalk girth and leaf area responded positively to fertilizer application and organic manure amendment. However, 60 kg/ha N application was slightly better than 120 kg/ha N. Sulphur application at 30 kg/ha was more effective in maize stalk girth and leaf area but statistically at par with half its application rate on plant height and foliage production. Across all the agronomic parameters, 10 tons/ha CD gave comparable difference with 5 tons/ha CD, showing a better agronomic efficiency of the higher rate of added organic matter in plant nutrition in a savanna soil.

Soil chemical properties determined at the end of study revealed that application of either 5 or 10 ton/ha CD significantly improved soil pH, OC, N and S contents. Organic carbon content obtained from 5 tons/ha CD was higher than the corresponding results from either 60 or 120 kg/ha N fertilizer application. Also, contribution of N to the soil was higher with 5 tons/ha CD in relation to 60 kg/ha N application and 10 tons/ha CD contributed more inorganic N to the soil than with 120 kg/ha N fertilizer.

The third phase involved three years of field experiment to investigate maize response to application of CD, N and S fertilizers, in order to determine optimum combination levels of the amendment with those of inorganic fertilizers and evaluate the contribution of each factor to soil fertility. Results showed that plant height, number of leaves per plant, stalk girth and leaf area increased weekly along with increasing levels of N, S and CD. A similar performance was obtained from grain yield and yield components. This shows that the initial low fertility status of the soil significantly ($P < 0.05$) improved due to the application. Also, it revealed resource benefit of the amendments to maize production in the Northern Guinea Savanna (NGS) Alfisols of Nigeria. Agronomic parameters, grain yield and yield derivatives did not only appreciate due to the application of varying rates of N, S and CD, but were significantly ($P < 0.01$) increased from 2009 to 2011. This indicated that there was an improvement in soil fertility along the duration of field experiment. This might be attributed to the positive residual effects of the organic manure amendment and the previous application of N, P, K and S fertilizers.

However, 120 kg/ha fertilizer N application showed a tendency to acidify the soil in relation to S fertilization. Development of soil acidity was lower in S fertilizer rates than in N rates. This might be attributed to the presence of calcium in gypsum (sulphur fertilizer source), which may have controlled incidence of soil acidity from sulphatic fertilizer source.

Organic carbon content, soil nitrogen and sulphur increased as their application levels increased and along with the years of study.

Fourth phase of the study dwelt on use of a simulation model to simulate maize yield against the application of full recommended rates of N, P and K fertilizers in a savanna soil of Nigeria. Objective of the study was to evaluate maize response to fertilizer application in a NGS Alfisols of Nigeria using yield data obtained from unfertilized plots as a basis for comparison. Such studies influence site – specific fertilizer recommendations for various arable crops and help to assess the productive potentials of different soils and the appropriate intervention method(s).

To achieve this, the system for Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) was used based on initial soil chemical properties. Results showed that maize grain yield increased significantly ($P < 0.01$) when full recommended rates of N, P and K fertilizers were supplied; especially when incidence of pest and diseases, weed infestation and adverse management practices were minimized. Grain yield was however poor when these fertilizers were omitted. Acute low soil fertility was therefore a major yield limiting factor for sustainable maize crop production in the Nigerian savanna.

The simulation study further revealed that maize grain yield as high as 12,000 kg/ha could be obtainable in a savanna soil when full recommended rates of the major nutrients N, P and K are applied, but simulated grain yield from the control plot varied between 1,500 – 2,000 kg/ha. The result also showed that in locations where soil N and P are low, a recommendation higher than 120 kg N/ha may give relatively higher yields, especially when P deficiency is addressed. Potassium deficiency in the soil according to the simulation output was not of any serious yield limiting constraint. Rather, its external application is expected to sustain soil fertility in terms of K availability and promote efficient crop use of applied N and P fertilizers.

The study revealed that effective management of organic manure where it is ground and incorporated for 2-4 weeks in the soil prior to planting was of greater benefit to the soil in terms of nutrient release characteristics due to increase in soil and organic manure contact, increase in soil moisture content and adequate aeration to initiate quick mineralization than where the organic matter is left on the soil surface which may become desiccated due to rising temperature conditions thereby contributing low amount of nutrients to the soil. The study also revealed that organic matter application maintained soil pH within plant tolerable limits throughout the period of observation despite negative effects of N and S fertilizer application on soil properties as all growth and yield parameters peaked at 120 and 30 kg/ha N and S respectively; especially in field studies, indicating that organic matter possessed a good content of liming elements required for mitigating high soil acidity arising from the application of these elements. Therefore, this amendment is an effective strategy in sustaining soil resources and contributing to efficient use of the applied fertilizers.

Sustainable input of organic matter of a high substrate quality can mitigate negative occurrence on soil properties. For this study, application of N, S and cowdung had a collective benefit and a positive contribution to growth and yield of maize in a northern Guinea savanna soil in terms of improvements in soil physical properties by the organic matter, increasing availability of plant nutrients, efficient utilization of N, P and K by the crop due to sulphur additions, as well as increasing the uptake of nutrients by the crop.

6.2 Conclusion

1. Nitrogen at 120 kg/ha and S at 30 kg/ha were nutritionally optimum for maize production in the Northern Guinea savanna. The study has shown that sulphur was initially deficient in the soil and that its application as gypsum alleviated its deficiency and significantly increased maize yield.

2. Mineral sulphur fertilizer application did not positively affect organic manure mineralization as the least effect was obtained from sulphur rates compared to the positive effects of N and CD application.
3. Cowdung application at 10 ton/ha was more effective than 5 ton/ha considering the low organic matter content of the savanna soil, though the potentials of CD at 10 ton/ha may be inadequate in the absence of mineral N and S feretilizers.
4. The application of organic manure increased and stabilized soil pH thereby increasing plant uptake of applied nutrients. Also, soil organic carbon content significantly increased beyond the threshold which underscores the high residual value of organic manure amendments of both soil and succeeding crops. Its continuous application is therefore advocated.
5. There was a linear increase (regression) in grain yield up to 2,500 kg/ha in 2010 with rates of N fertilizer application. Therefore, nitrogen is a major yield limiting nutrient in the soil of Northrn Guinea savanna.
6. The interaction of N, S and CD at their full application rates had a mean grain yield of 2,207.19 kg/ha which was significantly ($P < 0.01$) higher than with half rates (1,323.34 kg/ha) of the amendments and control (251.85 kg/ha). For improvement in soil fertility and sustainable increase in maize production in the soil, this combination is required.
7. The QUEFT model revealed that low soil fertility was a major constraint to sustainable maize production in the Northern Guinea savanna soil. Therefore, a balanced nutrition through application of N, P, K, S and CD is a necessity.
8. Continuous mineral N fertilizer application over a long period would not lead to significant increase in grain yield.

6.3 Recommendations

1. There is the need to empirically quantify maize sulphur fertilizer requirements in the savanna and the fertilizer material supplying sulphur in relation to content of sulphur in Single Supper Phosphate.
2. Regressional analysis showed that increase in grain yield was linear up to 10 ton/ha CD, therefore, input of easily mineralizable organic manure is important to increase soil fertility.
3. The potentials of mineral sulphur fertilizer on crop productivity need to be evaluated independently in the savanna soil but not in association with other possible sulphur carriers such as SSP fertilizer and organic manure.

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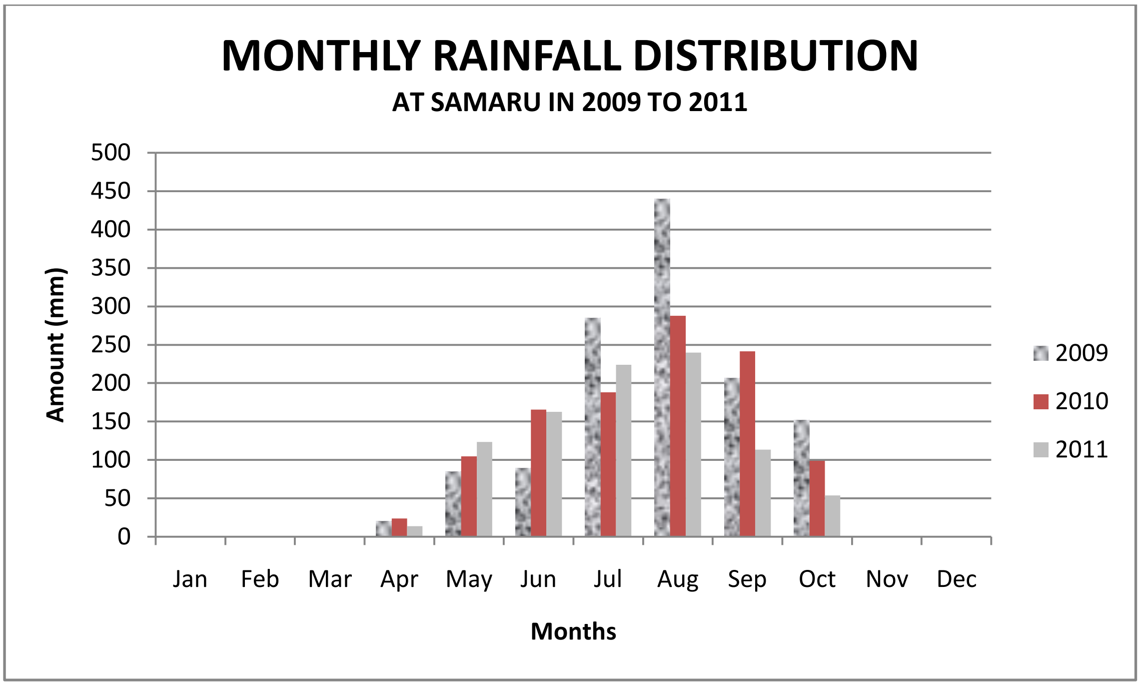
APPENDICES

Appendix i: Mean rainfall distribution during the period of experimentation at Samaru



Source: IAR Meteorological Unit, ABU, Zaria

Appendix ii: Analysis of variance (ANOVA) showing the amount of CO_2 fluxed during six weeks of incubation studies

Variable (CO_2)	Source	Degree of freedom	Sum of squares	Mean squares	F - value	Pr > F
	Replicate	2	0.001	0.001	1.52	0.229
	N	2	0.026	0.013	20.13	<0.001
Wk 1	S	2	0.000	0.002	0.02	0.981
	CD	2	0.061	0.030	46.86	<0.001
	Error	26	0.017	0.001		
	TOTAL	**34**	**0.105**			
	Replicate	2	0.001	0.001	0.42	0.523
	N	2	0.122	0.061	38.09	<0.001
Wk 2	S	2	0.065	0.032	20.24	<0.001
	CD	2	0.242	0.121	75.68	<0.001
	Error	26	0.242	0.002		
	TOTAL	**34**	**0.472**			
	Replicate	2	0.052	0.052	30.11	<0.001
	N	2	0.039	0.019	11.61	<0.001
Wk 3	S	2	0.003	0.001	0.75	0.484
	CD	2	0.025	0.013	7.31	0.003
	Error	26	0.045	0.002		
	TOTAL	**34**	**0.164**			
	Replicate	2	0.002	0.002	2.75	0.109
	N	2	0.009	0.005	6.45	0.005
WK 4	S	2	0.001	0.001	0.72	0.498
	CD	2	0.017	0.008	11.28	0.001
	Error	26	0.019	0.001		
	TOTAL	**34**	**0.048**			
	Replicate	2	0.001	0.001	1.45	0.239
	N	2	0.020	0.010	21.95	<0.001
Wk 5	S	2	0.002	0.001	2.1	0.143
	CD	2	0.007	0.003	7.26	0.003
	Error	26	0.012	0.001		
	TOTAL	**34**	**0.042**			
	Replicate	2	0.000	0.000	0.45	0.509
	N	2	0.006	0.003	7.07	0.004
Wk 6	S	2	0.001	0.001	1.1	0.349
	CD	2	0.005	0.003	6.53	0.005
	Error	26	0.011	0.001		
	TOTAL	**34**	**0.023**			

Appendix iii: Analysis of variance for growth parameters under greenhouse studies -

plant height

Variable	Source	Degree of freedom	Sum of squares	Mean squares	F - Value	Pr > F
	Replicate	2				
Plant height	N	2	6.378	3.189	1.66	0.199
Wk 2	S	2	0.012	0.006	0.00	0.997
	CD	2	24.714	12.357	6.45	0.003
	Error	54	103.440	1.916		
	TOTAL	**62**	**134.544**			
Plant height	Replicate	2				
Wk 3	N	2	5.192	2.596	0.57	0.571
	S	2	0.919	0.459	0.10	0.905
	CD	2	136.753	68.377	14.93	< 0.001
	Error	54	247.34	4.581		
	TOTAL	**62**	**390.204**			
Plant height	Replicate	2				
Wk 4	N	2	13.032	6.516	0.65	0.525
	S	2	1.694	0.847	0.08	0.919
	CD	2	301.087	150.543	15.08	< 0.001
	Error	54	539.213	9.985		
	TOTAL	**62**	**945.026**			
Plant height	Replicate	2				
Wk 5	N	2	25.249	12.625	0.96	0.388
	S	2	1.571	0.786	0.96	0.942
	CD	2	1095.765	547.882	41.78	<0.001
	Error	54	708.153	13.114		
	TOTAL	**62**	**1830.738**			
Plant height	Replicate	2				
Wk 6	N	2	9.227	4.614	0.19	0.824
	S	2	38.872	19.436	0.82	0.446
	CD	2	1267.161	633.58	26.72	< 0.001
	Error	54	1280.573	23.714		
	TOTAL	**62**	**2595.833**			
Plant height	Replicate	2				
Wk 7	N	2	18.733	9.366	0.15	0.857
	S	2	15.948	7.974	0.13	0.877
	CD	2	2006.892	1003.446	16.59	< 0.001
	Error	54	3265.433	60.471		
	TOTAL	**62**	**5307.006**			

Plant height	Replicate	2				
Wk 2-7 combined	N	2	57.826	28.913	1.52	0.219
	S	2	12.183	6.092	0.32	0.726
	CD	2	3593.701	1796.851	94.75	< 0.001
	Error	324	6144.153	18.963		
	TOTAL	**332**				

Appendix iv: Analysis of variance for growth parameters under greenhouse studies – number of Leaves

Variable	Source	Degree of freedom	Sum of squares	Mean squares	F - Value	Pr > F
No. of Leaves	Replicate	2				
Week 2	N	2	0.914	0.457	0.88	0.42
	S	2	0.099	0.049	0.10	0.909
	CD	2	3.877	1.938	3.74	0.03
	Error	54	28.000	0.519		
	Total	**62**	**32.89**			
No. of Leaves	Replicate	2				
Week 3	N	2	0.963	0.482	0.45	0.641
	S	2	0.296	0.148	0.14	0.872
	CD	2	12.667	6.333	5.90	0.005
	Error	54	58.000	1.074		
	Total	**62**	**71.926**			
No. of Leaves	Replicate	2				
Week 4	N	2	8.173	4.086	4.30	0.019
	S	2	2.469	1.235	1.30	0.281
	CD	2	19.432	9.716	10.22	0.002
	Error	54	51.333	0.951		
	Total	**62**	**81.407**			
No. of Leaves	Replicate	2				
Week 5	N	2	5.407	2.704	2.41	0.099
	S	2	0.667	0.333	0.30	0.745
	CD	2	68.963	34.482	30.69	< 0.001
	Error	54	60.667	1.124		
	Total	62	135.704			
No. of Leaves	Replicate	2				
Week 6	N	2	3.062	1.531	1.32	0.276
	S	2	1.803	0.901	0.78	0.465
	CD	2	90.543	45.272	39.01	< 0.001
	Error	54	62.667	1.161		
	Total	**62**	**158.075**			
No. of Leaves	Replicate	2				
Week 7	N	2	9.852	4.926	1.42	0.25
	S	2	3.185	1.593	1.51	0.231
	CD	2	112.296	56.148	47.48	< 0.001
	Error	54	64.000	1.185		
	Total	**62**	**189.333**			

No. of Leaves	Replicate	2				
Week 2-7 combined	N	2	15.535	7.768	7.75	0.005
	S	2	3.831	1.916	1.91	0.149
	CD	2	242.177	121.088	120.84	< 0.001
	Error	324	324.667	1.002		
	Total	332	586.210			

Appendix v: Analysis of variance for growth parameters under greenhouse studies – stalk girth

Variable	Source	Degree of freedom	Sum of squares	Mean squares	F - Value	Pr > F
Stalk girth	Replicate	2				
Week 2	N	2	0.074	0.037	0.27	0.762
	S	2	0.125	0.063	0.46	0.634
	CD	2	3.292	1.646	12.09	< 0.001
	Error	54	7.353	0.136		
	Total	62	10.844			
Stalk girth	Replicate	2				
Week 3	N	2	0.094	0.047	0.10	0.908
	S	2	0.992	0.496	1.02	0.368
	CD	2	14.143	7.072	14.52	< 0.001
	Error	54	26.293	0.487		
	Total	62	41.522			
Stalk girth	Replicate	2				
Week 4	N	2	1.807	0.903	2.41	0.09
	S	2	0.759	0.379	1.01	0.371
	CD	2	31.334	15.667	41.79	< 0.001
	Error	54	20.247	0.375		
	Total	**62**	**54.147**			
Stalk girth	Replicate	2				
Week 5	N	2	1.861	0.931	1.52	0.228
	S	2	1.032	0.516	0.84	0.436
	CD	2	99.26	49.63	81.13	< 0.001
	Error	54	33.033	0.612		
	Total	**62**	**133.325**			
	Replicate	2				
	N	2	1.998	0.999	1.59	0.214
Stalk girth	S	2	1.257	0.628	1.00	0.375
Week 6	CD	2	79.383	39.691	63.14	< 0.001
	Error	54	33.947	0.629		
	Total	**62**	**116.585**			
	Replicate	2				
	N	2	2.174	1.087	1.42	0.25
Stalk girth	S	2	2.304	1.152	1.51	0.231
Week 7	CD	2	72.559	36.279	47.48	< 0.001
	Error	54	41.260	0.764		
	Total	**62**	**118.297**			

Stalk girth	Replicate	2				
Week 2-7 combined	N	2	5.914	2.957	5.91	0.003
	S	2	4.803	2.402	4.80	0.009
	CD	2	247.373	123.687	247.17	< 0.001
	Error	324	162.133	0.500		
	Total	**332**	**420.223**			

Appendix vi: Analysis of variance for growth parameters under greenhouse studies – leaf area

Variable	Source	Degree of freedom	Sum of squares	Mean squares	F - Value	Pr > F	LS
Leaf area	Replicate	2					
Week 2	N	2	118.75	59.38	0.28	0.759	ns
	S	2	19.29	9.64	0.05	0.956	ns
	CD	2	1,919.54	959.77	4.49	0.016	*
	Error	54	11,551.60	213.92			
	Total	62	13,609.18				
Leaf area	Replicate	2					
Week 3	N	2	851.34	425.67	0.61	0.549	ns
	S	2	373.62	186.81	0.27	0.767	ns
	CD	2	23,698.06	11,849.03	16.91	< 0.001	**
	Error	54	37,845.83	700.85			
	Total	62	62,768.86				
Leaf area	Replicate	2					
Week 4	N	2	3,227.17	1,613.58	1.04	0.362	ns
	S	2	2,817.58	1,408.79	0.91	0.411	ns
	CD	2	68,651.85	34,325.93	22.05	< 0.001	**
	Error	54	84,051.77	1,556.51			
	Total	62	158,748.36				
Leaf area	Replicate	2					
Week 5	N	2	12,316.41	6,158.20	4.25	0.019	*
	S	2	10,489.03	5,244.52	3.62	0.033	*
	CD	2	111,882.69	55,941.35	38.63	< 0.001	**
	Error	54	78,193.33	1,448.03			
	Total	62	212,881.46				
Leaf area	Replicate	2					
Week 6	N	2	5,085.36	2,542.68	1.44	0.246	ns
	S	2	17,645.78	8,822.89	4.99	0.01	*
	CD	2	167,744.14	83,872.07	47.48	< 0.001	**
	Error	54	95,397.51	1,766.62	47.48		
	Total	62	285,872.80				
Leaf area	Replicate	2					
Week 7	N	2	14,352.26	7,176.13	2.93	0.062	ns
	S	2	9,995.27	4,997.63	2.04	0.139	ns
	CD	2	85,993.09	42,996.54	17.57	< 0.001	**
	Error	54	132,160.10	2,447.41			
	Total	62	242,500.71				

Leaf area Week 2- 7 combined	Replicate	2					
	N	2	17,302.34	8,651.17			
	S	2	25,910.06	12,955.03	6.38	0.002	**
	CD	2	369,642.53	184,821.27	9.56	< 0.001	**
	Error	324	439,200.20	1,355.56	136.34	< 0.001	**
	Total	332	**852,055.14**				

*NS = Not Significant, * = Significant at P = 0.05, ** = Significant at P = 0.01,*
LS = Level of Significance

Appendix vii: Analysis of variance for growth parameters during field studies (2009)

		GROWTH PARAMETERS AT 10 WAP				
Variable	Source	Degree of freedom	Sum of squares	Mean squares	F-values	Pr> f
Plant Height	Replicate	2	5.708	2.854	0.42	0.661 ^{NS}
	N	2	6297.231	3148.616	461.08	<0.001**
	S	2	2322.585	1161.292	170.06	<0.001**
	CD	2	4899.523	2449.762	358.74	<0.001**
	Error	52	355.098	6.829		
	TOTAL	60	13880.145			
Number of Leaves	Replicate	2	2.199	1.099	4.35	0.018*
	N	2	112.863	56.432	223.37	<0.001**
	S	2	47.644	23.822	94.29	<0.001**
	CD	2	28.055	14.028	55.53	<0.001**
	Error	52	13.137	0.256		
	TOTAL	60	203.898			
Stem Girth	Replicate	2	0.336	0.168	2.42	0.098 ^{NS}
	N	2	33.923	16.962	245.15	<0.001**
	S	2	17.482	8.741	126.34	<0.001**
	CD	2	17.603	8.802	127.21	<0.001**
	Error	52	3.598	0.069		
	TOTAL	60	72.942			
Leaf Area	Replicate	2	9551.34	4775.668	3.77	0.029*
	N	2	958525.747	479262.874	378.28	<0.001**
	S	2	269356.599	134678.299	106.3	<0.001**
	CD	2	212250.416	106125.208	83.76	<0.001**
	Error	52	65881.84			
	TOTAL	60	1515565.486			

Appendix viii: Analysis of variance for growth parameters during field studies (2010)

		GROWTH PARAMETERS AT 10 WAP				
Variable	Source	Degree of freedom	Sum of squares	Mean squares	F-values	Pr> f
Plant height	Replicate	2	41.698	20.849	0.08	0.926 ^{NS}
	N	2	69232.575	34616.288	128.01	<0.001
	S	2	14346.187	7173.094	26.53	<0.001
	CD	2	59438.957	29719.479	109.9	<0.001
	Error	52	10461.889	270.421		
	TOTAL	60	157121.306			
Number of Leaves	Replicate	2	6.578	3.289	7.4	0.002
	N	2	36.516	18.258	41.06	<0.001
	S	2	16.469	8.235	18.52	<0.001
	CD	2	22.428	11.214	25.22	<0.001
	Error	52	23.122	0.445		
	TOTAL	60	105.113			
Stem Girth	Replicate	2	4.327	2.164	20.53	<0.001**
	N	2	51.285	25.642	243.33	<0.001**
	S	2	40.119	20.059	190.36	<0.001**
	CD	2	52.397	26.199	248.61	<0.001**
	Error	52	5.479	0.105		
	TOTAL	60	153.607			
Leaf Area	Replicate	2	22237.605	11118.803	1.67	0.978 ^{NS}
	N	2	615259.872	307629.936	46.28	<0.001**
	S	2	68989.125	34494.563	5.19	<0.009*
	CD	2	479490.509	239745.258	36.07	<0.001**
	Error	52	345633.255	6646.793		
	TOTAL	60	1531610.366			

Appendix ix: Analysis of variance for growth parameters during field studies (2011)

		GROWTH PARAMETERS AT 10 WAP				
Variable	Source	Degree of freedom	Sum of squares	Mean squares	F-values	Prg f
Plant Height	Replicate	2	96.635	48.318	0.19	0.827 NS
	N	2	1452.22	726.11	2.87	0.065 NS
	S	2	886.134	443.067	1.75	0.183 NS
	CD	2	9707.142	4853.571	19.22	<0.001**
	Error	52	13134.112	252.579		
	TOTAL	60	25276.243			
Number of Leaves	Replicate	2	1.189	0.595	0.50	0.609 NS
	N	2	1.607	0.804	0.67	0.514 NS
	S	2	0.905	0.452	0.38	0.689 NS
	CD	2	10.348	5.174	4.35	0.018 *
	Error	52	61.904			
	TOTAL	60	75.953			
Stem Girth	Replicate	2	0.109	0.054	0.09	0.913 NS
	N	2	2.647	1.323	2.21	0.119NS
	S	2	0.802	0.401	0.67	0.516 NS
	CD	2	3.132	1.566	2.62	0.083 NS
	Error	52	31.111			
	TOTAL	60	37.801			
Leaf Area	Replicate	2	18365.357	9182.678	0.57	0.569 NS
	N	2	58681.261	29340.742	1.8	0.172 NS
	S	2	50977.483	79548.395	1.58	0.216 NS
	CD	2	159096.789	16125.303	4.93	0.011*
	Error	52	838515.736			
	TOTAL	60	1125636.626			

Appendix x: Analysis of variance (ANOVA) for soil chemical properties obtained during green house studies

Variable	Source	Degree of freedom	Sum of squares	Mean squares	F - Value	Pr > F	LS
Soil pH	Replicate	2					
(H2O)	N	2	0.941	0.471	1.96	0.15	ns
	S	2	0.191	0.096	0.4	0.67	ns
	CD	2	20.137	10.068	42.04	< 0.001	**
	Error	54	12.933	0.239			
	Total	**62**	**34.202**				
Organic	Replicate	2					
carbon	N	2	0.001	0	0.01	0.99	ns
(OC)	S	2	0.114	0.057	1.49	0.24	ns
	CD	2	4.877	2.439	63.96	< 0.001	**
	Error	54	2.059	0.038			
	Total	**62**	**7.051**				
Nitrogen	Replicate	2					
conc.	N	2	0.034	0.017	10.2	0.0002	**
	S	2	0.024	0.012	7.14	0.0018	**
	CD	2	0.071	0.035	21.24	< 0.001	**
	Error	54	0.089	0.002			
	Total	**62**	**0.218**				
Sulphur	Replicate	2					
conc.	N	2	143.409	71.705	12.23	0.0001	**
	S	2	190.788	95.394	16.27	0.0001	**
	CD	2	348.402	174.201	29.71	0.0001	**
	Error	54	316.591	5.863			
	Total	**62**	**999.19**				

*NS = Not Significant, * = Significant at P = 0.05, ** = Significant at P = 0.01, LS = Level of Significance*

Appendix xi: Analysis of variance (ANOVA) for grain yield and yield components 2009

Variable	Source	Degree of freedom	Sum of squares	Mean squares	F - Value	Pr > F	LS
Grain yield	Replicate	2	394,777.69	197,388.80	1.82	0.173	ns
	N	2	5,367,423.20	2,683,711.60	24.72	< 0.001	**
	S	2	323,795.83	161,897.90	1.49	0.235	ns
	CD	2	4,455,822.30	2,227,911.00	20.53	< 0.001	**
	Error	52	5,644,329.00	108,544.79			
	Total	60	16,186,148.02				
Cob yield	Replicate	2	1,423,542.22	711,771.10	5.6	0.006	**
	N	2	5,899,461.10	2,949,730.60	23.22	< 0.001	**
	S	2	433,621.60	216,810.80	1.71	0.192	ns
	CD	2	5,346,098.60	2,673,049.30	21.04	< 0.001	**
	Error	52	6,605,635.70	127,031.46			
	Total	60	19,708,359.22				
Stover	Replicate	2	3,278,044.80	1,639,022.00	7.76	0.001	**
	N	2	4,388,734.90	2,194,367.50	10.38	0.001	**
	S	2	1,495,625.70	747,812.80	3.54	0.036	*
	CD	2	8,089,339.80	4,044,669.90	19.14	< 0.001	**
	Error	52	10,988,453.00	211,316.40			
	Total	60	28,240,198.20				

*NS = Not Significant, * = Significant at P = 0.05, ** = Significant at P = 0.01,*
LS = Level of Significance

Appendix xii: Analysis of variance (ANOVA) for grain yield and yield components 2010

Variable	Source	Degree of freedom	Sum of squares	Mean squares	F - Value	Pr > F	LS
Grain yield	Replicate	2	850,945.07	425,472.50	3.98	0.025	*
	N	2	18,204,099.00	9,102,049.90	85.05	< 0.001	**
	S	2	1,436,937.40	718,468.70	6.71	0.001	**
	CD	2	11,015,559.00	5,507,779.80	51.46	< 0.001	**
	Error	52	5,565,135.70	107,021.80			
	Total	60	37,072,676.17				
Cob yield	Replicate	2	550,401.40	275,200.70	2.06	0.138	ns
	N	2	22,664,672.30	11,332,336.00	84.69	< 0.001	**
	S	2	1,396,496.30	698,248.20	5.22	0.008	**
	CD	2	15,258,931.00	7,629,465.90	57.02	< 0.001	**
	Error	52	6,958,195.30	133,811.50			
	Total	60	46,828,696.30				
Stover	Replicate	2	331,539.00	165,769.50	1.48	0.237	ns
	N	2	13,636,103.00	6,818,051.60	60.97	< 0.001	**
	S	2	2,610,737.90	1,305,368.90	11.67	< 0.001	**
	CD	2	10,933,258.00	5,466,629.00	48.89	< 0.001	**
	Error	52	5,814,722.80	111,821.60			
	Total	60	33,326,360.70				

*NS = Not Significant, * = Significant at P = 0.05, ** = Significant at P = 0.01, LS = Level of Significance*

Appendix xiii: Analysis of variance (ANOVA) for grain yield and yield components 2011

Variable	Source	Degree of freedom	Sum of squares	Mean squares	F - Value	Pr > F	LS
Grain yield	Replicate	2	1,446,298.80	723,149.40	2.73	0.075	ns
	N	2	19,084,810.00	9,542,405.10	36	< 0.001	**
	S	2	239,931.90	119,965.90	0.45	0.639	ns
	CD	2	5,860,106.70	2,930,053.40	11.05	< 0.001	**
	Error	52	13,784,130.10	265,079.40			
	Total	60	40,415,277.50				
Cob yield	Replicate	2	3,131,870.00	1,565,935.00	3.37	0.042	*
	N	2	30,833,187.00	15,416,593.00	33.16	< 0.001	**
	S	2	185,840.80	92,920.40	0.2	0.819	ns
	CD	2	8,012,305.60	4,006,152.80	8.62	0.001	**
	Error	52	24,175,617.00	464,915.70			
	Total	60	66,338,820.40				
Stover	Replicate	2	458,937.00	229,468.50	0.91	0.408	ns
	N	2	21,574,917.90	10,787,458.90	42.91	< 0.001	**
	S	2	68,507.57	34,253.78	0.14	0.873	ns
	CD	2	7,412,002.00	3,706,001.40	14.74	< 0.001	**
	Error	52	13,072,765.00	251,399.33			
	Total	60	42,587,129.47				

*NS = Not Significant, * = Significant at P = 0.05, ** = Significant at P = 0.01, LS = Level of Significance*

Appendix xiv: Analysis of variance (ANOVA) for grain yield and yield components 2009 - 2011 combined

Variable	Source	Degree of freedom	Sum of squares	Mean squares	F - Value	Pr > F	LS
Grain yield	Replicate	2	2,230,852.00	1,115,426.00	7.01	0.001	**
	N	2	38,096,689.00	19,048,344.00	119.73	< 0.001	**
	S	2	1,501,062.00	750,531.45	4.72	0.0102	*
	CD	2	20,215,544.00	10,107,772.00	63.53	< 0.001	**
	Error	160	25,454,764.00	159,092.30			
	Total	168	87,498,911.00				
Cob yield	Replicate	2	3,809,425.00	1,904,712.80	7.81	0.001	**
	N	2	51,939,592.00	25,969,796.00	106.44	< 0.001	**
	S	2	1,561,284.80	780,642.40	3.2	0.043	*
	CD	2	26,681,499.00	13,340,749.00	54.68	< 0.001	**
	Error	160	39,035,836.00	243,974.00			
	Total	168	123,027,636.80				
Stover	Replicate	2	2,732,450.00	1,366,225.00	7	0.001	**
	N	2	34,569,531.00	17,284,765.40	88.61	< 0.001	**
	S	2	2,990,912.00	1,495,455.80	7.67	0.001	**
	CD	2	26,176,985.00	13,088,492.30	67.09	< 0.001	**
	Error	160	31,212,012.00	195,075.10			
	Total	168	97,681,890.00				

*NS = Not Significant, * = Significant at P = 0.05, ** = Significant at P = 0.01,*
LS = Level of Significance