SORGHUM GRAIN YIELD AND NUTRIENT DYNAMICS UNDER VARYING RATES OF FERTILIZER APPLICATION IN THE SUB-SUDANIAN ZONE OF BURKINA FASO

BY

DIEUDONNÉ OUATTARA

BSc Biology (Ouagadougou)
BTS Agriculture (Matourkou)

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DIEUDONNÉ OUATTARA

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BTS Agriculture (Matourkou)

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DECLARATION

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

Dieudonné OUATTARA ……………………… ……….......................

(Student) 20360733 Signature Date

Certified by:

Dr. Vincent Logah …………………….. ……….....................

(Principal Supervisor) Signature Date

Dr. Andrews Opoku …………………….. ……….....................

(Co-supervisor) Signature Date

Dr. Korodjouma OUATTARA ……………….. ……….....................

(Co-supervisor) Signature Date

Certified by:

Dr. Enoch A. Osekre ………………….. ……….......................

(Head of Department) Signature Date

DEDICATION

This work is dedicated to my parents Sankouo and Marie-louise, to my wife Aline and my daughter Sabine for their never ending love.

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ABSTRACT

Soil fertility depletion is known as the most important limitation to food security in Burkina Faso. Low yield of sorghum is constrained by inadequate supply of fertilizers and there is the need to establish optimum rates for sustainable use by farmers. This study is a short-term experiment conducted during the 2014 cropping season on a Luvisol in the sub-sudanian zone of Burkina Faso and was laid in a splitplot, arranged in a randomized complete block design with three replications. Cattle manure (CM) at two rates (0 t ha^{-1} and 5 t ha^{-1}) constituted the main plot whilst mineral fertilizer (kg ha^{-1}) at eleven rates (0N-0P-0K, 40N-0P-0K, 60N-0P-0K, 40N15P-0K, 60N-15P-0K, 60N-7.5P-0K, 60N-22.5P-0K, 60N-15P-10K, 60N-15P-20K, 60N-15P-30K and 90N-15P-20K-15S-2.5Zn-10Mg-0.5B) constituted the sub-plots. Analysis of variance showed that sorghum grain N, P and K uptake were

significantly ($P < 0.05$) influenced by the application of mineral fertilizer and cattle manure while their interaction did not significantly affect ($P > 0.05$) these parameters. Sorghum straw N, P and K uptake were significantly influenced ($P < 0.05$) by cattle manure and mineral fertilizer rates applied as well as their interaction except the effect of manure on straw K uptake. Soil nutrient contents during plant growth decreased due to the larger quantities of nutrients exported by plant uptake. The highest grain yield response was observed under sole application of 60 kg N ha^{-1} and 22.5 kg P ha^{-1}. However, the yield obtained under these treatments was not significantly different from the grain yield observed under the applications of 40 kg N ha^{-1} and 15 kg P ha^{-1}. Since lower N and P rates gave similar grain yield as the reference plot (90N-15P-20K-15S-2.5Zn-10Mg-0.5B), sole application of 60 kg N ha^{-1} and 22.5 kg P ha^{-1} can be considered as appropriate rate for optimum grain yield production. The interaction effect of cattle manure and mineral fertilizer did not significantly ($P > 0.05$) increase

sorghum grain yield. The highest grain yield obtained in this case, was with the interaction between 5 t of cattle manure ha^{-1}, 60 kg N ha^{-1} and 7.5 kg P ha^{-1} mineral fertilizer rates applied. No significant difference ($P > 0.05$) in sorghum grain yield was obtained above this fertilizer rate which can undoubtedly be suggested as the optimum rate. The Value Cost Ratio (VCR) of 2.01 and 2.23 obtained respectively under 60N-22.5P-0K and the interaction of cattle manure with 60N-7.5P-0K at the beginning of the wet season slightly exceeded the critical value of 2 required to motivate farmers to apply mineral fertilizer. Thus, fertilizer requirement for sustainable sorghum grain production at the study area in Burkina Faso is 5 t ha^{-1} of cattle manure combined with 60 kg N ha^{-1} and 7.5 kg P ha^{-1}.

CHAPTER ONE

1.0 INTRODUCTION

In the tropics particularly in dry land areas, the decline in soil productivity continues to be a major concern to scientists and policy makers due to its direct implication for food security. According to Smaling (1995), there is a virtual equilibrium for soils under natural vegetation, but as soon as the natural forest or savanna are cleared and so the land altered, this equilibrium is broken and soil fertility declines at a rate depending on the intensity of cropping and replacement of nutrient loss in the systems.

In Burkina Faso, the decline in soil productivity is mainly as a result of an increase in human population and a decrease of fallow periods which exacerbate soil nutrient depletion (Bationo *et al.*, 2008). From 2002 to 2004, Burkina Faso recorded nutrient depletion of 43 kg ha^{-1} (Henao and Baanante, 2006).

Fertilizer is part of the technological trinity (improved seed, irrigation and fertilizer) responsible for bringing about the green revolution of Latin America and Asia. Its adequate and efficient use should, therefore, be a major ingredient in achieving food security in sub-Saharan Africa (SSA). At present, average fertilizer use rate in SSA is the lowest in the world and the region needs to take affirmative action to improve the situation (Henao and Baanante, 2006). The average fertilizer use rate in SSA is around 10 kg ha^{-1} whereas it has reached 222 kg ha^{-1} in Asia, 160 kg ha^{-1} in Oceania and 138 kg ha^{-1} in South America (Hernandez and Torero, 2011). The reasons for the dismal fertilizer use intensity in SSA are many and varied, and could be analysed with respect to response rate (effectiveness), profitability (efficiency) and sustainability of fertilizer use (Dittoh *et al.*, 2012).

Most fertilizer recommendations are based on fertilizer tests conducted during the 1970s. Most soils in SSA are characterized by imbalances in nutrients stocks due to continuous cultivation, changes in cropping systems and soil profiles, creating a decrease in the efficiency of fertilizers applied. This situation, combined with adulterated products, has made farmers sceptical about the fertilizers that are recommended and sold in the market (Bumb *et al.*, 2011). The authors therefore indicated that additional research, soil testing and fertilizer trials were needed to develop sound crop and area-specific recommendations. In Burkina Faso, the last update of fertilizers recommendation was done in 1992 and was based on agroecological zones and plant requirements by Institut de l'Environement et de Recherches Agricoles (INERA) under a project called "Projet Engrais Vivriers" (Hien *et al.*, 1992). In addition, there is a negative nutrient balance indicating that farmers mine their soils and therefore pose a major constraint to sustainable crop production (Bationo *et al.*, 2008).

Dittoh *et al.* (2012) reported that fertilizer's full agronomic potential is often unrealized because of poor soil fertility caused by mismanagement of fertilizer at the farm level, failure of extension service to inform farmers about appropriate technology, poor availability of fertilizer and lack of complementary inputs. The use of organic inputs such as crop residues, manure and compost improved the physical, chemical and microbiological properties of the soil as well as nutrient supply and therefore has great potential for improving soil productivity and crop yield (Satyanarayana *et al.*, 2002). Consequently, practices which maintain or increase soil organic matter reserves must be adopted to achieve a sustained productive agriculture
(Ouattara, 2007; Melenya *et al.*, 2015).

It is in this context that this study was conducted to establish optimum rates for sustainable use of fertilizers by farmers in sorghum production within the framework of integrated soil fertility management (ISFM) practices.

Working on the hypothesis that significant differences will be observed between the effects of cattle manure, mineral fertilizer and their interaction on soil nutrients content and crop uptakes, the objectives of the study were to:

i. evaluate N, P, K uptake under varying rates of mineral and organic fertilizer applications; ii. determine the impact of varying fertilizer rates on soil nutrient dynamics; iii. evaluate the impact of varying rates of cattle manure and mineral fertilizer on the yield of sorghum and determine the appropriate rate for sustainable production of sorghum in the sub-sudanian zone of Burkina Faso; iv. assess the cost-benefit of cattle manure and mineral fertilizer use for sorghum production in the sub-sudanian zone of Burkina Faso.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Soil nutrient depletion

In West Africa including Burkina Faso where continuous cropping systems without restoration of the soil fertility occur, nutrients outputs generally exceed nutrient inputs (Bationo *et al.*, 1998). During the last 30 years, soil fertility depletion has been estimated at an average of 660 kg N ha^{-1}, 75 kg P ha^{-1} and 450 kg K ha^{-1} from about 200 million hectares of cultivated land in 37 African countries (Bationo *et al.*, 2012a). Bonzi (2002) reported that sorghum residues exported an amount of N varying between 33 – 36 kg ha^{-1}. Therefore, nutrient balances are usually negative, indicating soil mining.

According to Smaling (1993), Africa loses 4 billion dollars per year due to soil nutrient mining. This is equivalent to 1.4 t of urea ha^{-1}, 375 kg ha^{-1} of triple superphosphate (TSP) or 0.9 t ha^{-1} of phosphate rock (PR) of average composition and 896 kg ha^{-1} of potassium chloride (KCl) during the same period. These figures signify the balance between nutrient inputs (in fertilizers, manure, atmospheric deposition, biological nitrogen fixation (BNF) and sedimentation) and nutrient outputs in harvested products, crop residues removals, leaching, gaseous losses, surface runoff and erosion (Stoorvogel and Smaling, 1990). This enormous amount of nutrient depletion in Sub-Saharan Africa's agricultural land is a real concern for researchers, in order to sustain soil productivity by alternative sustainable soil fertility replenishment strategies. In Burkina Faso, the use of plants residues is still low in some parts of the country because they are mined for other uses with higher economic value such as food for animal, fuel and materials for building (Bationo *et al.*, 1995).

2.2 Soil nutrient replenishment

Nutrient replenishment is the recapitalization of soil fertility. It may be define as nutrients that are added to replace the nutrient removed or lost from the soil through leaching, volatilization, erosion, crop uptake and harvest. According to Feng and Liu (2009), soil nutrient is depleted gradually as population grows when farmers are unable to adequately substitute losses by returning nutrients to the soil via crop residues, manures, fallowing and mineral fertilizers. Therefore, Roy and Nabhan (2001) reported that soil nutrient must be replenish for halting soil fertility decline. This may be obtained through the application of mineral and organic fertilizers.

In tropical Africa, nitrogen (N) is usually the limiting factor of crop production due to the fact that it is largely taken-up by almost all plants (Bationo *et al.*, 2008). In soil nitrate can be leached beyond the effective root zone of most crops because of its mobility or splashed away after high intensity rainfall (Alva *et al.*, 2006). In SubSaharan Africa (SSA), high cost and lack of inorganic fertilizers have an effect on the level of fertilizers used for crops (Akande *et al.*, 2007). In Burkina Faso, soils are mainly characterised by nutrient deficiencies, particularly, nitrogen and phosphorus (Ouattara *et al.*, 2006; Bationo *et al.*, 2012b; Bado *et al.*, 2013). At the field scale nitrogen inputs mainly come from inorganic fertilizers, biological nitrogen fixation (BNF), biomass returns to the soil, animal manures or composts produced outside the field (Bado *et al.*, 2013).

2.2.1 Use of manure in crop production

Manure is a complex material that contains valuable nutrients and potential pollutants (Schnitkey and Miranda, 1993). Animal manure has been used as a source of fertilizer for crop production for centuries. This source of essential plant nutrients and organic matter is often used to build and maintain soil fertility, and increase the soil's water holding capacity. Ouattara (2000) showed that soil water evaporation on organic manure fertilized plots was lower than those without manure application. This, according to him, was due to higher water retention and protection of the soil by the biomass on the plots, which received organic manure.

Dunjana *et al.* (2014) reported that soil management practices that increase soil organic matter (SOM) via cattle manure application increases the soil pore space and thus the specific surface area of the soil, water transmission and storage porosity. In SSA, cattle manure application as fertilizer is very common activity in smallholder farming areas (Materechera, 2010). The nutrient content of manure varies, since its value is considerably affected by factors such as diet, amount of bedding, storage and application method (Harris *et al.*, 2001). Therefore, animal wastes should be analysed to know its nutrients composition before application. Over large areas, animal manure cannot meet crop nutrient demand because of the relatively low nutrient content of the materials and the limited quantities available (Bayu *et al.*, 2005) thus, suggesting a combination with mineral fertilizer.

Given the largely biological nature of the N cycle, organic inputs play a crucial role in N replenishment (Bingham and Cotrufo, 2015). They provide carbon (C) for microbial activities (An *et al.*, 2015). Soil micro-organisms utilize the N from organic inputs to build their bodies (immobilization) resulting in the formation of soil organic N which builds up soil humic substance (Ibeawuchi *et al.*, 2015). Therefore fertilizer N not used by crops is subject to leaching and de-nitrification losses (Prasad, 2009) because inorganic fertilizers do not have such C sources.

2.2.2 Use of mineral fertilizer in crop production

In modern agriculture chemical fertilizers are used to solve known plant-nutrient deficiencies; to provide appropriate levels of nutrient to satisfy plants demand, which aid in withstanding stress conditions; to maintain optimum soil fertility conditions; and to recover crop value. Increased use of fertilizer is one of the main ingredients in achieving food security in SSA. The use of mineral fertilizer on crops increase yield but the massive and injudicious applications could cause environmental degradation as in Asia and Latin America between the mid-1980s and early 1990s (Bationo *et al.*, 2008).

The use of mineral fertilizers by many smallholder farmers remains low in sudanosahelian zone of West Africa because of socio-economic constraints. Bationo *et al.* (2005) reported that use of inorganic fertilizers is hampered by lack of adequate foreign exchange to import fertilizers, poor infrastructure and poor distribution mechanisms. Therefore, chemical fertilizers that can maintain and improve soil fertility and by then increase crop yield are often not affordable in SSA for farmers (Bostick *et al.*, 2007). The profitability of fertilizer use is limited by the low response rate of crop, coupled with high fertilizer price and fluctuating crop price and resulting to the low demand for it by smallholder farmers (Dittoh *et al.*, 2012). In semi-arid areas the sub-optimal response rates contribute even further to lower demand because of a highly variable returns to fertilizer use due to variable rainfall (Dittoh *et al*., 2012). In essence, the use of fertilizers is to ensure that soil fertility is not a limitation in crop production.

In Burkina Faso, the last update of fertilizers recommendation was done in 1992 by the project PEV (Projet Engrais Vivriers) based on agro-ecological zones and plants requirements. The recommended nutrient requirement for improved variety of sorghum was 37 kg N ha^{-1}, 23 kg P ha^{-1}, 14 kg K ha^{-1} and 6 kg S ha^{-1}. The following recommendations per agro-ecological zone was reported by Hien *et al.* (1992):

i. In the Sahel zone (amount of annual rainfall less than 600 mm), 50 kg ha^{-1} of

NPK (14-23-14) fertilizer plus 50 kg ha^{-1} of urea (46 % N); ii. In the Soudan zone (amount of annual rainfall within 600 mm and 800 mm), 75 kg ha^{-1} of NPK (14-23-14) fertilizer plus 50 kg ha^{-1} of urea (46 % N); iii. In the Sub-Soudan zone (amount of annual rainfall greater than 800 mm), 100 kg ha^{-1} of NPK (14-23-14) fertilizer plus 50 kg ha^{-1} of urea (46 % N). However, continuous cereals monoculture using chemical fertilizers as the main source of nutrient input in poorly buffered soils in the tropics has resulted in significant yield decline and soil degradation after only a few years of cropping (Bationo and Mokwunye, 1991). On Alfisols in Burkina Faso, Bationo *et al.* (2005) reported that 25 – 50 % of the native organic matter disappeared during the first 2 years of cultivation with mineral fertilizer application and continuously this practice amplified nutrient leaching, lowered the base saturation and increased soil acidification.

The soil P stock serves as a major sink for added P which gradually releases plantavailable P for up to 10 years (Buresh *et al.*, 1997). According to Sharma *et al.* (2012), Alfisols located in West Africa are not only low in organic matter and plant available nitrogen, but are also deficient in P, one of the most important factor limiting crop productivity. Reijneveld *et al.* (2010) reported that uncontrolled use of organic manures and fertilizers particularly build up the soil P and its excessive supplementation increases the risk of losses to the aquatic environment through erosion, overland flow, and subsurface leaching. Sharma *et al.* (2012) found that P application to sorghum in rainfed Alfisols beyond 23 kg ha^{-1} might not be much economical to farmers. Continuous application of mineral fertilizers increases P fixation to 84 % while the use of organic fertilizer combine with mineral fertilizer decreases it to 49 % compared to the control with 69 % of P fixation (Lompo *et al.*, 2008).

Crop responses to K fertilization are uncommon in Africa except in sandy savannah soils (Ssali *et al.,* 1986) while the level of K-mining (15 kg ha^{-1} y^{-1}) is six times that of P-mining. This is perhaps due to the high potential stock of potassium in tropical soil of Africa.

2.2.3 Integrated nutrient management

The term integrated nutrient management is used for the conservation and regulation of the productivity of the soil and crop nutrient supply. Integrated nutrient management has three main objectives (FAO, 1998). First of all, the management of nutrients is meant to maintain the productivity of soil through balanced fertilization. This can be achieved in modern agriculture by applying a variety of fertilizers including mineral fertilizers combined with organic fertilizers of plant and animal origin, such as crop residues and farmyard manure, and biological source of plant nutrients. According to Bationo and Buerkert (2001), combining organic resources and mineral fertilizer at recommended rate increased soil organic matter by increasing not only the total above ground biomass but also the below ground biomass production (roots).

Another purpose of integrated nutrient management is to improve the soil nutrient budget/nutrient stock. Thirdly, integrated nutrient management aims at improving the efficiency of the nutrients that are applied. Thus, farmers can minimize and limit losses as well as limit the environmental impacts of their agricultural activities, which is one of the basic requirements of sustainability in agriculture.

Powell *et al.* (2004) stated that the combination of manure with mineral fertilizer resulted in higher yields than manure applied alone. Bahrani *et al.* (2007) reported that the use of organic fertilizer together with chemical fertilizer had a higher positive effect on microbial biomass and hence soil health compared to sole application of organic fertilizers. Application of organic manure in combination with chemical fertilizer has been reported to increase N, P and K uptakes in sugarcane leaf tissue, guinea corn, and maize plant compared to chemical fertilizer alone (Bokhtiar and Sakurai, 2005). According to Quansah (2001), integrated plant nutrition increase crop yields more than either chemical or organic fertilizers applied alone.

2.3 Nutrients affecting plant growth and yield

Inorganic fertilizers exert strong influence on plant growth, development and yield (Law-Ogbomo and Law-Ogbomo, 2009). Inorganic fertilizers, because of containing available and sufficient growth nutrients, improved cell activities, enhanced cell multiplication and enlargement and growth of crop (Fashina *et al.,* 2002).

2.3.1 Primary nutrients

2.3.1.1 Nitrogen

Nitrogen is a primary nutrient of plant commonly present in the air, soil, organic amendment and commercial fertilizers. It promotes rapid growth, increases leaf size and quality, hastens crop maturity, and promotes fruit and seed development (Roy *et al.,* 2006). Nitrogen play a role in almost all plant metabolic processes because of being a constituent of amino acids, which are required to synthesize proteins and other related compounds (Sanginga and Woomer, 2009).

It is also an integral part of chlorophyll manufactured through photosynthesis. Nitrogen fertilizer is available in both organic (manures) and inorganic forms. The amount of nitrogen in organic sources varies with the type of material and its state of decomposition. However, the following inorganic fertilizers as stated by Tucker (1999) are sources of N: urea (46 % N), di-ammonium phosphate (46 % N), ammonium nitrate (33.5 % N), mono-ammonium phosphate (18 % N), potassium nitrate (13 % N), sodium nitrate (16 % N), calcium nitrate (15.5 % N) and liquid nitrogen (30 % N).

Legume crops require little or no nitrogen fertilizer because of beneficial bacteria that live in their roots and capture nitrogen from the atmosphere (Tucker, 1999). Bado *et al.* (2006) reported that groundnut and cowpea increased soil mineral N by 15 kg N ha^{-1} and 22 kg N ha^{-1}, respectively. Nitrogen is also used by microbes as a source of energy to break down organic matter (Tucker, 1999).

In the soil, N in organic form is converted into ammonium N by soil microorganisms (bacteria and fungi) through mineralization (Richardson *et al.*, 2009) (Figure 2.1). Nitrogen in the form of NH_4^+ has a positive charge and may be held to the exchange sites of the soil. This process is called micelle fixation (Pidwirny, 2002). As this fixation is reversible, NH_4^+ may be released from the colloids by way of cation exchange. When released, NH_4^+ may be chemically altered through bacteria action or processes resulting in the production of NO_3^- (Richardson *et al.*, 2009) (Figure 2.1). Normally NO_3^- concentration increase in the soil solution because of its negative charge (it may not be adsorbed onto the soil colloids). If NO_3^- is not taken up by the roots, it can be transported below the root zone and leached or denitrified (Richardson *et al.*, 2009).

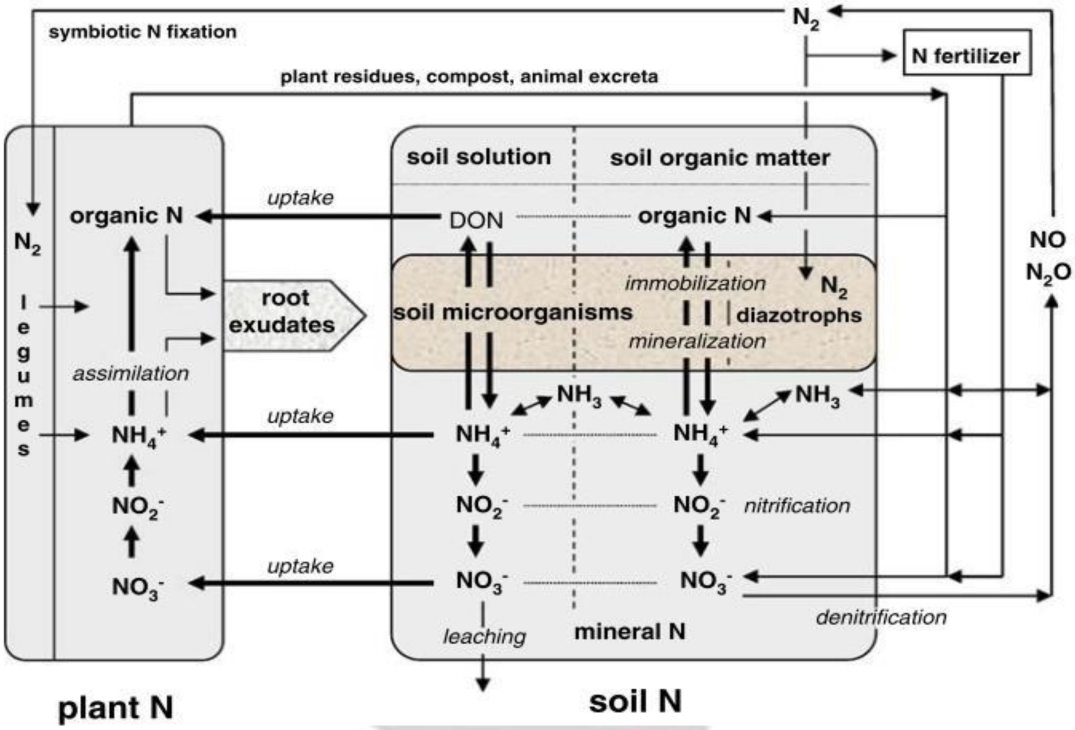


Figure 2.1: The plant-soil N cycle and pathways for N transformation mediated by physiological processes (DON = dissolved organic nitrogen). Adapted from Richardson *et al.* (2009).

According to Simonne and Hochmuth (2003), as NO_3^- is soluble in water and mobile it is easily leached from the root zone by excessive rainfall or irrigation.

Major causes of N deficiency consist of pH imbalance (acidic or alkaline) hampering nutrient absorption, insufficient soluble N in the soil solution, excess leaching, waterlogging and plants competition for limited nitrogen reserves (Sanginga and Woomer, 2009). Nitrogen-deficient plants exhibit slow stunted growth, and their foliage is pale green (Roy *et al.*, 2006). The characteristic symptom of N deficiency is chlorosis of lower and matures leaves (Sanginga and Woomer, 2009). In severe cases, the lower leaves have a “fired” form on the tips, turn brown, usually disintegrate, and fall off (Tucker, 1999). When grain crops, such as maize and sorghum, are deficient, they generally show yellow leaf, stunted growth with frail stems and low yields of poor quality grain (Tucker, 1999). In difference, too much nitrogen causes excessive vegetative growth, delays maturity, increases lodging, promotes diseases and poses an environmental threat to surface and ground water (Tucker, 1999; Roy *et al.*, 2006).

Nitrogen deficiency can be corrected using a fertilizer containing ammonium, nitrate or urea depending on the physiology and growth of the crop, and soil climatic conditions (Sanginga and Woomer, 2009).

2.3.1.2 Phosphorus

Phosphorus (P) is the most important nutrient element (after nitrogen) limiting crop production in most regions of the world (Kogbe and Adediran, 2004). Without phosphorus, normal plant growth cannot be achieved. It is a constituent of nucleic acids, phospholipids, the coenzymes DNA and NADP, importantly ATP and is involved in plant energy relations (Roy *et al.*, 2006). Phosphorus enhances seed germination and early growth, stimulates flowering, enhances bud set, aids in seed formation, hastens maturity and provides winter hardiness to crops planted in late fall and early spring (Tucker, 1999).

Phosphorus early deficiency symptoms of plants are not distinct and thus more difficult to identify but severe deficiency results in stunted growth (with a limited root system and thin stems) and arrested physiological development (Sanginga and Woomer, 2009). In many plants, seedlings look stunted and older leaves may turn purple or bronze because of P deficiency (Sanginga and Woomer, 2009). The plants may produce only small ear containing fewer, smaller kernels than usual and grain yield is often severely reduced (Jones *et al.*, 2003).

Plants extract P as orthophosphate anions exclusively from the soil solution in either $H_2PO_4^-$ or HPO_4^{2-} form (Richardson *et al.*, 2009). The authors stated that most soils have low concentration of orthophosphate in solution and must therefore be replenished from other pools of soil P to satisfy plant requirements. Phosphorus in the forms of iron and aluminium phosphates such as strengite ($FePO_4.2H_2O$) and variscite ($AlPO_4.2H_2O$) can be strongly held to the soil surface making P virtually unavailable for plant uptake (Richardson *et al.*, 2009). Compaoré *et al.* (2003) found very low exchangeable phosphorus in Alfisols of Burkina Faso and suggested that the only possibility to increase significantly soil P availability and to alleviate P deficiency is the application of P as inorganic and/or organic fertilizers to reach a positive P balance in these soils.

2.3.1.3 Potassium

Potassium is involved in osmotic regulation of cells in its ionic form, regulating the tugor of non-woody plant organs and stomatal functions (Sanginga and Woomer, 2009). Potassium is essential for photosynthesis and activation of enzymes to metabolize carbohydrates for the manufacture of amino acids and proteins (Roy *et al.*, 2006).

Potassium-deficient plants show chlorosis (loss of green colour) along the leaf margins or tips starting with the bottom leaves and progressing up the plant. In severe cases, the whole plant turns yellow, and the lower leaves fall off. Potassium deficiency in grain crops can reduce grain size and yield (Tucker, 1999).

An application of potassium fertilizer could correct deficiency problems and, if diagnosed early by soil testing in the growing season, will benefit the current crop (Tucker, 1999) because symptoms induced by K deficiency are irreversible (Sanginga and Woomer, 2009). Tucker (1999) stated that fertilizers such as potassium nitrate (13-0-44), muriate of potash (0-0-60), potassium sulfate (0-0-50) and mixture of potassium and magnesium sulfate (22 % K_2O) are sources of potassium.

In soils, potassium is moderately mobile as compared to phosphate. It exists as K^+ in soil solution and is absorbed by roots in that form. Although K^+ can be fixed to some extent by negative charges on clay surface where Ca^{2+} or Mg^{2+} can displace it into the soil solution, when amendment of gypsum or dolomite (Singh and Trehan, 1997). Thus if K^+ is not taken up by plants, it might be lost by leaching. One way to reduce

K leaching is to add organic matter such as compost to the soil (Singh and Trehan, 1997). According to Bationo *et al.* (2008), among the plant nutrients, N and P are the most limiting for crop production in SSA.

2.3.2 Secondary nutrients

The secondary nutrients such as calcium (Ca), magnesium (Mg) and sulfur (S) are required in smaller amounts than the primary nutrients.

2.3.2.1 Calcium

Calcium is an essential plant nutrient. It is required for structural roles as a constituent of cell walls and membranes (White and Broadley, 2003). It is responsible for elasticity and expansion of cell walls, which preserves growing parts from becoming rigid and breakable (Tucker, 1999). It is immobile inside plant and remains in the older tissue throughout the growing season. Calcium helps in nitrogen absorption and carbohydrate translocation. Indeed, calcium might be considered as the pieces of assemblage in plant, without which cell manufacture and development would not occur (McLaughlin and Wimmer, 1999).

The calcium content of soil depends on soil type, liming practices and cropping systems. In sandy coastal plain soils, where pH has not been properly maintained, is found the lowest amount of calcium or in soils that have a low nutrient-holding capacity and are more subject to leaching (Tucker, 1999). Despite the importance of calcium, its low mobility makes its uptake and distribution limiting processes for many key plant functions (Hu and Schmidhalter, 2005).

Calcium deficiency symptoms appear in the meristem regions (new growth) of leaves, stems, buds and roots. Younger leaves are affected first and are usually deformed. In extreme cases, the growing tips die (Tucker, 1999). Soil reserves are replenished and maintained with frequent applications of lime. Calcium deficiency is generally an indication of the need for lime amendment. Soils that are properly amended with lime with provide adequate calcium for several years (Tucker, 1999). Calcium can also be supplied by application of fertilizers such as calcium nitrate (19.4 % Ca), calcium sulphate (22.5 % Ca) and normal superphosphate (20.4 % Ca).

2.3.2.2 Magnesium

Magnesium occupies the centre-spot in the chlorophyll molecule and thus, is vital for photosynthesis. It is associated with the activation of enzymes, energy transfer, production of proteins, metabolism of carbohydrates, etc. (Roy *et al.*, 2006). It regulates uptake of other essential elements, serves as a transporter of phosphate compounds throughout the plant, facilitates the translocation of carbohydrates (sugars and starches) and enhances the production of oils and fats and its deficiency is most prevalent on sandy coastal plain, soils where the native magnesium content is low (Tucker, 1999).

Deficiency symptom is predominantly interveinal chlorosis. The bottom leaves are always affected first and the symptoms progress up the plant as the deficiency becomes more severe (Roy *et al.*, 2006). Depending on the stage of crop growth, magnesium deficiency can be corrected by amendment of lime or fertilizer to the soil. However, nothing can be done to correct the affected leaves, once a deficiency symptom has appeared. Usually, magnesium is applied to the soil through use of commercial fertilizers or dolomitic lime containing a minimum of 6 % Mg (Tucker, 1999).

2.3.2.3 Sulphur

In the synthesis of amino acids required to manufacture proteins, sulphur is an essential component. Sulphur is required for production of chlorophyll and utilization of phosphorus and other essential nutrients. According to Tucker (1999), sulphur is important as nitrogen for optimizing crop yield and quality. It increases the size and weight of grain crops and enhances the efficiency of nitrogen for protein manufacture. Crops that have a high nitrogen requirement must have adequate sulphur to optimize nitrogen utilization (Tucker, 1999).

Sulphur deficiencies are regularly misdiagnosed as nitrogen problems, leaving farmers to wonder why their nitrogen applications are ineffective and frequently occurs on very sandy soils with low organic matter content during seasons of excessive rainfall (Tucker, 1999; Roy *et al.*, 2006). Sulphur deficiency is characterized by stunted growth, delayed maturity in cereals crop and general yellowing of plants (Roy *et al.*, 2006). However, unlike nitrogen deficiency sulphur deficiency symptoms begin in the young, upper leaves first (Roy *et al.*, 2006). Fertilizers that provide sulphur include potassium sulphate (18 % S), potassiummagnesium sulphate (23 % S), magnesium sulphate (14 % S), gypsum (16.8 % S), ammonium sulphate (23.7 % S) and elemental sulphur (90 % S) (Tucker, 1999).

Micronutrients

Micronutrients such as iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B) and molybdenum (Mo) are required in smaller amounts than secondary nutrients. They are available in manganese, zinc and copper sulphates, oxides, oxy-sulphates and chelates, as well as in boric acid and ammonium molybdate (Tucker, 1999).

2.4 Residual effects of fertilizer application

As fertilizer rates are increased, the efficiency of fertilizer nutrient use decreases leaving in the soil an increasing proportion of the added nutrient. In Burkina Faso, large amounts of fertilizers are used in cotton fields with sorghum mostly as succeeding crop. When there is a continuous farming on the same site for several years, the residual effects of fertilizer treatments may considerably affect the soil chemical properties and consequently crop yield (Bado *et al.*, 2006).

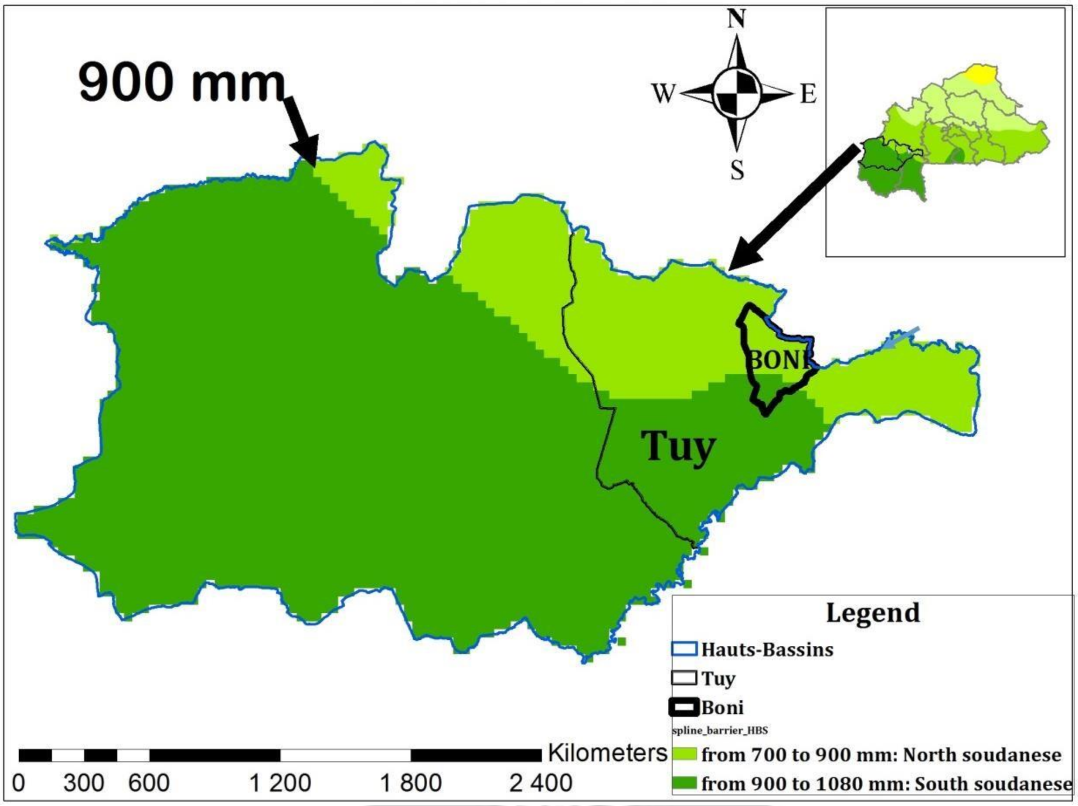
Sieling *et al.* (2006) studied the residual effects of mineral N fertilizers applied in one year on yield and N uptake of the subsequent crop and found only small amounts of residual N fertilizers (1 – 7 % of the applied N amount) taken up. Only organic N from manure or compost after mineralization can bring some residual N for the following crop (Gilley and Eghball, 2002). Akande *et al.* (2004) reported that an increase in soil available P of between 112-115 % and 144-153 % was observed after applying rock phosphate with poultry manure on okra respectively for two-years field trial. This is especially so for rock phosphate which may be poorly available to the crop to which it was applied (Lompo *et al.*, 2008).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location of the study area

The study was carried out in 2014 at the Institut de l'Environement et de Recherches Agricoles (INERA) experimental field located in Boni, a village in the province of Tuy, about 12 km away from Houndé the city centre of Burkina Faso. The area lies between latitudes 11°.09′ and 11°.06′ North and longitudes 03°.25′ and 03°.28′ West of the Greenwich meridian. (Figure 3.1).



Source: Oula Damien, 2014

Figure 3. 1: Map of the study area (Houndé, Boni)

3.2 Climate of the study area

The study area is located in the sudanian agro-ecological zone of Burkina Faso and is characterized by one wet season in the year. The rainy season starts from May and ends in October. Rainfall is erratic and the number of rainy days is 54. The rainfall distribution at the area is unimodal (Figure 3.2) with mean annual precipitation between 800 mm and 950 mm (Figure 3.3).

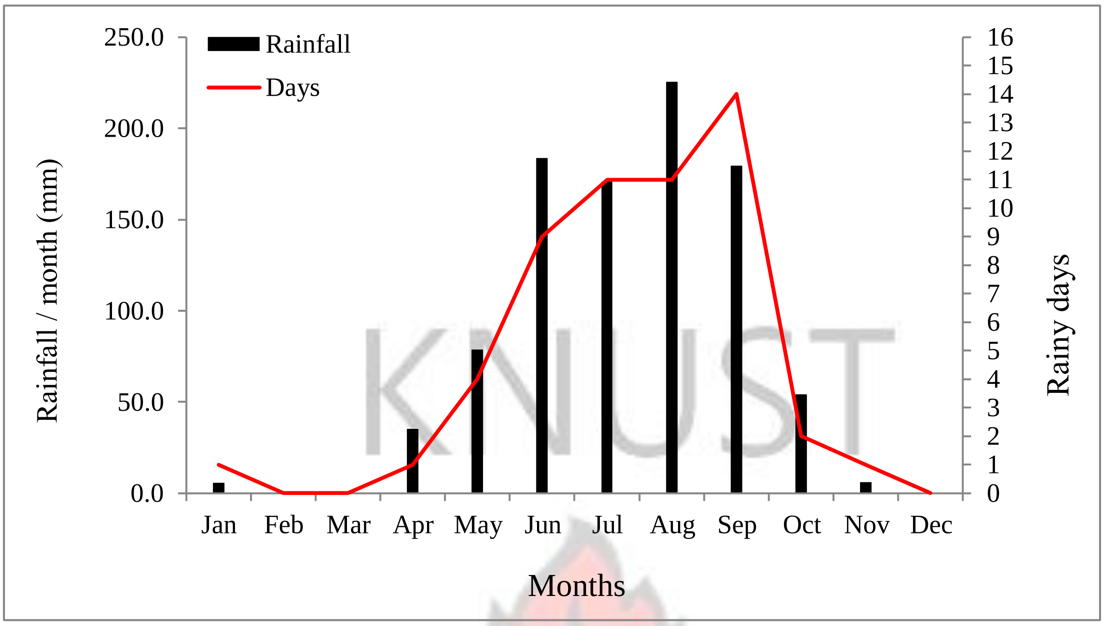


Figure 3. 2: Rainfall distribution and rainy days per month at Boni in 2014

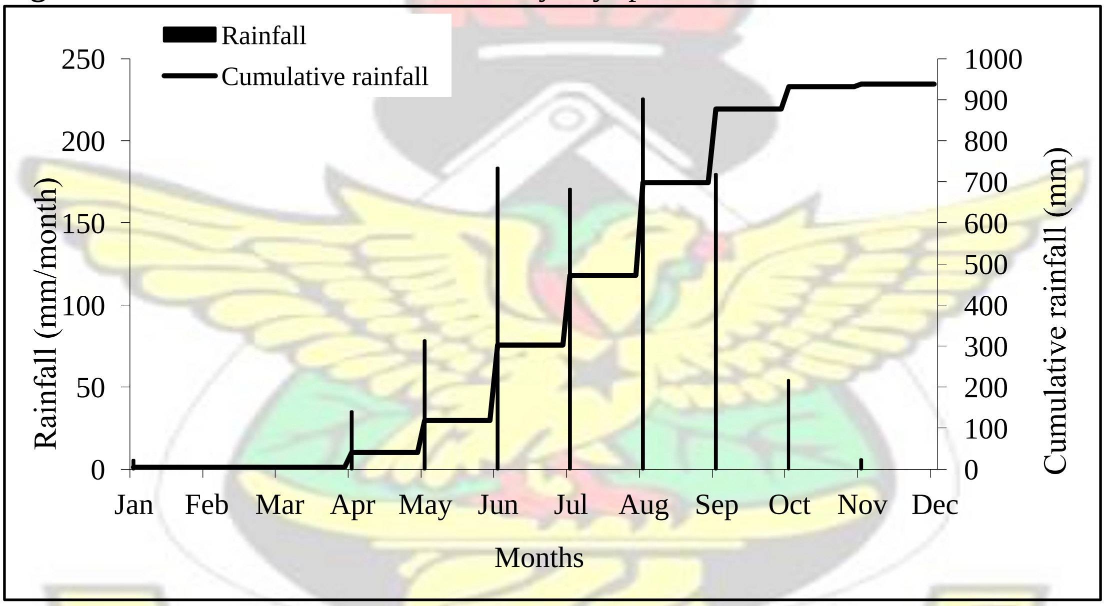


Figure 3. 3: Cumulative rainfall distribution at Boni in 2014.

3.3 Soil of the study area

The soil type is Luvisol according to WRB classification for soil resources (FAO, 2014) and has a silty loam texture. The soil was slightly acid (pH = 4.57) and was low in fertility (Table 4.1). Luvisols are soils with a pedogenetic clay differentiation (especially clay migration) between a topsoil with a lower and a subsoil with a higher clay content, high-activity clays and a high base saturation at some depth. Many

Luvisols were known as *sols lessivés* (France) and *Alfisols* with high-activity clays (US Soil Taxonomy) (FAO, 2014).

3.4 Field experiment

3.4.1 Experimental design and treatments

The experiment was a split-plot arranged in a randomized complete block design (RCBD) with three replications. Cattle manure at two rates (0 t ha^{-1} and 5 t ha^{-1}) constituted the main plot while mineral fertilizer at eleven rates constituted the subplots (Table 3.1). The mineral fertilizers applied were urea (46 %), triple super phosphate (45 % P_2O_5 water soluble), muriate of potash (60.8 % K_2O), kieserite ($MgSO_4$ with 15 % MgO and 22 % S), borax-pentahydrate (48 % B_2O_3) and zinc sulphate ($ZnSO_4$ 36.8 %). Calculations showing rates of organic and inorganic fertilizers applied per plot are shown in appendix 2.

The total land area measured 52 m x 43 m (2236 m^2) with each sub-plot measuring 6 m x 4 m.

Table 3.1 N-P-K fertilizer rates applied

Treatments	**N-P-K (kg ha^{-1})**
T_1	0-0-0
T_2	40-0-0
T_3	60-0-0
T_4	40-15-0
T_5	60-15-0
T_6	60-7.5-0

T_7	60-22.5-0
T_8	60-15-10
T_9	60-15-20
T_{10}	60-15-30
T_{11}	90-15-20-15S-2.5Zn-10Mg-0.5B

3.4.2 Land preparation and sowing

The field was ploughed and harrowed to a fine tilth. An improved sorghum *(Sorghum bicolor L. Moench)* variety called Kapelga was sowed (four seeds per hill) at a spacing of 80 × 40 cm. The seedlings were thinned to two per hill one week after germination giving a total population of 62500 plants ha^{-1}. The various treatments were then imposed two weeks after planting. During the growing period, the plots were manually weeded twice with hoe.

3.5 Soil sampling and preparation

Three composite soil samples (each consisting of four sub-samples) were taken randomly from the experimental field at a depth of 0 - 20 cm for initial characterization. These samples were air-dried, sieved through 0.5 and 2 mm mesh and stored in room temperature for the physical and chemical analyses.

After harvesting, three soil samples were randomly taken from each plot at 0 – 20 cm depth and composited. These samples were brought to the laboratory through a cooler and stored in a freezer for wet samples analysis (NH_4^+-N determination). Part of the soil samples were air-dried, crushed using a wooden mortar and pestle and then sieved through a 2 mm mesh for routine analyses.

For soil nutrient content monitoring during plant growth, soil samples were taken from each plot at 0 – 20 cm depth at two weeks interval. These samples were brought to the laboratory through a cooler and stored in a freezer for NH_4^+-N determination.

3.6 Soil chemical and physical analyses

3.6.1 Soil pH

Soil pH was measured in a 1:2.5 soil-water ratio using a glass electrode (Cyber scan 510, Singapore) pH meter. Twenty grams (20 g) soil sample was weighed into a plastic pH tube and 50 mL of distilled water added. The suspension was stirred thoroughly during 30 minutes and allowed to stand for 15 minutes. After calibrating the pH meter with buffers at pH 4.0 and 7.0, the pH was read by immersing the electrode into soil suspension.

3.6.2 Soil moisture

The results of soil analyses were calculated on the basis of oven dried sample weight. Therefore, the moisture correction factors (mcf) were determined before analyses. A porcelain crucible was placed in the oven at a temperature of 105 °C and left for 2 hours. Afterwards it was cooled down to room temperature in a desiccator and the empty crucible weighed (Empty Crucible weight =A). A 10 g soil sample was weighed into the crucible, giving a new weight B (Sample + Crucible weight). The crucible with the sample was oven-dried at 105 °C for 12 hours and cooled down to room temperature in a desiccator before weighing (C).

Calculation

$$\text{M (moisture content)\%} = \frac{(B - C) \times 100\ \%}{(C - A)}$$

$$\text{mcf (moisture correction factor)} = \frac{100 + M\ (\%)}{100}$$

where:

A = Empty Crucible weight (g)

B = Sample + Crucible weight (g)

C = Sample + Crucible oven-dried weight (g) M = percentage of moisture content.

3.6.3 Soil organic carbon

A modified Walkley and Black procedure as described by Nelson and Sommers (1996) was used in the determination of organic carbon. One gram of soil sample was weighed into an Erlenmeyer flask. A reference sample and a blank were included. Ten millilitres of 1.0 *N* (0.1667 *M*) potassium dichromate was added to the sample and the blank flasks. Concentrated sulphuric acid (20 ml) was carefully added to the soil from a measuring cylinder, swirled and allowed to stand for 30 minutes in a fume cupboard. Distilled water (250 ml) and 10 ml concentrated orthophosphoric acid were added and allowed to cool. A diphenylamine indicator (1 ml) was then added and titrated with 1.0 *M* ferrous sulphate solution. The organic carbon content was calculated as:

$$\% \text{ organic carbon} = \frac{M \times 0.39 \times mcf\ (V_1 - V_2)}{w}$$

where:

M = molarity of ferrous sulphate

V_1 = ml ferrous sulphate solution required for blank
V_2 = ml ferrous sulphate solution required for sample w =

weight of air - dry sample in gram mcf = moisture

correcting factor (100 + % moisture) / 100)

0.39 = 3 × 0.001 × 100 % × 1.3 (3 = equivalent weight of carbon, 1.3 = compensation factor for incomplete oxidation of the organic carbon)

3.6.4 Total nitrogen

This was determined by the Kjeldahl digestion and distillation procedure as described in Soils Laboratory Staff (1984). A 0.5 g soil sample was weighed into a Kjeldahl digestion flask. To this 5 ml distilled water was added. After 30 minutes, concentrated sulphuric acid (5 ml) and selenium mixture were added and mixed carefully. The sample was then digested for 3 hours until a clear digest was obtained. The digest was diluted with 50 ml distilled water and mixed well until no more sediment dissolved and allowed to cool. The volume of the solution was made to 100 ml with distilled water and mixed thoroughly. A 25 ml aliquot of the solution was transferred to the reaction chamber and 10 ml of 40 % NaOH solution added followed by distillation. The distillate was collected in 2.0 % boric acid and was titrated with 0.02 *N* HCl using bromocresol green as indicator. A blank distillation and titration was also carried out to take care of the traces of nitrogen in the reagents as well as the water used. The total nitrogen (% nitrogen in the sample) was calculated as:

$$\% N = \frac{N \times (a - b) \times 1.4 \times mcf}{w}$$

where:

N = concentration of HCl used in titration

a = ml HCl used in sample titration b =

ml HCl used in blank titration

w = weight of air-dry soil sample mcf = moisture correcting

factor (100 % + % moisture) / 100)

1.4 = 14 × 0.001 × 100 % (14 = atomic weight of N)

3.6.4.1 Ammonium nitrogen

Ammonium ions are held in exchangeable form in soils. The NH_4^+-N is usually extracted with 10 % NaCl or KCl solution. The NH_4^+-N in KCl / NaCl extract may be determined by distillation (Dhyan *et al.*, 1999).

A ten grams (10 g) fresh soil sample was weighed into a conical flask and 20 ml of NaCl solution (10 % with a pH of 2.5) was added and the mixture shaken for 30 minutes. The mixture was transferred into Kjeldhal tube and 20 ml of 40 % NaOH was introduced for distillation process. The distillate was collected in 2 % Boric acid and was titrated against N / 100 H_2SO_4.

3.6.5 Available phosphorous

The available phosphorus was extracted with Bray's No.1 extracting solution (0.03 *M* NH_4F and 0.025 *M* HCl) as described by Bray and Kurtz (1945). Phosphorus in the extract was determined by the blue ammonium molybdate method with ascorbic acid as the reducing agent using a spectrophotometer.

A 5 g soil sample was weighed into a shaking bottle (50 ml) and 35 ml of extracting solution of Bray's No.1 added. The mixture was shaken for 10 minutes on a reciprocating shaker and filtered through a Whatman No. 42 filter paper. An aliquot of 5 ml of the blank, the extract, and 10 ml of the colouring reagent (ammonium molybdate and tartarate solution) were pipetted into a test tube and uniformly mixed. The solution was allowed to stand for 15 minutes for the blue colour to develop to its maximum. The absorbance was measured on a spectronic 21D spectrophotometer (Cecil 3021 from England) at a wavelength of 660 nm at medium sensitivity.

A standard solution of 0, 1, 2, 3, 4 and 5 mg P l^{-1} was prepared from 20 mg l^{-1} phosphorus stock solution.

Calculation:

$$P\ (mg\ kg^{-1}\ soil) = \frac{(a - b) \times 35 \times 15 \times mcf}{w}$$

where:

a = mg l^{-1} P in sample extract b

= mg l^{-1} P in blank mcf =

moisture correcting factor 35 =

ml extracting solution 15 = ml

final sample solution w =

sample weight in gram

3.6.6 Available potassium

Potassium in soil exists as water soluble, exchangeable and fixed (lattice-K). The first two forms constitute only small part (not more than 1 %) and are considered to be easily available to plant. These forms are determined by ammonium acetate method (Njukeng *et al.*, 2013). A 5 g soil sample was weighed into a 100 ml conical flask. Twenty five (25) ml of 1 *N* ammonium acetate solution was added and the mixture shaken for 5 minutes. The solution obtained was filtered through Whatman No.1 filter paper and K concentration in the filtrate measured using flame photometer.

Calculation

$$Available\ K\ (mg\ kg^{-1}\ soil) = \frac{C \times 25}{Sample\ weight\ (g)} \times mcf$$

where:
C = Concentration of potassium in filtrate.

Mcf = Moisture correction factor.

25 = Volume of ammonium acetate.

3.6.7 Exchangeable cations

Exchangeable calcium, magnesium, potassium and sodium in the soil were determined in 1.0 *M* ammonium acetate extract (Black, 1986) whilst the exchangeable acidity (hydrogen and aluminium) was determined in 1.0 *M* KCl extract (Page *et al.*, 1982).

3.6.8 Exchangeable bases extraction

A 5 g soil sample was weighed into a leaching tube and leached with 100 ml buffered 1.0 *M* ammonium acetate solution at pH 7.

3.6.8.1 Determination of calcium and magnesium

To analyse for calcium and magnesium, a 25 ml aliquot of the extract was transferred into an Erlenmeyer flask. To this were added 1 ml portions each of hydroxylamine hydrochloride, 2.0% potassium cyanide, 2.0% potassium ferrocyanide. A 10 ml ethanolamine buffer and 0.2 ml Eriochrome Black T solution were also added. The solution was titrated with 0.01 *M* EDTA (ethylene diamine tetra acetic acid) to a pure turquoise blue colour.

Determination of calcium only

A 25 ml aliquot of the extract was transferred into a 250 ml Erlenmeyer flask and the volume made up to 50 ml with distilled water. Following this, were added 1 ml each of hydroxylamine, 2.0 % potassium cyanide and 2.0 % potassium ferrocyanide solution. After a few minutes, 5 ml of 8.0 *M* potassium hydroxide solution and a spatula of murexide indicator were added. The resultant solution was titrated with 0.01 *M* EDTA solution to a pure blue colour.

Calculation:

The concentrations of calcium + magnesium or calcium were calculated using the equation:

$$\text{Ca + Mg (or Ca) (cmol}^{(+)}\ \text{kg}^{-1}) = \frac{0.01 \times (Va - Vb) \times 100}{w}$$

where:

w = weight (g) of air – dried soil used

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

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

0.01 = concentration of EDTA

3.6.8.2 Determination of exchangeable potassium and sodium

Potassium (K) and sodium (Na) in the leachate were determined by flame photometry. A standard series of potassium and sodium were prepared by diluting both 1000 mg l^{-1} K and Na solutions to 100 mg l^{-1}. In doing this, 25 ml portion of each solution was taken into 250 ml volumetric flask and made up to the volume with distilled water. Portions of 0, 5, 10, 15, 20 ml of the 100 mg l^{-1}standard solution were put into 200 ml volumetric flasks. One hundred millilitres of 1.0 *M* NH_4OAc solution was added to each flask and made to the volume with distilled water. This resulted in standard series of 0, 2.5, 5.0, 7.5, 10 mg l^{-1} for K and Na. Potassium and sodium were measured directly in the leachate by flame photometry at wavelengths of 766.5 and 589.0 nm, respectively.

Calculation:

$$\text{Exchangeable K (cmol}^{(+)}\ \text{kg}^{-1}) = \frac{(a - b) \times 250 \times mcf}{10 \times 39.1 \times w}$$

$$\text{Exchangeable Na (cmol}^{(+)}\ \text{kg}^{-1}) = \frac{(a - b) \times 250 \times mcf}{23 \times w}\ 10 \times$$

where:

a = mg l^{-1} K or Na in the diluted sample percolate

b = mg l^{-1} K or Na in the diluted blank percolate

w = weight (g) of air- dried sample mcf = moisture

correcting factor

3.6.9 Cation exchange capacity

The measurement of soil cation exchange capacity (CEC) was determined by using a single extraction with 1.0 *M* silver thiourea (AgTU). A 2.0 g soil sample was weighed into an extraction bottle and 30 ml of 1.0 *M* AgTU solution was added. The bottle with its contents was shaken for 2 hours. The mixture was then titrated with

0.01 *M* of AgTU solution.

3.6.10 Soil texture

The soil texture was determined by the Hydrometer method (Huluka and Miller, 2014). A 40 g of soil was weighed into 250 ml beaker and oven dried at 105 °C over night. The sample was removed from the oven and then placed in a desiccator to cool, after, which it was weighed and the oven dry weight taken. A 100 ml of dispersing agent commonly known as Calgon (sodium hexa-metaphosphate) was added to the soil. The mixture was then placed on a hot plate and heated until the first sign of boiling was observed. The content in the beaker was washed completely into a shaking cup and then shaken for 5 minutes. The sample was sieved through a 50 µm mesh into a 1.0 l cylinder. The sand portion was separated by this method while the silt and clay went through the sieve into the cylinder.

The sand portion was dried and further separated using graded sieves of varying sizes into coarse, medium and fine sand. These were weighed and their weights taken.

The 1.0 l cylinder containing the dispersed sample was placed on a vibrationless bench and then filled to the mark. It was covered with a watch glass and allowed to stand overnight. The hydrometer method was used to determine the silt and the clay contents. The cylinder with its content was agitated to allow the particles to be in suspension. It was then placed on a bench and hydrometer readings taken at 30 seconds, 4 minutes, 1 hour, 4 hours and 24 hours intervals. At each hydrometer reading, the temperature was also taken. Coarse silt, medium silt, fine silt and clay portions were then calculated graphically. The various portions were expressed in percentage. Using the textural triangle, the texture was determined.

3.7 Plant analysis

Plants were sampled from 1 m^2 from each subplot for yield component evaluation. Sorghum grain and straw parts sampled at harvest were kept in paper envelopes and oven-dried at 60 °C for 48 hours after which they were milled to pass through 2 mm mesh sieve for the analysis of total N, P and K contents.

3.8 Characterization of cattle manure

Cattle manure used in the experiment was characterized for pH, organic carbon, N, P and K contents. Triplicate sample analyses were carried out.

3.9 Data collection

3.9.1 Sorghum grain and straw yield

Sorghum was harvested after 4 months in the delineated area of 14.56 m^2 in the middle of each treatment plot skipping the border rows. After sun drying the ears, the grain was removed and further dried to a moisture content of 13 %. The weight of the grain (yield per plot) were taken and extrapolated to kg ha^{-1}. The harvested straw was also sun dried for three weeks and weights per plot converted to kg ha^{-1}.

3.9.2 Nutrient uptake

The nutrient (N, P, and K) uptake in sorghum grain and straw was determined. This was calculated as product of the nutrient concentrations obtained from the tissue analysis (grain or straw) multiplied by the yield.

Nutrient uptake = Nutrient concentration in grain/straw x yield (kg ha^{-1})

3.9.3 Determination of value cost ratio

A survey was done to obtain the price of sorghum grain after harvest at the experimental location. The VCR was calculated by the following formula (Pervaiz *et al.*, 2004):

$$Value\ Cost\ Ratio\ (VCR) = \frac{\text{Value of yield obtained}}{\text{cost of fertilizer used}}$$

VCR > 2 means that the treatment is beneficial financially against investment in fertilizer use contrary to a VCR below 2 (not beneficial in terms of finance against investment in fertilizer use).

3.10 Statistical analysis

All data were subjected to ANOVA using GenStat (2007) statistical package (Version 9). Standard error of difference was used for means separation. Regression analyses were carried out to establish the relationships between principal parameters measured for predictive purposes.

CHAPTER FOUR

4.0 Results

This chapter deals with the results of this study and is followed by the discussions in chapter five.

4.1 Initial physico-chemical properties of the soil

The soil of the study area was characterized before the establishment of the experiment. The results are presented in Table 4.1 and showed that at 0 – 20 cm depth, the soil had low nitrogen and phosphorus contents, very low organic carbon level and was very acidic with a pH (H_2O) of 4.57. The soil is a Luvisol with a silty loam texture consisting of 39.4 % sand, 43.35 % silt and 17.25 % clay at 0 – 10 cm depth.

Table 4.1 Initial physico-chemical characteristics of soil at the study site

Soil properties	Mean values
pH (1:2.5 H_2O)	4.57
Organic carbon (%)	0.46
Total nitrogen (%)	0.06
Available P (mg kg^{-1})	4.32
Exchangeable bases (cmol$^{(+)}$ kg^{-1})	
Calcium (Ca^{2+})	1.12
Magnesium (Mg^{2+})	0.32
Potassium (K^+)	0.11
Sodium (Na^+)	0.04
Sum of anions (S)	1.58
Saturation rate (S/CEC) (%)	27.00
Cation Exchange Capacity (CEC) (cmol kg^{-1})	5.80
Particles size distribution (%)	
Sand	39.40
Silt	43.35
Clay	17.25
Texture	Silty loam

4.2 Chemical characteristics of cattle manure used

The chemical composition of the cattle manure (CM) used as main plot treatment in the trial is presented in Table 4.2. The laboratory analysis of the manure showed a slightly high carbon content of 20.59 %. The C/N ratio was < 20 indicating that it was high quality.

Table 4.2 Chemical characteristics of the cattle manure used

Organic material	Carbon (%)	Total N (%)	C/N	Total P (%)	Total K (%)
Cattle manure	20.59	1.21	17.02	0.41	2.15

4.3 Effect of cattle manure and mineral fertilizer application on sorghum grain N, P and K uptake

The results in Table 4.3 show that the mineral fertilizer and the manure rates significantly ($P < 0.05$) influenced sorghum grain nutrient (NPK) uptake while their interaction did not significantly affect the parameters.

With mineral fertilizer application, the N uptake in sorghum grain ranged from 48.30 kg ha^{-1} in the reference plot where all the nutrients (90N-15P-20K-15S-2.5Zn-10Mg-0.5B) were applied to 23.60 kg ha^{-1} in the control plots. Grain N uptake on 60N22.5P-0K, 60N-15P-0K, 60N-15P-30K, 60N-7.5P-0K and 40N-15P-0K treated plots were not significantly different from that of the reference plot. The variation in phosphorus and potassium rates did not influence significantly nitrogen uptake in sorghum grain. The results showed lowest P and K uptake of 3.74 kg ha^{-1} and 6.25 kg ha^{-1} respectively in the control plot. The effect of mineral fertilizer on grain N, P,
K uptake followed a decreasing trend of 90N-15P-20K-15S-2.5Zn-10Mg-0.5B > 60N-22.5P-0K > 60N-15P-0K > 60N-15P-30K > 60N-7.5P-0K > 40N-15P-0K > 60N-15P-20K > 60N-15P-10K > 60N-0P-0K > 40N-0P-0K > Control.

With manure application, the mean sorghum grain nutrient uptake was significantly ($P < 0.05$) higher than that of the control plots. The interaction effect of mineral fertilizer and cattle manure was not significant on grain nutrient uptake (Appendix 1).

Table 4.3 Effect of cattle manure and mineral fertilizer on N, P and K uptake by grain

Mineral fertilizer rates (kg ha^{-1})	Nutrient uptake (kg ha^{-1})		
	N	P	K
Control	23.60	3.74	6.25
40N-0P-0K	29.30	4.43	7.41
60N-0P-0K	32.20	4.81	8.04
40N-15P-0K	36.80	5.72	9.56
60N-15P-0K	40.60	6.24	10.42
60N-7.5P-0K	36.90	5.86	9.79
60N-22.5P-0K	45.40	6.95	11.61
60N-15P-10K	33.80	5.29	8.83
60N-15P-20K	36.00	5.64	9.43
60N-15P-30K	37.40	5.68	9.49
90N-15P-20K-15S-2.5Zn-10Mg-0.5B	48.30	6.85	11.45
F pr.	0.01	0.03	0.03
LSD (0.05)	11.88	1.81	3.03
Cattle manure (t ha^{-1})			
0	33.4	5.13	8.57
5	39.4	6.01	10.03
F pr.	0.02	0.03	0.03
LSD (0.05)	5.07	0.77	1.29
Manure x mineral fertilizer *F pr.*	0.40	0.42	0.42
LSD (0.05)	16.81	2.57	4.28

4.4 Effect of cattle manure and mineral fertilizer on N, P and K uptake by sorghum straw

The results in Tables 4.4.a and 4.4.b show that sorghum straw N, P and K uptake were significantly affected ($P < 0.05$) by manure, mineral fertilizer rates and their interaction except the effect of manure on straw K uptake.

The N uptake of sorghum straw was highest (43.76 kg ha^{-1}) under 60N-15P-10K fertilizer rate and lowest (11.87 kg ha^{-1}) under 60N-0P-0K fertilizer rate. The means of sorghum straw N uptake under 60N-15P-10K, 60N-22.5P-0K, 40N-0P-0K, 60N15P-30K and 40N-15P-0K were significantly higher than that of the reference plot (90N-15P-20K-15S-2.5Zn-10Mg-0.5B), the control and the other fertilizer rates. Sorghum straw P uptake was also highest (1.048 kg ha^{-1}) under 60N-15P-10K and lowest (0.36 kg ha^{-1}) in 60N-15P-20K mineral fertilizer treated plots. Phosphorus uptake under 60N-15P-10K, 60N-22.5P-0K, 60N-7.5P-0K, 60N-15P-30K, 60N-15P-0K and 40N-15P-0K were significantly higher than that of the control but lower than the reference plot. The potassium uptake by sorghum straw was highest in the control plot and lowest under 40N-15P-0K.

Table 4.4.a Effect of cattle manure and mineral fertilizer on N, P and K uptake by sorghum straw

	N	P	K
Control	13.66	0.47	79.80
40N-0P-0K	33.54	0.54	47.70
60N-0P-0K	11.87	0.65	39.10
40N-15P-0K	20.31	0.74	27.70
60N-15P-0K	16.90	0.78	52.90
60N-7.5P-0K	16.53	0.80	39.50
60N-22.5P-0K	34.01	1.04	58.20
60N-15P-10K	43.76	1.05	56.70
60N-15P-20K	13.55	0.36	53.00
60N-15P-30K	24.59	0.79	36.70

90N-15P-20K-15S-2.5Zn-10Mg-0.5B	13.02	0.86	52.80
F pr.	< 0.001	< 0.001	< 0.001
LSD (0.05)	6.739	0.21	18.43
Cattle manure rates (t ha^{-1}) 0			
	18.43	0.67	46.70
5	25.52	0.80	52.20
F pr.	< 0.001	0.004	0.161
LSD (0.05)	2.87	0.09	7.86

$^{-1}$) Straw nutrient uptake (kg ha^{-1}) Mineral fertilizer rates (kg ha

Table 4.4.b Cattle manure and mineral fertilizer interaction effect on N, P and K uptake by sorghum straw

Mineral fertilizer rates (kg ha^{-1})	Straw N, P, K uptake (kg ha^{-1})					
	N		P		K	
	Cattle manure rates (t ha^{-1})					
Control			0.57	0.37		112.10
40N-0P-0K	15.34	51.73	0.41	0.67	49.92	45.50
60N-0P-0K	14.80	8.94	0.85	0.45	55.10	23.15
40N-15P-0K	30.12	10.50	0.97	0.51	31.53	23.90
60N-15P-0K	19.62	14.17	0.54	1.01	50.51	55.20
60N-7.5P-0K	13.36	19.70	0.76	0.85	32.54	46.62
60N-22.5P-0K	23.06	44.96	0.74	1.34	55.22	61.24
60N-15P-10K	11.28	76.24	0.66	1.44	42.03	71.31
60N-15P-20K	17.40	9.70	0.32	0.40	64.50	41.50
60N-15P-30K	33.27	15.91	0.78	0.79	31.32	42.01
90N-15P-20K-15S-2,5Zn-10Mg-0,5B	8.97	17.07	0.72	1.00	53.40	52.24
F pr.	< 0.001		< 0.001		< 0.001	
LSD (0.05)	9.53		0.30		26.06	

0 **5** **0**

15.49 11.82 **0** **5** 47.51

5

4.5 Soil ammonium nitrogen dynamics under fertilizer application

The results in Tables 4.5.a and 4.5.b show that soil ammonium nitrogen content was significantly ($P < 0.05$) influenced by mineral fertilizer and its interaction with cattle manure at 2 and 6 weeks after application. However, soil ammonium nitrogen was not significantly ($P > 0.05$) affected 4 weeks after fertilizer application. Cattle manure rates applied did not influence significantly ($P > 0.05$) soil ammonium N content at all times of sampling. The means of soil ammonium N under 60N-0P-0K, 40N-15P-0K, 60N-15P-0K and 60N-15P-10K were higher and significantly different from that of the reference plot (90N-15P-20K-15S-2.5Zn-10Mg-0.5B), the control and the other treated plots.

At six (6) weeks after fertilizer application, the means of soil ammonium N obtained under four mineral fertilizer rates (60N-22.5P-0K,60N-15P-30K,40N-15P-0K and 60N-15P-20K) was not significantly different from the mean of the reference plot (90N-15P-20K-15S-2.5Zn-10Mg-0.5B). Generally, the results showed a decreasing trend of soil ammonium nitrogen content after cattle manure application.

Table 4.5.a. Effect of cattle manure and mineral fertilizer application on soil NH_4^+-N

Mineral fertilizer rates (kg ha^{-1})	NH_4^+-N (mg kg^{-1} soil)		
	2 WAFA	4 WAFA	6 WAFA
Control	38.24	37.58	38.91
40N-0P-0K	39.00	35.55	38.48
60N-0P-0K	42.11	38.18	41.80
40N-15P-0K	41.02	36.56	34.20
60N-15P-0K	40.47	36.25	36.10
60N-7.5P-0K	37.45	38.67	35.67
60N-22.5P-0K	38.24	36.68	34.60
60N-15P-10K	40.20	36.20	35.56
60N-15P-20K	34.92	35.50	33.85

60N-15P-30K	33.80	35.50	34.37
90N-15P-20K-15S-2.5Zn-10Mg-0.5B	36.40	42.13	32.03
F pr.	< 0.001	0.459	< 0.001
LSD (0.05)	2.70	5.615	2.867
Cattle manure rates (t ha^{-1}) 0			
	38.60	37.53	35.38
5	38.10	36.55	36.80
F pr.	0.076	0.583	0.158
LSD (0.05)	0.637	4.81	2.281
CV (%)	0.5	3.7	1.8

* WAFA: Week After Fertilizer Application

Table 4.5.b. Cattle manure and mineral fertilizer interaction effect on soil NH_4^+-N

Mineral fertilizer rates (kg ha^{-1})	NH_4^+-N (mg kg^{-1} soil)					
	2 WAFA		4 WAFA		6 WAFA	
	Cattle manure rates (t ha^{-1})					
		5	0		0	0 5 5
	36.76	39.73	37.13	38.03	36.68	41.15
40N-0P-0K	38.40	39.60	35.44	35.66	38.36	38.61
60N-0P-0K	42.08	42.13	38.28	38.08	39.15	44.44
40N-15P-0K	40.26	41.77	36.92	36.21	34.94	33.45
60N-15P-0K	39.48	41.45	38.76	33.75	38.21	33.99
60N-7.5P-0K	37.20	37.71	41.28	36.06	36.15	35.20
60N-22.5P-0K	39.20	37.27	37.65	35.72	29.30	39.90
60N-15P-10K	43.56	36.84	35.09	37.3	37.32	33.81
60N-15P-20K	34.97	34.87	35.60	35.39	30.99	36.72
60N-15P-30K	36.84	30.75	37.85	33.14	37.24	31.50
90N-15P-20K-						

15S-2,5Zn-10Mg-0,5B	35.86	36.94	38.80	45.46	30.80	33.25
F pr.	0.009		0.632		< 0.001	
LSD (0.05)	3.651		7.896		4.007	
CV (%)			12.9			

* WAFA: Week After Fertilizer Application

4.6 Soil available phosphorus dynamics under fertilizer application

The results in Tables 4.6.a and 4.6.b show that soil available phosphorus content was significantly ($P < 0.05$) influenced by mineral fertilizer rates, manure rates and their interaction. The highest mean value was observed under 60N-15P-10K whilst the lowest was under 60N-15P-30K mineral fertilizer rates. The soil available phosphorus obtained under all the mineral fertilizer rates were significantly ($P < 0.05$) different from that of the reference plot and the control two weeks after fertilizer application. Only plots under 40N-15P-0K and 60N-0P-0K produced statistically ($P > 0.05$) similar values to that of the reference plot.

At four weeks after fertilizer application, all fertilizer rates produced significantly higher values than the control. A similar observation was made at 6th week. In general, the soil available phosphorus content declined over time (Tables 4.6.a and 4.6.b) indicating crop uptake or losses. The interaction effect of cattle manure and mineral fertilizer on soil available P declined over time (Table 4.6.b). Soil available P under 60N-22.5P-0K and 60N-15P-0K with 5 t ha^{-1} cattle manure treated plots increased at 6 weeks after fertilizer application.

Table 4.6.a. Effect of cattle manure and mineral fertilizer application on soil available P

Mineral fertilizer rates (kg ha^{-1})	Available phosphorus (mg kg^{-1} soil)		
	2 WAFA	**4 WAFA**	**6 WAFA**
Control	9.95	6.97	7.77

40N-0P-0K	6.82	6.16	6.68
60N-0P-0K	9.36	7.72	7.91
40N-15P-0K	9.38	7.66	9.87
60N-15P-0K	9.74	10.42	11.67
60N-7.5P-0K	9.13	10.27	10.98
60N-22.5P-0K	8.65	6.32	6.69
60N-15P-10K	24.39	6.83	7.60
60N-15P-20K	11.10	8.98	6.07
60N-15P-30K	5.59	12.53	4.96
90N-15P-20K-15S-2,5Zn-10Mg-0,5B	10.65	7.62	8.63
F pr.	< 0.001	< 0.001	< 0.001
LSD (0.05)	0.17	0.21	0.18
Cattle manure rates (t ha^{-1}) 0	9.08	6.96	6.92
5	11.78	9.67	9.24
F pr.	< 0.001	< 0.001	0.001
LSD (0.05)	0.21	0.34	0.35

* WAFA: Week After Fertilizer Application

Table 4.6.b. Cattle manure and mineral fertilizer interaction effect on soil available P

Mineral fertilizer rates (kg ha^{-1})	Available phosphorus (mg kg^{-1} soil)					
	2 WAFA		4 WAFA		6 WAFA	
	Cattle manure rates (t ha^{-1})					
	0	5	0	5	0	5
Control	6.99	12.91	4.34	9.60	6.41	9.14
40N-0P-0K	5.82	7.81	6.26	6.06	7.22	6.15
60N-0P-0K	6.50	12.21	7.06	8.37	4.62	11.19
40N-15P-0K	7.18	11.58	5.82	9.49	11.27	8.46
60N-15P-0K	7.07	12.41	6.37	14.48	6.52	16.81
60N-7.5P-0K	7.26	10.99	9.14	11.40	12.23	9.73
60N-22.5P-0K	7.98	9.31	7.94	4.71	4.51	8.88
60N-15P-10K	28.48	20.30	6.83	6.82	7.94	7.26
60N-15P-20K	8.79	13.41	9.51	8.46	5.61	6.54
60N-15P-30K	5.21	5.97	7.26	17.80	4.53	5.38

90N-15P-20K-15S-2,5Zn-10Mg-0,5B	8.61	12.69	6.04	9.20	5.23	12.04
F pr.	< 0.001		< 0.001		< 0.001	
LSD (0.05)	0.25		0.33		0.31	

* WAFA: Week After Fertilizer Application

4.7 Soil exchangeable potassium dynamics under fertilizer application

The different fertilizer rates significantly influenced soil exchangeable K content at all periods of sampling (Table 4.7.a). The highest values were recorded on plots treated with 60N-15P-10K, 60N-15P-20K, 60N-0P-0K at 2, 4 and 6 weeks after fertilizer application. This not withstanding, the control plot produced a higher value than all the treated plots except the reference plot at 6 WAFA. The soil exchangeable K content under all the treated plots and the control declined over time. For example, in the reference plot, there was 7.69 % decline at 4 WAFA compared to 0.13 $cmol_{(+)}$ kg^{-1} soil recorded at 2 WAFA. At 6 WAFA, there was a 8.33 % decline over the mean value (0.12 $cmol_{(+)}$ kg^{-1} soil) recorded at 4 WAFA. Generally, the sharpest decline in the nutrient content was observed at 4 WAFA in all plots.

Cattle manure treated plots differed significantly (P < 0.05) from the control at all periods of sampling. Like the chemical fertilizer plots, the cattle manure amended plots registered a decline in K content over time, the highest decline observed at 4 WAFA. Cattle manure and chemical fertilizer application interacted significantly (P < 0.05) to affect the soil exchangeable K content at all periods of sampling (Table 4.7.b).

Table 4.7.a. Soil exchangeable K under fertilizer application

Mineral fertilizer rates	**Exchangeable potassium (cmol$_{(+)}$ kg^{-1} soil)**		
(kg ha^{-1})	**2 WAFA**	**4 WAFA**	**6 WAFA**
Control	0.13	0.12	0.11
40N-0P-0K	0.11	0.10	0.09

60N-0P-0K	0.11	0.12	0.11
40N-15P-0K	0.10	0.11	0.08
60N-15P-0K	0.11	0.12	0.10
60N-7.5P-0K	0.13	0.11	0.10
60N-22.5P-0K	0.11	0.10	0.10
60N-15P-10K	0.13	0.12	0.10
60N-15P-20K	0.12	0.12	0.10
60N-15P-30K	0.10	0.12	0.10
90N-15P-20K-15S-2,5Zn-10Mg-0,5B	0.13	0.12	0.11
F pr.	< 0.001	< 0.001	< 0.001
LSD (0.05)	0.002	0.003	0.001
Cattle manure rates (t ha^{-1})			
0	0.11	0.11	0.10
5	0.12	0.12	0.11
F pr.	0.059	0.004	0.007
LSD (0.05)	0.004	0.004	0.003

* WAFA: Week After Fertilizer Application

Table 4.7.b. Cattle manure and mineral fertilizer interaction effect on soil exchangeable K

Mineral fertilizer rates (kg ha^{-1})	**Exchangeable potassium (cmol$_{(+)}$ kg^{-1})**					
	2 WAFA		**4 WAFA**		**6WAFA**	
	Cattle manure rates (t ha^{-1})					
	0	**5**	**0**	**5**	**0**	**5**
Control	0.12	0.14	0.11	0.14	0.10	0.12
40N-0P-0K	0.10	0.12	0.10	0.11	0.09	0.09
60N-0P-0K	0.11	0.12	0.10	0.13	0.10	0.12
40N-15P-0K	0.10	0.10	0.10	0.11	0.08	0.09
60N-15P-0K	0.10	0.12	0.11	0.13	0.09	0.10
60N-7.5P-0K	0.13	0.13	0.13	0.10	0.09	0.10
60N-22.5P-0K	0.11	0.10	0.10	0.12	0.09	0.10

60N-15P-10K	0.15	0.12	0.11	0.12	0.11	0.10
60N-15P-20K	0.12	0.12	0.11	0.12	0.10	0.10
60N-15P-30K	0.10	0.10	0.11	0.13	0.10	0.10
90N-15P-20K-15S-2,5Zn-10Mg-0,5B	0.12	0.15	0.10	0.13	0.10	0.12
F pr.	< 0.001		< 0.001		< 0.001	
LSD (0.05)	0.004		0.004		0.002	

* WAFA: Week After Fertilizer Application

4.8 Effect of cattle manure and mineral fertilizer application on sorghum grain and straw yields

The analysis of variance (Table 4.8.a) show that manure and mineral fertilizer rates applied to the plots significantly (P < 0.05) affected sorghum grain while their interaction did not significantly influence the parameter. Sorghum straw yield was significantly affected by the manure rates. The effect of mineral fertilizer rates and their interaction with manure were not significant (P > 0.05) on sorghum straw yield.

The mean value of grain yield ranged from 1082 to 2009 kg ha^{-1} respectively under control and 60N-22.5P-0K fertilizer rate. The differences in grain yield between the control and different mineral fertilizer rates were significant (P < 0.05) except with 40N-0P-0K, 60N-0P-0K and 60N-15P-10K. Only plots under control, 40N-0P-0K and 60N-0P-0K mineral fertilizer rates produced grain yield which differed significantly from that of the reference plot. The grain yields obtained from the other plots were not significantly different from that of the reference plot. The effect of mineral fertilizer rates on sorghum grain yield was in a decreasing order of 60N22.5P-0K > 90N-15P-20K-15S-2.5Zn-10Mg-0.5B > 60N-15P-0K > 60N-7.5P-0K >

40N-15P-0K > 60N-15P-30K > 60N-15P-20K > 60N-15P-10K > 60N-0P-0K > 40N0P-0K > Control. The increase in grain yield percentage over control ranged from

18.48 % (40N-0P-0K) to 85.67 % (60N-22.5P-0K). Cattle manure treated plots produced significantly higher ($P < 0.05$) grain yield than the unamended plots.

The interaction effect of cattle manure and mineral fertilizer rates on grain yield (Appendix 3) was highest (2220.7 kg ha^{-1}) in the reference plot (90N-15P-20K-15S2.5Zn-10Mg-0.5B). The lowest grain yield recorded on 40N-15P-0K treated plots differed significantly ($P < 0.05$) from that of the reference plot. In terms of sorghum straw yield (Tables 4.8.a; Appendix 3), the mean values ranged from 5781 to 3823 kg ha^{-1}. There were no significant differences among the control and the mineral fertilizer rates.

Table 4.8.a. Effect of manure and mineral fertilizers on sorghum grain and straw yields

Mineral fertilizer rates (kg ha^{-1})	Grain yield (kg ha^{-1})	% Increase over control	Straw yield (kg ha^{-1})
Control	1082	-	4750
40N-0P-0K	1282	18.48	4235
60N-0P-0K	1391	28.56	3823
40N-15P-0K	1654	52.87	4693
60N-15P-0K	1803	66.64	4636
60N-7.5P-0K	1694	56.56	4579
60N-22.5P-0K	2009	85.67	5781

60N-15P-10K	1528	41.22	5208
60N-15P-20K	1631	50.74	4006
60N-15P-30K	1643	51.85	4407
90N-15P-20K-15S-2.5Zn-10Mg-0.5B	1980	82.99	4235
F pr.	0.022		0.153
LSD (0.05)	514.09		1262.28
Cattle manure rates (t ha^{-1}) 0		-	
	1482		4192
5	1736	17.14	4964
F pr.	0.024		0.006
LSD (0.05)	219.21		538.24
Manure x mineral fertilizer *F pr.*	0.387		0.215
LSD (0.05)	727.04		2109.40
CV (%)	27.50		23.70

4.9 Relationship between sorghum grain yield and soil nutrient (NPK) content

The sorghum grain yield was linearly related significantly to soil ammonium nitrogen with F probability of 0.02 as presented in Table 4.9.a. The relationship between sorghum grain yield and soil available phosphorus and potassium (Tables 4.9.b and 4.9.c) was not significant ($P > 0.05$). Soil ammonium nitrogen was negatively correlated to sorghum grain yield as shown in Equation 4.9.1.

Table 4.9.a. Simple linear regression between sorghum grain yield and soil NH_4^+-N content

Parameter	Coefficients	Std error	Significance
Constant	2323	311	< 0.001
NH_4^+-N (mg kg^{-1} soil)	-19.23	8.3	0.02

Std error: Standard error; r = coefficient of correlation

Sorghum grain yield = 2323 (±311) – 19.23 (±8.3) N-NH_4 in soil (Equation 4.9.1)

($r = 0.99$, $P < 0.001$)

Table 4.9.b. Simple linear regression between sorghum grain yield and soil available P

Parameter	Coefficients	Std error	Significance
Constant	1469	85.8	< 0.001
Avail. P (mg kg^{-1} soil)	15.64	8.74	0.075

Std error: Standard error; r = coefficient of correlation

Sorghum grain yield = 1469 (±85.8) + 15.64 (±8.74) P in soil (Equation 4.9.2)

(r = 0.91, P < 0.001)

Table 4.9.c. Simple linear regression between sorghum grain yield and soil exchangeable K

Parameter	Coefficients	Std error	Significance
Constant	1406	273	< 0.001
Exchangeable K ($cmol^{(+)}$ kg^{-1} soil)	4.72	6.28	0.453

Std error: Standard error; r = coefficient of correlation

Sorghum grain yield = 1406 (±273) + 4.72 (±6.28) K in soil (Equation 4.9.3)

(r = 0.99, P < 0.001)

4.10 Value-Cost Ratio

The VCR was calculated using the equation presented in 3.13. The increased grain yield values (obtained from the means of the interactive effect of cattle manure and mineral fertilizers) and the fertilizers cost was used to estimate the returns on investments at harvest and at the beginning of the wet season. The prices of sorghum grain were 115 Francs CFA kg^{-1} after harvest and 140 Francs CFA kg^{-1}.

After harvest (Table 4.10.a), two plots under 40N-15P-0K and 60N-22.5P-0K mineral fertilizer treatments had respectively VCR values of 1.65 and 1.23 whilst the other plots gave VCR less than 1 indicating unsatisfactory risk coverage against investment in fertilizer used. The interaction effect of cattle manure and 60N-7.5P0K, 60N-22.5P-

0K, 60N-0P-0K and 60N-15P-0K gave VCR greater than 1 (1.83 – 1.23) whilst the other plots had VCR less than 1. All the treatments showed unsatisfactory risk (VCR < 2) coverage against investment in fertilizer used after harvest.

At the beginning of the wet season (Table 4.10.b), all the mineral fertilizer treated plots showed no benefit against investment in fertilizer used (VCR less than 2) except 60N-22.5P-0K fertilizer rate which had a VCR of 2.01. However, 40N-15P0K and 60N-15P-0K treated plots gave VCR > 1. Cattle manure interaction with 60N-7.5P-0K mineral fertilizer rate obtained a VCR of 2.23 showing satisfactory risk coverage against investment in fertilizer used.

Table 4.10.a VCR after harvest

Value Cost Ratio (VCR) Mineral fertilizer rates (kg ha^{-1})	**0 t ha^{-1}**	**5 t ha^{-1}**
Control	-	-
40N-0P-0K	0.30	0.85
60N-0P-0K	-0.07	1.25
40N-15P-0K	1.23	0.74
60N-15P-0K	0.98	1.23
60N-7.5P-0K	0.25	1.83
60N-22.5P-0K	1.65	1.36
60N-15P-10K	0.66	0.59
60N-15P-20K	0.73	0.70
60N-15P-30K	0.70	0.65
90N-15P-20K-15S-2.5Zn-10Mg-0.5B	0.51	0.80

*115 FCFA kg^{-1} grain of sorghum (data from survey)

Table 4.10.b VCR at the beginning of the wet season

Mineral Fertilizer rate (kg ha^{-1})	Value Cost Ratio (VCR)	
	0 t ha^{-1}	5 t ha^{-1}
Control	-	-
40N-0P-0K	0.36	1.04
60N-0P-0K	-0.08	1.52
40N-15P-0K	1.50	0.90
60N-15P-0K	1.20	1.50
60N-7.5P-0K	0.31	2.23
60N-22.5P-0K	2.01	1.65
60N-15P-10K	0.80	0.72
60N-15P-20K	0.89	0.85
60N-15P-30K	0.85	0.79
90N-15P-20K-15S-2.5Zn-10Mg-0.5B	0.62	0.97

*140 FCFA kg^{-1} grain of sorghum (data from survey)

CHAPTER FIVE

5.0 DISCUSSION

5.1 Chemical characteristics of the manure used

The mean C: N ratio (17) recorded for cattle manure used in this study (Table 4.2) was less than 20. This indicates that the manure was of high quality as reported by Lloyd *et al.* (2003). High quality manures are known for faster decomposition and release of plant nutrients with less immobilization than poor quality ones.

5.2 Effect of cattle manure and mineral fertilizer on N, P and K uptake by grain and sorghum straw

The observation that sole applications of mineral fertilizer and cattle manure significantly increased sorghum grain and straw N, P and K uptake relative to the control (Tables 4.3 and 4.4.a) was due to their supply of nutrients to the soil. The application of cattle manure might have promoted sorghum root growth and development with increased soil moisture content (Ouattara *et al.*, 2006) resulting in adequate nutrient uptake. The results affirms the findings of Fatondji (2002) that 5 t ha^{-1} cattle manure induced positive response to nutrient uptake. Guled *et al.* (2010) and Shaheen *et al.* (2010) also reported that application of farm yard manure and mineral fertilizer significantly increased the uptake of N, P and K in grains and stover of sorghum. The comparatively higher nutrient uptake recorded in 60N-22.5P0K, 60N-15P-0K, 60N-15P-30K, 60N-7.5P-0K and 40N-15P-0K treated plots translated to relatively higher yields (Table 4.8.a).

5.3 Soil ammonium nitrogen content and its relationship with grain yield

The cattle manure applied did not increase significantly ($P > 0.05$) soil ammonium N content at all times of sampling (Table 4.5.a) despite its high quality (C/N ratio < 20). This observation could be attributed to low activities of soil microorganisms for the mineralisation of organic nitrogen due to low soil organic carbon content (0.46 %) of the study site. In contrast, Sanchez *et al.* (2002) reported that N mineralization increased because of the abundance of low C/N ratio substrate. Soil ammonium nitrogen content was significantly ($P < 0.05$) increased by the application of mineral fertilizer (Table 4.5.a) and its interaction with cattle manure (Table 4.5.b) due to the significant contribution of the mineral fertilizer to soil nitrogen content.

The decline in NH_4^+-N in all the treated plots over time could be due majorly to plant uptake even though leaching losses and ammonia volatilization can influence the process (Powlson, 1993). The sole applications of cattle manure and mineral fertilizer generally improved N uptake by sorghum plants as confirmed by the larger quantities of N contained in harvested sorghum (Tables 4.3; 4.4.1 and 4.4.2). This result is in conformity with findings of Bationo *et al.* (1998) and Zougmoré *et al.* (2004) that adequate addition of nutrients does not only stimulate improved biomass production but also extracts considerable quantities of nutrients from the soil. Zingore *et al.* (2007) also stated that the relationship of N and P removed in cropped products at farm and plot scales were consistent with the trends for N and P inputs as they significantly decreased with resource endowment of the farms.

5.4 Soil available phosphorus

Phosphorus is an essential macro nutrient for plant growth and is generally added to soil as a fertilizer thereby increasing the physiological efficiency of crops. Soil available P content was significantly ($P < 0.05$) increased by cattle manure, mineral fertilizer and their interactions with respect to the control (Tables 4.6.a and 4.6.b), due to the addition of P to the soil from the nutrient sources. When phosphorus fertilizer is applied to soil and dissolved by the soil water, various reactions occur between the phosphate and soil constituents which remove P from the solution phase and render it less available. This phenomenon is called P fixation or sorption (Idris and Ahmed, 2012). The decrease in soil available P content with time could possibly be due to crop uptake and P fixation. Lompo *et al.* (2008) studied the long- term effect of mineral and organo-mineral fertilizers on phosphorus dynamics in a Lixisol of Burkina Faso and reported that mineral fertilizer increased P fixation while the organo-mineral application decreased it. The grain yield of sorghum was not significantly correlated linearly to the soil available P content in this study (Table 4.9.b).

5.5 Soil exchangeable potassium

The result of this study showed a decline in soil exchangeable K content during the season (Tables 4.7.a and 4.7.b). A similar observation was made by Logah (2009) during the 2006 major cropping season in Ghana. However, when cattle manure was applied to the phosphorus treated plots, the interaction between the two nutrient sources generally reduced the decline in soil exchangeable K content with time (Table 4.7.b). Though this observation was not binding in some cases with respect to the nutrient application, the nutrient content in the sole P treated plots declined much more with time than when manure was added. Cattle manure and mineral fertilizer rates significantly affected soil exchangeable K in this study due to K supply from the added fertilizers despite the possibility of soil K being leached from the soil. The variation in K rates added to the soil did not significantly increase sorghum grain yield (grain yield was not significantly correlated linearly to soil exchangeable K content in Table 4.9). This suggests that K was not a limiting factor to sorghum growth in the study area (Ouattara *et al.*, 2006; Bado *et al.*, 2013). Bationo *et al.* (2008) reported that in SSA, N and P are the most limiting for crop production.

5.7 Effect of cattle manure and mineral fertilizer on sorghum grain yield

The relatively higher sorghum grain yield under cattle manure and mineral fertilizer rates could be related to N and P availability to plants and nutrient release from the manure.

With only mineral fertilizer application, plant nutrient needs were possibly met under

60N-22.5P-0K, 60N-15P-0K, 60N-7.5P-0K, 40N-15P-0K, 60N-15P-30K, 60N-15P20K and 60N-15P-10K treated plots which gave similar yields as the reference plot. This result could be attributed to the nutrients being readily made available from the mineral fertilizers applied and being taken by the plants. The lower rate of mineral fertilizer (40N-15P-0K) which produced grain yield similar ($P > 0.05$) to that of the reference plot (Table 4.8.a) showed that an increase beyond this rate cannot significantly increase sorghum grain yield. In Burkina Faso, Bado *et al.* (2013) reported for sorghum mono cropping, an optimum dose of 45 kg ha^{-1} N to produce at least 1600 kg ha^{-1} grain yield. The nutrient requirements for an improved variety of sorghum was 37 kg N ha^{-1}, 23 kg P ha^{-1}, 14 kg K ha^{-1} and 6 kg S ha^{-1} (Hien *et al.*, 1992) in the sub sudanian zone of the country. The results obtained in this study with a grain yield of 1654 kg ha^{-1} (52.87 % yield increase over the control) under 40N15P-0K mineral fertilizer rate showed a decrease in P rate to 35 % of the required rate. The rate of N was less than the 45 kg ha^{-1} which produced grain yield of 1600 kg ha^{-1} in the study of Bado *et al.* (2013). This not withstanding, variations in rainfall patterns and other local conditions could account for the yield differences observed in this study and that of Bado *et al.* (2013).

The interaction of cattle manure and mineral fertilizer did not increase significantly ($P > 0.05$) sorghum grain yield (Table 4.8.a and Appendix 3). This might be related to the additive effect between the two sources of nutrients. In a study in Burkina Faso, Bationo *et al.* (2005) reported that with low-quality manure applied with urea, there were additive effects at all levels of manure with inorganic-N. Ouédraogo *et al.* (2007) reported that low nutrient utilization efficiency due to moisture stress during grain filling induced antagonistic effect between sheep dung and urea. In this study, the interaction of cattle manure with 60N-7.5P-0K, 60N-22.5P-0K, 60N-15P-0K, 60N-0P-

0K, 60N-15P-20K, 60N-15P-30K and 60N-15P-10K gave similar grain yields to that of the reference plot. The variation in K rates did not significantly influence the intended grain yield. The low rate of mineral fertilizer in combination with 5 t ha^{-1} of cattle manure which recorded grain yield of 2197.8 kg ha^{-1} similar to the reference plot was 60 kg N ha^{-1} and 7.5 kg P ha^{-1}. This shows that an increase beyond this rate cannot significantly increase sorghum grain yield. Therefore, a reduction in mineral fertilizer P rate from 15 to 7.5 kg ha^{-1} in combination with cattle manure application can increase grain yield.

5.8 Value-cost ratio

The typical value-cost ratio (VCR) of fertilizer use for sorghum in West Africa is 1.9 (Bumb *et al.*, 2011). In this study, the VCR from sole manure application was negative (VCR < 1) indicating that increased grain yield cannot be correlated positively with cost of investment for cattle manure. Opoku (2011) obtained negative return on investment for using 5 t ha^{-1} sole manure application at Maradi.

The results of no satisfactory risk coverage against investment for mineral fertilizer in sole application obtained after harvest (Table 4.10.a) could be due to high cost of mineral fertilizer and low price of sorghum grain at the study location. Bationo *et al.* (2012b) affirmed that farm-level fertilizer prices in Africa are among the highest in the world. Mineral fertilizer applied alone can cause decline in soil organic carbon as observed on a ferruginous soil in Burkina Faso where 25 - 50 % of indigenous organic matter disappeared with mineral fertilizer application during the first 2 years of cultivation (Bationo *et al.*, 2005). Consequently, research results from long-term field experiments in the West African agro-ecosystems showed that without recycling of organic materials, the use of mineral fertilizers resulted in higher yields, but this increase was not sustainable (Bationo *et al.*, 2004).

The interaction of cattle manure and mineral fertilizer after harvest showed the highest VCR (1.83) less than 2 (Table 4.10.a), indicating that the increased grain yield obtained could not cover the nutrients investment made.

The highest VCR of 2.01 and 2.23 obtained respectively under sole application of 60N-22.5P-0K and the interaction of cattle manure with 60N-7.5P-0K at the beginning of the wet season marginally exceeded the critical value of 2 required to motivate farmers to apply mineral fertilizers. Therefore, the rate of application that can motivate farmers is 60 kg N ha^{-1} and 22.5 kg P ha^{-1} whilst the interaction between 5 t of cattle manure ha^{-1} and 60 kg N ha^{-1} and 7.5 kg P ha^{-1} mineral fertilizer is suggested (based on this study) for sustainable sorghum grain production at the study location in Burkina Faso.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Sorghum grain N, P and K uptake increased with the sole applications of mineral fertilizer and cattle manure while their interaction had no significant influence on these parameters. Conversely, N, P and K uptake by sorghum straw were generally increased by the sole applications of cattle manure, mineral fertilizer as well as their interaction.

Soil exchangeable K declined during the growing season under the different fertilizer rates whilst NH_4^+-N and available P distinctly showed decline four weeks after fertilizer application. The decline in the soil exchangeable K content was reduced when the different fertilizer rates were combined with cattle manure.

Based on grain yield response from sole application of mineral fertilizer, 60 kg N ha^1 and 22.5 kg P ha^{-1} can be considered appropriate rates for optimum sorghum grain yield. The combined application of cattle manure (5 t ha^{-1}) and mineral fertilizer (60 kg N ha^{-1} and 7.5 kg P ha^{-1}) gave the highest grain yield and could be appropriate for sorghum production in the study area.

The VCR of 2.01 and 2.23 obtained from the use of 60N-22.5P-0K and cattle manure at 5 t ha^{-1} with mineral fertilizer at 60N-7.5P-0K respectively at the beginning of the wet season were found to be the most cost effective options.

6.2 Recommendations

Based on the results of this study, 100 kg ha^{-1} (2 bags) of NPK (14-23-14) and 100 kg ha^{-1} (2 bags) of urea (46%) per hectare is recommended to farmers for sustainable sorghum production at the study area.

Although this study has provided the optimum rate of fertilizer for sorghum production in the sub-sudanian zone of Burkina Faso, long-term research should be carried out to assess nutrient availability to plants and water use efficiency under varying fertilizer rates in relation to crop yield.

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APPENDICES

Control			3.60			
40N-0P-0K	27.1	31.4	3.96	4.91	6.62	8.21

60N-0P-0K	23.2	41.2	3.49	6.14	5.82	10.25
40N-15P-0K	41.3	32.4	6.33	5.11	10.59	8.53
60N-15P-0K	38.8	42.5	5.82	6.65	9.72	11.12
60N-7.5P-0K	26.3	47.5	4.12	7.60	6.88	12.70
60N-22.5P-0K	43.1	47.7	6.65	7.25	11.12	12.11
60N-15P-10K	32.5	35.2	5.23	5.35	8.73	8.93
60N-15P-20K	36.5	35.5	5.55	5.74	9.27	9.59
60N-15P-30K	36.3	38.6	5.62	5.74	9.39	9.60
90N-15P-20K-15S-2,5Zn-10Mg-0,5B	41.2	55.3	6.02	7.69	10.06	12.83
F pr.	0.37		0.39		0.39	
LSD (0.05)	16.47		2.52		4.20	
(%)	27.5		27.5		27.5	

Mineral fertilizer rate (kg ha^{-1})	**Grain nutrient uptake (kg ha^{-1})**					
	N		**P**		**K**	
	Cattle manure rate (t ha^{-1})					
	0	**5**	**0**	**5**	**0**	**5**
	21.4	25.8		3.88	6.02	6.48

Appendix 1: Interaction of cattle manure and mineral fertilizer effect on grain N, P, K uptake

Appendix 2: Mineral fertilizer rates per hectare and per plot

Fertilizer type	**Fertilizer rate**

	Nutrient rate ($kg\ ha^{-1}$)	Fertilizer rate ($kg\ ha^{-1}$)	Fertilizer rate per plot ($g\ 24\ m^{-2}$)
Urea (46 % N)	40 N	86.96 Urea	208.70 Urea
	60 N	130.43 Urea	313.03 Urea
	90 N	195.65 Urea	469.56 Urea
TSP (45 % P_2O_5)	7.5 P_2O_5	16.66 TSP	39.98 TSP
	15 P_2O_5	33.33 TSP	79.99 TSP
	22.5 P_2O_5	50.00 TSP	120.00 TSP
KCl (60.8 % K_2O)	10 K_2O	16.45 KCl	39.46 KCl
	20 K_2O	32.89 KCl	78.94 KCl
	30 K_2O	49.34 KCl	118.42 KCl
$MgSO_4$ (25 % MgO)	10 MgO	40.00 $MgSO_4$	96.00 $MgSO_4$
$Na_2B_4O_7$, $5H_2O$ (48 % B_2O_3)	0.5 B_2O_5	1.04 Na_2B_4O7, $5H_2O$	2.5 Na2B4O7, 5H2O
$ZnSO_4$ (36.8 % Zn)	2.5 Zn	6.79 ZnSO4	16.29 ZnSO4

Appendix 3 Interaction effect of cattle manure and mineral fertilizer on

sorghum grain yield

Mineral fertilizer rate (kg ha^{-1})	**Grain yield (kg ha^{-1})**		**Straw yield (kg ha^{-1})**	
	Cattle manure rate (t ha^{-1})			
	0	**5**	**0**	**5**
Control	1042	1122	5037	4464
40N-0P-0K	1145	1419	2862	5609
60N-0P-0K	1007	1774	3640	4006
40N-15P-0K	1832	1477	4693	4693
60N-15P-0K	1683	1923	4693	4579
60N-7.5P-0K	1190	2198	3549	5609
60N-22.5P-0K	1923	2095	5151	6410
60N-15P-10K	1511	1545	4464	5952
60N-15P-20K	1603	1660	3663	4350
60N-15K-30K	1625	1660	4579	4235
90N-15P-20K-15S-2.5Zn-10Mg-0.5B	1740	2221	3777	4693
F pr.		0.36		0.22
LSD (0.05)		727.03		1785.13
(%)		27.50		23.70