UNIVERSITY FOR DEVELOPMENT STUDIES

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DEPARTMENT OF AGRONOMY

EFFECT OF FOUR NPK FERTILIZER FORMULATIONS AND THEIR APPLICATION RATES ON GROWTH AND YIELD OF MAIZE *(Zea mays* L.) IN THE GUINEA SAVANNAH AGROECOLOGY OF GHANA

RICHARD KWADWO KOMBAT

2015

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2015

DECLARATION

I hereby declare that this work is the result of my own research and the thesis either in full or part has never been presented in any other institution for a degree. All other references made from other researches have accordingly been cited.

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I hereby declare that the preparation and presentation of the thesis was supervised in accordance with the guidelines on supervision of thesis laid down by the University for Development Studies.

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ii

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ABSTRACT

Most farmers in the Northern Region of Ghana are unaware of other NPK formulations such as NPK 20-10-10, 20-20-20, 17-17-17, 23-10-10 and 23-10-5 but the most commonly used one is NPK 15-15-15. Pot and field experiments were set-up at the University for Development Studies (UDS) in the Guinea Savanna Zone of Ghana from January to April (Dry season) and June to October (Rainy season) respectively, to study the growth and yield response of maize to the application of NPK fertilizer formulations. In both pot (Experiment I) and field (Experiment II) studies, 4 x 4 factorial experiments were laid out in Randomized Complete Block Design (RCBD) with four replications. The sixteen treatments were made up of four NPK formulations; 15-15-15, 23-10-5, 23-10-10 and 20-10- 10, each applied at four rates; 0, 350, 375 and 400 kg/ha where 0 kg/ha was the control. Vegetative growth and yield parameters of maize were measured in both experiments. With all the parameters, application at 375 and 400 kg NPK/ha recorded the best performance in respect to the fertilizer formulations, and at all instances did not differ significantly from each other. Grain yield highly correlated positively with chlorophyll content, leaf area, stem girth, cob length, cob weight, stover weight, number of seeds per cob and thousand seed weight. Result for cost benefit analysis revealed that all control plots recorded losses, whiles all treated plots recorded profits. The application at 375 kg/ha maximised the most profit in all fertilizer formulations, except for NPK 23-10-10, where maximum return was achieved by application at 400 kg/ha. Among various formulations, NPK 15-15-15 recorded the highest average return, followed by 23-10-5, 20-10-10 and 23-10-10. The study recommends that irrespective of NPK fertilizer formulation, application at 375 kg/ha is recommended in maize production for maximum grain yield and profit; but for application at 350 kg/ha, 23-10-10 NPK is recommended for optimum yield and profit. Also based on accessibility and affordability, NPK ISIS-IS is highly recommended among the various formulations.

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May the Almighty God bless you all!

DEDICATION

I dedicate this piece of work to the greater glory and honour of God, for seeing me through this course, and not forgetting my dear children, especially Emmanuel Kombat and Jesse Kombat.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Field study

LIST OF EQUATIONS

CHAPTER ONE

INTRODUCTION

1.1 Background

Maize *(Zea mays* L.) is a member of the *Poaceae* family and it is among the popular cereal crops with high yielding potential (Jaliya *et al.*, 2008). Maize is primarily grown for the grain which is used for food but the crop is also cultivated for fodder especially in developed countries (Badu-Apraku *et al.*, 2003). Maize grain is a major source of feed for poultry and livestock across the globe (Morris *et al.*, 1999). Maize grain is nutritionally enriched, containing 72% starch, 10% protein, 4.8% oil, 8.5% fibre, 3.0% sugar and l.7% ash (Chaudhary, 1983), with the endosperm containing approximately 80% carbohydrates, 20% fat and 25% minerals; whiles the embryo contains about 80% fat, 75% minerals and 20% protein found in the kernel (Van Kempen *et al., 2003).*

Maize is the largest staple crop in Ghana and contributes significantly to consumer diets (F AO, 2008). It is the number one crop in terms of area planted and accounts for 50-60% of total cereal production (MoF A, 2000). Additionally, maize represents the second largest commodity crop in the country after cocoa and it is one of the most important crops for Ghana's agricultural sector and for food security. Utilization of maize varies among people in different parts of the world. It is consumed indirectly as secondary produce, mainly in meat, eggs and dairy products in developed countries (DARSA, 2003). In developing countries, maize is consumed directly and serves as staple diet for some 200 million people (Morris *et 01.,* 1999; DARSA, 2003). Most people regard maize as a breakfast cereal. However, in a processed form it is also found as fuel (ethanol) and starch. Starch in turn involves enzymatic conversion into products such as sorbitol, dextrine, sorbic and lactic acid, and appears in household items such as beer, ice cream, syrup, shoe polish, glue, fireworks, ink, batteries, mustard, cosmetics, aspirin and paint (Du Plessis, 2003).

Successful maize production depends on correct application of production inputs that will sustain the environment as well as agricultural production. Keen among these inputs is fertilization. Maize is a heavy feeder, particularly of nitrogen, phosphorus, and potassium; and requires adequate and balanced supply of these nutrients to attain optimum yield (Adediran and Banjoko, 2003). The assimilation of nitrogen, phosphorus and potassium reaches a peak during flowering. At maturity, the total nutrient uptake of a single maize plant is approximately 8.7 g of nitrogen, 5.1 g of phosphorus and 4.0 g of potassium (FAO, 2005). Each ton of grain produced removes 15.0 to 18.0 kg of nitrogen, 2.5 to 3.0 kg of phosphorus and 3.0 to 4.0 kg of potassium from the soil (FAO, 2005).

1.2 Problem statement

Food security is an urgent global issue (Jain, 2010). World population is expected to grow by over 2.3 billion between 2009 and 2050. Nearly all of this growth is forecast to take place in the developing countries, among which sub-Saharan Africa's population would grow the fastest (+114 percent) (pinstrup-Aderesen, 2002; FAO, 2009). The need to produce more food and fibre to feed a growing population is challenged with a multiplicity of factors.

Eighty percent (80%) of the growth in crop production in developing countries is expected to come from higher yields and increased cropping intensity, with the remainder coming from land expansion (Kabat, 2013). Arable land expansion of about 120 million in developing countries faces competition for other infrastructure development and expansion. With limited land resources, the impact of continuous cultivation has contributed adversely to the rapid depletion and imbalances of soil plant nutrients. Several decades of nutrient depletion has transformed the originally fertile arable lands that yielded 2 to 4 t/ha of cereal grain, into infertile ones where cereal crops yields of less than 1 t/ha are common (Bekunda *et 01.,* 1997). Low soil fertility has been identified as one of the major biophysical constraints adversely affecting maize production in the tropics (Sanchez *et 01., 1997).*

According to Adesina *et a1.* (1997) though there is increase in the production of fertilizer in Sub- Saharan Africa, crop yield is still not high. Therefore, it is glaring that high productivity is the function of the use of new innovations like fertilizer technology. Although 95% of farmers in Ghana are aware of inorganic fertilizer, 47% have used it in the last 2 years (AGRA, 2010). The most common fertilizers reported in the study area were sulfate of ammonia and NPK 15:15:15, according to 38% of the farmers. The only other fertilizer reported by more than 5% of farmers in the study area was urea. Farmers, however, are unaware of the NPK formulations such as NPK 20-10-10,20-20-20, 17-17-17, 23-10-10 and 23-10-5 (AGRA, 2010).

1.3 **Justification**

The projected trends in population growth will mean that market demand for food would continue to grow (Jain, 2010). Demand for cereals as human food and animal feed, is projected to reach some 3 billion tons by 2050 (HEF, 2009). This implies significant increases in the production of several key commodities. Annual cereal production, for instance, would have to grow by almost one billion tons, 72% of which is expected to come from developing countries, up from the 58% today (HEF, 2009).

The low fertility status of most tropical soils hindered maize production because maize has a strong exhausting effect on the soil. According to Adediran and Banjoko (2003), maize fails to produce good grain in the absence of adequate nutrients. Inorganic fertilizers exert strong influence on plant growth, development and yield (Stefano *et al.*, 2004). The availability of sufficient growth nutrients from inorganic fertilizers lead to improved cell activities, enhanced cell multiplication and enlargement and luxuriant growth (Fashina *et al., 2002).* Luxuriant growth resulting from fertilizer application leads to larger dry matter production (Obi *et al.*, 2005), owing to better utilization of solar radiation and more nutrient (Saeed *et al., 2001).*

With the introduction of new and high yielding crop varieties, soil nutrient mining will be on the increase when mineral fertilizer additions are absent or not in adequate amounts. Safo *et al* (1998) noted that, for most crops, the best fertilizer type, rate and time of application are not known and that this constitutes a constraint to the use of mineral fertilizer. They also noted that mineral fertilizers are not used because of their high cost, suggesting that mineral fertilizers should be included in fertilizer trials as those may be more financially acceptable to producers.

1.4 Objective

The objectives of this study were to determine;

- Growth and yield response of maize to NPK fertilizer formulations and application rates
- Most suitable NPK fertilizer formulations for improved growth and yield of maize in the Guinea savanna zone of Ghana
- Most appropriate NPK rate for improved growth and yield of maize in the Guinea savanna zone of Ghana
- The most economical NPK fertilizer formulation and application rate.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and botany of maize

There are numerous theories as to the ancestors of modem com and many scientific articles and books have been written on the subject. According to Galinat (1995) it is widely accepted that maize was domesticated from its ancestor teosinte *(Zea mexicana)*, though several authors have diverse opinions as to whether it is actually so. Evidence suggests that cultivated com arose through natural crossings, perhaps first with gamagrass to yield teosinte and then possibly with backcrossing of teosinte to primitive maize to produce modem races. Com is perhaps the most completely domesticated of all field crops. Its perpetuation for centuries has depended wholly on the care of man. It could not have existed as a wild plant in its present form.

Although maize is indigenous to the western hemisphere, its exact place of origin is far less certain. Archeological evidence of com's early presence in the western hemisphere was identified from com pollen grain considered to be 80,000 years old obtained from drill cores 200 feet below Mexico City (Oladejo and Adetunji, 2012). Another archeological study of the bat caves in New Mexico revealed com cobs that were 5,600 years old by radiocarbon determination. Most historians believe com was domesticated in the Tehuacan Valley of Mexico. The original wild form has long been extinct (Oladejo and Adetunji, 2012).

Maize plant is often 2.5 m in height, though some natural strains can grow 12 m. The stem is commonly composed of 20 internodes which are 18 cm in length (Karl, 2013). A leaf grows from each node, which is generally 9 cm in width and 120 cm in length (Stevenson and Goodman, 1972). Maize can form 8-20 leaves which are usually arranged spirally on the stem in two opposite rows. Its leaf is typical of the grasses, consisting of a sheath, ligules, auricles and a blade. The leaf blade is distinctively conspicuous, long, narrow, undulating and tapers towards the tip and is glabrous to hairy. The plant has a fine root system that grows profusely. Total root length, excluding the root hairs, can reach 1.5 m under optimal conditions.

The female inflorescence (ear) is enclosed by bracts and the silk (Hitchcock and Chase, 1971). The silk of the flowers at the bottom appear first and before those on the upper part of the ear. The silk remains receptive to pollen for approximately three weeks; its receptivity however, decreases after the tenth day.

2.2 Production

Maize is the largest staple crop in Ghana and contributes significantly to consumer diets. It is the number one crop in terms of area planted and accounts for 50-60% of total cereal production followed by paddy rice (23%), sorghum (13%) and millet (9%). Additionally, maize represents the second largest commodity crop in the country after cocoa. Maize is the most important cereal crop on the domestic market in Ghana, however, it is the 7th largest agricultural commodity in terms of value of production over the period 2005-2010 accounting for 3.3% of total agricultural production value (FAOSTAT, 2006). Maize is also an important component of poultry feed and to a lesser extent the livestock feed sector as well as a substitute for the brewing industry.

Maize production in Ghana is currently dominated by smallholder farmers who rely mostly on rain fed conditions with limited use of improved seeds, fertilizer, mechanisation, and post-harvest facilities. As a result, average yields in Ghana are well below attainable levels and post-harvest losses are high. Maize yields in Ghana average approximately 1.5 Mt/ha though the Ministry of Food and Agriculture in 2009 recorded an average yield of 1.9 Mt/ha which was still below an estimated achievable yield of around 2.5 to 4 Mt/ha (MoF A, 2009). However, yields as high as 5.0-5.5 Mt/ha have been realized by farmers using improved seeds, fertilizer, mechanisation and irrigation.

2.3 Climate and soil requirements

Maize is a warm weather crop and is not grown in areas where the mean daily temperature is less than 19 DC or where the mean of the summer months is less than 23^{D}C. According to Fageria *et al* (1997) maize does well within a temperature range of 21-300C. Minimum temperature for germination is 12 DC. Germination will, however, be faster and less variable at soil temperatures of 16 to 18 DC (Belfield and Brown, 2008). At 20 DC, maize should emerge within five to six days. The critical temperature detrimentally affecting yield is approximately 32 DC. Frost can damage maize at all growth stages and a frost-free period of 120 to 140 days is required to prevent damage. While the growth point is below the soil surface, new leaves will form and frost damage will not be too serious. Leaves of mature plants are easily damaged by frost and grain filling can be adversely affected. Approximately 10 to 16 kg of grain are produced for every millimeter of water used. A yield of 3152 kg/ha requires between 350 and 450 mm of rain per annum. At maturity, each plant will have used 250 litres of water in the absence of moisture stress (Belfield and Brown, 2008).

Maize thrives in well drained sandy loam soil with a pH of 5.7-7.5 and 500-800 mm of rainfall evenly distributed throughout the growing season for good yield. The most suitable soil for maize is one with a good effective depth, favourable morphological properties, good internal drainage, an optimal moisture regime, sufficient and balanced quantities of plant nutrients and chemical properties that are favourable specifically for maize production (paliwal *et al.*, 2000). Although large-scale maize production takes place on soils with a clay content of less than 10% (sandy soils) or in excess of 30% (clay and clay-loam soils), the texture classes between 10 and 30% have air and moisture regimes that are optimal for healthy maize production (paliwal *et al., 2000).*

Maize can be grown on a wide variety of soils, but performs best on well-drained, well-aerated, deep warm loams and silt loams containing adequate organic matter and well supplied with available nutrients (Paliwal *et al*, 2000). Although it grows on a wide range of soils, it does not yield well on poor sandy soils, except with heavy application of fertilizers. On heavy clay soils, deep cultivation and ridging is necessary to improve drainage. Maize is suited for off-season cropping in swamps provided drainage is adequate though planting in swamps is not always

Recommended for environmental reasons. It does not tolerate water logging; it can be killed if it stands in water for as long as two days.

Maize can be grown successfully on soils with a pH of 5.0 - 7.0 but a moderately acid environment of pH 6.0 - 7.0 is optimum (Benneh *et a1.,* 1990). Outside the range results in nutrient deficiency and mineral toxicity. Liming is required for good yields on more acid soils. Maize has a high nitrogen requirement; and high yields of maize make a heavy drain on soil nutrients. High yields are obtained from optimum plant population with appropriate soil fertility, and adequate soil moisture. Where possible, it is advisable to have soils routinely analysed in order to know the characteristics of the soils and to get advice on how to improve soil fertility and/or correct soil pH for optimum maize production.

Low organic carbon(<1.5%), total nitrogen (<0.2 %), exchangeable potassium (<100 mg/kg) and available phosphorus (<10 ppm) are characteristics of soils in the major maize production areas in Ghana (Adu, 1995; Benneh *et a1., 1990).* Large proportions of the soil are also shallow and contain iron and manganese at high concentrations (Adu, 1969). These shortcomings together with poor soil fertility management, is a major constraint to maize production in the country.

2.4 The Ghanaian soil

Relative to other continents in the world, most of the soils in Sub-Saharan Africa (SSA) are naturally not very fertile (Kolawole and Joyce, 2009). They are typically low in available nitrogen and commonly deficient in sulphur, magnesium and zinc (Grant, 1981). Additionally, they are heavily leached, with high acidity (pH<5.5), low amount of soil organic matter and cation exchange capacity (Alwis, 1995). In addition to chronic macronutrient deficiencies, micronutrients such as zinc and boron are reportedly limited at site subjected to continuous cropping (Wendt *et al.*, 1995). Physically, SSA soils are low in soil organic matter coupled with poor land cover resulting in poor soil structure, root depth and subsequent susceptibility to periodic soil erosion.

The soils of Ghana are highly weathered with predominantly light textured surface horizons in which sandy loams and loams are the common textural classes (FAO, 2006). The lower soil horizons have relatively heavier textures varying from coarse sandy clay loams/sandy loams to clays. Heavier textured soils are normally abundant in the valley bottoms, which are ideal for rice cultivation (FAO, 2006). The B-horizons - subsurface horizons showing features of accumulation or significant alterations - may contain abundant coarse material either as gravel or stone/concretionary materials. The coarse nature of the soils has an adverse impact on their physical properties, particularly their water holding capacity. Thus crop water stress is not uncommon during the growing season.

Nutrient input and output balances are very essential for maintaining balances in soil nutrient (Buri *et al.*, 2008). Considerably more plant nutrients are being removed and lost than are being applied, with a consequent progressive impoverishment of soils. Traditional, soil exhausting cultivation practices are still used extensively (Gerner *et al.*, 1995). According to FAO (2004a) almost all the crop balances in Ghana show a nutrient deficit (the difference between the quantities of plant nutrients applied and the quantities removed or lost). This represents a loss of potential yield and progressive soil impoverishment.

2.5 Economic importance

Maize is the third most important cereal grain in the world after wheat and rice, providing nutrients for humans and animals (IITA, 2009). Maize is an important food in Asia, Africa, Latin America, and parts of the former Soviet Union (Adetiminrin *et al.*, 2008). Each country has one or more maize dishes that are unique to its culture; *ogi* (Nigeria), *kenkey* (Ghana), *koga* (Cameroon), *to* (Mali), *injera* (Ethiopia), and *ugali* (Kenya). Most of these products are processed in traditional ways. In Africa, ground maize is cooked into a paste or mush and eaten while still warm, accompanied by a thick low-alcoholic beer. In some areas of Africa, maize mush is fried or baked. In Central and Latin America, maize is consumed in the form of maize bread or tortillas. It is also used as animal feed and raw material for industrial use. In industrialised countries, a larger proportion of the grain is used as livestock feed and as industrial raw material for food and nonfood uses. On the other hand, the bulk of maize produced in developing countries is used as human food, although its use as animal feed is currently on the rise (IITA, 2009). It also serves as a basic raw material for the production of starch, oil, protein, alcoholic beverages, food sweeteners, and fuel. Maize has the highest average yield per hectare among the cereals (Morris, 2002).

Maize constitute a major staple food in Ghana especially in the savanna agroecological zone where it is even replacing sorghum and millet which were the major staples some years ago (Quarrie *et al.*, 1999). Domestic maize production seems to be meeting the local demand for human consumption. However, human consumption is competing with the poultry industry and to a lesser extent the livestock industry. While there is no reliable data for maize used in animal feed, the Government of Ghana estimates that 85% of all maize grown in Ghana is used for human consumption and the remaining 15% is used for the animal feeding sector (mainly poultry) (Morris, 2002). The per capital consumption of maize in Ghana in 2000 was estimated at 42.5 kg (MoFA, 2000), and an estimated national consumption of 943000 Mt in 2006 (SRID, 2007). Data obtained from major feed mills in Ghana indicates that about 250 000 Mt of maize is used for poultry feed annually.

Maize is currently produced on nearly 100 million hectares in 125 developing countries and is among the three most widely grown crops in 75 of those countries. About 67% of the total maize production in the developing world comes from low and lower middle income countries and thus maize plays an important role in the livelihoods of millions of poor farmers (FAOSTAT 2008).

Maize is a multipurpose crop because every part of its plant has economic value. The grain, leaves, stalk, tassel and cob can all be used to produce a large variety of food and non-food products (UTA, 2001). According to Ogunsumi *et al (2005)* maize has a variety of uses. Its grain is a rich source of starch, vitamins, proteins and minerals. The oil present in com (rich in embryo) is far and widely used for cooking and manufacture of soaps. Sticky gum contains dextrin used for sealing envelopes and labels. Corn silk contains maizeric acid, fixed oils, resin, sugar, mucilage, salt and fibres essential for our diet. Corn starch is well recognized for its uses in cosmetics and pharmaceutical industries as diluents. Corn syrup from maize contains high fructose and act as sweetener and retains moisture when added to certain foods. Corn seeds are functional in making alcohol and stem fibres for manufacture of paper. Maize is also a source of raw materials for industries to produce products such as com flakes, maltodextrines (com oil). Corn syrup and products of fermentation and distillation are produced from maize (Agbato 2003). Roasted seeds are used as coffee substitute. Phytochemical secondary metabolites such as saponin, allantoin, sterol, stigmasterol, alkaloids, hordenine and polyphenols are found in the leaves, seeds and silk (Breadley, 1992).

From the ancient time com has been used to pacify kapha, pitta, anorexia, general debilities, emaciation and haemorrhoids (Kumar and Jhaliya, 2013). It is a potent antioxidant that guards body from harming by free radicals responsible for cellular damage and/or cancer. It has the potential to alleviate pain and possess analgesic activity as well (Owoyele *et al.*, 2010). Due to production of sex related hormones assemble; maize is good for sexual health especially for men with erectile dysfunctions (Kumar and Jhaliya, 2013). It is believed to improve symptoms of rheumatism as the presence of B-complex is able to improve joint motility. Major nutrient of com silk is potassium that is a powerful diuretic. In Europe and some other countries such as French, Spain, Greece, and India, com silk is used to conquer urinary tract infections and kidney stones (Lans, 2006). In China it has been widely taken in case of fluid retention and jaundice. Corn silk improves blood pressure and support liver functioning as well as producing bile. Roots, leaves and the silk are used as decoction for bladder while the decoction of cob as tea is used to treat stomach complaints. Maize acts as a good emollient for ulcer, wound and swelling. In some places decoction of corn silk and parched corn is extremely useful in nausea and vomiting (Kumar and Jhaliya, 2013).

2.6 Fertilizer formulations

The use of appropriate land improvement/intensification technology seems to offer an opportunity to substantially increase farm production and income levels. Dankyi *et al.* (2005) made reference to poor soil nutrition in maize production as among the causes of low yield. In response, some fertilizer companies have also come out with various formulations of fertilizers. There exist a comprehensive range of fertilizer formulations that supply the most essential plant nutrients, a combination of N, P and K designed to maximise crop yield and quality. Formulated to meet precise crop requirements, these NPKs are some of the most highly efficient sources of N, P and K available. Each NPK formulation is tailored to supply precise amount of N, P and K, so that when accurately applied to a crop the fertilizers ensure accurate addition of these major nutrients. However, some NPK fertilizers have been formulated such that in addition to supplying N, P and K, supply secondary macro nutrients and micro nutrients essential for specific crops. These include essential nutrients, from magnesium (Mg) and sulfur (S) to manganese (Mn) and zinc (Zn), which ensure balanced nutrition throughout the growing season and result in improved yield and quality (Du-Plessis, 2003). NPK fertilizers are mostly ammonium nitrate base compound fertilizer. It contains some or all of the following: ammonium salts, phosphate salts, potassium salt, inert fillers, secondary nutrients and coating agents. For example NPK 15-15-15 are formulated to supply 15% each of N, P20S and K20, whiles 23-10-10 and 20-10- 10 are formulated to respectively supply 23 and 20% of N, and 10% each ofP20s and K20 respectively. On the other hand, actyva supplies Sulphur (S), magnesium oxide (MgO) and zinc (Zn) in addition to 23, 10 and 5% of N, P and K respectively (Nyalemegbe *et al., 2012).*

Regardless of the availability of numerous fertilizer formulations on the Ghanaian market, the use of adequate fertilizer remains low due primarily to poverty among farmers, coupled with their unawareness of different fertilizer formulations (Banziger et al., 1997).

2.7 Fertilizer Recommendations

Soil conditions have changed over the years and the old recommendations are not the most efficient today hence the need to update fertilizer recommendations for crops in Ghana. It is therefore necessary to update fertilizer recommendation for maize. Over supply or under supply of plant nutrients can have negative consequences on crop growth and this may result in the desired outcome not being obtained. The principle of balanced fertilization requires that this damaging effect be eliminated through the judicious use of fertilizers in order to sustain an economically viable and environmentally friendly agriculture that will meet the requirements of the future (Ernst and Mutert, 1995).

With the introduction of new and high yielding crop varieties, soil nutrient mining will be on the increase when mineral additions are absent or not in adequate amounts. Safo *et al* (1998) noted that, for most crops, the best fertilizer type, rate and time of application are not known and that this constitutes a constraint to the use of fertilizer. They also noted that mineral fertilizers are not used because of their high cost, suggesting that lower rates of mineral fertilizers should be included in fertilizer trials because they may be more acceptable financially to producers. IFDC (1998) reported that annual rate of nutrient depletion from soils of Ghana between 1993-95 in kg of N + *P20S* + K20 per ha was 51-100 kg while the average annual rate of nutrients required to achieve optimum levels of crop production in kg of N + *P20S* + K20 per ha was greater than 80 kg/ha.

2.8 Fertilizer use in Ghana

During the 1970s, fertilizer consumption increased ten-fold with a peak of about 31 000 tonnes total nutrient in 1977 (FAO, 2005). The FAO Fertilizer Programme was very active in Ghana and this probably contributed to the increase. However, this level still represented a low average rate of fertilizer use per hectare of cultivated land. From 1984 onwards fertilizer consumption fell following the introduction of the Structural Adjustment Programme and the removal of most agricultural support, including fertilizer subsidies (F AO, 2005). It increased in the second half of the 1990s following an improvement in the national economy but fell again as a result of renewed financial problems and depreciation of the Cedi. Nevertheless, in 2002 it recovered to the level of the early 1980s. However, at about 5 kg per hectare of cultivated land, it is at half the level of sub-Saharan Africa and at a quarter of the level of Africa as a whole. Currently, fertilizer use in

Sub-Saharan Africa averages 9 kilograms per hectare, the lowest of any developing region by far (FAO, 2004b).

Although the importance of mineral fertilizer is clearly emphasised in development plans, its adoption in Ghana is very slow. The average application rate is less than 8 kg/ha, which is relatively lower than in other countries like Malawi and Kenya where application rates are 22 and 32 kg/ha (Fuentes *et al.*, 2012). The major cash crops like cocoa and cotton account for the highest application rates in Ghana. Application rate is moderate for maize and negligible for crops such as millet, cassava, sorghum and yam (FAO, 2005). The number of households using fertilizer is less than 20% on average, although it varies from one place to another within the country (Quinones and Diao, 2011).

Fertilizer consumption (kg/ha of arable land) in Ghana was measured as 11.88 kg/ha (World Bank, 2006). Fertilizer consumption (100 g/ha of arable land) measures the quantity of plant nutrients used per unit of arable land. Fertilizer products cover N, P (including ground rock phosphate) and K fertilizers. Traditional nutrients, such as animal and plant manures, are not included.

2.9 Fertilizer use in Sub-Saharan Africa

Food production in Sub-Saharan Africa continues to lag behind population growth. Population growth will greatly increase the amount of food needed to adequately feed Sub-Saharan Africa's population. Food security on the continent has worsened since 1970 and the proportion of the malnourished population has remained within the 33-35% range in Sub-Saharan Africa (Rosegrant *et al., 2005).*

Agriculture in Sub-Saharan Africa is characterised by over-reliance on primary agriculture low soil fertility and minimum use of external farm inputs (Kherallah *et al.*, 2002). There is an overall decline in farm input investment including fertilizers seeds and technology adoption. Soil fertility management must be enhanced if Africa is to overcome its food production crisis. Mineral fertilizers and improved management strategies play vital roles in achieving such efficacy.

The need for fertilizer application is widely recognised as it is readily observed that plants grown in soil with freshly applied fertilizer shows better response to growth and yield (F AO. 2003). Mineral fertilizer will remain a key component of soil fertility management and an essential element of any agricultural development strategy or plan to increase food production in Sub-Saharan Africa (Donovan and Casey. 1998). According to Viyas (1983). 50-75% of crop yield improvement obtained in some non-African developing countries since the mid-1960s has been attributed to fertilizers. Soil nutrient depletion is a fundamental bio-physical limiting factor responsible for slow growth of crop production. and is a consequent of most African agriculture (Stoorvogel *et al.;* 1993). Estimated net loss in SSA has averaged about 660 kg of nitrogen. 75 kg of phosphorus and 450 kg of potassium per hectare over the last thirty years over about 100 million hectares of cultivated lands (Smaling, 1993; Sanchez *et al.*, 1995). According to Dudal and Byrnes (1993), the outcome of low fertilizer use in the nearest future will be nutrient mining and continuous use of marginal lands the effects of which will be devastating than those anticipated for increased fertilizer use. With reference to the high soil nutrient depletion and poor soil fertility management coupled with low use of mineral fertilizers in Sub-Saharah Africa, many authors have suggested an increase by 15% or more per annum of fertilizer consumption (Desai and Gandhi, 1990; Larson, 1993).

Estimated net loss in SSA has averaged about 660 kg of nitrogen, 75 kg of phosphorus and 450 kg of potassium per hectare over the last 30 years over about 100 million of cultivated lands (Smaling *et al*., 1997; Sanchez *et al*., 1995). This is proportional to 1.4 ton urea ha^{-1}, 375 kg triple superphosphate (TSP) ha^{-1} or 0.9 ton phosphate rock (PR) of average composition ha^{-1}, and 896 kg KC1 ha^{-1}. These figures are representative of balance between nutrient inputs as fertilizers, atmospheric deposition, microbial N_2 fixation and sedimentation, and nutrient outputs as harvested products, crop residue removals, losses through leaching, gaseous losses, surface runoff and erosion.

Nutrient depletion rates are site specific; they are dependent on the extent of land usage in previous years. This results in a land mining to variable degrees in respective sites. Nutrient depletion at certain sites is almost negligible either due to low-intensive land usage or nutrient replacement through fertilizer application. Per annum nutrient depletion on cultivated lands in Africa is estimated at 4.4 million tons nitrogen, 0.5 million tons phosphorus and 3 million tons potassium, which according to FAO (1998) is higher in magnitude than annual fertilizer consumption.

2.10 NPK fertilizer application and maize production

Maize is a heavy feeder and thus very responsive to timely and adequate application of NPK fertilizer. Fertilizer recommendations are made based on routine soil analysis, hence they vary from one soil to another as different soils vary in properties. Application of 15% each of the primary macro-nutrients, NPK either at planting or two weeks afterwards of 50 kg bag per acre followed by topdressing with either sulphate of ammonia or urea at 50 kg or 25 kg per acre, respectively, just before tasseling is accepted as the recommended rate of mineral fertilizer for maize production in Ghana (MoFA, 1998). The use of chemical fertilizers brings about increase in yield of crops because the elements in those fertilizers are readily available to be used by crops as compared to organic fertilizers. According to Ashgar *et al.* (2010), mineral fertilizers play an important role in increasing maize yield and their contribution is 40-45%. NPK fertilizers exert strong influence on plant growth, development and yield and the availability of sufficient growth nutrients in NPK fertilizers lead to improved cell activities, enhanced cell multiplication and enlargement and luxuriant growth (Fashina *et al.*, 2002).

Mineral fertilizers have proven very useful in modem agriculture in supplying readily available nutrients essential for crop growth. These available nutrients are used to correct known plant-nutrient deficiencies which aid plants in withstanding stress conditions, maintain optimum soil fertility conditions and to improve crop quality. NPK fertilizers are very crucial to the nutrition of most cereal crops especially maize. The usefulness of NPK fertilizer on maize is evident throughout its growth stages. The fertilizers are influential on growth parameters such as plant height, stem girth, and biomass accumulation. The fertilizer dictates the pattern of vegetative growth to a significant extent (Niehues *et al., 2004).*

Nitrogen promotes rapid vegetative growth (leaf and stems) at the expense of reproductive parameters, and consequently results in prolonging maturity in maize (Ekwere *et al.,* 2013). Jaliya *et al.* (2008) conducted a research and reported that increase in fertilizer rate resulted in increased number of grains/cob, cob weight/plant, cob yield per ha, grain weight per plant, grain yield per ha and 100-grain weight. Results from an experiment conducted in Kenya by Achieng *et al.* (2010) revealed a significantly higher number of cobs, stover yield and grain yield of maize when treated with NPK (17: 17: 17) at the rate of 144, 60 and 120 kg/ha of each respectively at planting followed by 56 kg/ha top-dressing with urea, supplemented by Mg (MgS04.7H20) at 20 kg/ha and B (Na2B407.10H20) at 5 kg/ha at planting. Another study carried out in Nigeria revealed an extensive residual effect of NPK in the soil. Grain yield of maize positively correlated with soil organic carbon, CEC, aggregate stability and bulk density (Mbah and Onweremadu, 2009). Obdiebube *et al.* (2012) studied the effect of different levels of NPK (15:15:15) at the rate of 0.10, 0.13, 0.15 kg/ha and a control (0 kg/ha) on maize. Results from the study showed that 0.15 kg/ha level improved parameters measured (plant height, number of leaves, leaf area, fresh weight, ear length, 100 seed weight and grain yield) better than the lower application rates. Kolawole and Joyce (2009) also conducted a field study to estimate the effect of NPK 15:15:15 fertilizer on the growth and yield of maize. NPK fertilizer applications .

significantly increased plant height, stem girth, number of leaves, leaf area, leaf area index, dry matter accumulation and yield. The optimum level of NPK 15: 15: 15 fertilizer for successful production of maize grains was 400 (60 kg N + 27.16 kg P + 49.80 kg K) kg / ha compound fertilizer based on the fact that it had the greatest dry cob yield (12.44 t / ha), grain yield (7.95 t /ha), relative grain yield (2.26) and 100-seed weight (11.62 g).

Xie *et al* (2004) investigated the effect of N-P20S-K20, kg/ha at 0-0-0,195-75-90, 0-75-90, 195-0-90 and 195-75-0 on two high quality maize varieties. The yield increase produced by the balanced NPK application was significantly higher than the unbalanced NPK and treatment without fertilizer in both maize hybrids in the order NPK>NP>PK>NK. Egbe *et al.* (2012) studied the impact of N application on growth and yield of maize grown alone and in combination with *Calliandra* prunings, *Gliricidia* prunings or Senna prunings. The greatest grain yield was observed in *Calliandra* + fertilizer (4696kg/ha) and least in control (3332 kg/ha). Ahmed *et al.* (2006) also combined organic fertilizer source with 50% of recommended NPK fertilizers and found that these fertilizers produced the greatest grain and biological yields of maize over the 50% NPK treatment and were statistically similar to the 100% NPK fertilizer. A similar study revealed that the application of poultry manure plus inorganic fertilizers resulted in greatest grain yield whiles the least yield was obtained when only inorganic fertilizer was applied (Adamu and Leye, 2012).

Shepherd *et al.* (1997) worked on nitrogen, phosphorus and other nutrients at different concentration responses and found out that under conditions of minimal phosphate, growth is substantially reduced. Hoekstra (1988) also reported that characterisation studies in the highlands of western Kenya identified decline in soil fertility as a factor limiting crop production. Crop production on tropical soils is highly limited by nitrogen and phosphorus deficiencies mainly because of the continuous cropping without or little application of these nutrients. There have been concerns about the continued decline in soil productivity under smallholder farming systems, hence increased call for increased fertilizer use, as limited use of fertilizers adds to decline in yields and narrows marginal profits (Heisey and Mwangi, 1996).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Location and site characteristics

Two experiments; Experiment I (pot study) and Experiment II (field study) were carried out. Both experiments were conducted at the University for Development Studies, Tamale, Ghana, during the 2014 cropping season from January to April and June to October, 2014, respectively, for the pot and field studies.

The experimental location lies on an altitude of 183m, and latitude 09° 25' N and longitude 0° 58'W. The area is within the Guinea savannah agroecological zone and is subjected to marked wet and dry season with a unimodal rainfall approximately 1000 mm which is evenly distributed from May to October, reaching a peak in August and September. Temperature distribution is uniform with mean monthly minimum of 23.4°C and maximum of 34.5°C. The minimum relative humidity is 46% and maximum relative humidity 76.8% (SARI, 2008).

3.2 Soil Sampling and analysis

Soil samples were taken along the two diagonals of the field prior to the pot experiment. Ten cores, picked at a 15 cm depth along each diagonal at a regular interval of 5.17 m were composited. The samples were air dried by placing them on a shallow tray in a well-ventilated area. The soil lumps were crushed so that the gravel, roots and organic residues could be separated. Smashing of any soft gravel was avoided. The soil was sieved through a 2 mm sieve, and then gently rubbed the clumbs through the mesh leaving the gravels, roots and other debris in the sieve.

Soil analysis was carried out at the soil chemistry laboratory of the Savanna Agriculture Research Institute (SARI), in the Northern Region of Ghana. A glass electrode was used in the determination of soil pH in 0.01 M $CaCl_2$. Particle-size distribution was determined by the hydrometer method (Bouyoucos, 1951). Organic matter (O.M) was determined by Walkley and Black (1934) dichromate digestion method and total soil nitrogen was determined by the micro-kjeldahl technique (Bremner and Mulvancy, 1982). Available P was determined by Murphy and Riley method (1962). Ammonium acetate was used in the extraction of exchangeable K^+, Ca^{2+} and Mg^{2+}. Potassium was determined using the flame photo meter and Ca and Mg by EDTA titration.

3.3 Design of experiment

Both pot and field experiments were 4 x 4 factorial; comprising 4 levels of NPK fertilizer formulations and 4 rates of application. The 16 treatments (Table 1) were laid out in Completely Randomized Design (CRD) and Randomized Complete Block Design (RCBD) for the pot and field studies respectively, with four replications.

Table 1: Treatment combinations for Experiment I and II

Trt	Fertilizer formulation	Application rate
T1	15-15-15	0 kg/ha (Control)
T2	15-15-15	350 kg/ha (225 kg NPK/ha as basal and 125 kg SA/ha
T3	15-15-15	375 kg/ha (250 kg NPK/ha as basal and 125 kg SA/ha
T4	15-15-15	400 kg/ha (275 kg NPK/ha as basal and 125 kg SA/ha
T5	23-10-5	0 kg/ha (Control)
T6	23-10-5	350 kg/ha (225 kg NPK/ha as basal and 125 kg SA/ha
T7	23-10-5	375 kg/ha (250 kg NPK/ha as basal and 125 kg SA/ha
T8	23-10-5	400 kg/ha (275 kg NPK/ha as basal and 125 kg SA/ha
T9	23-10-10	0 kg/ha (Control)
T10	23-10-10	350 kg/ha (225 kg NPK/ha as basal and 125 kg SA/ha
T11	23-10-10	375 kg/ha (250 kg NPK/ha as basal and 125 kg SA/ha
T12	23-10-10	400 kg/ha (275 kg NPK/ha as basal and 125 kg SA/ha
T13	20-10-10	0 kg/ha (Control)
T14	20-10-10	350 kg/ha (225 kg NPK/ha as basal and 125 kg SA/ha
T15	20-10-10	375 kg/ha (250 kg NPK/ha as basal and 125 kg SA/ha
T16	20-10-10	400 kg/ha (275 kg NPK/ha as basal and 125 kg SA/ha

SA= Sulphate of ammonia Trt= Treatment

3.4 Set up of Experiment I

3.4.1 Pot preparation and planting

Cylindrical plastic containers (7221.78 cm^3) were used as the experimental unit. Holes were perforated underneath the containers to drain excess water during the process of watering. Each container was filled with 11 kg sandy loam soil of Nyankpala soil series on 5th January, 2014. They were watered and made to stand overnight. The containers were arranged with 40 cm space in a row and 80 cm between rows. Planting was done the following day. Three seeds were planted to each pot, and thinned to two seedlings after emergence.

3.4.2 Cultural practices

The pots were cleared of weeds by hand picking at 2 Weeks After Planting (WAP) and 6 and 9 WAP. Two liters of water was applied to each pot twice a day, morning and evening. Basal application of respective NPK fertilizer formulations; 15-15-15, 20-10-10, 23-10-5 and 23-10-10, was done at 2 WAP and top-dressing with sulphate of ammonia were done 8 WAP. The treatments (Table 1) were applied by side placement, 5 cm away from the plants. One plant in each pot was tagged for data collection.

- **Plant height**

The height of each plant tagged per pot was measured from its base to the flag leaf at 3, 4, 5 and 6 WAP, and recorded in centimeters (cm).

❖ **Number of leaves**

Number of leaves on and above the second node from the soil surface were counted and recorded at 7 W AP .

❖ **Chlorophyll content**

Leaf chlorophyll concentration was measured with a SP AD chlorophyll meter (Minolta SPAD- 502) that measures a relative index of leaf chlorophyll concentration. The instrument was first calibrated and clipped to three points: lower, middle portion and towards the top of the leaves. The leaves (from top, middle and base of plant) were selected and averages were computed .

❖ **Stem girth**

Using a micro meter screw gauge, the girth of each stem was measured at the third internode from the soil surface and recorded in millimeters (mm) .

❖ . **Leaf area**

Leaf length was measured from the junction of the leaf blade and leaf sheaths, and leaf width measured at the widest part of the leaf. They were measured on three leaves sampled from tagged plants from the bottom, middle and upper sections of the canopy. Leaf area was calculated according to the following equation:

$$\boldsymbol{Leaf\ area = LLxLWxK} \quad \textbf{(Equation 1)}$$

Where LL= leaf length, LW= leaf width and K is a constant = 0.73 according to McKee (1964); Dwyer and Stewart (1986); Stewart and Dwyer (1999).

❖ **Shoot and roots biomass**

Plants were uprooted prior to tasseling. The roots were cut from the shoots. The fresh shoot and roots were weighed and recorded. They were then kept in brown paper envelops and oven dried at 80°C for 48 hours. The dried shoot and roots weights were recorded

3.5 Set up of Experiment II

3.5.1 Land preparation and planting

Field was ploughed and harrowed on the 19th June, 2014 and 26th June, 2014 respectively. On 27th June, 2014, the field was lined, pegged and divided into 16 plots, each measuring 12 m with 1 m and 2 m alleys between plots and replications respectively. Planting was done on 30th June, 2014 at a spacing of80 cm x 40 cm and seeding rate of 2 per stand giving a total of 40 stand and 80 plants per experimental unit. The design used was RCBD, with four replications.

3.5.2 Cultural practices

Hand weeding was done at 2 W AP, then twice afterwards at 3 weeks interval. Basal application of respective NPK fertilizer formulations; 15-15-15, 20-10-10, 23-10-5 and 23-10-10, was done at 2 W AP and top-dressing with sulphate of ammonia were done 8 WAP. The fertilizer, NPK formulations were applied by side placement, 5 cm away from the plants. Five plants in each plot were tagged for data collection.

❖ **Plant height**

Heights of the tagged plants (5 plants) in each plot was measured and recorded from their bases to the flag leaf at 3, 4, 5 and 6 W AP. Their means were computed prior to analysis and recorded in cm .

❖ **Number of leaves**

Number of leaves on and above the second node from the soil surface were counted and recorded at 7 WAP .

❖ **Chlorophyll content**

Leaf chlorophyll concentration was measured with a SPAD chlorophyll meter (Minolta SPAD- 502) that measures a relative index of leaf chlorophyll concentration. The instrument was first calibrated and clipped to three points: lower, middle portion and towards the top of the leaves. The leaves (from top, middle and base of plant) were selected and averages were computed.

❖ **Stem girth**

Using a micro-meter screw gauge, the girth of each stem was measured at the third internode from the soil surface and recorded in millimeters (mm).

❖ **Leaf area**

Leaf length was measured from the junction of the leaf blade and leaf sheaths, and leaf width measured at the widest part of the leaf. They were measured on three leaves sampled from tagged plants from the bottom, middle and upper sections of the canopy. Leaf area was calculated using equation (1).

- **Stover weight**

After harvest, the stovers were uprooted, chopped into pieces and kept in brown envelops. It was then dried in an oven at 80°C for 24 hours. The weight after oven-drying was recorded in grams (g).

- **1000 seed weight**

Thousand seeds, counted at random from each treatment at 13% moisture content were weighed and recorded in grams (g).

- **Grain yield**

After harvesting and threshing, the seeds were dried to 13% moisture content and their weight was recorded and converted to kg per ha.

3.5.3 Statistical analysis

Count and percentage data were transformed using square root and arc-sine transformations, respectively. Data collected on various parameters were subjected to analysis of variance using Genstat statistical package, 12th edition. Means were separated using LSD at 5 % probability level. Correlation analysis was also conducted for the parameters measured.

3.5.4 Cost-benefit analysis

The Cost-Benefit (CB) ratio was calculated according to Adegede and Dittoh (1985).

CHAPTER FOUR

RESULTS

4.1 Initial soil physico-chemical properties

The result of the initial soil physico-chemical property, showed that the soil used for the experiments is sandy loam texture, slightly acidic, low in total nitrogen and low in available phosphorus (Table 2).

Table 2: Physico-chemical properties of the soil used for the study

Soil parameter	Level
pH	5.26
Organic carbon (%)	0.51
Exchangeable acidity	
CEC (Cmol/kg)	2.10
Nitrogen (%)	0.04
Phosphorus (mg/kg)	8.70
Exchangeable bases	
Potassium (mg/kg)	68.00
Calcium (Cmol/kg)	1.40
Magnesium (Cmol/kg)	0.40
Particle size distribution (%)	
Sand	53.6
Clay	0.36
Silt	46.04
Texture	Sandy loam

4.2 Growth and yield response of maize planted in pots (Experiment I)

4.2.1 Plant height

Plant height increased with time, with plants in untreated control plots recording the least height throughout the entire growth period (Figure 4.1). At 3 WAP, plants fertilized with 23-10-5 NPK at 400 kg/ha were the tallest, though significantly similar to the height of plants treated with 350 and 375 kg/ha. Similar results were obtained for 15-15-15, 20-10-10 and 23-10-10 NPK formulations (Figure 4.1). These trends were the same throughout the growth period of the plant.

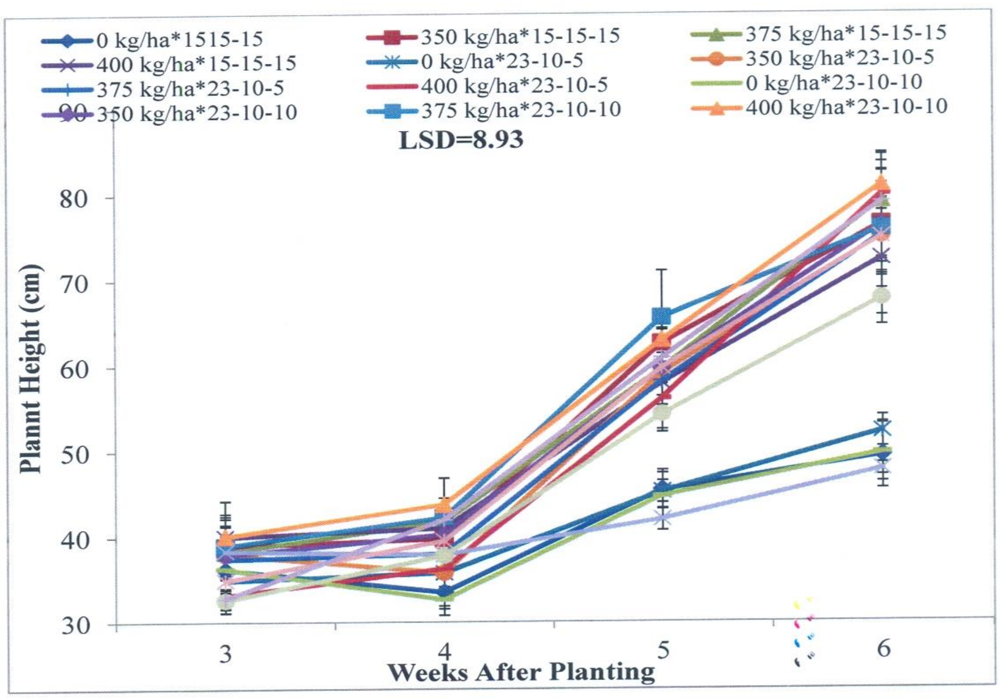

Figure 4.1: Effect of NPK fertilizer formulations and application rates on plant height. Bars represent SEM.

exception of NPK 15-15-15, number of leaves of plants treated with 375 or 400 kg/ha from all formulations did not significantly differ (Table 3).

Table 3: Effect of NPK fertilizer formulations and application rates on number of leaves at 7 WAP

Rate	NPK fertilizer formulation				
(kg/ha)	15-15-15	23-10-5	23-10-10	20-10-110	**Mean**
0	9.00	9.00	8.00	9.00	**9.00**
350	11.00	12.00	11.00	11.00	**11.00**
375	11.00	12.00	12.00	12.00	**12.00**
400	12.00	11.00	12.00	12.00	**11.00**
Mean	**11.00**	**11.00**	**11.00**	**11.00**	

LSD (0.05): NPK formulation= 0.58 NPK application rate= 0.58 NPK formulation x application rate= 1.16

4.2.3 Chlorophyll content

The results for chlorophyll content showed significant (*P<0.05*) different with respect to the main effect of application rate, as well as the interaction between NPK fertilizer formulation and application rate. The main effect of NPK fertilizer formulation was however not significant (*P>0.05*). For all the fertilizer formulations, plants in control plots recorded the lowest chlorophyll content and differed significantly from other application rates (Figures 4.2a and 4.2b). The highest chlorophyll content at 3 WAP was recorded by plants that received 400 kg/ha of NPK 23-10-5 (Figure 4.2a). It did not, however, differ from plants treated with 350 and 375 kg/ha of NPK 23-10-5, 375 and 400 kg/ha of NPK 15-15-15 and 23-10-10, as well as 350 and 400 kg/ha of NPK 20-10-10. The trend varied slightly at 7 WAP (Figure 4.2b). Plants that received 23-10-5 NPK applied at 400 kg/ha recorded the highest chlorophyll content, though similar to plants in plots treated with NPK 23-10-5, 15-15-15 and 23-10-10 applied at 375, 375 and 400 kg/ha respectively.

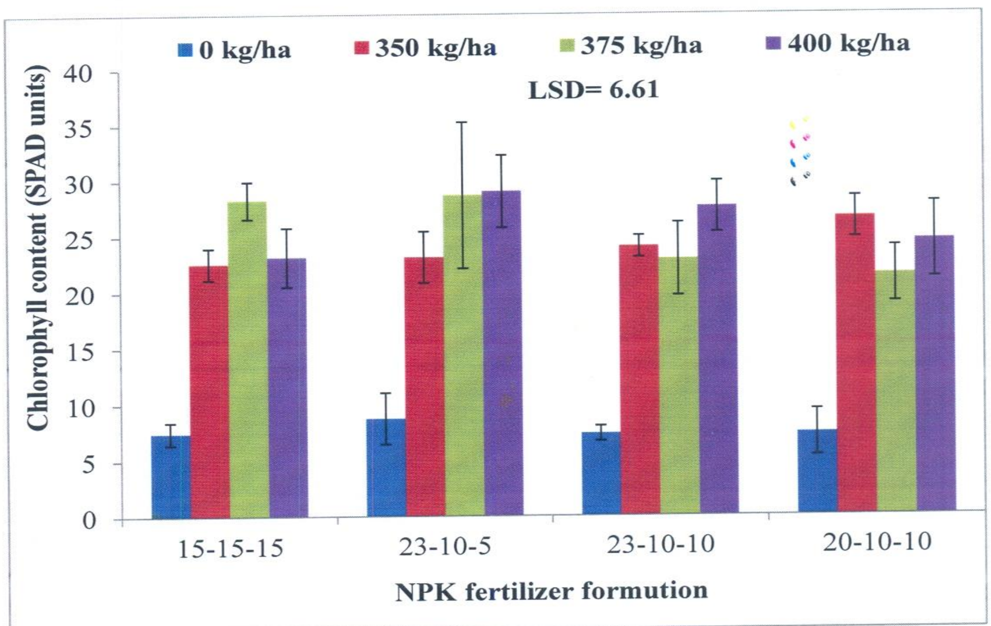

Figure 4.2a: Effect of NPK formulations and application rates on chlorophyll content at 3 WAP. Bars represent SEM.

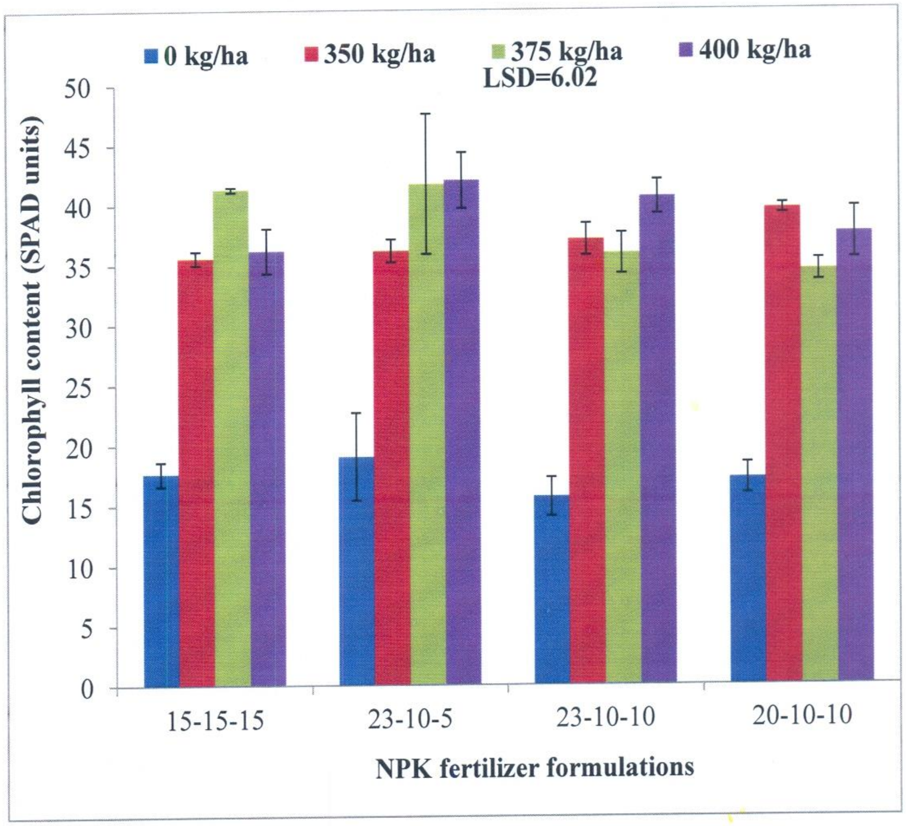

Figure 4.2b: Effect of NPK formulations and application rates on chlorophyll content at 7 WAP. Bars represent SEM.

4.2.4 Leaf area

Leaf area was significantly (*P<0.05*) affected by main effect of application rate as well as NPK fertilizer formulation by application rate interaction. The main effect of NPK formulation did not significantly (*P>0.05*) affect leaf area. Throughout the sampling periods, plants in plots that received 400 kg/ha of 23-10-5 recorded the greatest leaf area (Figures 4.3a and 4.3b). It was, however, similar to the area recorded by plants treated with 375, 400 and 375 kg/ha of NPK 23-10-5, 23-10-10 and 15-15-15 respectively (Figure 4.3a and 4.3b). The next highest in terms of leaf area were plants in plots treated with 350 kg/ha of NPK 23-10-10, performance of which were similar to plants in plots treated with 375 kg/ha of NPK 23-10-10, as well as plants treated with NPK 15-15-15, 23-10-5 and 20-10-10, applied at 350, 375 and 400 kg/ha (Figure 4.3a and 4.3b). The least leaf area was recorded in respective control plots.

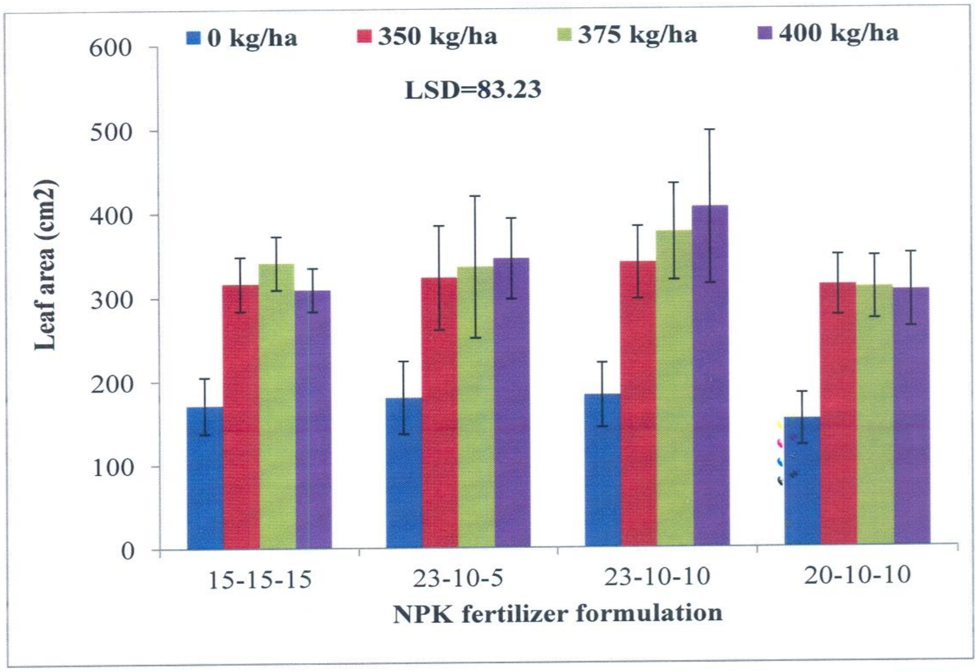

Figure 4.3a: Effect of NPK formulations and application rates on leaf area at 3 WAP. Bars represent SEM.

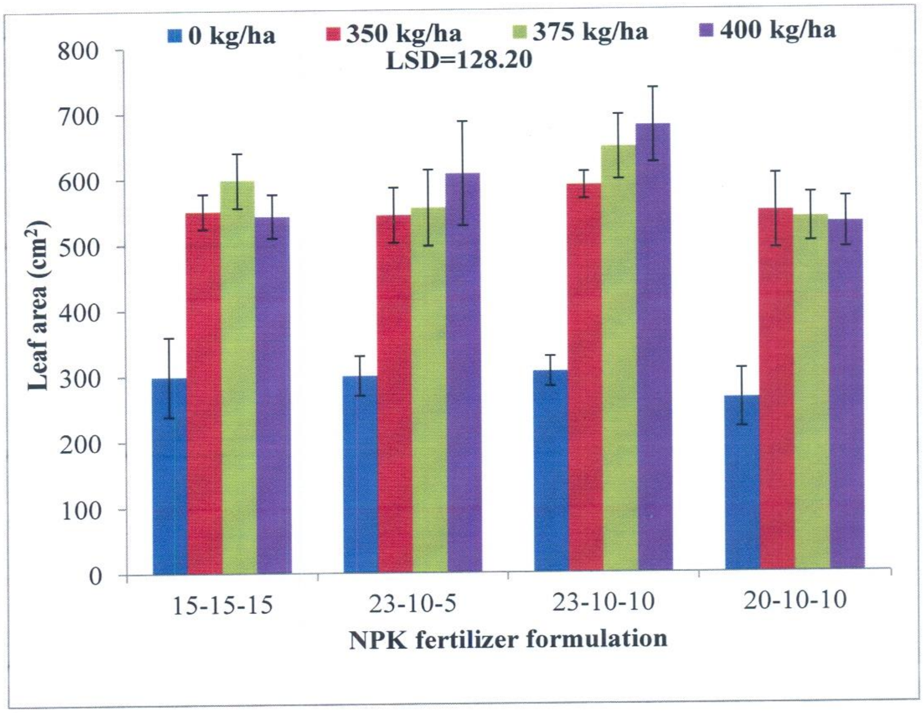

Figure 4.3b: Effect of NPK formulations and application rates on leaf area at 7 WAP. Bars represent SEM.

4.2.5 Stem girth

Stem girth response to NPK fertilizer application was highly variable and similar at both the 3 WAP and 7 WAP sampling periods. The widest girth was recorded by plants that received 400 kg/ha of NPK 23-10-10, and was significantly the same as the girth recorded by plants treated with 375 and 350 kg/ha of the same fertilizer formulation, as well as 400 and 375 kg/ha of NPK 15-15-15 and 23-10-5 (Figure 4.4a and 4.4b). However, plants from plots treated with 350 kg/ha of NPK 15-15-15, 350, 375 and 400 kg/ha of NPK 23-10-5 and 20-10-10, as well as 350 and 375 of NPK 23-10-10 performed similar.

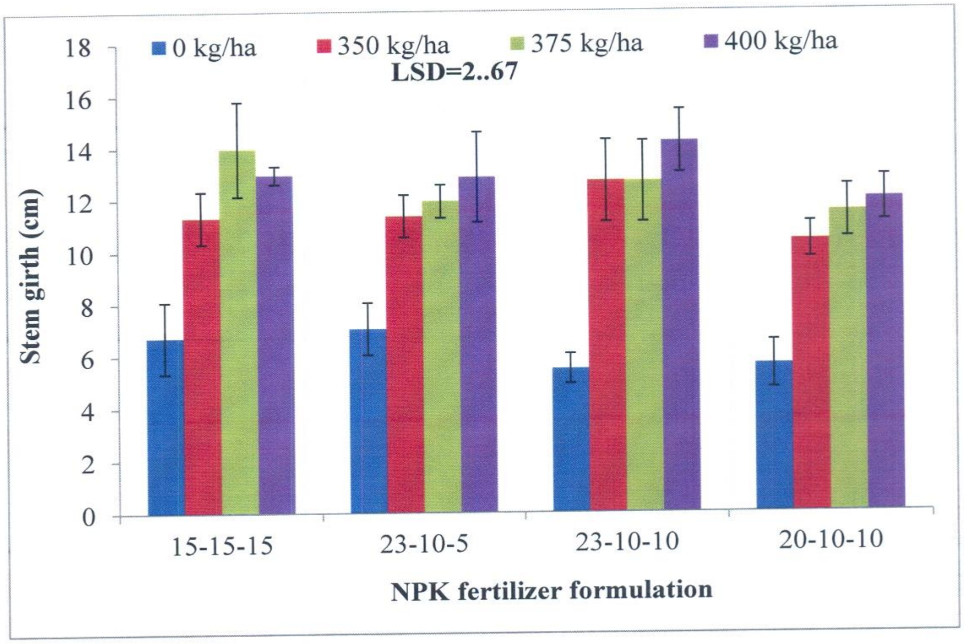

Figure 4.4a: Effect of NPK formulations and application rates on stem girth at 3 WAP. Bars represent SEM.

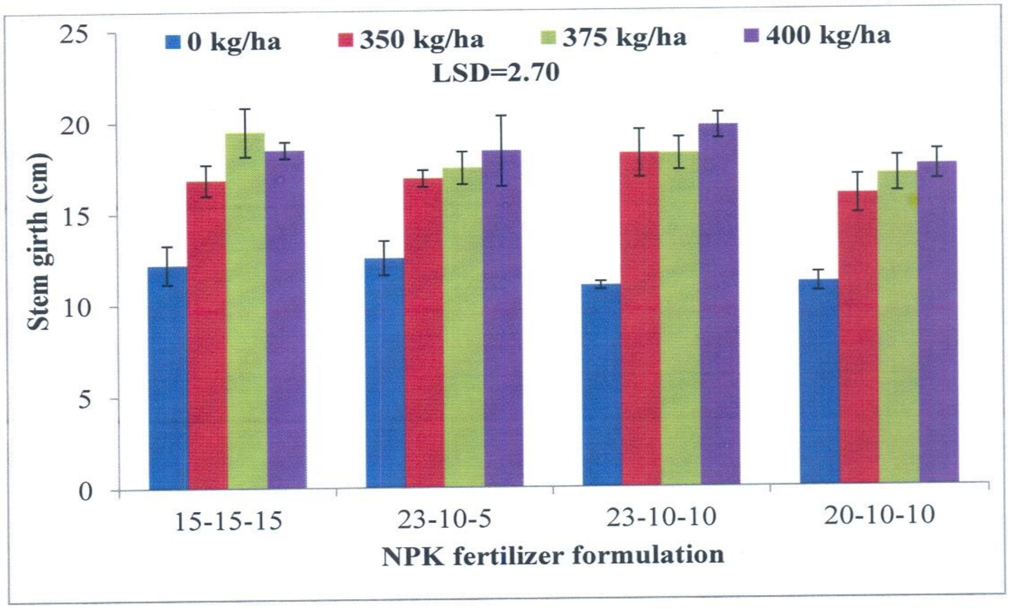

Figure 4.4b: Effect of NPK formulations and application rates on stem girth at 7 WAP. Bars represent SEM.

4.2.6 Fresh and dry shoot weight

The greatest fresh shoot biomass was recorded by plants treated with 23-10-10 NPK applied at 400 kg/ha (Figure 4.5a). The performance of plants treated with 375 and 400 kg/ha of NPK 23-10-5 was generally significantly similar to plants treated with the other NPK formulations at similar application rates (Figure 4.5a). The greatest dry shoot weight was recorded by plants treated with 400 kg/ha of NPK 23-10-10 (Figure 4.5b). Plants from plots treated with 375 kg/ha and the other types of NPK formulations recorded statistically similar values (Figure 4.5b).

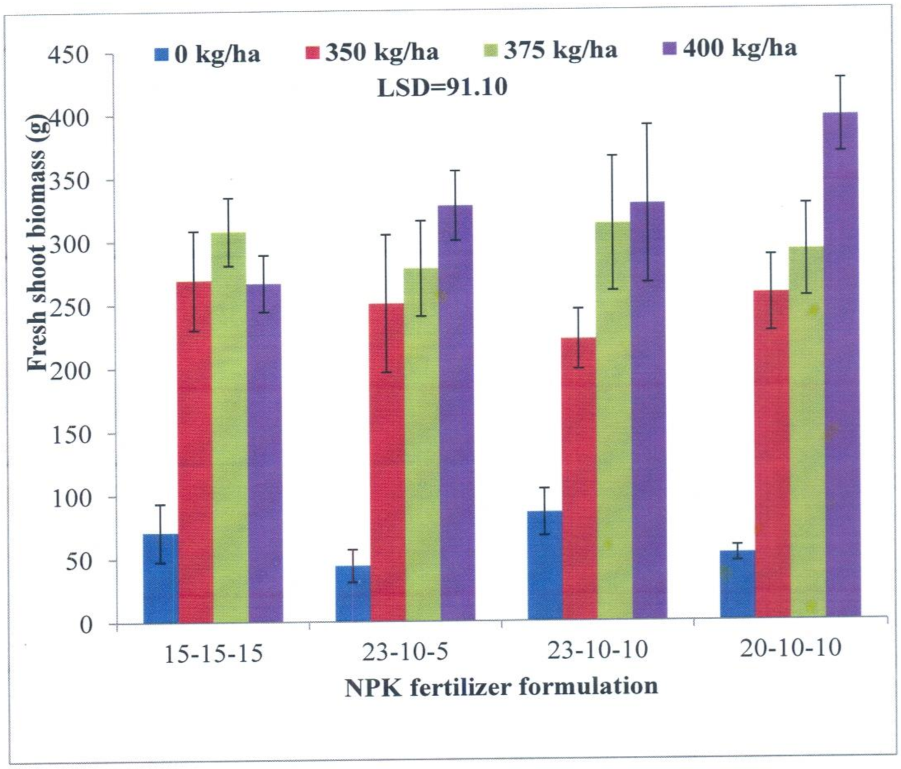

Figure 4.5a: **Effect of NPK formulations and application rates on fresh shoot biomass. Bars represent SEM.**

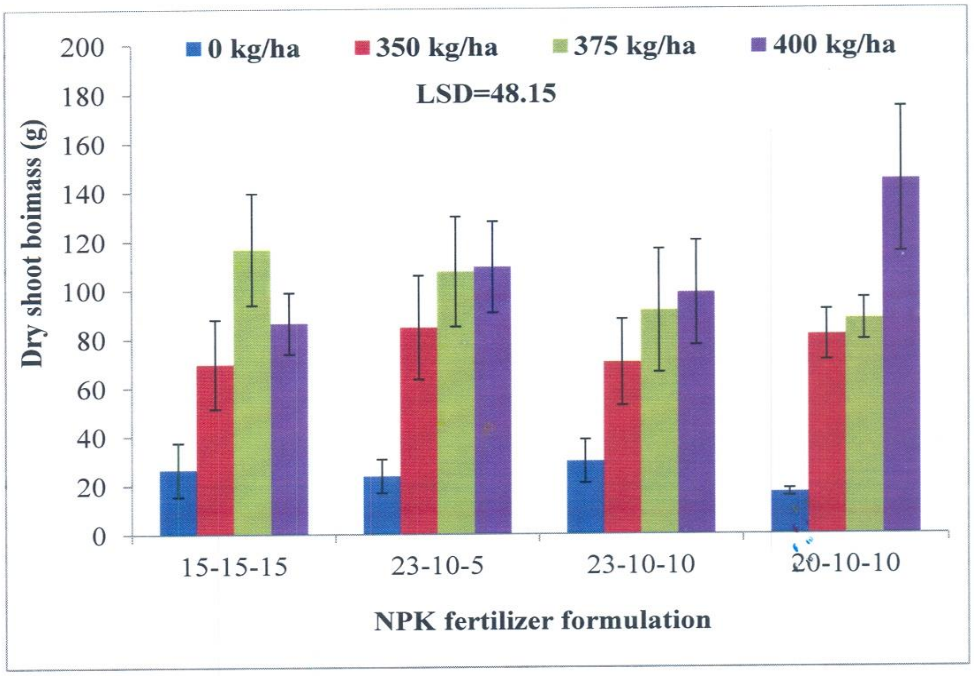

Figure 4.5b: **Effect of NPK formulations and application rates on dry shoot biomass. Bars represent SEM.**

4.2.7 Fresh and dry root weights

Pattern of response to treatments were similar in fresh and dry root weights (Figures 4.6a and 4.6b). In either parameter, plants treated with 400 kg/ha of NPK 23-10-10 recorded the highest weight, but was significantly similar to those recorded by the 375 kg/ha rate of NPK 20-10-10 and NPK 23-10-5 formulations. Plants treated with 23-10-10 at 350 and 375 kg/ha were similar (Figures 4.6a and 4.6b). Plants in the control plots of respective fertilizer formulations recorded the least values.

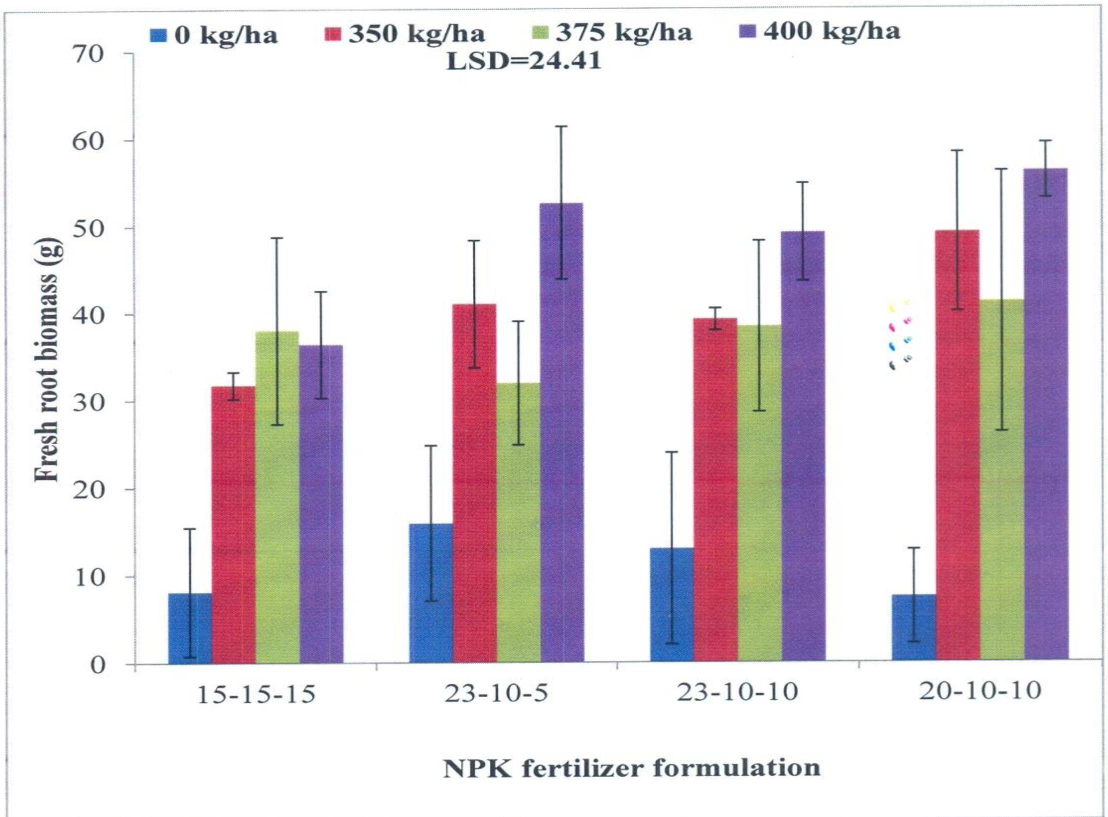

Figure 4.6a: **Effect of NPK formulations and application rates on fresh root biomass. Bars represent SEM.**

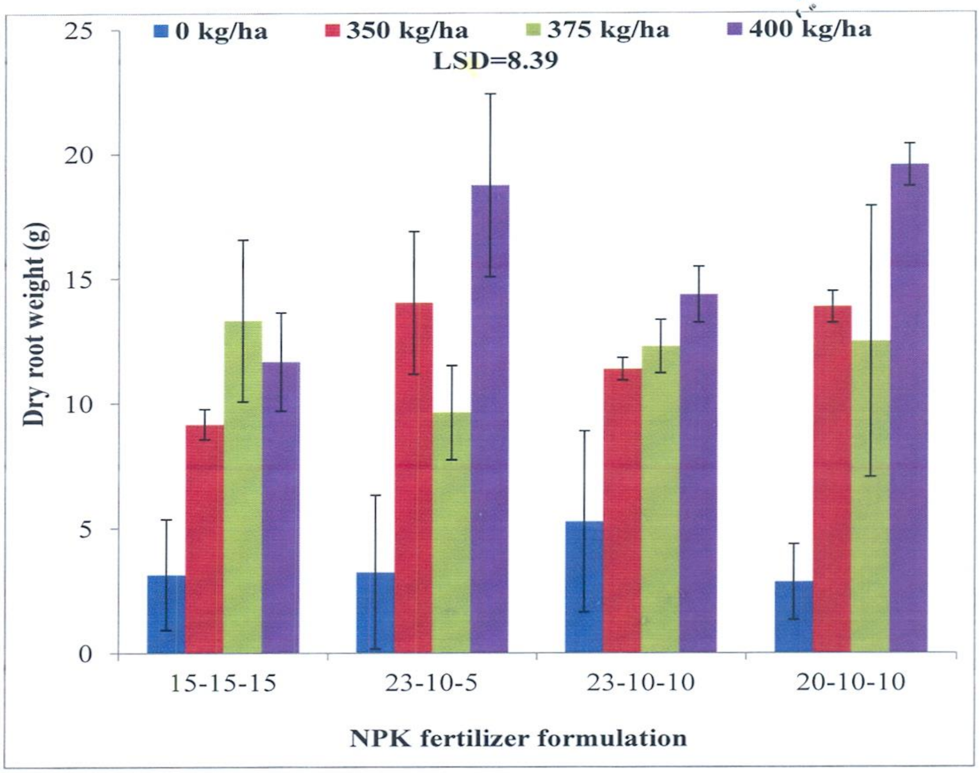

Figure 4.6b: Effect of NPK formulations and application rates on dry root biomass. Bars represent SEM.

4.3 Growth and yield response of maize planted in the field (Experiment II)

4.3.1 Plant height

Plants fertilized with NPK 15-15-15 applied at 375 kg/ha were the tallest at 3 WAP, this was however statistically similar to the remaining treatments except for the control plots (Figure 4.7). Similar trend in height were achieved at subsequent sampling periods. At 5 WAP, however, the height achieved from 15-15-15 NPK

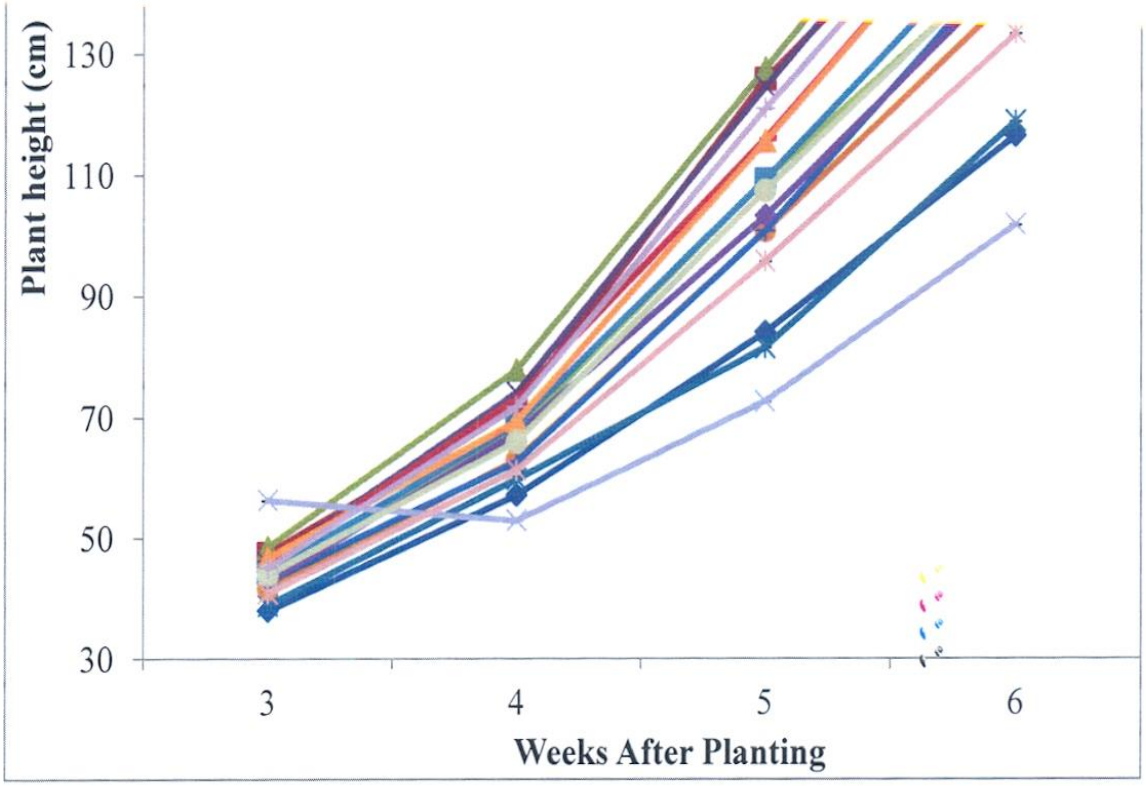

Figure 4.7: **Effect of NPK fertilizer formulations and application rates on plant height. Bars represent SEM.**

4.3.2 Number of leaves

The main effect of application rates and NPK fertilizer formulation by application rate interaction, significantly (*P<0.5*) affected number of leaves. The main effect of NPK fertilizer formulation however, did not significantly (*P>0.05*) affect number of leaves (Table 4). The control plots for all fertilizer formulations recorded the least number of leaves. The greatest number of leaves was obtained by plants fertilized with 23-10-10 NPK at 400 kg/ha. This was similar to the leaves obtained by plants in plots fertilized with 400 kg/ha of the other types of NPK formulations (Table 4).

Table 4: Effect of NPK fertilizer formulations and application rates on number of leaves at 7 WAP

	NPK fertilizer formulation				
Rate (kg/ha)	15-15-15	23-10-5	23-10-10	20-10-10	**Mean**
0	12.00	12.00	11.00	12.00	**12.00**
350	13.00	12.00	12.00	13.00	**13.00**
375	13.00	13.00	13.00	13.00	**13.00**
400	14.00	13.00	14.00	13.00	**14.00**
Mean	**13.00**	**13.00**	**13.00**	**13.00**	

LSD (0.05): NPK formulation= 0.49 NPK application rate= 0.49 NPK formulation x rate= 0.98

4.3.3 Chlorophyll content

The results of chlorophyll content showed significant (*P<0.05*) difference with respect to the main effect of application rate as well as NPK formulation by application rate interaction. The greatest content of chlorophyll in respective NPK chlorophyll as those treated with 375 kg NPK/ha. For NPK 23-10-5, similar content of chlorophyll were recorded between plants in plots that received 400 and 350 kg/ha. The least content of chlorophyll in respective NPK formulations were recorded by plants from the control plots.

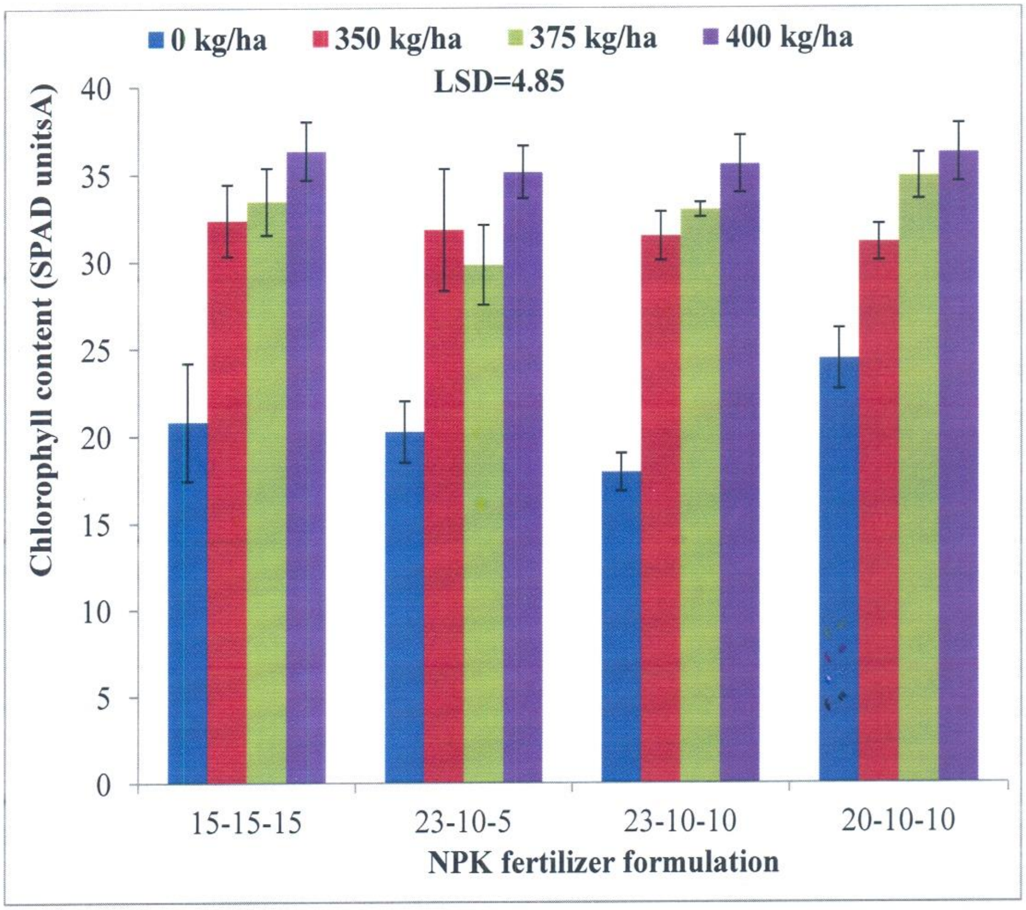

Figure 4.8a: **Effect of NPK fertilizer formulations and application rates on chlorophyll content at 3 WAP. Bars represent SEM.**

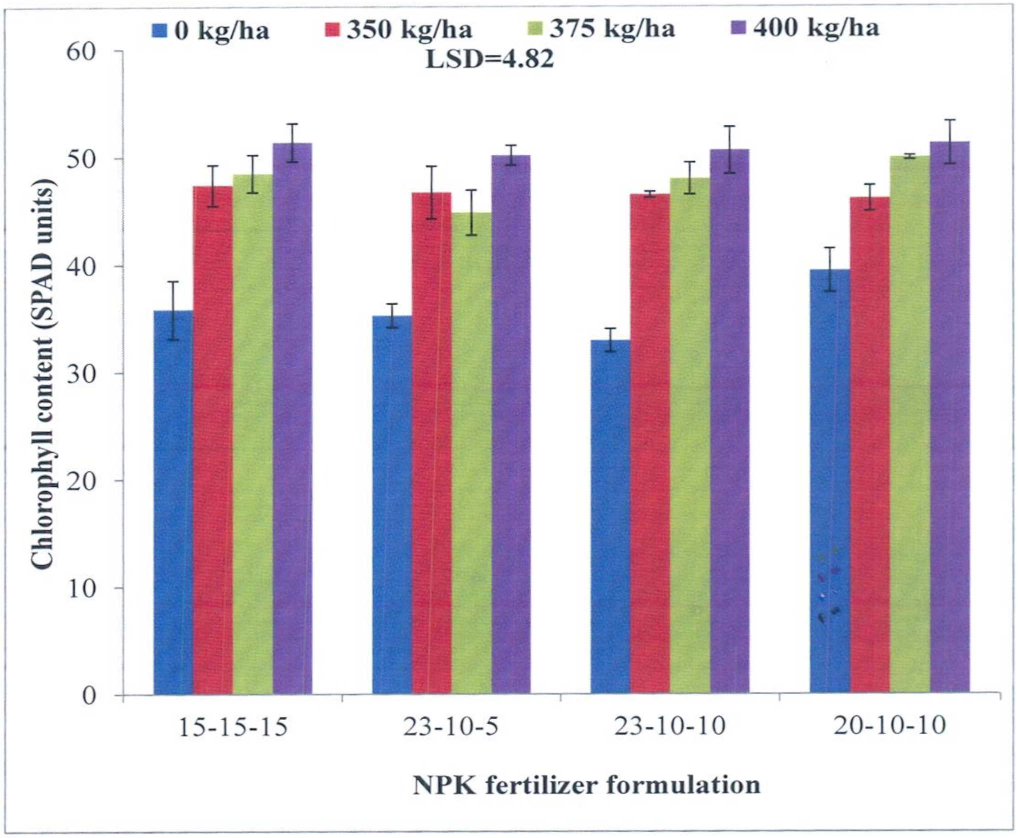

Figure 4.8b: **Effect of NPK fertilizer formulations and application rates on chlorophyll content at 7 WAP. Bars represent SEM.**

4.3.4 Leaf area

Among the NPK formulations, the greatest leaf area were recorded by plants treated with 400 kg/ha fertilization (Figures 4.9a and 4.9b). However, plants treated with 400 kg NPK/ha in respect to NPK formulations recorded similar leaf area as those treated with 375 kg NPK/ha, but varied significantly from plants treated with 350 kg NPK/ha fertilization. The least leaf area was recorded by plants from the untreated control.

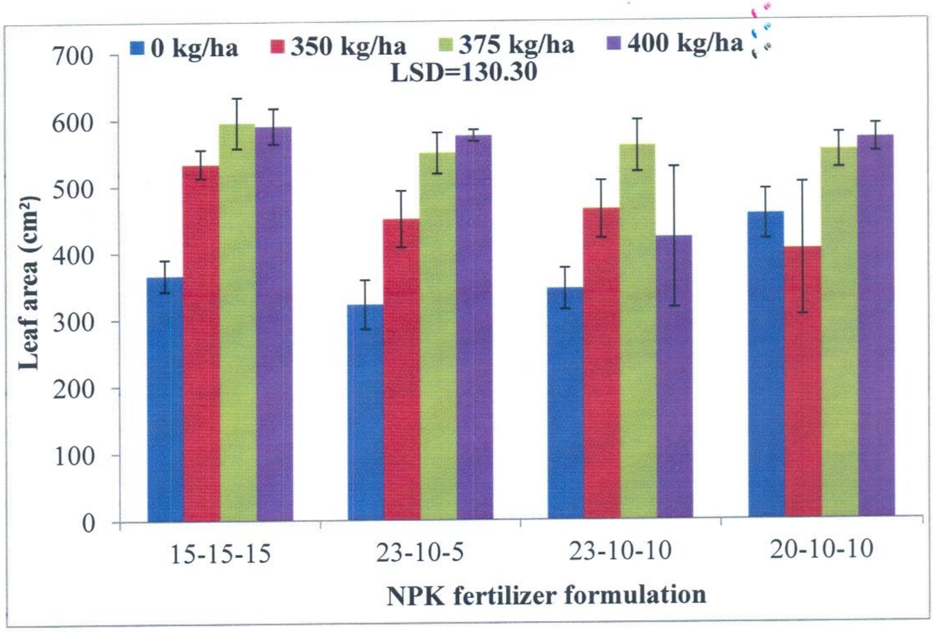

Figure 4.9a: Effect of NPK fertilizer formulations and application rates on leaf area at 3 WAP. Bars represent SEM.

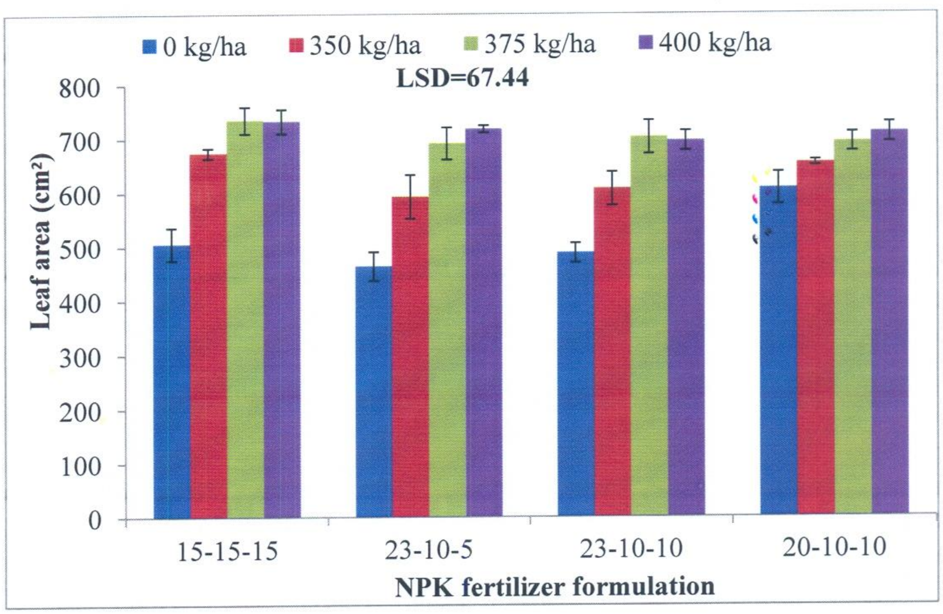

Figure 4.9b: Effect of NPK fertilizer formulations and application rates on leaf area at 7 WAP. Bars represent SEM.

4.3.5 Stem girth

The widest stem girth were recorded by plants that received 400 kg NPK/ha among the fertilizer formulations, and were similar to values recorded by plants treated with 375 kg NPK/ha fertilization (Figures 4.10a and 4.10b). However, plants that received 375 and 400 kg NPK/ha fertilization in respect to fertilizer formulations differed significantly from plants that received 350 kg NPK/ ha fertilization. The least girth was recorded by plants from the untreated control

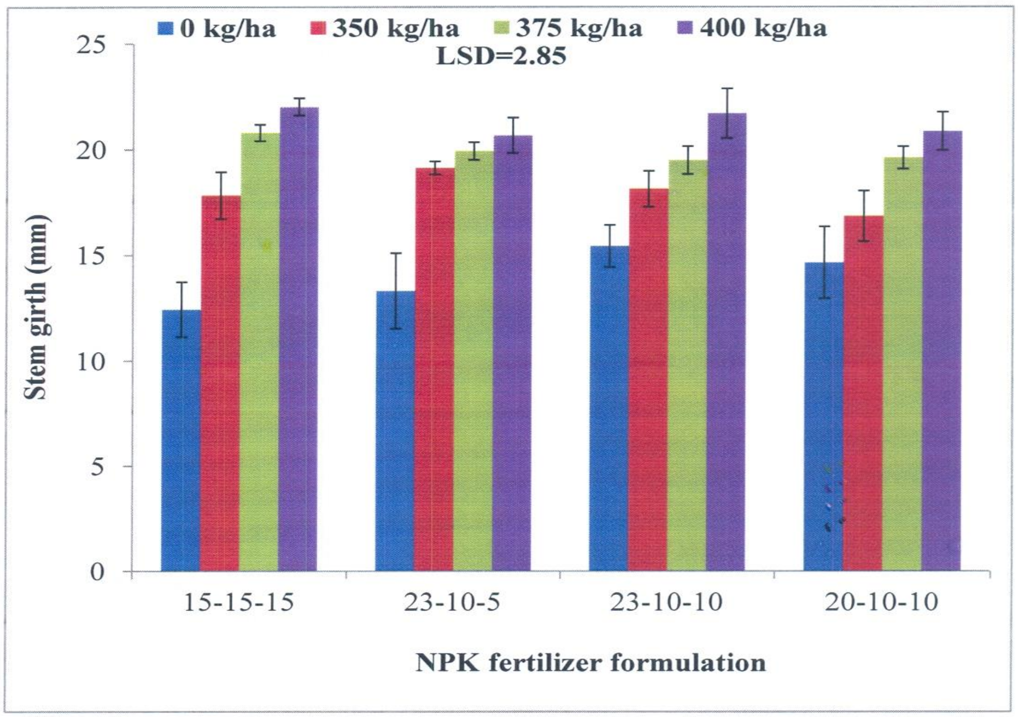

Figure 4.10a: Effect of NPK fertilizer formulations and application rates on stem girth at 3 WAP. Bars represent SEM.

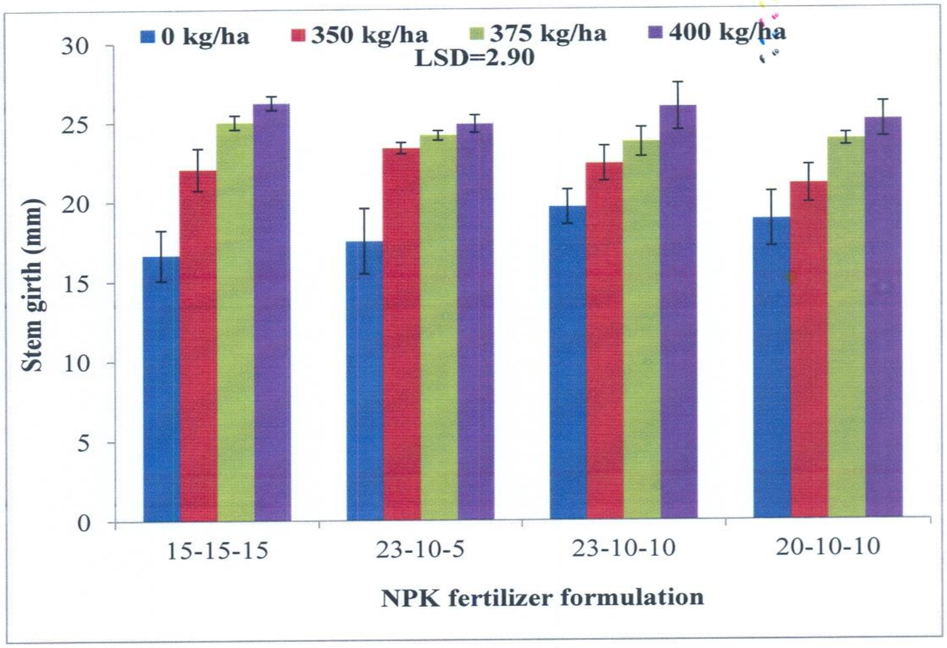

Figure 4.10b: Effect of NPK fertilizer formulations and application rates on stem girth at 7 WAP. Bars represent SEM.

4.3.6 Cob length

The greatest cob length was recorded by plants treated with 375 kg/ha of NPK 23-10-5 (Figure 4.11). This value was however, similar to the length recorded for plants treated with 400 kg/ha of NPK 23-10-5 and 23-10-10, as well as 375 and 400 kg/ha of NPK 15-15-15 and NPK 20-10-10. For NPK 15-15-15 and 20-10-10 formulations however, plants that received 350 kg/ha fertilization obtained similar cob length as plants treated with 375 kg NPK/ha (Figure 4.11).

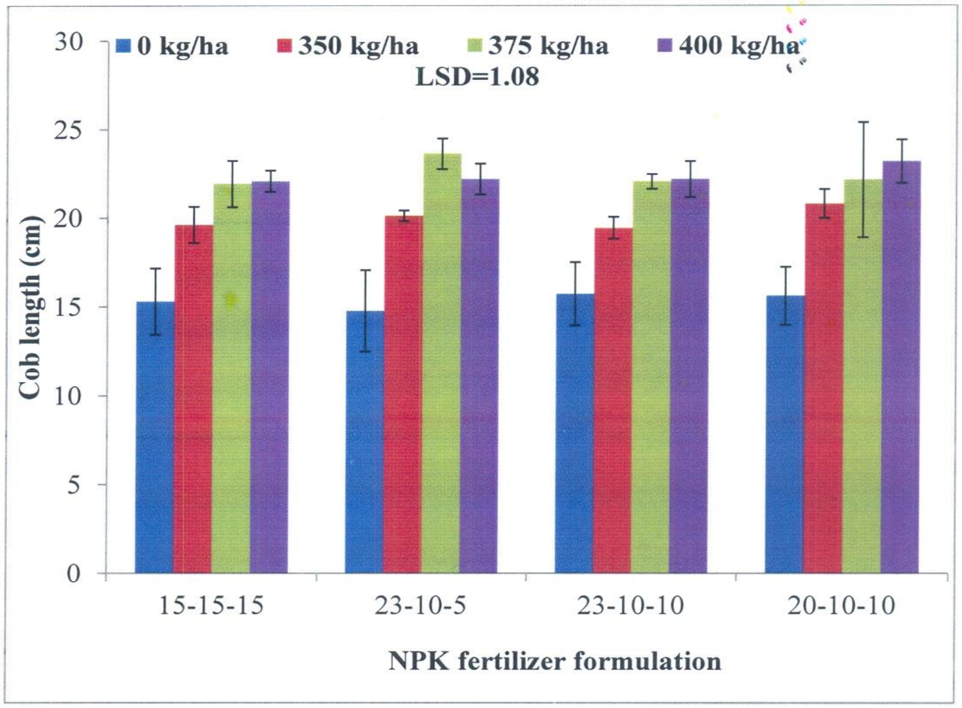

Figure 4.11: **Effect of NPK fertilizer formulations and application rates on cob length. Bars represent SEM.**

4.3.7 Cob weight

The greatest cob weight was obtained by plants treated with 400 kg/ha of NPK 15-15-15 (Figure 4.12). This was, however, statistically similar to the weight recorded by plants treated with 375 kg/ha of other fertilizer formulations. Plants from the untreated control recorded the lowest cob weight (Figure 4.12).

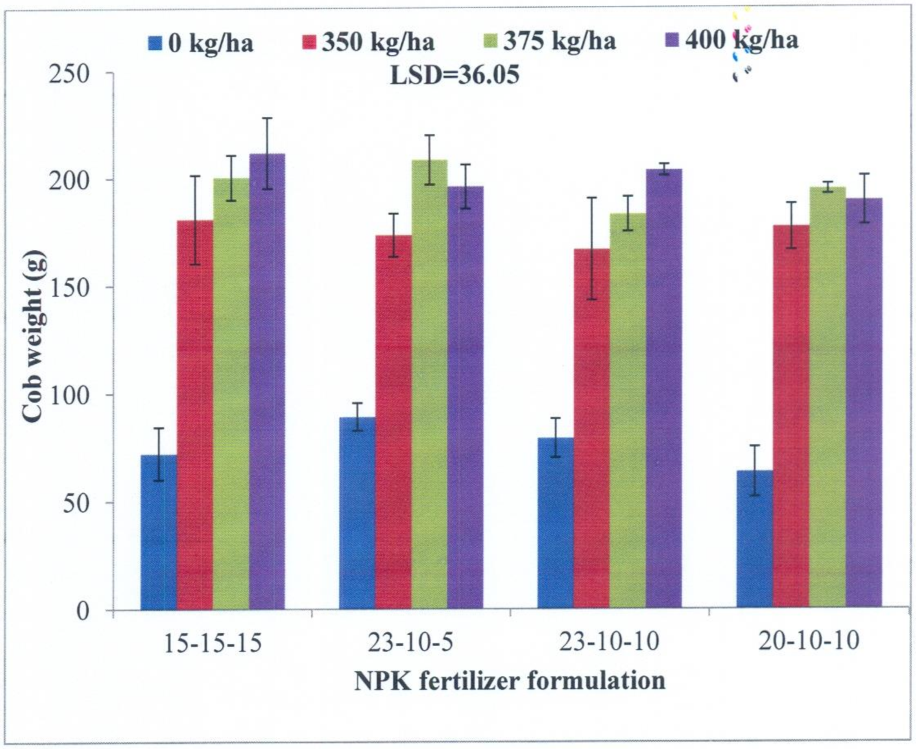

Figure 4.12: Effect of NPK fertilizer formulations and application rates on cob weight. Bars represent SEM.

4.3.8 Number of seed per cob

Plants from the untreated control produced the lowest number of seeds per cob (Figure 4.13). The highest number of seeds per cob was produced by plants from plots treated with 400 kg/ha of NPK 15-15-15, and was significantly similar to the number of seeds produced by plants that received 375 kg/ha of NPK 15-15-15, as well as 375 and 400 kg/ha of NPK 23-10-5 (Figure 4.13).

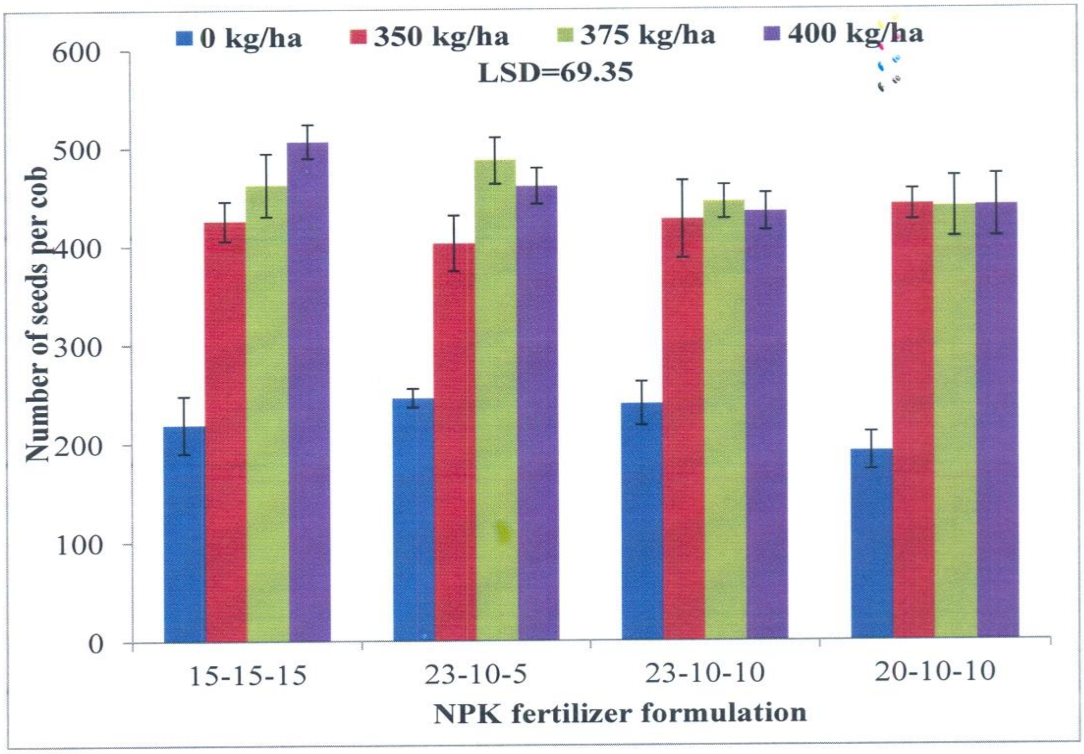

Figure 4.13: Effect of NPK fertilizer formulations and application rates on number of seeds per cob. Bars represent SEM.

4.3.9 1000 seed weight

Plants treated with 350, 375 and 400 kg/ha of the various NPK formulation performed similar in terms of 1000 seed weight (Figure 4.14). The least seed weight was recorded by plants in the control (Figure 4.14).

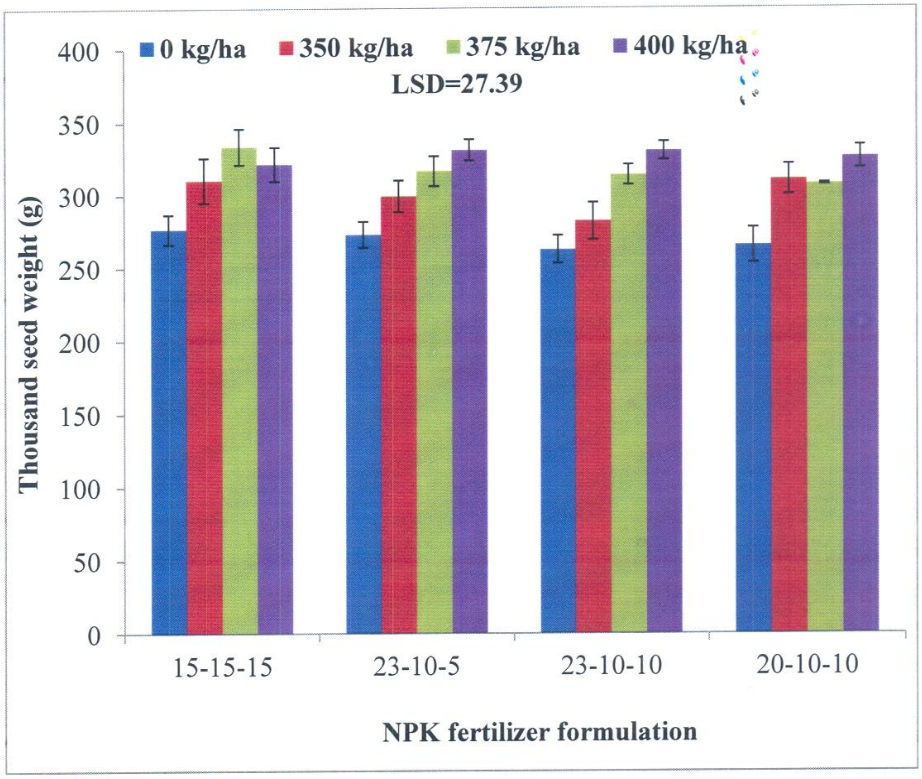

Figure 4.14: **Effect of NPK fertilizer formulations and application rates on 1000 seed weight. Bars represent SEM.**

4.3.10 Stover weight

The greatest stover weight was recorded by plants in plots treated with 400 kg/ha of NPK 23-10-10 (Figure 4.15). This value was, however, similar to the weight recorded for plants treated with 400 kg/ha of NPK 15-15-15 and 20-10-10, as well as 375 and 400 kg/ha of NPK 23-10-5 (Figure 4.15). Plants in the untreated control plots of respective fertilizer formulations recorded the least weight (Figure 4.15).

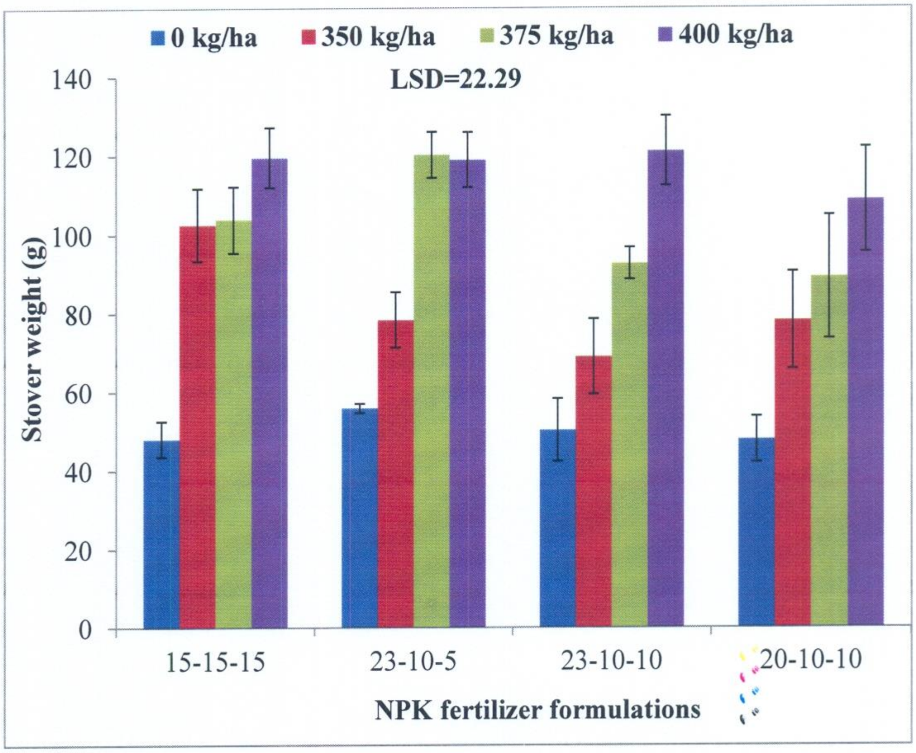

Figure 4.15: **Effect of NPK fertilizer formulations and application rates on stover weight. Bars represent SEM.**

4.3.11 Grain yield

The least of yields were recorded in respective control plots for various fertilizer formulations (Figure 4.16). Contrary, plants treated with 15-15-15 NPK applied at 375 kg/ha recorded the greatest grain yield (Figure 4.16). This was however, similar to the yield obtained for plants treated with 400 kg/ha of 15-15-15, as well as 375 and 400 kg/ha of NPK 23-10-5 and 20-10-10. Plants in the untreated control plots recorded the least grain yield (Figure 4.16).

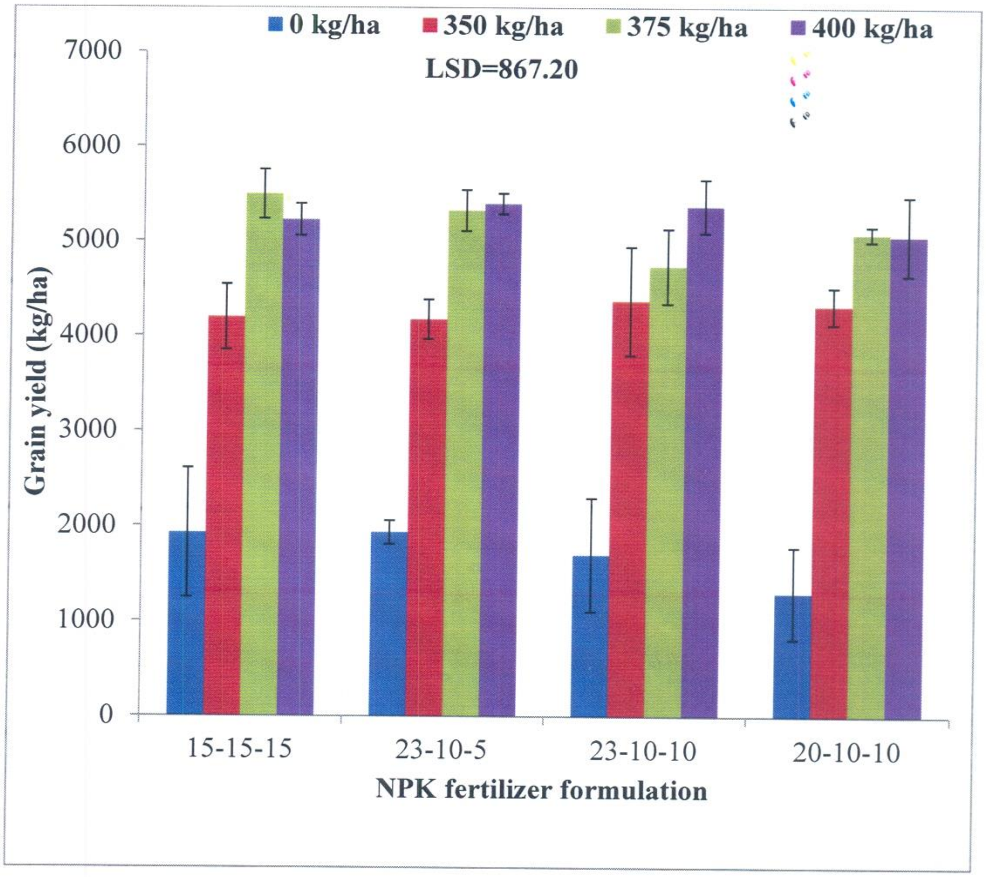

Figure 4.16: **Effect of NPK fertilizer formulations and application rates on grain yield. Bars represent SEM.**

4.4 Correlation among parameters

Analysis of correlation for treatments showed that total grain yield was highly positively correlated with chlorophyll content, leaf area, stem girth, cob length, cob weight, stover weight, number of seeds per cob and thousand seed weight; r= 0,78, 0.77, 0.73, 0.82, 0.89, 0.70, 0.85 and 0.81 respectively (Table 5).

Table 5: Spearman's correlation relationship among parameters measured in maize

	CHL	CL	CW	GY	LA	NL	NSC	PH	SG	SW	TSW
CHL	-										
CL	0.73	-									
CW	0.80	0.85	-								
GY	0.78	0.82	0.89	-							
LA	0.85	0.68	0.71	0.77	-						
NL	0.42	0.45	0.50	0.49	0.67	-					
NSC	0.78	0.79	0.92	0.85	0.71	0.42	-				
PH	0.46	0.39	0.53	0.59	0.49	0.52	0.48	-			
SG	0.67	0.71	0.73	0.73	0.68	0.45	0.71	0.47	-		
SW	0.68	0.65	0.74	0.70	0.69	0.46	0.74	0.49	0.72		
TSW	0.61	0.65	0.74	0.81	0.66	0.52	0.67	0.59	0.65	0.66	

CHL= Chlorophyll content, CL= Cob length, CW= Cob weight, GY= Grain yield, LA= Leaf area, NL= Number of leaves, NSC= Number of seeds per cob, PH= Plant height, SG= Stem girth, SW= Stover weight

4.5 Cost-benefit analysis

According to Adegede and Dittoh (1985), when cost-benefit analysis is less than one then the business enterprise is running at loss. When it is equal to 1 the business is breaking even and when it is greater than one the business is running at profit. The higher the cost-benefit analysis from one, the higher the profit margin, and the lower the cost-benefit from one, the higher the loss. It was indicative from the results that all control plots recorded losses (Table 6). All the treated plots recorded profits. Application at 375 kg/ha maximized profit in all fertilizer formulations, except for NPK 23-10-10, where maximum return was achieved by application at 400 kg/ha (Table 6). Among the various formulations NPK IS-ISIS recorded the highest average return (1.76), followed by 23-10-5 (1.70), 20-10- 10 (1.69) and 23-10-10 (1.67) (Table 6).

Table 6: Cost-benefit analysis of the response of maize to NPK fertilizer formulations and application rates in the Guinea Savannah zone of Ghana. Analyses based on one hectare production

NPK FORMULATION	Rate kg/ha	Service Charge (GHC)	Input Cost (GHC)	Labour Cost (GHC)	Total Cost (GHC)	Total Revenue (GHC)	C/B Analysis
15:15:15	0	100	80	1030	1210	1186.46	0.98
	350	135	479	1055	1669	2584.23	1.53
	375	137.5	507.5	1085	1730	3380.92	1.95
	400	140	536	1110	1786	3215.38	1.80
23:10:5	0	100	80	1030	1210	1189.54	0.98
	350	135	535	1055	1725	2569.23	1.48
	375	137.5	567.5	1085	1790	3275.08	1.82
	400	140	600	1110	1850	3320.62	1.79
23:10:10	0	100	80	1030	1210	1044.31	0.86
	350	135	514	1055	1704	2689.23	1.57
	375	137.5	545	1085	1767.5	2914.46	1.64
	400	140	576	1110	1826	3308.23	1.81
20:10:10	0	100	80	1030	1210	797.54	0.66
	350	135	500	1055	1690	2657.23	1.57
	375	137.5	530	1085	1752.5	3124.92	1.78
	400	140	560	1110	1810	2734.15	1.72

CHAPTER FIVE

5.0 DISCUSSION

5.1 Soil fertility

The low fertility status as observed in the initial soil physico-chemical analysis is believed to be as a result of continuous cropping of the experimental field, erosion and bush burning. This made the response of maize to NPK fertilization apparent. Tisdale *et al*., (2003) explained Mitschelick`s principle on the positive response of crops to the supply of the limiting elements in the soil. Plants exhibit marked deficiency symptoms when essential nutrient elements are limited in availability; hence they tend to be highly responsive to the supply of these nutrients if their unavailability has not reached the level where yield reduction has already occurred.

5.2 Growth and yield response of maize plants

5.2.1 Plant height

Plant height is an important growth character directly linked with the productive potential of plants in terms of grains. Plants in the control plots exhibited stunted growth. This is believed to be the sole reliance of plant in these plots on native soil nutrients, which from the chemical analysis was evidently deficient in N, P and K. The significant increase in plant height in the fertilizer treated plots is regarded as a reflection of the effective role of the primary fertilizer nutrients, N, P and K. The increase in plant height with respect to increased NPK application rate indicates maximum vegetative growth of the plants under higher N availability, and the role

Of P and K in effective root proliferation and N uptake respectively. This result is in conformity with the findings of Babatola (2006), as well as Kolawole and Joyce (2009) who reported that increasing level of fertilizer application results in a consequent increment in crop growth and yield.

5.2.2 Number of leaves

Number of leaves obtained for individual plants throughout the sampling periods of the experiments for various fertilizer formulations were dependent on application rates, as it increased with increase in fertilizer application rates with respect to time. These findings are in lined with the view of Stefano *et al. (2004)* who reported that, fertilizer application resulted in luxuriant growth with excessive leaves. Greater number of leaves on fertilizer treated plants contributes to a better canopy and suppression of weeds which reflected in increased grain yield.

5.2.3 Chlorophyll content

Increased chlorophyll of plants from respective NPK formulation due to increase in application rate can be attributed to difference in nitrogen content and uptake at different application rates. The higher chlorophyll values of plants treated with respective NPK fertilizers could be attributed to increased photosynthetic activity that resulted that resulted in increased crop yield crop yield (Ramesh *et al., 2002).* All plants treated with the various NPK formulations recorded significantly higher chlorophyll content than the untreated control. This is because NPK fertilization supplied soil macronutrients, which are assimilated by plants and utilized for various metabolic activities to synthesize chlorophyll, required for their normal growth and developments (Morteza and Shankar, 2013). The 375 and 400 kg/ha of various fertilizer formulations significantly increased the availability of N, P and K more than the other rates of application and this resulted in increased chlorophyll yield. In general, N supply and availability is fundamental to the synthesis of proteins, enzymes and chlorophyll, whiles P and K function in the proliferation of strong root system and N uptake respectively. These nutrients were absorbed by plants in the present study through the applied fertilizers, which worked in coordination and contributed in chlorophyll structure and synthesis, and resulted in high grain yield.

5.2.4 Leaf area

Luxuriant growth was expressed through greater leaf area mostly in plots treated with 400 and 375 kg NPK/ha and rarely in plots treated with 350 kg NPK/ha from all NPK fertilizer formulations. This was attributed to higher availability of potash which is known to stimulate the synthesis of carbohydrate for the development of the framework structure of maize, which according to Hersshey (2002) and Kiran (2004) have been reported to be accelerated by sufficient quantities of nitrogen.

The increase in leaf area was probably possibly due to the improved leaf expansion in plants treated with NPK fertilization.

In general 375 and 400 kg/ha of NPK especially from 15-15-15 and 20-10-10 enhanced leaf area development in the treated plants. Leaf area is a key determinant of crop growth due to its influence on photosynthesis. This implies that, higher availability of N, P and K at higher application rates were important for leaf growth of maize. This result is similar to the findings of Gobron (2009). Increasing NPK fertilizer rate probably increased the photosynthetic activity and leaf area also increased (Dwyer and

Anderson, 1995; T6th *et al.*, 2002, Vig *et al.*, 2008) and this reflected in increased yield of grains. The increase in leaf area with increasing fertilizer levels might also be due to increased amount of cellular constituents, mainly protoplast and also due to the influence of phytochroms in promotion of cell division, cell enlargement, cell differentiation and cell multiplication resulting in increases in total leaf area per plant and leaf area index. This observation in the present study is similar to the findings by Arun *et al. (2007).*

5.2.5 Stem girth

The low response in stem girth recorded from the unfertilized plots is attributed to the low fertility conditions of the soil. This implies that, amendments of the soil with the various NPK fertilizer formulations should improve its nutrient holding status for efficient crop performance (Morteza and Shankar, 2013).

5.2.6 Stover weight

The trend of result obtained for stover weight is similar to the findings of Olufolaji *et al.* (2002) in a related study on *Celocia argentea*. Increase in stover is as a result of the effective role of NPK as part of the essential primary nutrients and prerequisite for the production of the meristematic and physiological activities such as leaves, roots, shoots as well as dry matter production, leading to an efficient absorption and translocation of water and nutrients, interception and utilization of solar radiation and carbon dioxide (Stone *et al.,* 2001). These consequently result in ensuring an effective photosynthesis, and subsequent efficient translocation of assimilates from sources to sinks, hence the production of higher stover weight (Kolawole and Joyce, 2009). Jaliya *et al.* (2008) also made similar observations. Increased stover production was a result of increased fertilizer application might also be due to the role of NPK in determining the efficient use of sunshine by increased biomass production, as inadequacy of nitrogen reduces the sunshine use efficiency or ability to photosynthesize as reported by Wadsworth (2002).

5.2.7 Cob length and weight

The greater cob length and weight with increase in fertilizer levels could be attributed to adequate nutrient supply, which in tum improved all growth and yield influencing characters. NPK fertilizer supplied nutrient elements N, P and K and therefore higher rates results in higher amounts of these elements. This result is in agreement with earlier findings by Whitbread *et al. (2004).*

5.2.8 Seeds per pot

The increase in number of seeds per cob with increased fertilizer application could be attributed to the increased physiological processes in maize, leading to higher growth and increased supply of photosynthates to silks. This might be due to better utilization of NPK supply (Selvaraju and lruthayaraj, 1994).

5.2.9 Seed weight

Increased seed weight with increasing NPK rate might be due to the formation of more leaf area which might have intercepted more light and produced more carbohydrates in the source which was translocated into the sink (the grain) and resulted in more increased seed weight than the control. This result is in agreement with the findings of Miao *et al* (2006) and Raja (2003), who indicated that higher rate of N level increased seed weight in maize.

Increase in stem girth and leaf area of plants also have a direct increase in stover weight and this has implication on livestock feeding because stover is used in feeding livestock after harvesting the grain. The trend of result obtained for stover weight is similar to the findings of Olufolaji *et al.* (2002) in a related study on *Celocia argentea*. Increase in stover is as a result of the effective role of NPK as part of the essential primary nutrients and prerequisite for the production of the meristematic and physiological activities such as leaves, roots, shoots as well as dry matter production, leading to an efficient absorption and translocation of water and nutrients, interception and utilization of solar radiation and carbon dioxide (Stone *et al.*, 2001). These consequently result in ensuring an effective photosynthesis, and subsequent efficient translocation of assimilates from sources to sinks, hence the production of higher stover weight (Kolawole and Joyce, 2009). Jaliya *et al.* (2008) also made similar observations.

5.2.10 Grain yield

The greatest rate of NPK formulation gave the greatest grain yield. Results obtained for grain yield was in agreement with findings of Adediran and Banjoko (2003). Result of the present study indicated that 375 and 400 kg/ha levels of the fertilizer NPK formulations notably 15-15-15 significantly produced similar results as evident from the growth parameters to the yield components. This implies that exceeding 375 kg/ha may not be economically and environmentally useful in maize production. The difference in response of the NPK fertilizer rate in the various fertilizer formulations may be attributed to differences in their supply of the elements N, P and K. Also, since grain yield highly and positively correlated with leaf area and yield components, an increase in these parameters resulting from increasing NPK fertilization will consequently increase grain yield. The plants without fertilizer treatment had the lowest yield which could have been partly due to deficiency of nutrients as revealed by low nutrient status of the soil from the initial physic-chemical analysis. This agrees with statement by F AO (2003) that increment in maize production occurred with higher levels of fertilizer application, especially NPK.

5.3.0 Cost-benefit analysis

According to Adegede and Dittoh (1985), when cost-benefit analysis is less than one then the business enterprise is running at loss. When it is equal to one (1) the business is breaking even and when it is greater than one the business is running at profit. The higher the cost-benefit analysis from one, the higher the profit margin and the lower the cost-benefit from one, the higher the loss. The results obtained for cost-benefit analysis indicated that all fertilizer treatments in various NPK fertilizer formulations resulted in profits and this could be as a result of the efficiency of NPK to supply essential plant nutrients in optimum quantities and proportions required by maize plant to increase grain yield and consequently profit. Similar result for increased net profit in maize due to NPK fertilization has been reported by Dev (1998).

The supply of a more balance proportion of essential nutrients by NPK 15-15-15, relative to 20-10-10, 23-10-5 and 23-10-10 could account for its highest average return. According to Dev (1998), balanced and adequate fertilizer application is essential for increasing crop yields and net returns, whiles ensuring sustainability.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The results of the study revealed significant increase in growth parameters, yield components and grain yield following the application of 375 and 400 kg/ha of the various NPK fertilizer formulations notably NPK 15-15-15 and NPK 20-10-10.

In general, growth parameters were increased as NPK fertilizer rate increased. Control treatments showed the least performance in terms of growth parameters, yield components and grain yield. An increasing trend on measured parameters in all the fertilizer formulations were observed with increasing rates of NPK fertilization.

This study revealed that, fertilizer application rates has a profound effect on the overall performance of maize. Application of NPK fertilizer at the different levels used in this study had significantly effect on the growth and yield of maize. Fertilizer application rate of 400 or 375 kg/ha was effective for the optimum growth and yield of maize, and in most cases did not vary significantly from each other in terms of growth and yield of maize.

The cost/benefit ratio for the 400 kg/ha and 375 kg/ha from various NPK fertilizer formulations were similar, but the values obtained for cost/benefit from NPK 15-15-15 were the highest among the fertilizer formulations. In general, however, the cost-benefit analysis revealed that application at 375 kg/ha was more profitable than application at 400 kg/ha for 15-15-15, 20-10-10 and 23-10-5 NPK. Contrary maximum profit was achieved by application at 400 kg/ha for 23-10-10 NPK.

With respect to various formulations, the highest average profit was obtained by 15-15-15 NPK, followed by 23-10-5, 20-10-10 and 23-10-10 respectively.

6.2 **Recommendations**

The study therefore recommends that;

- irrespective of NPK fertilizer formulation, application at 375 kglha is recommended in maize production in the study area for maximum yield and profit.
- based on accessibility and affordability NPK 15-15-15 is highly recommended among the various formulations.
- for application at 350 kglha, 23-10-10 NPK is recommended for optimum yield and profit.

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APPENDICES

***Footnote**: Interaction between NPK fertilizer formulation and application rate showed no significant difference (P>0.05) in almost all parameters measured in both experiments according to analysis with Genstat discovery, edition 12. However, mean separation using LSD (0.05) showed significant different between treatment means.

Experiment I (Pot Study)

Variate: Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	120.59	40.20	0.98	
Rep.*Units* stratum					
NPK_formulation	3	328.47	109.49	2.67	0.049
Rate	3	6656.62	2218.87	54.11	<.001
Weeks	3	46030.24	15343.41	374.20	<.001
NPK_formulation.Rate	9	564.13	62.68	1.53	0.140
NPK_formulation.Weeks	9	214.03	23.78	0.58	0.813
Rate.Weeks	9	4893.24	543.69	13.26	<.001
NPK_formulation.Rate.Weeks					
	27	508.18	18.82	0.46	0.991
Residual	189	7749.63	41.00		
Total	255	67065.14			

Variate: Number of leaves 7 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1.6719	0.5573	0.83	
REP.*Units* stratum					
NPK_formulation	3	0.9219	0.3073	0.46	0.712
Rate	3	95.2969	31.7656	47.52	<.001
NPK_formulation.Rate	9	7.3906	0.8212	1.23	0.302
Residual	45	30.0781	0.6684		
Total	63	135.3594			

Variate: Chlorophyll content at 3 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	463.01	154.34	7.17	
REP.*Units* stratum					
NPK_formulation	3	54.70	18.23	0.85	0.475
Rate	3	3676.05	1225.35	56.95	<.001
NPK_formulation.Rate	9	238.12	26.46	1.23	0.301
Residual	45	968.19	21.52		
Total	63	5400.07			

Variate: Chlorophyll content at 7 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	94.09	31.36	1.75	
REP.*Units* stratum					
NPK_formulation	3	65.80	21.93	1.23	0.311
Rate	3	5205.46	1735.15	97.08	<.001
NPK_formulation.Rate	9	244.43	27.16	1.52	0.170
Residual	45	804.29	17.87		
Total	63	6414.07			

Variate: Leaf area at 3 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	316016.	105339.	30.85	
REP.*Units* stratum					
NPK_formulation	3	27137.	9046.	2.65	0.060
Rate	3	324117.	108039.	31.64	<.001
NPK_formulation.Rate	9	11757.	1306.	0.38	0.937
Residual	45	153673.	3415.		
Total	63	832700.			

Variate: Leaf area at 7 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	44174.	14725.	1.82	
REP.*Units* stratum					
NPK_formulation	3	60310.	20103.	2.48	0.073
Rate	3	989033.	329678.	40.68	<.001
NPK_formulation.Rate	9	33639.	3738.	0.46	0.893
Residual	45	364718.	8105.		
Total	63	1491873.			

Variate: Stem girth at 3 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	95.629	31.876	9.10	
REP.*Units* stratum					
NPK_formulation	3	19.755	6.585	1.88	0.147
Rate	3	466.574	155.525	44.38	<.001
NPK_formulation.Rate	9	21.846	2.427	0.69	0.712
Residual	45	157.690	3.504		
Total	63	761.495			

Variate: Stem girth at 7 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	28.297	9.432	2.69	
REP.*Units* stratum					
NPK_formulation	3	19.755	6.585	1.88	0.147
Rate	3	466.574	155.525	44.38	<.001
NPK_formulation.Rate	9	21.846	2.427	0.69	0.712
Residual	45	157.690	3.504		
Total	63	694.163			

Variate: Fresh shoot weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	45976.	15325.	3.75	
REP.*Units* stratum					
NPK_formulation	3	5841.	1947.	0.48	0.701
Rate	3	681030.	227010.	55.48	<.001
NPK_formulation.Rate	9	40258.	4473.	1.09	0.387
Residual	45	184125.	4092.		
Total	63	957229.			

Variate: Dry shoot weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	8729.	2910.	2.55	
REP.*Units* stratum					
NPK_formulation	3	1170.	390.	0.34	0.796
Rate	3	70832.	23611.	20.66	<.001
NPK_formulation.Rate	9	9673.	1075.	0.94	0.501
Residual	45	51436.	1143.		
Total	63	141840.			

Variate: Fresh root weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1693.6	564.5	1.92	
REP.*Units* stratum					
NPK_formulation	3	836.7	278.9	0.95	0.425
Rate	3	12575.7	4191.9	14.27	<.001
NPK_formulation.Rate	9	1050.8	116.8	0.40	0.930
Residual	45	13214.5	293.7		
Total	63	29371.2			

Total	63	3306.89

Experiment II (Field study)

Variate: Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	12338.8	4112.9	14.84	
Rep.*Units* stratum					
NPK_formulation	3	5128.9	1709.6	6.17	<.001
Rate	3	18459.6	6153.2	22.21	<.001
Weeks	3	393866.6	131288.9	473.86	<.001
NPK_formulation.Rate	9	6970.4	774.5	2.80	0.004
NPK_formulation.Weeks	9	2878.9	319.9	1.15	0.327
Rate.Weeks	9	10425.9	1158.4	4.18	<.001
NPK_formulation.Rate.Weeks					
	27	3834.2	142.0	0.51	0.979
Residual	189	52364.4	277.1		
Total	255	506267.7			

Variate: NL at WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	4.1225	1.3742	2.90	
REP.*Units* stratum					
NPK_formulation	3	1.0525	0.3508	0.74	0.533
Rate	3	25.8075	8.6025	18.16	<.001
NPK_formulation.Rate	9	2.9375	0.3264	0.69	0.715
Residual	45	21.3175	0.4737		

Total	63	55.2375			

Variate: Chlorophyll content at 3 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	190.57	63.52	5.49	
REP.*Units* stratum					
NPK_formulation	3	60.59	20.20	1.75	0.171
Rate	3	2045.08	681.69	58.90	<.001
NPK_formulation.Rate	9	87.92	9.77	0.84	0.580
Residual	45	520.80	11.57		
Total	63	2904.96			

Variate: Chlorophyll content at 7 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	50.43	16.81	1.47	
REP.*Units* stratum					
NPK_formulation	3	61.55	20.52	1.79	0.163
Rate	3	2043.99	681.33	59.40	<.001
NPK_formulation.Rate	9	86.86	9.65	0.84	0.583
Residual	45	516.20	11.47		
Total	63	2759.02			

Variate: Leaf area at 3 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	44242.	14747.	1.76	
REP.*Units* stratum					
NPK_formulation	3	46781.	15594.	1.86	0.149
Rate	3	356417.	118806.	14.19	<.001
NPK_formulation.Rate	9	107909.	11990.	1.43	0.203
Residual	45	376633.	8370.		
Total	63	931983.			

Variate: Leaf area at 7 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	13087.	4362.	1.95	
REP.*Units* stratum					
NPK_formulation	3	31913.	10638.	4.74	0.006
Rate	3	402557.	134186.	59.84	<.001
NPK_formulation.Rate	9	41380.	4598.	2.05	0.055
Residual	45	100901.	2242.		
Total	63	589837.			

Variate: Stem girth at 3 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	15.103	5.034	1.26	
REP.*Units* stratum					
NPK_formulation	3	4.044	1.348	0.34	0.799
Rate	3	492.680	164.227	41.01	<.001
NPK_formulation.Rate	9	37.276	4.142	1.03	0.428
Residual	45	180.199	4.004		
Total	63	729.302			

Variate: Stem girth at 7 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	64.616	21.539	5.38	
REP.*Units* stratum					
NPK_formulation	3	4.044	1.348	0.34	0.799
Rate	3	492.680	164.227	41.01	<.001
NPK_formulation.Rate	9	37.276	4.142	1.03	0.428
Residual	45	180.199	4.004		
Total	63	778.814			

Variate: Cob length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	2.9255	0.9752	1.71	
REP.*Units* stratum					
NPK_formulation	3	2.9255	0.9752	1.71	0.179
Rate	3	1.4122	0.4707	0.82	0.488
NPK_formulation.Rate	9	4.2365	0.4707	0.82	0.598
Residual	45	25.7224	0.5716		
Total	63	37.2220			

Variate: Cob weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	397.7	132.6	0.21	
REP.*Units* stratum					
NPK_formulation	3	1414.0	471.3	0.74	0.536
Rate	3	163744.3	54581.4	85.21	<.001
NPK_formulation.Rate	9	2914.6	323.8	0.51	0.863
Residual	45	28825.6	640.6		
Total	63	197296.1			

Variate: Number of seeds per cob

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	7946.	2649.	1.12	
REP.*Units* stratum					
NPK_formulation	3	6592.	2197.	0.93	0.436
Rate	3	610914.	203638.	85.88	<.001
NPK_formulation.Rate	9	22222.	2469.	1.04	0.423
Residual	45	106706.	2371.		
Total	63	754380.			

Total	63	54910.8			

Variate: Stover weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	3639.5	1213.2	4.95	
REP.*Units* stratum					
NPK_formulation	3	2079.3	693.1	2.83	0.049
Rate	3	39482.3	13160.8	53.74	<.001
NPK_formulation.Rate	9	3286.9	365.2	1.49	0.180
Residual	45	11020.0	244.9		
Total	63	59508.0			

Variate: Grain yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	9179274.	3059758.	8.25	
REP.*Units* stratum					
NPK_formulation	3	855507.	285169.	0.77	0.517
Rate	3	131044195.	43681398.	117.82	<.001
NPK_formulation.Rate	9	1915590.	212843.	0.57	0.811
Residual	45	16683187.	370737.		
Total	63	159677754.			