UNIVERSITY FOR DEVELOPMENT STUDIES

COMPARATIVE ANALYSIS OF CONVENTIONAL VS REDUCED NPK FERTILIZATION ON MAIZE PERFORMANCE: A FOCUS ON BRIQUETTED UREA TOPDRESSING, SULPHUR, ZINC and BORON.

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FACULTY OF AGRICULTURE, FOOD AND CONSUMER SCIENCES

DEPARTMENT OF CROP SCIENCE

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BY

GILBERT ASIBI ANAFO

(UDS/MCS/0004/22)

THESIS SUBMITTED TO THE DEPARTMENT OF CROP SCIENCE, FACULTY OF AGRICULTURE, FOOD AND CONSUMER SCIENCES, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN CROP SCIENCE

JULY, 2025

DECLARATION

Student

I hereby declare that this is the result of my original work and that no part of it has been presented for another degree in this University or elsewhere.

Signature: .... Date: 30/07/2025

Name: Gilbert Asibi Anafo

Supervisor

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

Principal Supervisor Signature: .... Date: 30/7/2025

Name: Prof. Raphael Adu-Gyamfi

Co-Supervisor

Signature: .... Date: 30-07-2025

Name: Prof. Vincent K. Avornyo

Head of Department

Signature: For .... Date: 30/07/2025

Name: Prof. Shirley Lamptey

ABSTRACT

Ghana's soils, particularly in the Guinea savannah ecological zone, experience a decline in fertility and productivity caused by nutrient depletion and leaching. Additionally, the excessive focus on primary nutrients (NPK) has pushed secondary and micronutrients into the background, resulting in farmers not achieving the maximum yield from their cultivated crops. The aim of the study was to assess if the incorporation of micronutrients (Zn and B) into a reduced NPK application rate (70-50-50) kg/ha could effectively substitute the standard recommended NPK rate of 90-60-60 kg/ha. The study also seeks to compare briquette urea with the traditional granular form of urea at top dressing. A total of seven fertilizer treatments were evaluated. The trial was laid out in a split plot design with top dressing assigned to the main plot and fertilizer rates assigned to the subplots. The results revealed that there was no significant difference in the use of granular or briquette urea for top dressing ($P > 0.05$). The recommended NPK rate generally improved plant height, leaf area index and leaf chlorophyll content compared to the reduced NPK rate. In terms of grain yield, the reduced NPK rate was not significantly different from the sole application of the recommended NPK rate ($P > 0.05$). The inclusion of Sulphur compensated for reduction of NPK rate only in cob length while the inclusion of micronutrients improved cob length, biomass and days to 50 % flowering. Although the Agronomic Efficiency of nitrogen applied was similar for the reduced and recommended NPK rates, the inclusion of S to the recommended rate contributed to a higher efficiency of nitrogen usage. The study has demonstrated that the inclusion of S to the recommended rate improves grain yield and agronomic efficiency of nitrogen. It is therefore recommended that NPK should be fortified with Sulphur. There is also the need for further work on partial budget analysis to determine the inclusion of the trace elements in fertilizer formulation.

ACKNOWLEDGMENT

I wish to express my profound gratitude to the Almighty God for seeing me through this program of study successfully. I also want to express my heartiest gratitude to my Supervisor, Prof. Raphael Adu-Gyamfi, Department of Crop Science, for his help, encouragement and guidance in the completion of this thesis. His constructive criticisms and valuable suggestions added worth to this thesis. I will also want to express my sincere gratitude to my Co-Supervisor Prof. Vincent K. Avornyo, Head of Department of Soil Science. I remain grateful to the Director and staff of the International Fertilizer Development Center (IFDC) for their support. To the Department of Crop Science, I am very grateful for the knowledge imparted during my studies. I also extend my heartfelt appreciation to my course mates for the good relationship we shared and continue to share.

DEDICATION

This thesis is dedicated to the Almighty God and my lovely wife and children for their patience which has played a huge role in the success of this work.

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LIST OF ACRONYMS

ANOVA……………Analysis of Variance

CRI…………………Crops Research Institute

CIMMYT…………. International Maize and Wheat Improvement Center

CV…………………....Coefficients of Variation

FAO…………………. Food and Agriculture Organization

FERARI………. ……. Fertilizer Research and Responsible Implementation

g………………………Gramme

Ha………………. … Hectare

IITA…………………. International Institute for Tropical Agriculture

IFDC……….............International Fertilizer Development Centre

K…………………… Potassium

Kg………………......Kilogram

Kg/ha………………. Kilogram per hectare

LAI…………………. Leaf area index

LSD………………Least Significant Difference

MCS………………MPhil Crop Science

MOFA……………...Ministry of food and Agriculture

N..…………………. Nitrogen

P……………………Phosphorus

S……………………Sulphur

SARI……………...Savannah Agriculture Research Institute

SEM………………. Standard Error of Means

T……………………Treatment

t/ha……………………Tonnes per hectare

WAP………………. …Weeks after Planting

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

In comparison to other cereal crops, maize (*Zea mays L.*) has been found to have a high potential for genetic yield. As a result, it is referred to as a "miracle crop" and a "cereal queen". It is grown as one of the most significant cereal crops on a global scale. Maize is also known as a key ingredient in livestock feed and as a raw material for producing a wide range of commercial goods. Other items made from maize include beverages and distillery goods, as well as corn sucrose, maltodextrins, maize oil, and corn syrup. Recently, maize has been used to produce biogas (Erenstein *et al*., 2022). In Africa, maize is cultivated throughout a wide range of terrain, and it is ranked as the second most common necessary staple product after cassava. It is grown across a wide range of topography in Africa, from the highlands of Ethiopia to the northern Sahel of Niger, including an adapted vegetation zone in Sierra Leone (Mukrimaa *et al*., 2016).

Nearly every component of the crop has economic value in Ghana. In other words, the leaves, grain, tassel, cob, and stem of the maize plant can be used to make a wide range of items, both food and non-food-related. Since maize is a primary food source for the majority of Ghanaians, maize production is crucial for guaranteeing household food security in Ghana.

If immediate action was not taken to close the gap, the domestic unmet demand for maize for consumption in Ghana was predicted to exceed 267,000 metric tons by 2015 (Millennium Development Authority, 2010).

In order to address a variety of issues, including climate change, the Council for Scientific and Industrial Research (CSIR) of Ghana, through the Crops Research Institute (www.udsspace.uds.edu.gh 2), has released a number of enhanced maize varieties that vary over the breadth of maturation periods. Among the maize cultivars with the most potential for increased grain output and enhanced nutritional status is *obatampa*. *Obatampa* is a white dent form with a flinty endosperm, high tryptophan and lysine levels, and a high protein content in maize (Obeng-Bio *et al.*, 2019). The CRI first made *Obatampa* available in 1992 in an effort to improve the protein nutritional status of big, low-income families whose main source of food is maize (Sarfo *et al*., 2023).

Maize is known to be a heavy consumer of nutrients, and effectively managing soil nutrients is crucial for maximizing its yield. Between 1969 and 1972, fertilizer guidelines were established for maize and other crops. However, soil conditions have evolved over the years, rendering those earlier recommendations less effective today. This highlights the necessity to revise fertilizer guidelines for maize in Ghana's northern savanna agro-ecological zone (AEZ). Over time, the application of NPK fertilizers has been the main strategy for replenishing nutrients, which is logical considering that NPK provides the essential nutrients needed for crop production (Chukwuka *et al*., 2015). The exclusive use of NPK has successfully boosted maize yields and supported food security. Nevertheless, there is still potential for further yield improvements, especially in northern Ghana, where the average yield of 1.5 t/ha falls short of the global average of 4.9 t/ha (Yigermal *et al*., 2019b).

It has been recommended that adding secondary nutrients like sulfur (S) and micronutrients such as boron (B) and zinc (Zn) to fertilizer blends could significantly enhance maize yields (Sutar *et al.*, 2018).

Boron, which is one of the key micronutrients in this research, is essential to maize production, impacting numerous physiological functions and boosting both yield and quality. As an essential micronutrient, boron is critical for root growth, leaf expansion, and cob development, all of which are vital for the overall health and productivity of maize plants(Bienert *et al*., 2023). When there is a boron deficiency, plants may suffer from poorer health, leading to decreased chlorophyll levels and thinner leaves, which can negatively influence yield potential. Proper management of boron, especially through foliar application, can greatly enhance maize growth and yield by improving photosynthetic efficiency and increasing biomass accumulation(Bayar *et al.*, 2024)

The suggestion to mix secondary nutrients like Sulfur and micronutrients (B and Zn) to enhance maize production has neither been confirmed nor refuted in the northern savannah area of Ghana. As a result, fertilizers used in northern Ghana predominantly contain nitrogen (N), phosphorus (P), and potassium (K), which restricts potential yield improvements that could come from incorporating secondary and micronutrients.

Thus, there is a pressing need to investigate how the addition of these nutrients affects growth and yield in fertilizer formulations for this region.

The aim of this research was thus to assess the impact of including sulfur (a secondary nutrient), along with boron and zinc (micronutrients), in fertilizer formulations for maize production in northern Ghana, and whether the inclusion of this secondary and micronutrients could compensate for the reduced NPK recommended rate of 90-60-60kg/ha.

1.2 Problem Statement

Despite the widespread adoption of nitrogen, phosphorus, and potassium (NPK) fertilizers to enhance maize yield, there is a significant oversight in current agricultural practices regarding the inclusion of essential secondary nutrients such as Sulphur (S) and micronutrients such as zinc (Zn) (Kabir *et al*., 2021). Sulphur plays a crucial role in protein synthesis, enzyme activation, and chlorophyll formation, all essential processes for plant growth and development (Sutar, 2017). Similarly, zinc is integral to enzyme activities, protein synthesis, and hormone regulation, influencing various physiological functions critical for optimal crop performance (Sutar, 2017).

However, many maize-growing regions suffer from soil deficiencies of Sulphur and zinc, which can severely limit crop yield potential (Kumar *et al*., 2017). The inadequate supplementation of these Secondary and micronutrients alongside NPK fertilization practices may lead to suboptimal nutrient uptake, reduced photosynthetic efficiency, and ultimately, lower maize yields (Kabir *et al.*, 2021)

Boron (B) deficiency in maize production has a substantial economic impact owing to lower yield and quality. According to studies, boron deficiency causes yield losses and low quality in maize harvests in some African and Asian nations (Bienert *et al*., 2023). Optimal B application levels are required to reduce these economic effects. Addressing boron deficit through correct management strategies is critical for optimizing maize yield and guaranteeing economic sustainability in agriculture(A. Haque, 2024).

One of the problems associated with the use of granular fertilizers is nutrient leaching, which can lead to the pollution of groundwater resources. Although data is not available, northern Ghana's surface water and groundwater resources may be negatively impacted by nutrient losses from surface runoff and leaching from agricultural areas due to continuous surface application of granular fertilizer. Optimizing nutrient uptake by ensuring its availability through briquette fertilizer can boost recovery, increase crop yield and reduce nutrient losses (Adu-Gyamfi *et al.* 2019).

1.3 Justification

In Ghana, NPK 90-60-60 and 100-40-40 kg/ha has been recommended as optimal fertilizer rates for the Guinea Savannah and the Transitional Zone respectively. However, preliminary study by FERARI shows that these rates can be reduced if Sulphur and micronutrients are applied (Vanlauwe *et al*., 2023). This study will confirm if the reduced rate combined, Zn, and Sulphur will make up for the reduced NPK rate. This study holds significant implications for agricultural practices by addressing critical gaps in optimizing maize production through the synergistic application of sulphur (S) and zinc (Zn) alongside the standard NPK fertilizer regime. By investigating the combined effects of S and Zn with NPK fertilizers, the study aims to provide empirical insights into enhancing nutrient use efficiency in the savannah region of Ghana.

Although sulfur has been shown in several studies to aid in the growth and development of maize, further research is needed to fully understand the contributions of sulfur alone as well as sulfur included in NPK formulation.

Zinc (Zn) plays a very important role in plant metabolism by influencing the activities of hydrogenase and carbonic anhydrase and stabilization of ribosomal proteins (de Campos Bernardi *et al.*, 2016). Among crops, maize shows high sensitivity to Zn deficiency for its physiological requirements.

Boron plays a crucial role in the formation and stability of cell walls, which is essential for the overall structure and function of plants (Haque, 2024). It contributes to the production of key metabolites, thereby boosting photosynthesis and the transportation of nutrients throughout the plant (Wilder *et al*., 2022). Applying boron to soil, especially in areas with low boron levels, can significantly enhance maize growth when used alongside zinc, resulting in increased grain yields (Júlio *et al*., 2022).

Nutrient utilization is crucial for the growth and yield of maize, as evidenced by the findings of Adu-Gyamfi *et al.* (2019). Their study showed that maize plants cultivated in Ghana's savanna agro-ecological zones recovered more than 77 % of the applied fertilizer when using fertilizer briquettes, leading to an increase in maize production of over 30 % compared to the split application of granular fertilizer sources. Agyin-Birikorang *et al*, (2018) findings demonstrated that the utilization of multi-nutrient fertilizer briquettes led to a nutrient use efficiency of over 66 %, in contrast to 35 % obtained from treatments utilizing granular fertilizer sources.

1.4 Objectives

1.4.1 Main Objective

To assess if addition of S and Zn to NPK fertilizer can result in reduced NPK recommended rate of 90-60-60kg/ha.

1.4.2 Specific Objectives

- To evaluate the impact of two rates of NPK kg/haon maize growth and yield.
- Assess the impact of Sulphur, Zinc and Boron on maize growth and yield
- Determine if inclusion of S, Zn and B compensate for reduced rate of NPK kg/ha
- To evaluate the effects of different forms of urea topdressing, specifically comparing granular and briquette applications.
- Assess the Agronomic Efficiency of Nitrogen (AEN) applied as a measure of nitrogen use efficiency

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and distribution of maize

Maize is also known as corn in America. It is explained that in the early days of British and American corporate trade, all cereals were referred to as maize. Since maize was the most extensively grown and utilized grain crop in trade, the term "maize" had been retained. The most commonly known crop is maize, which is thought to have come from the Arawac tribes of the indigenous inhabitants of the Caribbean, however the term "corn" is still up for debate. Linnaeus classified plants botanically using the term *Zea*, based on their common name (Fikadu *et al.,* 2022)

Teosinte is thought to be the source of cultivated maize (Z. *mexicana*). It is also known that maize was domesticated in the sixteenth century in the ancient world thought to have been one of the first crops to be grown by farmers between 7,000 and 10,000 years ago as a staple food crop. Archaeologists have confirmed that it was first thought to have been found in Mexico about 5,000 years ago (Yimenu Kassa, 2017).

2.2 Biology of maize

Zea mays L., commonly known as maize, is an annual plant that grows tall and has both male and female flowers on the same individual. Its margins are distinctly arranged in two rows and are covered in overlapping layers. This species belongs to the Poaceae family, also known as Graminae. In botanical classification, it is referred to as *Zea* maize. Maize is primarily pollinated by wind and commonly experiences both self-pollination and cross-pollination. For a large portion of the global population, maize serves as a main food source and demonstrates a strong ability to adapt (Ranum *et al*., 2014). Maize should be sown when the soil temperature reaches approximately 10°C, typically from early to mid-May. To ensure optimal growth and yield, it requires effective soil management along with proper agricultural practices, including suitable fertilizer use, pest and disease management, weed control, erosion prevention, and zero-tillage (Baum *et al*., 2019).

By utilizing pure-line male and female inbred varieties—specifically, crossing one male line with four female lines—it is possible to produce hybrid maize (*Zea mays* L.) seeds. Unlike foundation seeds, hybrid seed production requires segregation. To ensure that the female parent does not self-pollinate, male-sterile technology can be used, or detasseling can be performed prior to pollen release. Inbred and crossbred varieties are maintained according to genealogical standards, employing techniques such as isozyme profiling through enhanced laboratory testing and representative seed lots (Desta *et al.*, 2020)

2.3 Water requirement for maize production

Scientists and agronomists find the water requirements of maize (*Zea mays* L.) to be an intriguing topic. It aids in crop nutrition management planning (maize). A shortage of water reduces maize yield. For optimal growth and productivity during its crucial growth stages, maize requires a lot of water. (Moreno-Pizani, 2021). Competition for water among urban, municipal, industrial, and agricultural users has reportedly increased recently (Fang and Su, 2019). It is crucial for effective crop planning and management to increase maize yield by providing an adequate supply of water (de Wit *et al.*, 2019). The amount of water needed for evapotranspiration during the time when sufficient soil water is retained by irrigation or precipitation is known as the crop water requirement. This ensures that plant growth and productivity are not impeded (Djaman *et al*., 2018).

The amount of water needed for maize (or any other crop) to grow and develop depends on a number of factors, including the length of the crop's growing and developing stages, the environment's evaporative demand, the density of the canopy, crop species, and planting density expansion (Magagula *et al*., 2020). Moisture stress during the reproductive stage of maize can reduce the optimal yield, leading to the development of empty cobs or subpar grain formation. For this reason, the amount of water a plant needs are crucial for both its active development phase and its reproductive stage (Kwadwo and Christian, 2015).

A wide range of climatic conditions, including differences in rainfall patterns and distribution, are suitable for the cultivation of maize. Additionally, the crop is grown in rain-fed and irrigated environments. Rainfall is necessary for over 75 % of agricultural activities, especially in regions where crops are the primary source of food and income for people (Godfrey, 2018).

Waterlogging affects maize, especially in its early stages of growth (Jaiswal and Srivastava, 2018). However, during the growing season, maize thrives on soils that receive enough precipitation. The crop could withstand dry spells, especially during the first three to four weeks of growth. Given the semi-arid and dry sub-humid regions, which include the coastal savannah climate, rainfall quantity is not only the primary limiting factor for the development of rain-fed maize but also its unpredictable nature (Bagula *et al*., 2022). Water stress, on the other hand, can potentially limit the buildup of biomass and, as a result, lower the grain yield of the maize crop when it occurs at different stages of crop development. The extent of the decline in maize yield is not solely determined by the level of water stress or drought, but also on the crop's ability to withstand water stress or drought and how well the maize crop uses the water that is available in the soil for growth, biomass accumulation, and yield generation at that point in the crop's development (Sheoran, 2022).

2.4 Importance of maize production

Maize (*Zea mays* L.) is a key grain crop that serves as food for both humans and livestock in numerous parts of the world. The nutritional value of cereal crops, including maize, has seen considerable enhancement. This improvement is significant because it allows for widespread dissemination of its benefits to the public without altering their traditional dietary practices. Every component of the maize plant—its grain, cob, tassel, leaves, and stalk can be utilized to produce a variety of food and non-food items (Mamudu *et al*., 2017).

2.5 Nutritional benefits of maize

In Ghana, popular foods derived from maize grain include Akple, Banku, Kenkey, and Tuo Zaafi, which vary by region (Mamudu *et al*., 2017). As a staple grain and a beneficial source of carbohydrates, maize is nutritionally richer than other grains, consisting of approximately 72 % starch, 10 % protein, 10.2 % moisture, and 8.5 % fiber, among various other essential nutrients (Nirere *et al*., 2021). Additionally, maize grains are rich in various bioactive compounds such as carotenoids, tocopherols, lutein, ergocalciferols, and zeaxanthins (Burns, 2015) along with fat-soluble vitamins including provitamin A, vitamin B1 (thiamine), vitamin B2 (niacin), vitamin B3 (riboflavin), vitamin B5 (pantothenic acid), vitamin B6 (pyridoxine), vitamin C, vitamin E, vitamin K, folic acid, and selenium (Ghete *et al*., 2018)

2.5.1 Economic benefits of maize

Zea mays L., or maize, is a major contributor to the world economy, particularly in industrialized nations where it is used as an industrial raw material for the production of biofuels (Awata *et al.*, 2019). According to reports, because the US economy mostly depends on the maize production, maize is considered as the "mother grain" of the US (Saeed, 2020). Additionally, provides a source of income and foreign exchange because maize is used as a raw material for sticky gum, which contains dextrin for the development of envelope sealants, as well as a source of alcohol and stem fibers for the production of paper. Maize starch is used as diluents in many industries, including pharmaceutical and cosmetics (Narendra Kumawat *et al*., 2017)

Cash received from the sale of livestock and its byproducts that are fed maize provides an additional source of revenue. Additionally, local kenkey vendors used the maize husk, which is used to make door mats, to wrap their kenkey, increasing local income (Mamudu *et al*., 2017)

2.5.2 Health benefits of maize

In addition to its applications in medicine, maize (*Zea mays* L.) is an important provider of phytochemicals, which have been demonstrated to enhance human health and may help lower the risk of chronic diseases(Huma *et al*., 2019). Because of its properties, such as its potential as an antioxidant, diuretic, its effectiveness in lowering blood sugar levels, and its usage as a remedy for depression or fatigue, the maize plant is commonly utilized in traditional medicine in countries like China, France, India, Turkey, and the United States (Ghete *et al*., 2018). Furthermore, pharmacological studies have highlighted its remarkable therapeutic benefits, including anti-fatigue, antioxidant, effective diuretic, and hypoglycemic effects (Rouf Shah *et al*., 2016)

2.6 Nutrient requirements for maize growth and yield

For maize (*Zea mays* L.) to thrive, it requires a substantial amount of minerals, especially NPK(Aliyu *et al*., 2021). However, as maize seedlings are quite young and unable to handle high levels of fertilizer, fertilizer should be applied in 5 cm holes around the seedlings (Rop *et al*., 2019).

Ghana's maize production is limited due to its inability to effectively utilize available resources(Wongnaa *et al*., 2021). During the vegetative growth phase, maize requires increased nitrogen levels(Shrestha *et al.*, 2018). Nitrogen is one of the essential nutrients for maize to achieve optimal growth and development. Since nitrogen is the most limiting factor affecting maize crop yields, insufficient nitrogen levels lead to leaf chlorosis (Anas *et al*., 2020). Its Deficiency can lead to slow growth, weakened, and stunted plants. Although phosphorus is essential for maize development, it is not as critical as nitrogen(Dhlamini *et al*., 2020). Signs of phosphorus deficiency in maize include stunted growth and sometimes dark green plants, with older leaves exhibiting a purple hue. A lack of phosphorus during maize kernel production can lead to poor grain development and inadequate kernel setting (Ngure, 2020). Potassium (K) is a vital macronutrient necessary for the growth and development of plants, and it affects both the yield and quality of agricultural crops(Zhang *et al*., 2023). Symptoms of potassium deficiency in corn often include burnt leaf edges. Furthermore, it can lead to poor kernel development, weakened plants that may lodge, and a reduction in both grain quantity and quality.

2.7 The effect of inorganic fertilizer applications on maize production

The contribution of mineral fertilizers to global food production ranges from 40 % to 60 %. Nevertheless, in Sub-Saharan Africa, farmers apply less inorganic fertilizer than the recommended amount established by the African Head of State (Njoroge *et al*., 2018).

In recent decades, fertilizers based on nitrogen, phosphorus, and potassium (NPK) have been the most widely available and easily accessible to farmers worldwide for replenishing soil nutrients, particularly in underdeveloped nations (Nirere *et al*., 2021). According to findings, micronutrient deficiencies and deficiencies in NPK elements in most poor soils are major obstacles to the production of maize crops. Depletion of soil micronutrients is on the rise in most developing nations, particularly when continuous cropping occurs without nutrient replenishment (Otieno *et al*., 2019). The greatest impact on maize plant growth and development, increased maize grain yields, and the nutritional quality of maize grain seeds have been reported to come from the combined effects of macronutrients like nitrogen, phosphorus, and potassium, known as primary nutrients (Kugbe *et al*., 2019), with a small amount of secondary nutrients like calcium [Ca], magnesium [Mg], and sulfur [S], and micronutrients like boron [B], chlorine [Cl], copper [Cu], iron [Fe], manganese [Mn], molybdenum [Mo], nickel [Ni], and zinc [Zn] (Bua *et al*., 2020). Strong effects of inorganic fertilizers on crop growth, development, and yield suggest that NPK inorganic fertilizers are a good source of macronutrient requirements for crops, along with microelements like Fe, Mg, Zn, and Cu for crop growth, development, grain yield, and quality (Prayogo *et al*., 2021)

2.8 The effect of macronutrients (N, P and K) on maize production

The main method of nutrient replenishment in contemporary agricultural schemes has been the application of macronutrients like nitrogen (N), phosphorus (P), and potassium (K) fertilizers alone over time (Kulcheski *et al*., 2015). This approach has increased maize yield and improved food security (Kugbe *et al*., 2019). According to Chukwuka *et al*. (2015), NPK fertilizer nutrients continue to be the most important macronutrients needed for crop productivity and the standard of agricultural output. However, more corn production growth is needed, especially in northern Ghana (Yigermal *et al*., 2019). The mineral nutrients that crop roots absorb have an impact on the life cycle of crops. According to Klikocka and Marks (2018), there is a strong correlation between maize production and the uptake of N, P, and K by the grain and the entire plant. Crops require nutrients for both vegetative and agronomic growth, much as all other living organisms. For this reason, they need the elements nitrogen (N), phosphorus (P), and potassium (K) for growth, development, and food production. These are the main elements that crops receive via fertilizers, which can be organic or inorganic, as well as from soil minerals and organic matter (Asibi *et al*., 2019). The advancement of crop growth and development depends heavily on the uptake and accessibility of these essential components, particularly in Sub-Saharan Africa where soil nutrient depletion is a typical occurrence. According to Sharif *et al*., 2014, the capacity of soil replenishment in the soil as well as the amount, concentration, and activity in the rhizosphere have a major influence on how much nutrient uptake crops or plants can accomplish.

2.9 The effects of micronutrients on maize production

Compared to macronutrients like nitrogen (N), phosphorus (P), and potassium (K), micronutrients are necessary for plant growth but are needed in much smaller levels (Mugenzi *et al.*, 2018). Micronutrients that enhance the quality and yield increase of the maize crop, such as zinc (Zn), boron (B), copper (Cu), magnesium (Mo), nickel (Ni), and iron (Fe), are essential for plant growth and development (Dhakal *et al*., 2021). Zinc deficiencies have become more prominent in the past year; however, zinc application has been reported for increasing maize yield globally (Ahmad and Tahir, 2017). Micronutrients are not only enhancing grain yields, however involved in the improvement of the quality of the grains in terms of nutrition (Ehsanullah *et al*., 2015)

Micronutrient availability is influenced by a multitude of soil variables as well as crop type (de Valença *et al*., 2017) Because calcareous and alkaline soils, which are characterized by high pH and carbonate content (Cakmak *et al*., 1999); (Ma *et al*., 2014). Worldwide, there is an issue with soil deficiency in both zinc and iron that is hurting crop production reduction and food quality (Manzeke *et al.*, 2019).

2.10 Sulphur and its effect on growth and yield parameters of maize

According to Juhász *et al.*,(2021) sulfur (S) is a crucial nutrient for the growth of plants and animal life. It is also regarded as the fourth key nutrient element for plant growth and development (Channabasamma *et al.*, 2013). Protein synthesis, oil production, enzyme activity, and plant nitrogen metabolism are all significantly impacted by the element sulfur (Kumar *et al.*, 2017). The most common and readily obtainable type of sulfur is calcium sulfate, and a lack in it might hinder plants' ability to absorb phosphate and nitrogen. Thus, it is utilized in the formulation of fertilizers (Rebi *et al.*, 2020). Because sulfur is a component of the amino acids cysteine, cystine, and methionine, it is necessary for crops to accumulate chlorophyll and synthesis proteins (Kumar *et al.*, 2016). Worldwide, there are reports of a sulfur shortage in more than 70 nations. This has a negative impact on crop output and grain quality and has emerged as a significant production barrier (Ariraman *et al.*, 2020)

2.11 The effect of Zinc on the growth and yield of maize

Zinc (Zn) deficiency poses a significant nutrient challenge, especially in calcareous soils. Although the total concentration of zinc may appear adequate, the amount of readily available zinc is often lacking due to different soil and climate factors. The level of available zinc in soil is affected by several elements, including soil pH, lime content, quantity of organic matter, type and quantity of clay present, and the application rate of phosphorus fertilizer. Globally, the incidence of zinc deficiency is reported to be 30 %(Yifru and Sofiya, 2017). The nutrition of plants is heavily influenced by the interactions among various nutritional elements. The connection between boron and zinc has been inconsistent in soils that have low zinc levels in recent years. (Nasim *et al*., 2015)

Zinc influences the activities of carbonic anhydrase and hydrogenase as well as the stabilization of ribosomal proteins, all of which are crucial for plant metabolism (A. Bhat *et al*., 2018). With regard to its physiological needs, maize exhibits the highest sensitivity among crops to a zinc deficit. By regulating auxin synthesis, preserving the integrity of cellular membranes, and promoting the metabolism of carbohydrates, zinc stimulates the activity of plant enzymes (Marschner, 2012). Zn helps produce tryptophan, a precursor to indole-3-acetic acid (IAA), which makes it necessary for the synthesis of auxin. The vital functions of plants, including as photosynthesis, resistance to biotic and abiotic stressors, nitrogen metabolism, protection against reactive oxygen species, carbonic anhydrase activity, and chlorophyll synthesis, are significantly impacted by zinc (Ali and Al-Juthery, 2017).

2.12 The role of briquette fertilizer in maize nutrition

Maize requires a significant amount of nutrients, particularly nitrogen, because of its high yield potential. In maize cultivation, nitrogen is often the most critical nutrient. Implementing effective nitrogen management practices (such as source, rate, timing, and placement) can enhance maize yields. The type of nitrogen fertilizer used significantly influences maize production. (Abbasi *et al.*, 2013). The impact of the N fertilizer source on maize yield was also noted by (Szulc *et al*., 2013). Modern commercial N fertilizers that are frequently employed include urea and ammonium sulfate [$(NH_4)_2SO_4$], however their use efficiency in maize cultivation is low, leading to low yields and degradation of the environment. Thus, for increased maize productivity, quality, and profitability as well as a healthier environment, the development of novel alternative N fertilizers with high usage efficiency potentials is necessary.

An alternative N source that supplies N in addition to P and K with the intention of improving the N, P, and K use efficiency is briquetted NPK (NPKBriq) of large-sized super granules. The existing commercially available granular and prilled N, P, and K fertilizers are physically altered to create NPKBriq (Wu *et al*., 2017). It provides N, P, and K nutrients in a ratio appropriate for the intended crop and soil and is completely mineral-based (Agyin-Birikorang *et al*., 2018). Since it only requires a single application instead of the typical two to three separate applications of commonly used granular and prilled fertilizers, this type of NPKBriq fertilizer allows for nutrient-balanced, site-specific fertilization, which helps to reduce nutrient losses, particularly nitrogen, and saves on labor. When comparing NPKBriq to prilled and granular fertilizers, the former has a smaller surface area and dissolves more slowly, gradually releasing nutrients over time at a more controlled rate. This ultimately results in reduced nutrient losses, especially nitrogen, and helps preserve the quality of both water and air (Wang *et al*., 2020).

According to Agyin-Birikorang *et al.* (2012), under typical weather conditions, NPK Briq enhanced maize yield by 16 % when compared to ammonium sulfate (+P and K) and by 23 % to 34 % when compared to urea (+P and K); NPK Briq also led to higher N, P, and K utilization efficiencies. According to (Adu-Gyamfi *et al*., 2019), maize plants cultivated in Ghana's savanna agro-ecological zones recovered N77 % of the applied fertilizer with the use of fertilizer briquettes, increasing maize production by N30 % in comparison to split application of granular fertilizer sources. Similarly, (Agyin-Birikorang *et al*., 2018) demonstrated that the nutrient utilization efficiency of N66 % was achieved by employing multi-nutrient fertilizer briquettes, as opposed to 35 % from treatments using granular/prilled fertilizer sources.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental site

The experiment was conducted at the research and experimental farms of the University for Development Studies popularly called 'Farming for the Future'. The area lies within the Guinea Savannah Agroecological zone, between latitude 9° 11' 0" N and longitude 0° 19' 0" E, with an altitude of 163m above sea level. The climate of the area is tropical, greatly influenced by the South-West Monsoons from the South Atlantic and the Northeast Trade Winds (Harmattan) from the Sahara Desert. The area has a mono-modal rainfall pattern, which starts in April-May and ends in October. The average annual rainfall is about 800 mm to 1200 mm (Berdjour *et al*., 2020)

3.2 Treatment and Experimental design

The experiment considered two rates of NPK, the recommended rate for Guinea Savanna agroecological zone (90-60-60)kg/ha and its reduced rate (70-50-50) kg/ha of N-P_2O_5-K_2O. Sulphur at 20 kg/ha and trace elements Zn and Boron were added to these two levels making seven treatments. The Nitrogen was split into two basal and top dressing. The top dressing that was done at 6 WAP had two forms, granular and briquetted urea. The experiment was laid out in a Split plot design with four replications. The treatment structure used in the experiment is shown in table 1. The granular and briquetted urea fertilizers used as top dressing were assigned to main plot while the seven fertilizer treatments served as sub plot treatments.

Table 1: Nutrient rates of fertilizer used in the experiment

Treatment No	Fertilizer Rates	Amount of NPK per 25m^2 (kg)	Amount of SA per 25m^2 (kg)	Amount of Urea per 25m^2 (kg)	Zn +B
1	Control	0	0	0	
2	NPK (70-50-50)	0.6	-	0.2	
3	NPK + S (70-50-50-20)	0.6	0.2	0.1	
4	NPK (70-50-50 + TE)	0.6	-	0.2	0.7+0.5%
5	NPK (90-60-60)	0.7	-	0.3	
6	NPK + S (90-60-60+20)	0.7	0.2	0.2	
7	NPK (90-60-60+TE)	0.7	-	0.3	0.7+0.5%

3.3 Basal application of granular NPK and briquetted urea top dressing application

NPK 23-10-05 was used at the rates 70-50-50 kg/ha and 90-60-60 kg/ha enhance with trace elements and Sulphur as indicated in the treatment table above. Urea briquetting was done at IFDC in Accra. The briquetted urea was applied as a top dress. Briquettes were about 2cm in diameter and an average weight of 2.5 g. Basal fertilizer treatments were applied two weeks after planting while top dress was applied six weeks after planting. All fertilizers were buried by dibbling about 6-10 cm deep and 5-7 cm away from the plants.

3.4 Field preparations and agronomic practices

The land was tilled by double harrowing using a tractor. The experimental lay-out or demarcation was done using a tape measure, garden-lines, and pegs. The sub-plot size was 5 m × 5 m with 1 m between subplots and 2 m alley between blocks. The maize variety used was *Obatanpa* and a planting distance of 75 cm inter-row spacing and 40 cm intra-row spacing was adopted. Two seeds were planted per hole. Planting was done on July 11, 2023. Basal fertilization was applied 14 days after planting, while top dressing was done 28 days after the first application

3.5 Soil data

Soil was samples were taken with the aid of a spade by digging up to 8 inches along a zigzag pattern on the experimental site. Four samples were taken on each replication and later composited for analysis in the soil science laboratory of the University for Development Studies.

3.6 Weed control

Pre-emergence weedicides, glyphosate was used immediately after planting. Selective weedicide was used nine days after planting to control weeds in readiness for basal fertilizer application. Manual weeding was done five weeks after planting.

3.7 Pest control

At 4 WAP, fall armyworm (*Spodoptera frugiperda*) infestation was detected. It was controlled by spraying the crops with Emastar insecticide mixed with water. This was repeated at 6 WAP. A third control was done at 9 WAP but this time it was targeted at crops that were heavily infested by pouring the pesticides mixed with water into the whorl of the crop.

3.8 Maize variety

Obatanpa maize variety was used. It is a tropically adapted, open-pollinated, has 105 days maturity with white grain color. *Obatanpa* cultivar was developed by the Crops Research Institute (CRI), Kumasi, Ghana in collaboration with the International Institute of Tropical Agriculture (IITA), Ibadan; the International Maize and Wheat Improvement Center (CIMMYT), Mexico; and the Sasakawa Global 2000 (SG 2000). It has a grain yield potential of 6 t /ha.

3.9 Harvesting

Harvesting was done when 100 % of the maize plants attained physiological maturity. After removing the border plants, the inner 14.75 m^2 was divided into four quadrants. Two quadrants making a total of 7.35 m^2 were marked out and harvested for grain yield, biomass and straw weight data. Crops from this net plot were harvested and handled separately from the discard. The cobs were de-husked manually, dried for four days, shelled and kept in labeled bags for weighing

3.10 Data collection

During the study, data on the following parameters were taken: rainfall, chlorophyll content, plant height, leaf area index, leaf number, and days to 50 % flowering, days to 50 % maturity, cob length, cob weight, fresh straw weight, dry straw weight, biomass weight, grain yield and thousand seed weight

3.10.1 Rainfall

Rain gauge was mounted in the field to record rainfall data. The data was at the end of every rainfall and 8:00am after every rainy night and recorded in millimeters (mm). This data was cumulated monthly for the 2023 maize growing period. Averages were computed per month and used to generate a rainfall distribution graph

3.10.2 Plant height

This was measured in centimeters four weeks after planting and records were continued every two weeks until tasseling. The distances from the ground level to the longest growth point was measured. In the middle rows, plants numbering up to five were randomly sampled and tagged from each plot and used for this purpose and their means were reported as plant height.

3.10.3 Leaf number

This was recorded four weeks after emergence and continued every two weeks until tasseling. From the middle rows of each plot, five plants were randomly sampled and labelled. The number of leaves on the sampled plants was then counted every two weeks.

3.10.4 Leaf area index (LAI)

This was measured four weeks after emergence and was reported on a continuous basis every two weeks until tasseling. In the middle rows from each plot, five plants were randomly sampled and tagged and used for this purpose. The leaf area was then determined by measuring the width and length of each plant's fifth and sixth leaves. Leaf length was measured from the tip of the leaf to the point of attachment to the stalk. The width was taken from the middle where maximum width can be obtained. The average length (L) and width (W) were computed. The leaf area of individual leaf was calculated using the formula $Area = L\ x\ W\ x\ K$ where K is a constant, 0.75. In order to obtain the leaf area of a plant, the individual leaf area computed was multiplied by the total number of leaves on the plant. The leaf area was used to calculate the Leaf Area Index (LAI) by dividing the leaf area by the ground cover of a plant. The ground cover was obtained using the planting distance of 75 cm x 40 cm (3000 cm^2)

3.10.5 Content of chlorophyll

This was recorded four weeks after planting and its records were continued every two weeks until maturity. From the middle rows of each plot, five plants were randomly sampled and tagged and used for this reason. The chlorophyll content of the fifth and sixth leaves of the sampled plants were taken by using SPAD meter and their means reported as chlorophyll content.

3.10.6 Days to 50% and 100% silking

Field monitoring for 50 % silting commenced at cob initiation and development. The number of days it took for half of the cobs per plot to silk was recorded. Data on days to 100 % were estimated by counting the number of days it took for all plants to silk per plot to silk.

3.10.7 Biomass per hectare

An inner area of 7.35 m^2 was marked from the 25 m^2 plot for harvesting. Plants from this area were harvested from the ground. Total biomass was measured from all plants harvested from the marked 7.35 m^2. This was converted to kilograms per hectare (kg/ha). Five plants were randomly selected from the lot and their biomass was also taken.

3.10.8 Grain yield

Cobs of maize plants from each net plot of 7.35 m^2 were de-husked, dried for four days, shelled and kept in labelled bags for weighing. Weighing was done in kilograms using electronic scale. This was later expressed in kilograms per hectare (kg/ha).

3.10.9 Cob weight

Five cobs from the net plots of 7.35 m^2 were randomly selected, de-husked and weighed at harvest to obtain the cob weight. The average weight was computed for the cobs per plot.

3.10.10 Length of cob

This was recorded by selecting from each net plot of 7.35 m^2 five cobs randomly and measuring their length in centimeters (cm) with the attached grains. The averages of the five cobs were then recorded for the respective plot.

3.10.11 Thousand seeds weight of grain

1000 seeds were randomly selected from the grain yield of each net plot for weighing. Weighing was done in grams using electronic weighing scale. The seeds were later kept in well labelled envelopes to be used for the protein content analysis.

3.10.12 Agronomic Efficiency of Applied Nitrogen

Nitrogen use efficiency was assessed as Agronomic efficiency of applied nitrogen which was calculated by subtracting the yield of the crop (kg/ha) in a control treatment with no nitrogen from the yield of crop (kg/ha) with applied nitrogen and then dividing by the amount of fertilizer (nitrogen) applied (kg/ha).

$$Agronomic\ efficiency\ of\ applied\ N\ (AEN) = (YN - YO/FN)$$

where;

YN- crop yield (kg/ha) with applied nitrogen (N)

Y0- crop yield (kg/ha) in a control treatment with no nitrogen (N)

FN- amount of nitrogen applied (kg/ha)

3.11 Data analysis

The data collected were subjected to analysis of variance (ANOVA) using the GENSTAT Statistical package 12th edition and the means were separated using Least Significant Difference (LSD) at 5 % probability level and the Duncan Multiple Range Test (DMRT). Results are presented in tables and graphs

CHAPTER FOUR

4.0 RESULTS

4.1 Rainfall

The area recorded highest rainfall in July and lowest in August. Amount of rainfall recorded for the season was 1078.1mm and by October the rainfall started receding (Figure 1)

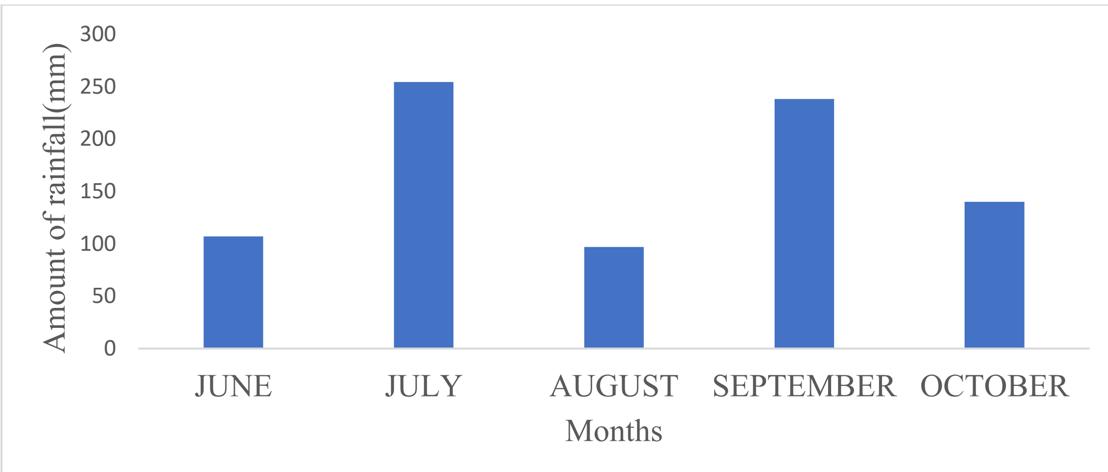

Figure 1: Rainfall recorded in the maize experimental field during the 2023 season (June to October)

4.2 Soil characteristics

Soil sampled from the field for the experiment was analyzed for mineral contents before the start of the experiment. The soil's physiochemical properties (pH, organic carbon, total N, available P, K, and Zn) were determined using standard laboratory methods at Soil Science Laboratory of the University for Development Studies, Ghana. Soil pH was determined by the glass electrode method of using a pH meter in a 1:2:5 soil-to-water ratio mixture. Bulk density was found to be 1.41g/cm^3. Textural class was determined using the USDA textural triangle. The table below (Table 1) indicates the soil parameters that were analyzed for and their quantities.

Table 2: Physical and chemical properties of the soil

PARAMETER	QUANTITY
PH(H_2O)1:2.5	5.9
EC(dSm-1)	3.175
OC (%)	1.397
OM	2.406
N (%)	0.0617
P (Cmol/Kg)	1.731
K (Cmol/Kg)	0.036
Na (Cmol/Kg)	2.079
Ca (Cmol/kg)	6.172
Mg (Cmol/kg)	1.188
BD (g/cm^3)	1.41
Sand (%)	83.96
Silt (%)	13.52
Clay (%)	2.52
Texture	Loamy Sand

4.3 Effect of fertilizer rates on plant height

The topdressing and the fertilizer rates did not have significant interaction effect ($P > 0.05$) on plant height across all the periods plant height was measured. The top dressing also did not have significant effect on ($P > 0.05$) plant height measurements made. However, plant height differed significantly among the fertilizer rates for all the weeks ($P < 0.001$). At 4 WAP, all the fertilizer treatments produced statistically similar plant height with no clear distinction, but all performed better than the control. The addition of 20 kg/ha of Sulphur to the recommended rates (90-60-60-20-0) kg/ha and the sole application of the recommended rates (90-60-60-0-0) kg/ha edged slightly ahead of the other treatments at 6 WAP and 8 WAP. By the 8th and 10th WAP, the addition of S and trace elements to the recommended rate (90-60-60-20-0 and 90-60-60-0-TE) kg/ha as well as the sole application of the recommended rate (90-60-60-0-0) kg/ha exerted their superiority in plant height over the reduced rates, distinguishing themselves completely at the top at 10WAP. Plant height in control plots with no fertilizer treatments lagged behind from 4-10 WAP (Figure 2).

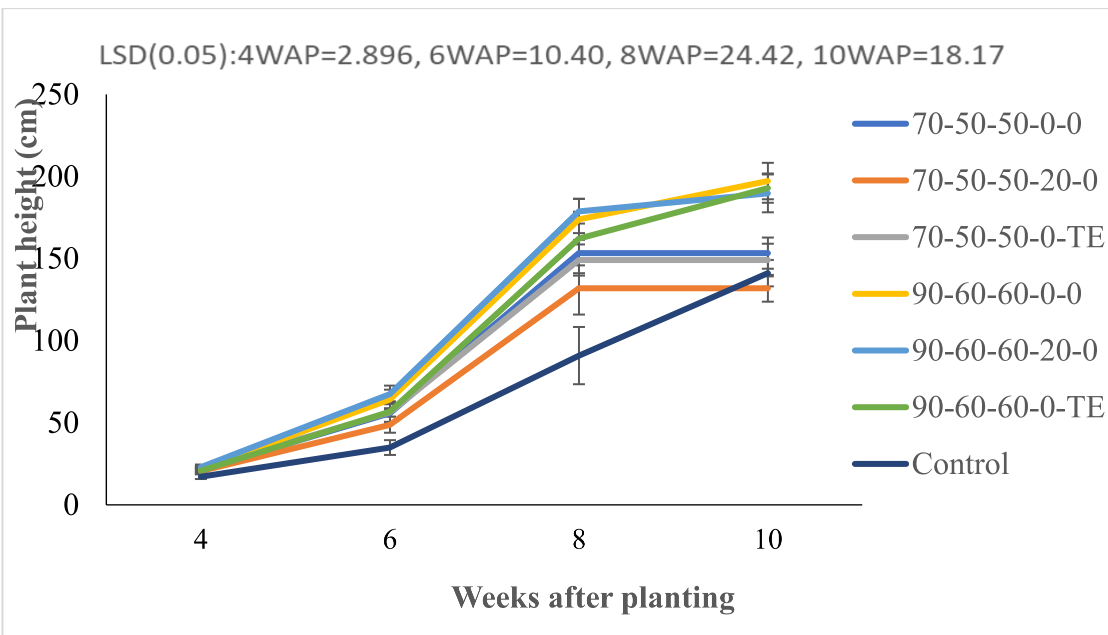

Figure 2: Effect of Fertilizer rates, S, Zn and B on plant height of maize. Errors bars represent standard error of mean (SEM).

4.4 Effect of fertilizer rates on leaf area index

The fertilizer rates, top dressing and their interaction effect did not cause any significant difference in leaf area index at 4WAP (P = 0.273). In the ensuing weeks, the interaction effect of the fertilizer rates and top dressing was not significant on plant height (P > 0.05). Similar observation was made on top dressing on plant height. However, the fertilizer rates had significant effect on leaf area index from 6-10WAP (P < 0.001). Leaf area index peaked at the 6 WAP and reduced afterwards (Figure 3). Between 6 to 8 WAP, the addition of trace elements to the recommended rates (90-60-60-0-TE) kg/ha led in LAI but was statistically apar with the sole application of the recommended rate (90-60-60-0-0) kg/ha at 8WAP. By the 10th week, the recommended rate with 20 kg/ha of S (90-60-60-20-0) kg/ha dominated. The top three treatments at the 10th week were all the recommended rates (90-60-60-0-0, 90-60-60-20-0 and 90-60-60-0-TE) kg/ha. Even though the reduced fertilizer rates treatments closely trailed the recommended rate treatments at 4-8 WAP, there was a clear separation from the reduced rate treatment in LAI at 10 WAP (Figure 3). The control treatment with no fertilizer lagged behind in all the weeks where LAI was assessed (Figure 3).

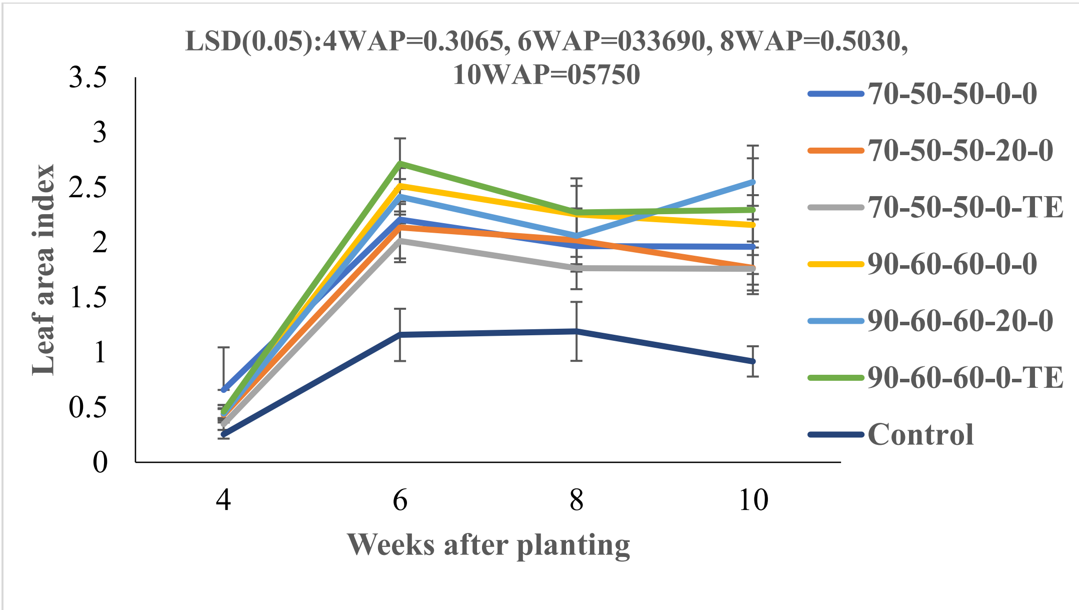

Figure 3: Effect of Fertilizer rates, S, Zn and B on leaf area index of maize in the during the 2023 growing season. Errors bars represent standard error of mean (SEM).

4.5 Effect of fertilizer rates on SPAD readings (leaf chlorophyll content)

The fertilizer rates and top-dressing interaction as well as the main effect of top dressing did not

significantly affect chlorophyll development in all the weeks where the parameter was assessed ($P > 0.05$). However, the fertilizer rates significantly ($P < 0.001$) influenced chlorophyll development measured as SPAD meter readings. At 4 WAP, all the fertilizer treatments produced a statistically similar reading in chlorophyll content. The incorporation of 20 kg/ha of S to the recommended rate (90-60-60-20-0) kg/ha edged ahead of the other treatments at 6 WAP and 8 WAP whiles the addition of trace elements to the recommended rate (90-60-60-0-TE) kg/ha peaked ahead of the other treatments in chlorophyll content at 10 WAP. At 8 WAP and 10 WAP, the sole application of the recommended rate (90-60-60-0-0) kg/ha produced statistically similar chlorophyll content as the treatments under reduced rate. Across all the four weeks, the three treatments under recommended rate produced the higher chlorophyll content. The reduced rate treatments recorded lower and statistically similar chlorophyll content that was also statistically apar with the sole application of the recommended rate across the weeks where chlorophyll content was assessed. The control plots lagged behind in chlorophyll content from 4-10 WAP (Figure4).

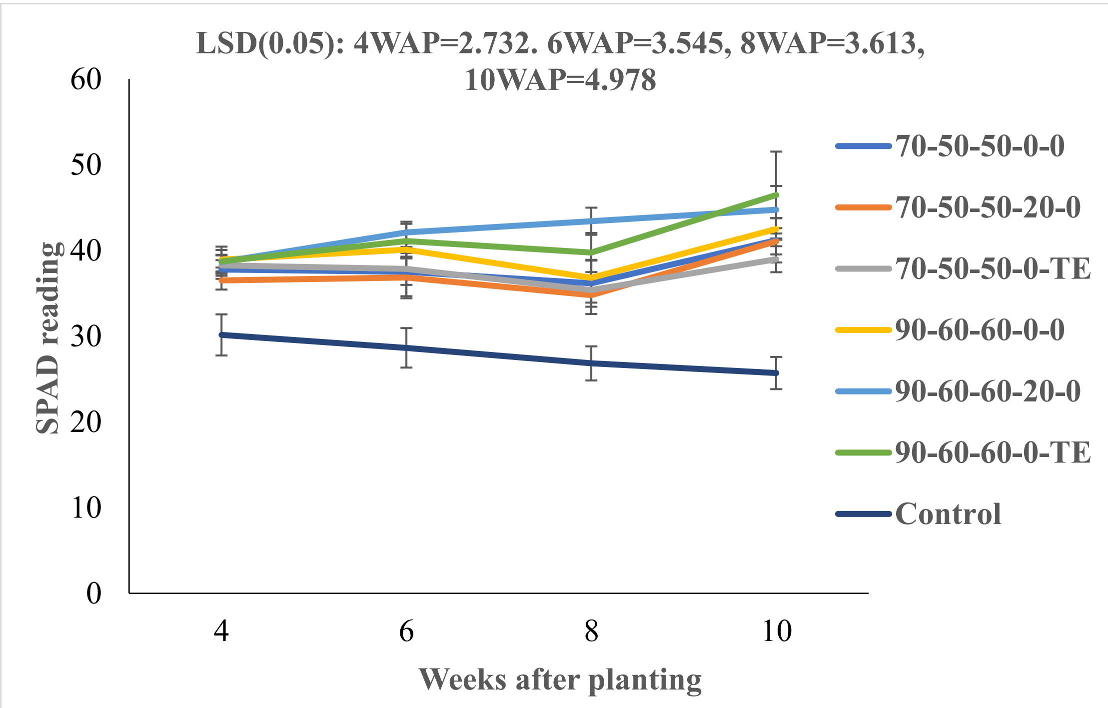

Figure 4: Effect of Fertilizer rates, S, Zn and B on chlorophyll content of maize during the 2023 growing season. Error bars represent standard error of mean (SEM)

4.6 Effect of fertilizer rates on days to 50 % flowering

The fertilizer rates and top-dressing interaction as well as the main effect of top dressing did not significantly (*P* > 0.05) affect days to 50 % flowering. However, the fertilizer rates significantly influenced the days to 50 % flowering (*P* < 0.001). Maize plants in the control plots took the longest time to flower compared to the plots treated with various rates of fertilizer. The addition of 20 kg/ha of Sulphur to the recommended rate (90-60-60-20-0) kg/ha caused the plants grown on them to flower earlier. When the trace elements were added to the reduce rate (70-50-50-0-TE) kg/ha its effect on flowering was not significantly different from the three treatments that received the recommended rate (Figure 5).

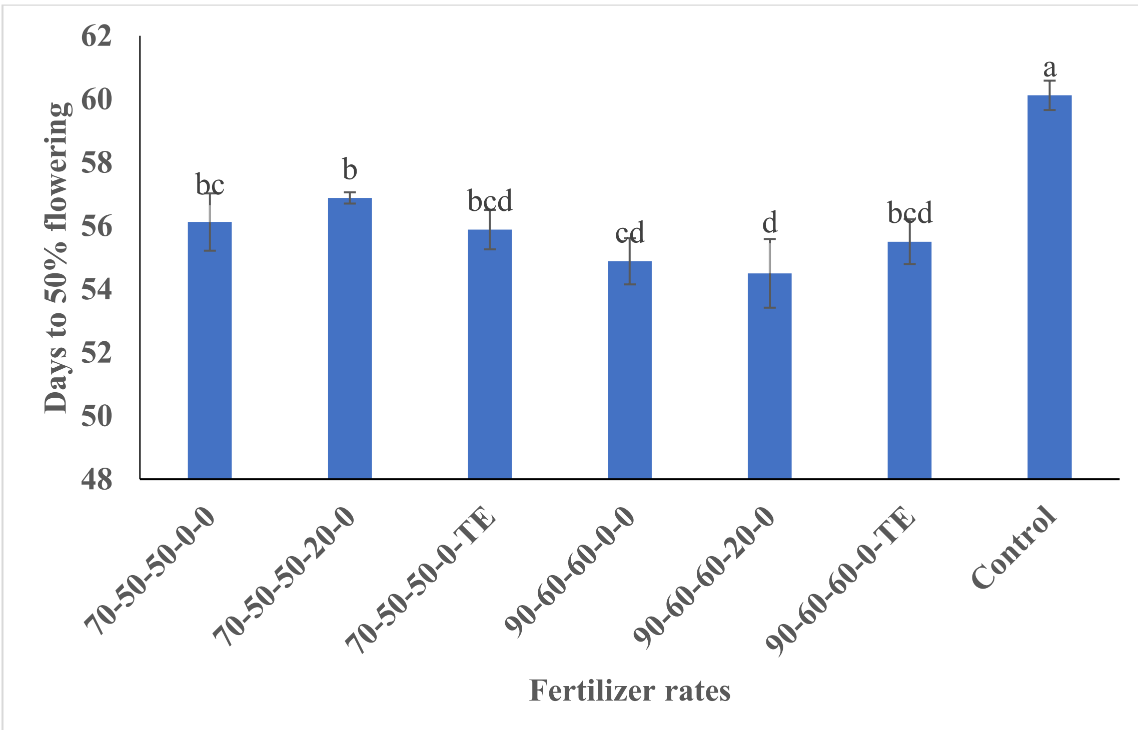

Figure 5: Effect of Fertilizer rates, S, Zn and B on days to 50 % flowering of maize during the 2023 growing season. Error bars represent standard error of mean (SEM).

4.7 Effect of fertilizer rates on maize cob length

The fertilizer rates and top-dressing interaction as well as the main effect of top dressing did not have significant ($P > 0.05$) effect on maize cob length. The cob length of the maize however, was significantly influenced by the various fertilizer rates ($P < 0.001$). The incorporation of 20 kg/ha of Sulphur to the recommended fertilizer rate (90-60-60-20-0) kg/ha caused plants receiving the treatment to record the longest cob length than all the treatments (Figure 6). The plants treated with reduced fertilizer rate that were incorporated with either Sulphur or the trace elements had similar cob length as those plants that grew on recommended fertilizer rate (90-60-60-0-0 and 90-60-60-0-TE) kg/ha. The untreated control plots produced the shortest cob length (Figure 6).

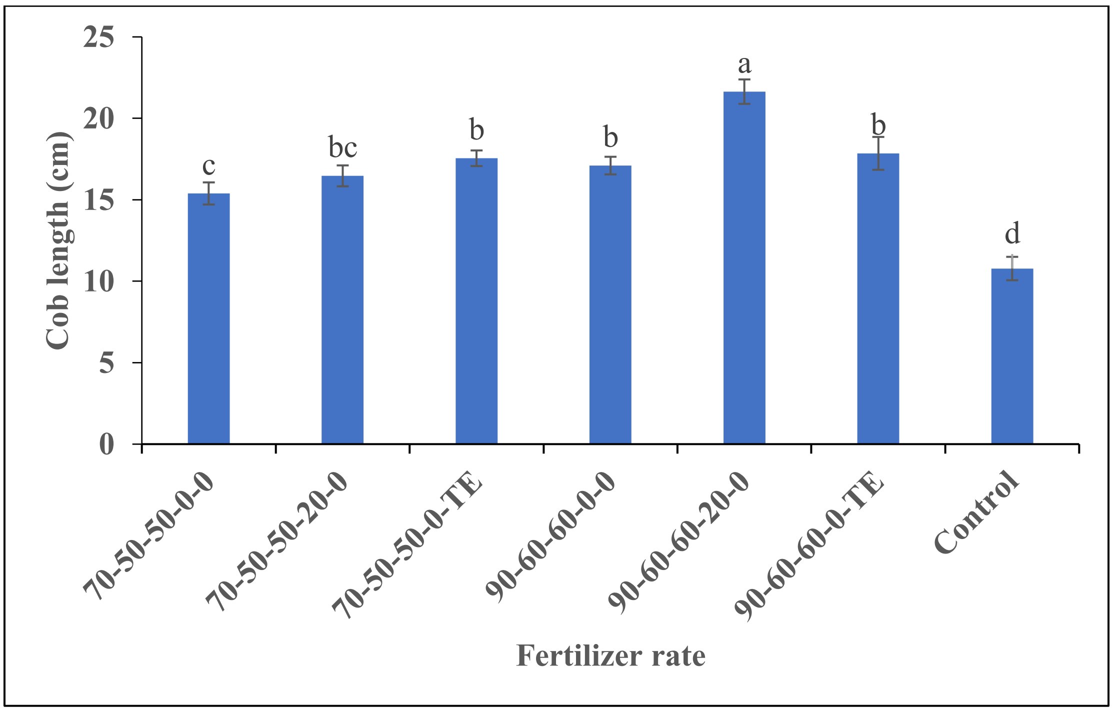

Figure 6: Effect of Fertilizer rates, S, Zn and B on cob length of maize during the 2023 growing season. Error bars represent standard error of mean (SEM).

4.8 Effect of fertilizer rates on maize cob weight

The fertilizer rates and top-dressing interaction as well as the main effect of top dressing did not have significant effect ($P > 0.05$) on maize cob weight. The weight of maize cobs was significantly affected by the various fertilizer rates ($P < 0.001$). The plants that received the recommended fertilizer rate produced higher cob weights but the incorporation of Sulphur and the trace elements (90-60-60-20-0 and 90-60-60-0-TE) were outstanding. The plants that received reduced fertilizer rate treatments produced lower and statistically similar cob weights (Figure 7). The control plots with no fertilizer treatments lagged behind, producing statistically lighter cobs compared to plots that received fertilizer treatments (Figure7).

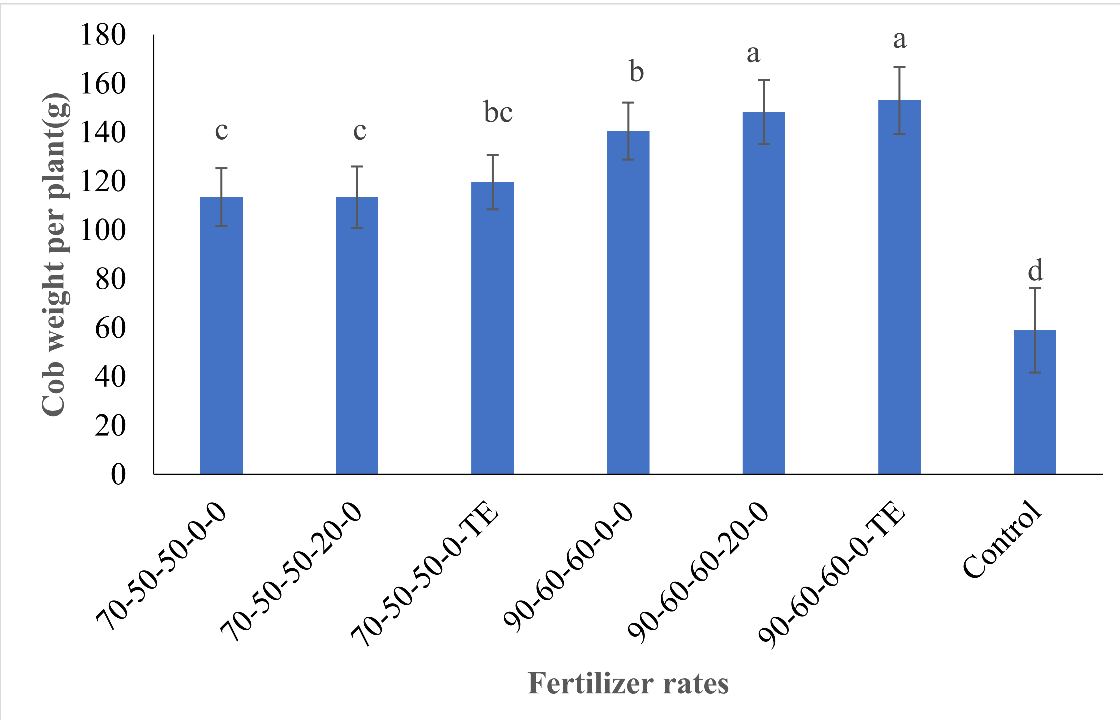

Figure 7: Effect of Fertilizer rates, S, Zn and B on cob weight of maize during the 2023 growing season. Error bars represent standard error of mean (SEM)

4.9 Effect of fertilizer rates on grain yield of maize

The fertilizer rates and top-dressing interaction as well as the main effect of top dressing did not have significant effect ($P > 0.05$) on maize grain yield. The grain yield was however, significantly affected by the fertilizer rates ($P < 0.001$). The addition of 20 kg/ha Sulphur to the recommended rate (90-60-60-20-0) kg/ha outperformed most of the treatments (Figure 8). The incorporation of trace elements to the recommended rate (90-60-60-0-TE) kg/ha also caused higher grain yield than the sole application of the recommended rate (90-60-60-0-0) kg/ha. Also, plants treated with the reduced rate had grain yield that was statistically similar to the grain yield of plots treated with the recommended rate alone (90-60-60-0-0) kg/ha. The control plots with no fertilizer treatment produced the lowest grain yield (Figure 8).

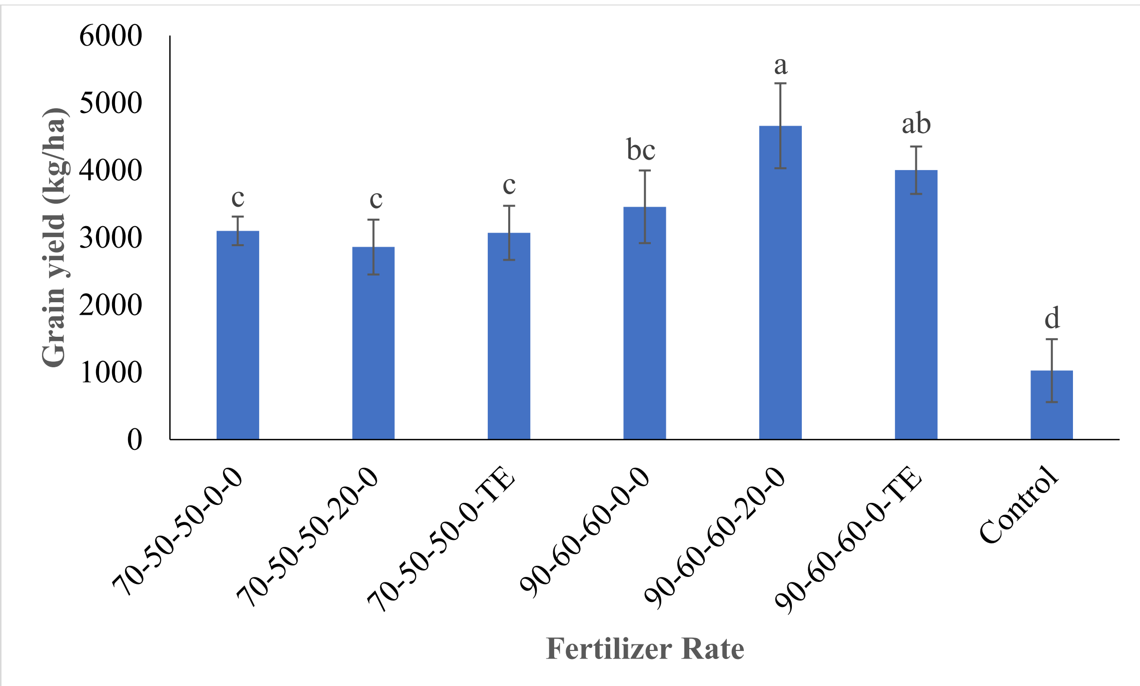

Figure 8: Effect of Fertilizer rates, S, Zn and B on grain yield of maize during the 2023 growing season. Error bars represent standard error of mean (SEM)

4.10 Effect of fertilizer rates and interaction on thousand seed weight

All fertilizer rate treatments had a significant influence on thousand grain weight of maize ($P < 0.001$). The incorporation of 20 kg/ha Sulphur to the recommended rate

(90-60-60-20-0) kg/ha had the highest thousand seed weight. The addition of trace elements to the recommended rate (90-60-60-0-TE) kg/ha and the sole application of the recommended rate (90-60-60-0-0) kg/ha produced thousand seed weight which were statistically similar to the reduced rates treatments. The control plots with no fertilizer treatments had the lowest thousand seed weight (Figure 9).

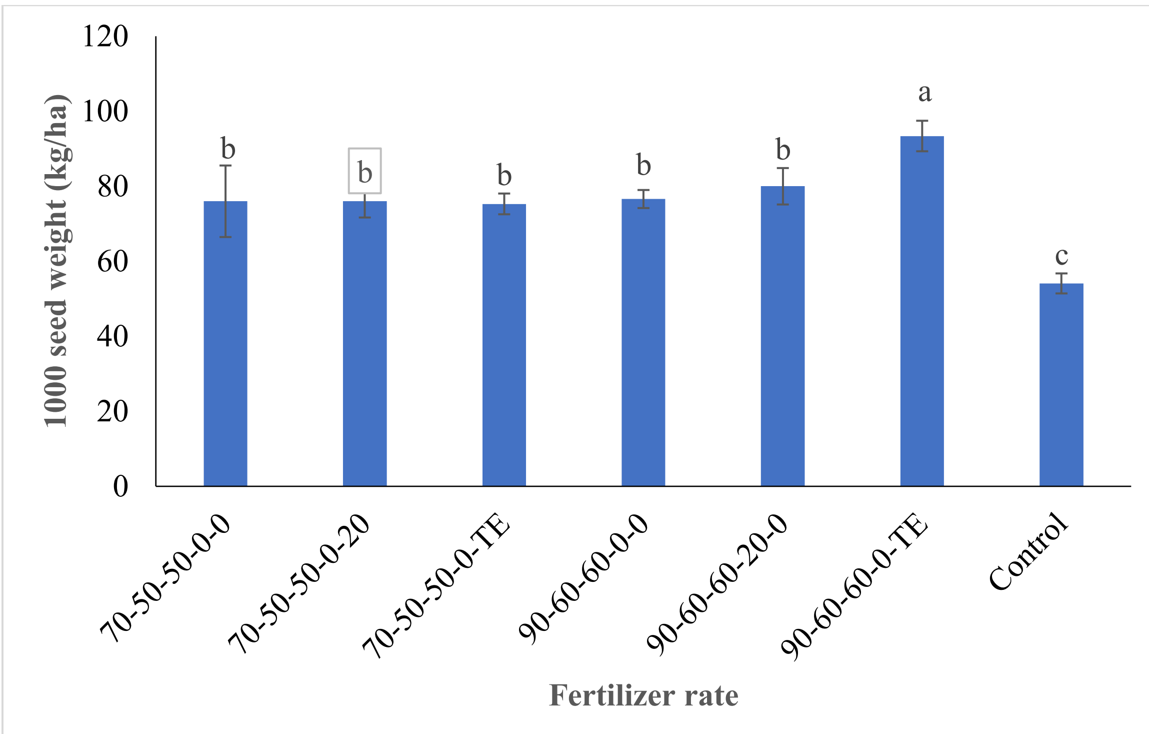

Figure 9: Effect of Fertilizer rates, S, Zn and B nutrients on thousand grain weight of maize during the 2023 growing season. Error bars represent standard error of mean (SEM)

4.11 Effect of top-dressing interaction on thousand seed weight

Top-dressing verses fertilizer rate interaction also significantly affected 1000 grain weight ($P < 0.001$). From table 3, the interaction showed that briquette top-dressing clearly exhibited superiority in its interaction with granular basal application across all the fertilizer treatments. The addition of 20kg of sulphur to the recommended rate (90-60-60-20-0) kg/ha recorded the highest level of interaction between briquette and granular fertilizers (Table 3).

Table 3: Fertilizer rate and topdressing interaction on 1000 grain weight

Fertilizer rate	Briquette topdressing	Granular basal
70-50-50-0-0	80.5	71.4
70-50-50-0-TE	79.6	72.4
70-50-50-20-0	77.9	72.8
90-60-60-0-0	75.4	77.8
90-60-60-0-TE	81.2	78.9
90-60-60-20-0	97.4	89.3

4.12 Effect of fertilizer rates on biomass of maize

The fertilizer rates and top-dressing interaction as well as the main effect of top dressing did not have significant effect ($P > 0.05$) on maize plant biomass. The biomass was significantly influenced ($P < 0.001$) by the fertilizer rates. All the three treatments that received the recommended rate produced similar biomass though that of the trace elements (90-60-60-0-TE) kg/ha was nominally higher (Figure 10). The incorporation of trace elements to the reduced rate (70-50-50-0-TE) kg/ha led to biomass production that was comparable to the recommended rate without additional nutrient (90-60-60-0-0) kg/ha and when 20 kg Sulphur was added to the recommended rate (90-60-60-20-0) kg/ha. However, all three reduced fertilizer rates (70-50-50) kg/ha produced similar and lower biomass weight. The control plots with no fertilizer treatments lagged behind, producing the lowest biomass (Figure 10).

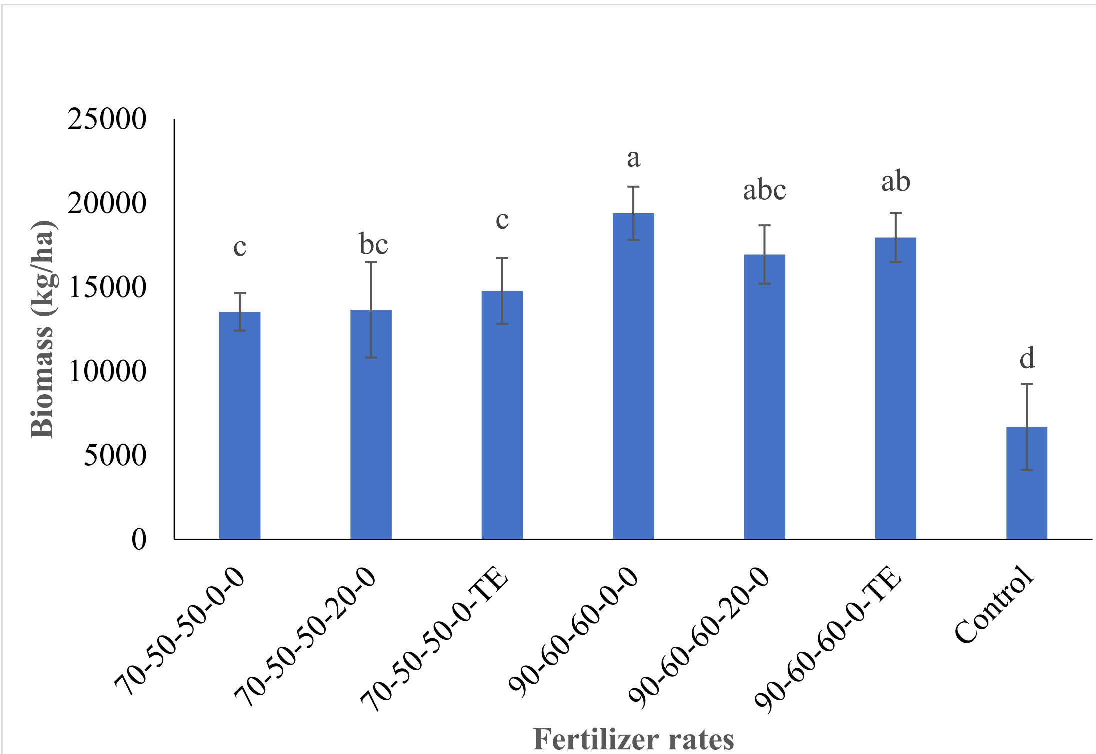

Figure 10: Effect of Fertilizer rates, S, Zn and B on biomass weight of maize during the 2023 growing season. Error bars represent standard error of mean (SEM)

4.13 Agronomic Efficiency of Applied Nitrogen (AEN)

The fertilizer rate had significant effect on Agronomic Efficiency of Applied Nitrogen (AEN) ($P < 0.001$). The addition of 20kg/ha of Sulphur to the recommended rate (90-60-60-20-0) kg/ha produced the highest efficiency of the AEN which was similar to the treatment that received the trace elements. Also, the sole application of the recommended rate (90-60-60-0-0) kg/ha had AEN similar to the plots treated with the reduced rate (Figure 13). It was observed that Agronomic efficiency of the nitrogen for the reduced rate treatments was not significantly different from those the recommended rate treatments except 90-60-60-20-0.

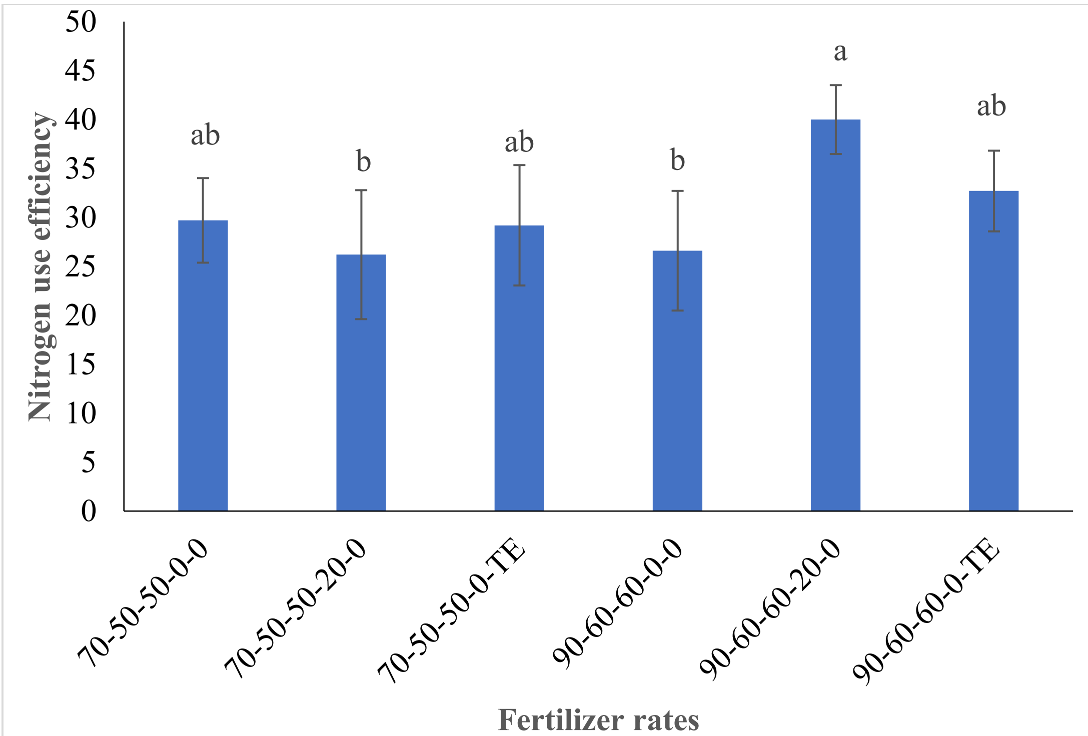

Figure 11: Effect of Fertilizer rates, S, Zn and B on nitrogen use efficiency of maize during the 2023 growing season. Error bars represent standard error of mean (SEM)

4.14 Correlation and Regression analysis

The yield of maize positively correlated with leaf area index, plant height, chlorophyll content (SPAD) at, cob weight and cob length, biomass and 1000 seed weight (Appendix 20, page 74). However, there was a negative correlation between days to 50 % flowering and grain yield (Appendix 20, page 74). The regression analysis of some selected parameters against grain yield has shown that grain yield had a positive linear relationship with leaf area index, plant height, chlorophyll content, biomass, cob length, cob weight and 1000 seed weight. About 49 %, 52 %, 48 %, variation in grain yield were respectively caused by leaf area index, plant height, chlorophyll content, (Figure 12, Figure 13, Figure 14). The number of days to 50 % flowering had a negative relationship with grain yield with an R^2 value of 0.5375 (Figure 19). Also, 58 %, 77 %, 64 % and 62 % variation in grain yield were respectively caused by cob length, cob weight, 1000 seed weight and biomass per hectare.

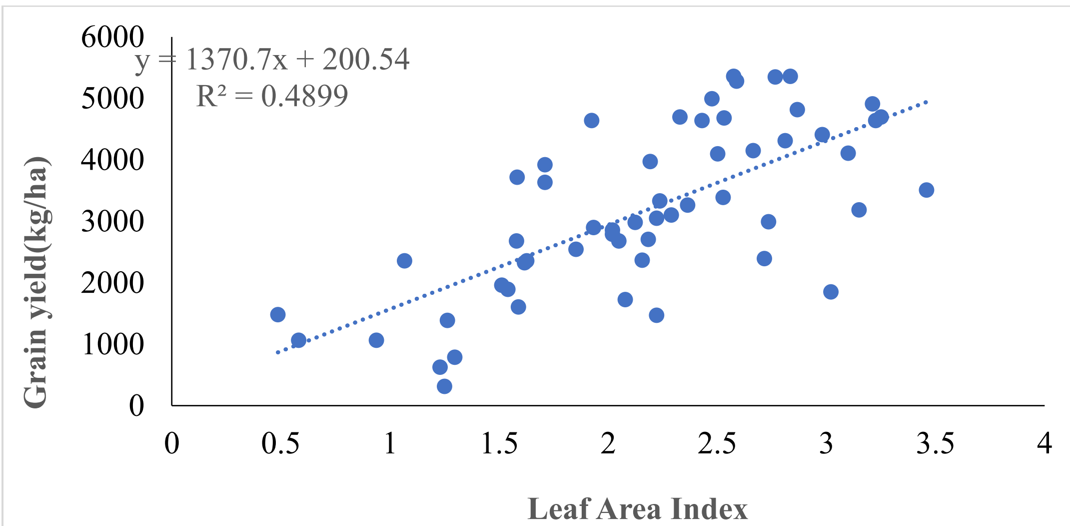

Figure 12: Regression analysis of the relationship between leaf area index and grain yield

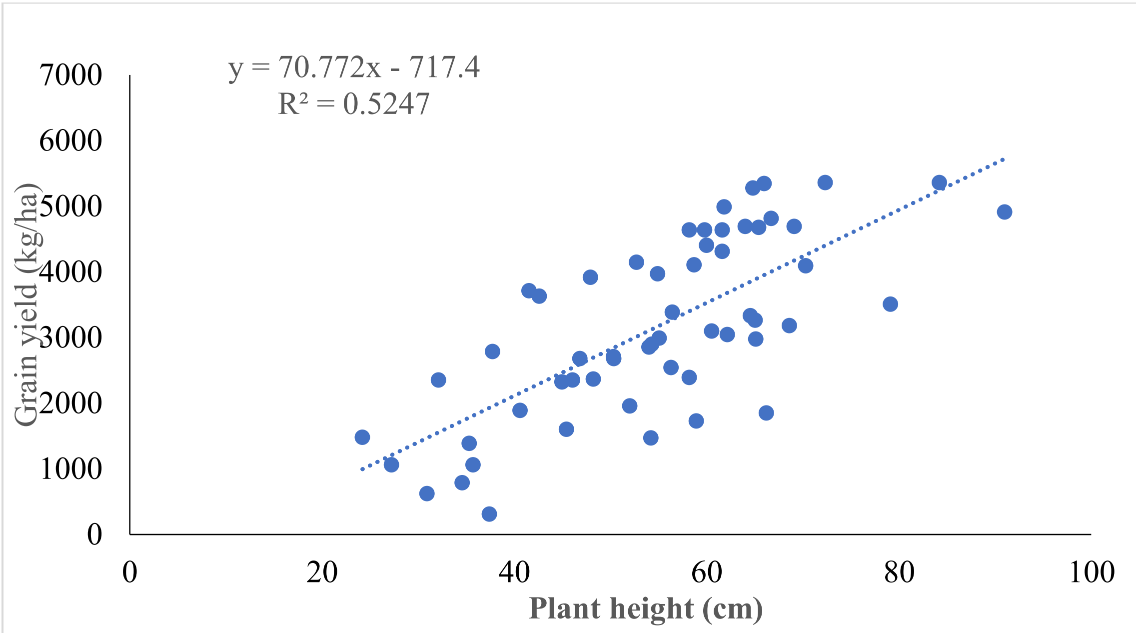

Figure 13: Regression analysis of the relationship between plant height and grain yield

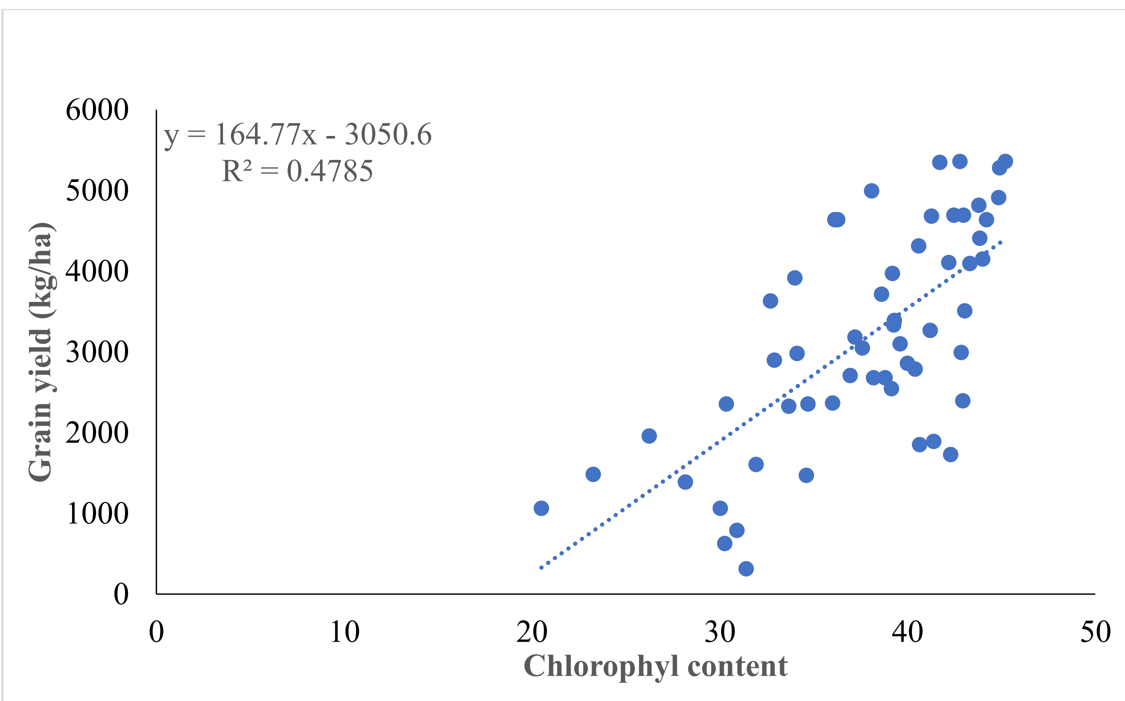

Figure 14: Regression analysis of the relationship between chlorophyll content and grain yield

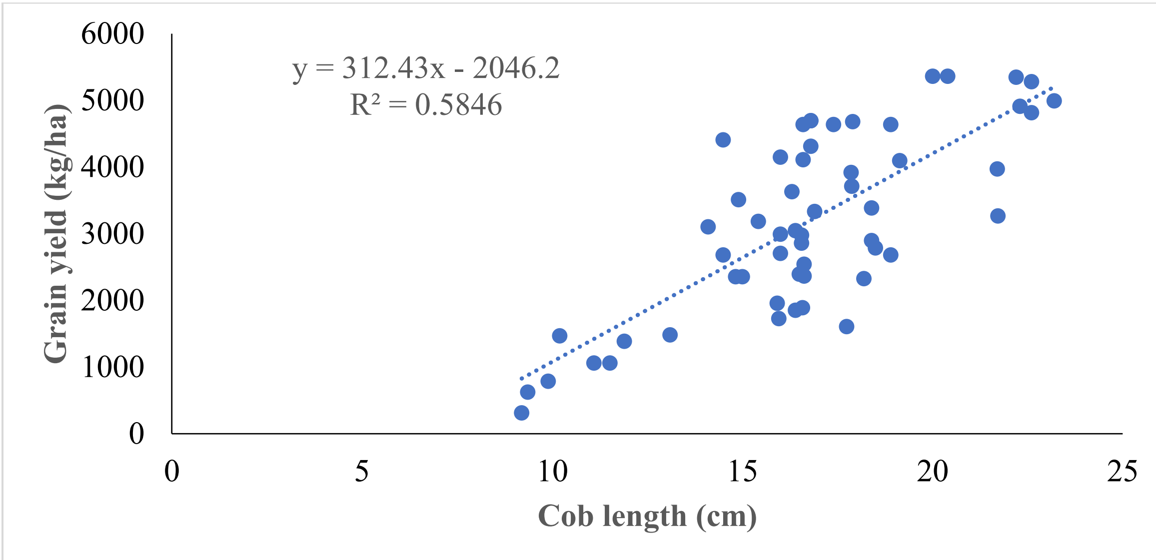

Figure 15: Regression analysis of the relationship between cob length and grain yield

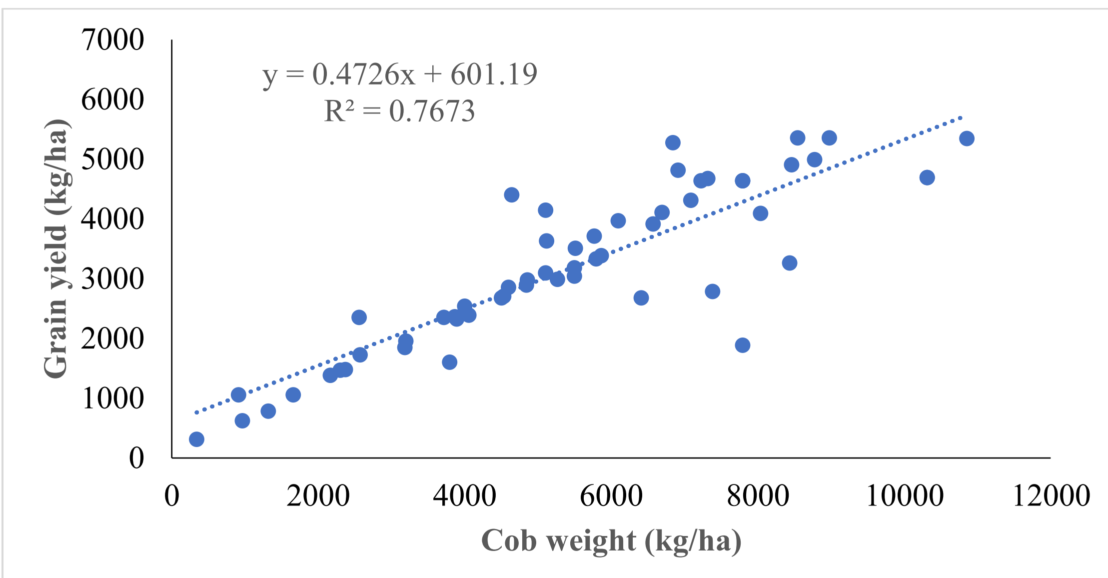

Figure 16: Regression analysis of the relationship between cob weight and grain yield

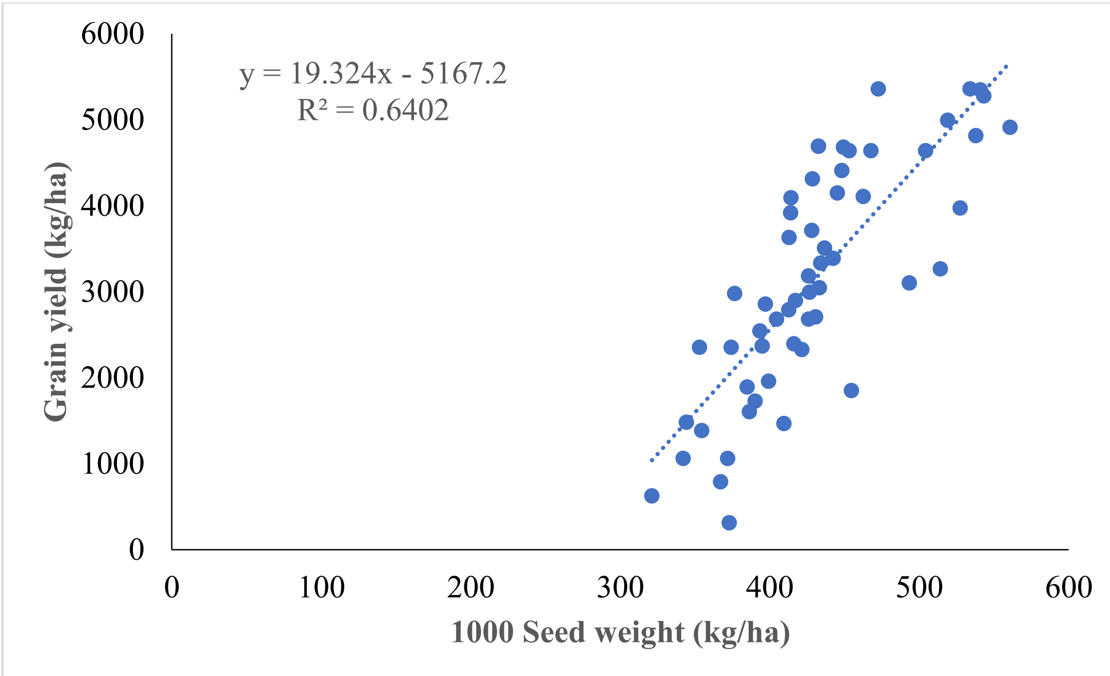

Figure 17: Regression analysis of the relationship between 1000 seed weight and grain yield

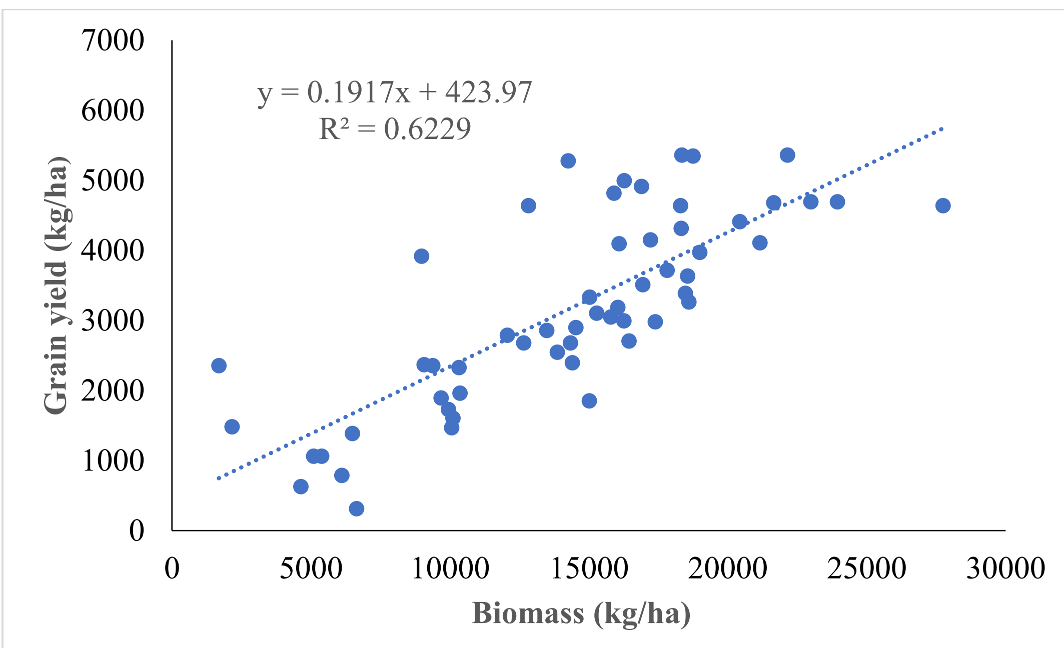

Figure 18: Regression analysis of the relationship between biomass and grain yield

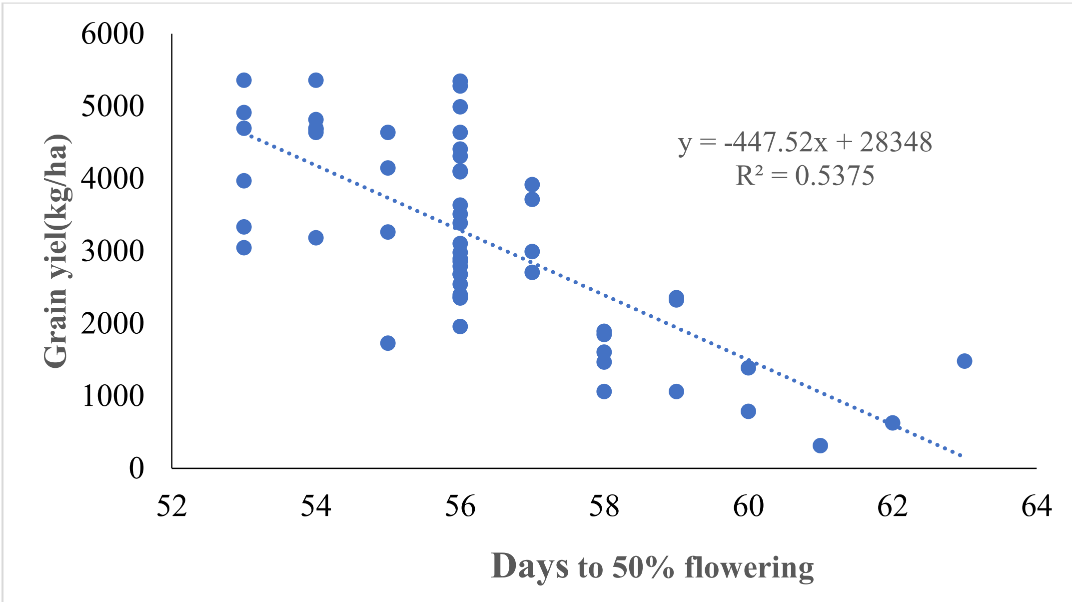

Figure 19: Regression analysis of the relationship between days to 50% flowering and grain yield

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effects of fertilizer rates on the plant height of maize

It was observed that increasing the rates of fertilizer led to an increase in plant height across all weeks 4, 6, 8 and 10. This is in conformity with (Asghar *et al*., 2010) who observed that increasing the levels of NPK resulted in the increase of plant growth parameters including plant height. The addition of Sulphur (S) and trace elements (Zinc and Boron) to the recommended rate (90-60-60-20-0 and 90-60-60-0-TE) kg/ha also resulted in a remarkable increase in plant height at 6, 8 and 10 WAP. This agrees with the findings of (Heena A. *et al*., 2024) who observed that the addition of Sulphur and micronutrients to NPK increased plant height. Sulphur which is a secondary nutrient performs specialized roles in enzymatic processes, metabolism and plant growth. It is one of the required nutrients for plant growth (Khan *et al*., 2006).

The application of the reduced fertilizer rate had minimal impact on plant height as all the three treatments lagged behind in all the weeks where plant height was assessed. This confirms the findings of Selassie (2015) who observed that in contrast to the reduced fertilizer rates, plants in the plots with the greatest fertilizer rate eventually showed the maximum plant height measured 60 days after emergence and at harvest, though these differences were statistically not significant.

5.2 Effects of fertilizer rates on the leaf area index of maize

Contrary to what was observed in plant height, fertilizer rates did not cause any significant difference in leaf area index at 4 WAP. This might be attributable to the fact the fertilizer had not made full impact on the leaf area of maize until the 6 WAP. All the three treatments under the recommended rate (90-60-60-0-0, 90-60-60-20-0 and 90-60-60-0-TE) kg/ha outperformed the reduced rate treatments and control. These results showed that increased plant nutrition delivery is necessary to achieve maximum leaf area indices. These results are also consistent with other studies showing that greater rates of N fertilizer enhanced the leaf area index by postponing leaf senescence (or "stay-green"), maintaining leaf photosynthesis, and extending the duration of the leaf area (Dugje and Odo, 2006). This also confirms the findings of (Berdjour *et al*., 2020) that higher rates of NPK levels significantly affected the leaf area of maize in the Guinea savanna zone of Ghana. The addition of 20 kg/ha of S to the recommended rate dominated in leaf area index at 10 WAP. This is probably due to the significant role Sulphur element plays in plant nitrogen metabolism, protein formation, oil synthesis and enzyme activity (Jeet *et al*., 2014). It also confirms other study (Waleed *et al*., 2020) who observed that the addition of Sulphur to NPK led to an increase in leaf area index of maize. The addition of trace elements (B and Zn) to the recommended rate (90-60-60) kg/ha also enhanced leaf area of maize as they played direct or indirect role in the plant metabolic functions, photosynthesis, vital processes in plants such as respiration, protein synthesis, and reproduction phase (Roohi *et al*., 2021).

5.3 Effects of fertilizer rates on the chlorophyll content of maize

Chlorophyll content of the leaves, measured as SPAD readings, was also impacted by the fertilizer rates. Across the four periods at which leaf chlorophyll content was measured, it was observed that the incorporation of trace elements and 20kg/ha of S to the recommended rates (90-60-60-0-TE and 90-60-60-20-0) kg/ha respectively consistently increased plant growth and leaf greenery. The recommended rate without Sulphur and trace elements (90-60-60-0-0) kg/ha was not different from the treatments under reduced rate with Sulphur and trace elements demonstrating the importance of Sulphur and trace elements in greenery of the crop. The excellent performance of Sulphur in combination with recommended NPK rate agrees with the findings of (Skudra and Ruza, 2017) who observed that the addition of Sulphur to nitrogenous fertilizer resulted in a remarkable increase in chlorophyll in the leaves, ear and stem of wheat. The relatively higher chlorophyll content in plants treated with the addition of Sulphur to the recommended rates (90-60-60-20-0) could be due to Sulphur's critical role in chlorophyll accumulation and proteins synthesis in crops, as it is a component of the amino acids cysteine, cysteine and methionine (Kumar *et al*., 2016). The higher development of chlorophyll in recommended rate incorporated with the trace elements (B and Zn) at 10 WAP could be attributed to the important roles they play in basic plant functions like photosynthesis, protein and chlorophyll synthesis (Cakmak, 2008). It is also consistent with the findings of (Wasaya *et al*., 2017) who observed that the application of Zn and B boosted leaf chlorophyll and relative water levels, which in turn improved crop allometry, yield components, and maize productivity. All three treatments under the reduced rate had lower chlorophyll content. This is consistent with the findings of Wu *et al*. (2019) who observed that the chlorophyll content, photosynthetic and chlorophyll fluorescence characteristics of maize cultivators are all greatly impacted by low-N stress.

5.4 Effect of fertilizer rates on the days to 50 % flowering of maize

The fertilizer rates influenced earliness to flowering. Plants that did not receive fertilizer (control) were late in flowering. The combination of S to the recommended rate (90-60-60-20-0) kg/ha caused the plants to reach flowering earlier than the reduced rate treatments with the exception of the one that received the trace elements (70-50-50-0-TE) kg/ha. This confirms the findings of (Yu *et al*. (2021) who reported that sulphate deficiency leads to decreased synthesis of Rubisco (ribulose-1,5-biphosphate carboxylase/oxygenase) enzyme that affects the assimilation rates of CO_2 which eventually results stunted growth and delayed maturity. The plants that received reduced rate of NPK were late in flower and this is consistent with observation made in okra where okra plants that received reduced NPK rate were late in flowering (Amina *et al*., 2023). From the results it appears that higher rate of NPK, Sulphur and trace elements have role in stimulating early flowering in maize.

5.5 Effect of fertilizer rates on maize yield parameters

The application of the different fertilizer rates caused a significant difference in maize cob length. The addition of 20 kg of S to the recommended rate (90-60-60-20-0) kg/ha produced the longest and biggest cobs. This is consistent with the findings of (Navatha *et al*., 2017) who observed that the incorporation of sulfur to NPK improves cob length in quality protein maize, according to the study on yield characteristics. This outcome also agrees with the findings of Jassim and Rahim-Hariz (2019) who observed that the effect of sulfur in increasing plant vegetative growth and plant leafy area, led to the increase in efficiency of the interception of sunlight, increase in the efficiency of photosynthesis processes which eventually reflected positively in cob length of maize. The synergistic relationship between N and S might have improved cob length rather than just the availability of S.

Cob weight is a very important yield parameter that is directly related to grain yield (Dhm, 2021). The addition of S and trace elements (B and Zn) to the recommended rate (90-60-60) kg/ha produced relatively higher cob weights compared to the other fertilizer treatments. This confirms the findings of Kareem *et al.* (2020) who observed that the addition of S to NPK produced higher cob weights and other yield products of maize. Also, the ability of the trace elements to cause higher cob weights as observed in this research is in conformity with the findings of Kugbe *et al*. (2019), who observed that the inclusion of S as a secondary nutrient, together with boron and zinc as micronutrients in NPK fertilizer formulation improved maize crop growth and grain yield components including cob weight in northern Ghana. The higher cob weight recorded in all the three treatments under recommended rate is also in tandem with the research findings of Setyorini *et al*. (2023) who observed that the application of the recommended rate of NPK fertilizers gave the highest weight of green cobs

Grain yield was influenced by the fertilizer rates. The incorporation of Sulphur at 20 kg/ha to the recommended rate improved grain yield over the sole recommended rate by about 26% and the equivalent for the trace elements B and Zn was about 14%. It was observed that grain yield obtained from the treatments under the reduced NPK rate was not different from the recommended rate without Sulphur and the trace elements, B and Zn. This agrees with the hypothesis made by Fertilizer Research and Responsible Implementation (FERARI) that Sulphur and trace elements addition to reduced NPK can make for the reduced NPK. The results clearly indicate that it is the addition of Sulphur and the trace elements that made the recommended rate to be better than the reduced rate. Lack of fertilizer application resulted in relatively low grain yield. The application of recommended rate of NPK increased grain yield by 74.5 % over the untreated control. When the rate was reduced, the grain yield over the untreated control declined to 65.9 %. Asghar *et al*. (2010) reported that higher NPK levels contribute to better grain production due to higher grain weight per cob, number of grains per cob, and number of grain rows per cob. Studies by other researchers have shown the beneficial effect of the addition of Sulphur and trace elements to NPK which results in higher cob weight, cob length and grain weight (Sutar *et al*., 2018); Kugbe *et al*., 2019). Study by (Wongnaa *et al*., 2021)) revealed that NPK treatment in combination with Sulphur tended to produce yields 0.7 t/ha higher, on average, than NPK alone which in our study was about 1.2 ton when the recommended rate was used with Sulphur. As observed in the grain yield, thousand seed weight was also affected by the fertilizer rates. Addition of 20 kg of S to the recommended rate led to denser grain weight. The other treatments that received recommended and reduced rates produced grains that were of the same weight. Differences in the grain yield among these treatments may be due to kennel number on the cobs which correlates with cob length. This sterling performance of 90-60-60-20-0 kg/ha is probably due to Sulphur’s role in plant growth, metabolism, enzymatic reactions and photosynthetic activity, culminating in higher grain yield and better grain quality. It also confirms the findings of Waleed *et al*. (2020) study, who observed that the combined use of NPK and S resulted in an increase in 1000 grain weight compared to the control with no fertilizer and other treatments. Jassim and Rahim-Hariz (2019) also found that this combination led to improved 1000 grain weight compared to the control group. These findings align with the observation in this study that NPK application with S outperformed NPK application without Sulphur in grain yield and other yield parameters.

Fertilizer rates also affected the biomass of maize. Relatively, the three recommended rate treatments produced above ground biomass that exceeded that of the reduced rate treatments. This indicates that an increase in the dosage of fertilizer leads to a corresponding increase in the plant biomass of maize. It is consistent with the findings of (Wei *et al*., 2016) who observed that increasing dose of fertilizer is connected with increasing biomass production. The addition of trace elements to the recommended and reduced rates made difference in biomass. This confirms the findings of Zain *et al*. (2015) who reported that the application of micronutrients led to an increase in grain and straw weight of wheat.

Agronomic Efficiency of Nitrogen applied (AEN) of the fertilizer rates applied had effect on nitrogen use efficiency measured as Agronomic Efficiency of Nitrogen applied (AEN). The results showed that the addition of Sulphur and the trace elements B and Zn to the recommended rate translated into higher AEN which surpassed all treatments. Without the addition of the S and the trace elements the reduced rate treatments were equivalent to the sole recommended rate, 90-60-60-0-0 kg/ha. This is a demonstration of Sulphur and the trace elements in ensuring nitrogen use efficiency (Hu, 2023). NUE is a topic that is useful for discussion and research because it is dependent on physiological and metabolic changes, such as the uptake of nitrogen from the soil, assimilation from roots to other parts, interaction between source and sink tissues for transportation, and regulatory pathways that control the amount of nitrogen in plants and their growth

The range of values of Agronomic Efficiency of Nitrogen applied for this research was 26.2 % (70-50-50-20-0) kg/ha to 40 % (90-60-60-20-0) kg/ha. This agrees with the findings of Haque and Haque (2016) who concluded that typical levels of nitrogen use efficiency in maize is always less than 50 %. Govindasamy *et al*. (2023) also observed that crops utilize only up to 50 % of the applied nitrogen effectively, with the remaining portion being lost to the environment through a variety of pathways such as volatilization, leaching, nitrification and denitrification. The relatively higher value recorded in this research when 20kg/ha of S was added to the recommended rate of NPK (90-60-60-20-0) kg/ha agrees with the findings of (Weldegebriel *et al*., 2018) who observed that the application of blended NPK+S in a recommended dosage significantly enhanced nitrogen uptake and efficiency in sorghum. The coarse textured soil of the Nyankpala series could be a reason for the low AEN values recorded across most of the treatments. This is explained by Davies *et al*. (2020) that coarse-textured soil is noted for recording low efficiency values most especially when rainfall is high. (Bindraban *et al*., 2015) reported that, the highest maize yields were found for farmers who used fertilizers containing NPK+S or NPK+S+Mg, and these correspond with higher agronomic efficiencies

5.6 Correlation and Regression analysis

The regression analysis of some selected parameters against grain yield has shown that grain yield had a positive linear correlation with leaf area index, plant height, chlorophyll content, total biomass, cob length, cob weight and 1000 seed weight. About 49 %, 52 %, 48 %, 58 %, 77 %, 64 % and 62 % variation in grain yield were respectively caused by leaf area index, plant height, chlorophyll content, cob length, cob weight, 1000 seed weight and biomass per hectare. The correlation coefficients show that as the plant gets taller, it has a better probability of producing more leaves, which boosts photosynthetic activity and may result in higher grain yields (Kuntoji *et al*., 2021). This is also consistent with the findings (Duvvada *et al*., 2024) who observed that the height of a plant, the elevation of cob attachment, the surface area of a leaf, and the chlorophyll content exhibit a positive correlation with the yield of maize, thereby underscoring the significance of optimal plant development in maximizing yield potential. This is because as the plant grows higher, more leaves are generated, resulting in increased chlorophyll formation, which contributes to photosynthetic activity and grain yield. A study by Yigermal *et al*. (2019) demonstrate that these growth characteristics significantly influence maize grain output, as taller plants and greater values of the other parameters lead to increased cob production and yield. A similar observation by (Kumar *et al*., 2024) confirms the findings as he observed that 1000 grain weight is significantly connected with grain yield in maize, underscoring its significance in determining the overall grain production of maize genotypes.

CHAPTER SIX

6.0 Conclusion and Recommendation

6.1 Conclusion

The trial was meant to confirm if the reduced NPK rate combined with the trace element, Zn, and Sulphur will make up for the recommended NPK rate. We also aimed at improving nutrient availability by the use of briquette fertilizer for top dressing, NPK 23-10-05 was used for basal application at two rates, 70-50-50 kg/ha and 90-60-60 kg/ha and were enhanced with trace elements and Sulphur. Briquetted urea was applied as a top dress. The following conclusions have been made from the analysis of the results of this study:

- The recommended NPK rate (90-60-60) kg/ha generally performed better in growth and grain yield than the reduced rate (70-50-50) kg/ha.
- The grain yield obtained from the reduced NPK rate treatments, with or without S, Zn and B, was similar to the recommended rate without the addition of S, Zn and B. This demonstrates that it is the addition of these three elements that made the recommended rate to show superiority over the reduced rate.
- The inclusion of Sulphur compensated for reduction of NPK rate only in cob length while that of the trace elements was in cob length, biomass and Days to 50 % flowering.

  The application of urea as top dressing did not make any difference whether granular or briquette forms that was used.

- Agronomic Efficiency of Nitrogen applied was the same among the reduced and recommended rates. However, the inclusion of 20 kg/ha Sulphur to the recommended rate led to a higher AEN.

6.2 Recommendation

- The sterling performance of Sulphur in maize production has become a topical issue and this study has demonstrated that its inclusion improves grain yield and Agronomic Efficiency of Nitrogen. It is therefore recommended that NPK should be fortified with Sulphur.
- The effect of the trace elements on grain yield is marginal and there is the need to do further analysis of their presence in the grain. The trace elements play a role in human health so their significant presence in the grain will determine its inclusion in fertilizer formulation.
- There is also the need for further work on partial budget analysis to determine the inclusion of the trace elements in fertilizer formulation.

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APPENDICES

Appendix 1: ANOVA table for plant height at 4WAP

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	4.878	1.626	0.06	
Top Dressing	1	0.165	0.165	0.01	0.944
Residual	3	85.646	28.550	3.50	
Fertilizer Rate	6	172.938	28.823	3.53	0.007
Top Dressing. Fertilizer Rate	6	37.481	6.247	0.77	0.602
Residual	36	293.658	8.157		
Totals	55	594.769			

Appendix 2: ANOVA table for plant height at 6WAP

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	121.9	40.6	0.15	
Top Dressing	1	57.6	57.6	0.22	0.672
Residual	3	792.8	264.3	2.51	
Fertilizer Rate	6	5475.5	912.6	8.68	<0.001
Top Dressing.Fertilizer Rate	6	343.1	57.2	0.54	0.771
Residual	36	3786.8	105.2		
Totals	55	10577.7			

Appendix 3: ANOVA table for plant height at 8WAP

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	947.9	316.0	0.15	
Top Dressing	1	3601.6	3601.6	0.22	0.371
Residual	3	9826.7	3275.6	2.51	
Fertilizer Rate	6	42934.9	7155.8	8.68	<0.001
Top Dressing. Fertilizer Rate	6	600.7	100.1	0.54	0.983
Residual	36	20877.4	579.9		

Totals	55	78789.2

Appendix 4: ANOVA table for plant height at 10WAP

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	828.6	276.2	0.69	
Top Dressing	1	1556.5	1556.5	3.87	0.144
Residual	3	1207.3	402.4	1.25	
Fertilizer Rate	6	17763.4	2960.6	9.22	<0.001
Top Dressing. Fertilizer Rate	6	3224.8	537.5	1.67	0.156
Residual	36	11556.1	321.0		
Totals	55	36136.8			

Appendix 5**: ANOVA table for LAI at 4WAP**

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	0.27947	0.09316	0.43	
Top Dressing	1	0.08514	0.08514	0.39	0.576
Residual	3	0.65183	0.21728	2.38	
Fertilizer Rate	6	0.72471	0.12079	1.32	0.273
Top Dressing.Fertilizer Rate	6	0.42718	0.07120	0.78	0.592
Residual	36	3.28993	0.09139		
Totals	55	5.45826			

Appendix 6: **Appendix 6: ANOVA table for LAI at 6WAP**

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	0.2205	0.0735	0.12	
Top Dressing	1	0.1938	0.1938	0.33	0.607
Residual	3	1.7752	0.5917	5.36	
Fertilizer Rate	6	6.5766	1.0961	9.93	<0.001
Top Dressing X Fertilizer Rate	6	0.4213	0.070	0.64	0.700
Residual	36	3.9728	0.1104		

Totals	55	13.1602

Appendix 7: **Appendix 7: ANOVA table for LAI at 8WAP**

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	1.2761	0.4254	0.63	
Top Dressing	1	1.5098	1.5098	0.22	0.233
Residual	3	2.0393	0.6798	2.76	
Fertilizer Rate	6	12.172	2.0288	8.24	<0.001
Top Dressing.Fertilizer Rate	6	0.4676	0.0779	0.32	0.924
Residual	36	8.8589	0.2461		
Totals	55	26.3242			

Appendix 8**: ANOVA table for LAI at 10WAP**

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	1.2761	0.4254	0.63	
Top Dressing	1	1.5098	1.5098	0.22	0.233
Residual	3	2.0393	0.6798	2.76	
Fertilizer Rate	6	12.172	2.0288	8.24	<0.001
Top Dressing.Fertilizer Rate	6	0.4676	0.0779	0.32	0.924
Residual	36	8.8589	0.2461		
Totals	55	26.3242			

Appendix 9: ANOVA table for CHLOROPHYLL CONTENT at 4WAP

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	53.875	17.958	0.63	
Top Dressing	1	60.341	60.341	0.22	0.142
Residual	3	15.376	5.125	2.76	
Fertilizer Rate	6	471.315	78.552	8.24	<0.001

Top Dressing.Fertilizer Rate	6	8.082	1.347	0.32	0.979
Residual	36	261.287	7.258		
Totals	55	870.275			

Appendix 10: ANOVA table for CHLOROPHYLL CONTENT at 6WAP

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	68.43	22.81	0.67	
Top Dressing	1	128.62	128.62	3.79	0.147
Residual	3	101.69	33.92	2.77	
Fertilizer Rate	6	953.96	158.99	13.01	<0.001
Top Dressing.Fertilizer Rate	6	86.76	14.66	1.18	0.337
Residual	36	439.93	12.22		
Totals	55	1779.40			

Appendix 11: Appendix 11: ANOVA table for CHLOROPHYLL CONTENT at 8WAP

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	56.40	18.80	0.48	
Top Dressing	1	129.53	129.53	3.29	0.168
Residual	3	118.24	39.41	3.11	
Fertilizer Rate	6	1244.56	207.43	16.34	<0.001
Top Dressing. Fertilizer Rate	6	85.51	14.25	1.12	0.369
Residual	36	456.91	12.69		
Totals	55	2091.151			

Appendix 12: ANOVA table for CHLOROPHYLL CONTENT at 10WAP

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	106.85	35.62	0.59	
Top Dressing	1	30.70	30.70	0.51	0.528

Residual	3	182.10	60.70	2.52	
Fertilizer Rate	6	2229.68	371.61	15.42	<0.001
Top Dressing. Fertilizer Rate	6	206.38	34.40	1.43	0.231
Residual	36	867.44	24.10		
Totals	55	3623.15			

Appendix 13: **ANOVA table for Days to 50% flowering**

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	4.054	1.351	0.22	
Top Dressing	1	0.875	0.875	0.14	0.730
Residual	3	18.339	6.113	3.15	
Fertilizer Rate	6	168.607	28.101	14.48	<0.001
Top Dressing. Fertilizer Rate	6	9.250	1.542	0.79	0.580
Residual	36	69.857	1.940		
Totals	55	270.982			

Appendix 14: **ANOVA table for Cob length**

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	0.753	0.251	0.09	
Top Dressing	1	2.719	2.719	1.01	0.388
Residual	3	8.050	2.683	1.30	
Fertilizer Rate	6	506.842	84.474	40.79	<0.001
Top Dressing. Fertilizer Rate	6	11.691	1.949	0.94	0.478
Residual	36	74.559	2.071		
Totals	55	604.615			

Appendix 15:**ANOVA table for Cob weight**

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	4182.6	1394.2	0.62	

Top Dressing	1	146.3	1946.3	0.87	0.420
Residual	3	1605.9	2234.5	4.09	
Fertilizer Rate	6	48938.6	8156.4	14.93	<0.001
Top Dressing. Fertilizer Rate	6	1605.9	267.7	0.49	0.811
Residual	36	19662.8	546.2		
Totals	55	83039.7			

Appendix 16: **ANOVA table for Grain yield**

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	5804170	1934723	0.50	
Top Dressing	1	1718015	1718015	0.45	0.551
Residual	3	181506208	3835403	7.68	
Fertilizer Rate	6	61673169	19278862	20.59	<0.001
Top Dressing. Fertilizer Rate	6	2288005	381334	0.76	0.603
Residual	36	17974518	499292		
Totals	55	100964084			

Appendix 17: **ANOVA table for 1000 seed weight**

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	167.32	55.77	0.38	
Top Dressing	1	2.07	2.07	0.01	0.913
Residual	3	444.55	148.18	2.34	
Fertilizer Rate	6	6370.20	1061.70	16.79	<0.001
Top Dressing x Fertilizer Rate	6	1880.57	313.43	4.96	<0.001
Residual	36	2276.60	63.24		
Totals	55	11141.30			

Appendix 18: **ANOVA table for Biomass weight**

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	1.404E+08	4.681E+07	0.88	
Top Dressing	1	1.966E+06	1.966E+06	0.04	0.860
Residual	3	1.594+08	5.315E+07	4.19	
Fertilizer Rate	6	8.355E+08	1.393E+08	10.98	<0.001
Top Dressing. Fertilizer Rate	6	5.490E+07	9.150E+06		0.72
0.635					
Residual	36	4.567E+08	1.269E+07		
Totals	55	1.649E+07			

Appendix 19: **ANOVA table for Harvest index**

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	0.08085	0.02695	2.30	
Top Dressing	1	0.00420	0.00420	0.36	0.592
Residual	3	0.03522	0.01174	0.42	
Fertilizer Rate	6	0.20336	0.03389	1.22	0.320
Top Dressing x Fertilizer Rate	6	0.19502	0.03250	1.17	0.345
Residual	36	1.00271	0.02785		
Totals	55	1.52136			

Appendix 20: **ANOVA table for AEN**

Source of variation	d.f	s.s.	m.s	v.r	Fpr
Rep Stratum	3	446.44	148.81	1.30	
Top Dressing	1	371.26	371.26	3.24	0.169
Residual	3	343.35	114.45	1.32	
Fertilizer Rate	6	7526.83	1254.47	14.44	<0.001
Top Dressing x Fertilizer Rate	6	376.42	62.74	0.72	0.635
Residual	36	3128.27	86.90		
Totals	55	12192.58			

Appendix 21: Correlation analysis of selected growth and yield parameters affected by application of different rates of fertilizer.

	SPAD	PH	LAI	DAF	CL	CW	BM	1000SW
	0.811826***							
	0.842015***	0.869856***						
`	-0.70835*	-0.783*	-0.66993*					
	0.665644***	0.582136***	0.493511***	-0.64609*				
	0.797141***	0.653722***	0.628331***	-0.68993*	0.774249***			
)SW	0.733016***	0.723543***	0.670149***	-0.65422*	0.775185***	0.70837***		
	0.802301***	0.723589***	0.788949***	-0.69492*	0.552677***	0.743709***	0.631587***	
	0.806944***	0.696609***	0.699918***	-0.73316*	0.764566***	0.875952***	0.789259***	0.80011***

SPAD= chlorophyll content, PH= plant height, LAI= leaf area index, DAF= days to 50% flowering, CL= cob length, CW= cob weight, BM= biomass, GY=grain yield, 1000SW= 100 seed weight. *=significant at 5%, **=significant at 1%, ***=significant at 0.1%