UNIVERSITY FOR DEVELOPMENT STUDIES

EFFECTS OF SOIL AND FOLIAR APPLICATION OF PHOSPHORUS, SULPHUR AND ZINC ON THE GRAIN YIELD OF MAIZE (*Zea mays L.*) IN KPALGA AND NYANKPALA IN THE NORTHERN REGION

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FACULTY OF AGRICULTURE, FOOD AND CONSUMER SCIENCES

DEPARTMENT OF CROP SCIENCE

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BY

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NOVEMBER 2024

DECLARATION

I, Simon Alebiye Anambire hereby declare that this result is my work and no previous submission in this university or elsewhere has been made for a degree. References made in this material have been cleared.

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ABSTRACT

Maize (*Zea mays L.*) has a very high yield potential compared to many cereal crops. Despite its importance and potential, maize production is beset by many problems which include soil nutrient deficiency with the average maize yield in the Guinea Savanna Ecological region as low as 1.5 t/ha. This trial carried out in two locations in the Guinea Savanna ecological zone explored the effects of soil and foliar applications of Zn, S and P. The treatments were made up of NPK grade (23-10-5) in combination with S, Zn and P supplement using Triple super phosphate (TSP). The additional nutrients were applied either through soil or foliar. The combinations of the NPK and the additional nutrients gave ten treatments which were laid out on 5m×5m plots in a randomized complete block design (RCBD) with four replications. Growth and yield data were collected and subjected to analysis of variance using Gentstat Statistical software. The study discovered that applying NPK +Zn through the soil increased plant height and the leaf area index, whereas applying NPK+S through the soil sped up flowering (tasseling) and generated the highest dry biomass yield. In comparison to foliar application, the soil application of NPK+ Zn +S was also quicker to reach days to 50% silking. The best grain production was also achieved with foliar applications of NPK +Zn + S and NPK+P. Nitrogen use efficiency assessed using Agronomic efficiency revealed that soil application of NPK+S and supplementation of P through foliar (NPK+[P] delivered the best efficiency among the treatments. It is therefore recommended that these treatments should be considered in the formulation of fertilizers for maize.

DEDICATION

I dedicate this thesis to my wife Geraldine Mensah, who has been my rock and support throughout my academic journey. Her love and encouragement have been invaluable, and I could not have completed this thesis without her.

I also dedicate this thesis to my two sons, Joed and Ethan Anambire, who have brought joy and laughter to my life. Their presence has been a constant reminder of the importance of hard work and determination. This thesis is a testament to the sacrifices they have made as a family and the love and support they have given me throughout the years.

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TABLE OF CONTENTS

DECLARATION i

ABSTRACT ii

DEDICATION iii

ACKNOWLEDGEMENT iv

LIST OF TABLES ix

LIST OF FIGURES x

LIST OF APPENDICES xi

ABBREVIATIONS AND ACRONYMS xii

CHAPTER ONE 1

INTRODUCTION 1

1.1 Background 1

1.2 Problem Statement 2

1.3 Justification 3

1.4 Main objective 4

1.5 Specific objectives 4

CHAPTER TWO 5

LITERATURE REVIEW 5

2.1 Origin of maize 5

2.2 Biology of Maize 6

2.3 Importance of maize to humans 7

2.4 Maize production in Ghana 8

2.5 Maize in Northern Ghana 9

2.6 Challenges of maize production in Ghana 9

2.7 Soil fertility management 10

2.8 The role of Nitrogen (N) in maize production 11

2.9 Nitrogen Use Efficiency 12

2.10 Agronomic Efficiency of Nitrogen 13

2.11 The role of Phosphorus(P) in maize production.. 14

2.12 The role of Potassium (K) in maize production 14

2.13 The role of Sulphur(S) in maize production.. 15

1.14 The role of Zinc (Zn) in maize production.. 17

2.15 Site-selection 17

2.16 Foliar fertilization.. 18

2.16.1 History of foliar fertilization.. 18

2.16.2 Mechanism for foliar fertilization.. 19

2.16.3 Timing of Foliar fertilization 20

2.16.4 The role of foliar application of fertilizer 21

2.16.5 Soil fertilization versus foliar fertilization... 22

2.16.6 The role of Adjuvants in foliar fertilization... 23

CHAPTER THREE 24

MATERIALS AND METHODS.. 24

3.1 Experimental site.. 24

3.2 Treatments and experimental design.. 24

3.3 Cultural Practices 26

3.3.1 Planting... 26

3.3.2 Fertilizer Application.. 26

3.3.3 Pest control.. 26

3.4 Data collection.. 27

3.4.1 Plant height 27

3.4.2 Leaf area and leaf area index 27

3.4.3 Leaf chlorophyll content 28

3.4.4 Days to 50% flowering 28

3.4.5 Days to 50% maturity 28

3.4.6 Days to maturity 28

3.4.7 100 Seed weight 28

3.4.8 Biomass and Grain yield 29

3.4.9 Nitrogen Use efficiency 29

3.4.9 Data analysis 30

CHAPTER FOUR 31

RESULTS 31

4.1 Rainfall distribution at Nyankpala experimental site 31

4.2 Soil Physical properties at experimental sites 32

4.2 Effect of fertilizer treatment on plant height 33

4.3 Effect of fertilizer treatment on Leaf Area Index (LAI) 34

4.4 Effect of fertilizer treatment on leaf Chlorophyll based on SPAD reading 35

4.5 Effect of Fertilizer treatment on 50% tasseling 35

4.6 Effect of Fertilizer treatment on days to 50% Silking 37

4.7 Effect of Fertilizer treatment on days to silking 38

4.8 Effect of Fertilizer treatment on days to maturity 40

4.9 Effect of fertilizer treatment on 100 seed weight 42

4.10 Effect of fertilizer treatment on Dry biomass 43

4.11 Effect of Fertilizer treatment on grain yield 44

4.12 Effects of fertilizer treatments on Agronomic Efficiency of Nitrogen (AEN) 45

4.13 Correlation between yield and growth parameters of maize 47

4.14 Regression between yield components and grain yield of maize........................ 48

CHAPTER FIVE 50

DISCUSSION.. 50

5.1 Effect of fertilizer treatments on growth parameters 50

5.2 Influence of fertilizer treatment on earliness to maturity...................................... 51

5.3 Utilization of applied nitrogen 53

5.4 Effect of fertilizer treatments on yield parameters... 56

CHAPTER SIX.. 58

CONCLUSION AND RECOMMENDATION.. 58

6.1 Conclusions 58

6.2 Recommendation... 59

REFERENCES 60

APPENDICES 70

LIST OF TABLES

TABLE 1: SHOWS THE IDEAL REQUIREMENTS OF THE VARIOUS FACTORS NECESSARY FOR FOLIAR NUTRIENT APPLICATION 20

TABLE 2: TIME REQUIRED FOR 50% ABSORPTION OF FOLIAR APPLIED NUTRIENTS.. 21

TABLE 3: NUTRIENT COMPOSITION USED AS TREATMENT 25

TABLE 4: SOIL PHYSICAL PROPERTIES 32

TABLE 5: AGRONOMIC EFFICIENCY OF NITROGEN 47

TABLE 6: SIMPLE CORRELATION COEFFICIENT(R) AMONG YIELD AND YIELD COMPONENTS OF MAIZE 48

LIST OF FIGURES

Figure 1: Rainfall distribution on Nyankpala experimental site during 2022 farming season 31

Figure:2 Effect of fertilizer treatment on plant height at 8 WAP. Error bars represent Standard Error of Means (SEM) 33

Figure 3: Effects of Treatments on Leaf Area index. Error bars represent SEM. Nutrients in parenthesis [ ] were foliar applied. 34

Figure 4: Effects of fertilizer treatments on maize leaf SPAD reading. Error bars represent the SEM 35

Figure 5: Interactive effects of fertilizer treatments and location on Days to 50% tasseling. Error bars represent SEM 36

Figure 6a: Effect of treatments on Days to 50% silking. Error Bars represent SEM.. 38

Figure 6b: Effect of treatment on days to silking. Error bars represent the SEM 39

Figure 7: Effect of treatment on days to silking. Error bars represent SEM 40

4.8 Effect of Fertilizer treatment on days to maturity 40

Figure 8a: Effects of treatment on days to maturity. Error bars represent SEM 41

Figure 8b: Effects of location on days to maturity. Error bars represent standard error of means 41

Figure 9 Effect of treatment on 100 seed weight. Error bars represent SEM 42

Figure 10: Effect of treatment on Dry Biomass. Error bars represent SEM 44

Figure 11: Effect of fertilizer treatment on grain yield. Error bars represent SEM 45

Figure 13: Regression between grain yield and (a) 100 seed weight (b) dry biomass (c) Cob weight and (d) plant height....... 49

LIST OF APPENDICES

APPENDIX 1: EFFECT OF FERTILIZER TREATMENTS ON PLANT HEIGHT 4 WAP 70

APPENDIX 2:EFFECT OF FERTILIZER TREATMENTS ON PLANT HEIGHT 6 WAP 70

APPENDIX 3: EFFECT OF FERTILIZER TREATMENTS ON PLANT HEIGHT 8 WAP 70

APPENDIX 4: EFFECT OF FERTILIZER TREATMENTS ON LAI 4 WAP 71

APPENDIX 5: EFFECT OF FERTILIZER TREATMENTS ON LAI 6 WAP 71

APPENDIX 6: EFFECT OF FERTILIZER TREATMENTS ON LAI 8 WAP 71

APPENDIX 7: EFFECT OF FERTILIZER TREATMENTS ON LEAVE SPAD READING 4 WAP 72

APPENDIX 8: EFFECT OF FERTILIZER TREATMENTS ON LEAVE SPAD READING 6 WAP 72

APPENDIX 9: EFFECT OF FERTILIZER TREATMENTS ON LEAVE SPAD READING 8 WAP 72

APPENDIX 10: EFFECT OF FERTILIZER TREATMENTS ON DAYS TO 50% TASSELING 73

APPENDIX 11: EFFECT OF FERTILIZER TREATMENTS ON DAYS TO 50% FLOWERING(SILKING)73

APPENDIX 12: EFFECT OF FERTILIZER TREATMENTS ON DAYS TO 50% MATURITY 74

APPENDIX 13: EFFECT OF FERTILIZER TREATMENTS ON DAYS TO SILKING 74

APPENDIX 14: EFFECT OF FERTILIZER TREATMENTS ON DAYS TO TASSELING 75

APPENDIX 15: EFFECT OF FERTILIZER TREATMENTS ON DAYS TO MATURITY 75

APPENDIX 16: EFFECT OF FERTILIZER TREATMENTS ON 100 SEED WEIGHT G 75

APPENDIX 17: EFFECT OF FERTILIZER TREATMENTS ON FIVE PLANTS COB WEIGHT G 76

APPENDIX 18: EFFECT OF FERTILIZER TREATMENTS ON FIVE PLANTS DRY WEIGHT G 76

APPENDIX 19: EFFECT OF FERTILIZER TREATMENTS ON FIVE PLANTS DRY ROOT WEIGHT G 76

APPENDIX 20: EFFECT OF FERTILIZER TREATMENTS ON FIVE PLANTS DRY SHOOT WEIGHT G77

APPENDIX 21: EFFECT OF FERTILIZER TREATMENTS ON GRAIN YIELD KG/HA...................... 77

APPENDIX 22: EFFECT OF FERTILIZER TREATMENTS ON WEIGHT OF ENTIRE HARVEST G 77

ABBREVIATIONS AND ACRONYMS

AD-Anno Domini

ADP Adenosine Diphosphate

AEN-Agronomic Efficiency of Nitrogen

ATP-Adenosine Triphosphate

Ca- Calcium

FAO- Food and Agriculture Organization

FERARI- Fertilizer Research and responsible Implementation

IFA-International Federation of Agriculture

IFDC -International Fertilizer Distribution Corporation

ISSER- Institute of Statistical, Social and Economic Research

Mg- Magnesium

MOFA-Ministry for Food and Agriculture

NPK: _Nitrogen, Phosphorus Potassium

NUE- Nitrogen Use Efficiency

RCBD-Randomized Complete Block Design

S- Sulphur

TSP- Triple superphosphate

WAP-Weeks After Planting

CHAPTER ONE

INTRODUCTION

1.1 Background

Maize (*Zea mays* L.) is one of the world's most widely cultivated cereal crops. Maize is produced in all continents except Antarctica. There are many different species of maize consisting of different colours. White, yellow and red maize is commonly cultivated. About 1500 AD, maize was brought to Africa after being cultivated in Central Mexico circa 1500 BC (Huma, 2019). The global production of maize exceeds 1.1 million metric tons. More than 50% of it is produced in the USA and China. The remainder is grown in Latin America, Southern Asia and Africa (Huma, 2019). Among the many positive health effects of maize are its B-complex vitamins, which are beneficial to the heart, brain, hair, and skin. They are also vital for healthy digestion. The thyroid gland and immune system are enhanced by the vitamins A, C, and K, as well as by the beta-carotene and selenium found in maize. Maize also has great nutritional benefits as they contain 72 per cent starch, 10 per cent protein, 8.5 per cent fibre, 4.8 per cent oil, 3 per cent sugar and 1.7 per cent ash. Maize is also important because it is a source of mineral vitamins, fibre and oil. The oil is for cooking and industries use it for manufacturing soap. Starch from maize is used in pharmaceutical industries (Huma, 2019). Alcohol is made from the seed and the stems are used for paper manufacturing. Maize is an essential food crop in Ghana and accounts for more than half of the cereal produced in Ghana. Maize yield is low in the world. It is much lower averaging 1.7 t/ha in Sub-Saharan Africa and 1.5 t/ha in Ghana (Kugbe *et al.*, 2019; Uzun *et al*., 2021). Maize serves as food for humans and serve as feed for farm animals. In Northern Ghana, it is a staple food crop that is cultivated by many smallholder farmers. Maize has a very high yield potential compared to many cereal crops, for this reason, it is often referred to as the 'Queen of Cereals'(Padma *et al.*, 2018; Sutar, 2017b).

1.2 Problem Statement

Despite its importance and high potential, maize production is beset by many problems, including soil nutrient deficiency, pests and diseases (Hengl *et al*., 2017). The yield of maize in Northern Ghana is as low as 1.5t/ha per year (Kugbe *et al*., 2019). It is estimated that during the last two decades maize production has seen a consistent increase in output in Ghana because of an increase in the area of production rather than increases in yield (ISSER, 2017).

The loss in soil fertility is a complicated and diverse issue that has been linked to a number of things, including soil degradation, excessive land use, poor soil management techniques, and climate change. Excessive land usage, especially through intense agricultural methods, can result in depleted soil and decreased fertility (FAO, 2018). Additionally, poor soil management techniques, such as monoculture and insufficient fertilization, can accelerate the reduction in soil fertility (Lal, 2004). There is evidence that climate change is also contributing to declining soil fertility, as rising temperatures and changing rainfall patterns can affect soil structure, water holding capacity, and nutrient cycling (Lal, 2010). These factors can have a negative impact on crop yields and the overall productivity of agricultural systems. Given the interconnectedness of the elements causing the loss in soil fertility, it is crucial to explore various nutrients and application methods to increase crop yield. Bekunda *et al*. (2005) concluded that soil fertility among smallholder farmers is a cause of declining yield of maize in Sub-Sahara Africa and for that matter Northern Ghana. The use of NPK has contributed significantly to the increase in the yield of maize. In order to increase the yield to the worldwide average of 4.9 t\ha (Kugbe *et al*., 2019), some other nutrients must be explored.

1.3 Justification

There is a projection that including plant nutrients like Sulphur, zinc and additional phosphorus can increase yield to astronomical levels.(Kihara *et al.,* 2017; Kugbe *et al*., 2019) Phosphorus is a macronutrient crucial for energy transfer, photosynthesis, and the synthesis of nucleic acids in plants. It enhances root development, promotes flowering, and increases fruit and seed production. Sulfur is essential for protein synthesis, enzyme function, and the formation of chlorophyll. It is a key component of amino acids such as cysteine and methionine, which are building blocks of proteins.). Adding sulfur to soils has been shown to improve grain quality and boost yields, especially in sulfur-deficient areas. Zinc is a micronutrient necessary for enzymatic activities, hormone production, and protein synthesis in plants. Application of zinc fertilizers, particularly in soils with low Zn availability, significantly enhances grain yield and quality. (Alloway,2008)

Foliar application involves spraying nutrients directly onto plant leaves, allowing for rapid absorption and utilization. (Brown, 2012) This method is particularly effective in addressing deficiencies during critical growth stages when root uptake is insufficient. Studies have demonstrated that foliar application of nutrients such as P, S, and Zn enhances photosynthetic efficiency, boosts metabolic activities, and improves overall crop resilience to stress conditions (Fernández and Eichert, 2009). Foliar feeding ensures precise nutrient delivery and minimizes nutrient loss compared to soil applications.

The combined application of P, S, and Zn can have synergistic effects on yield. Phosphorus supports root growth, which enhances the uptake of other nutrients, including sulfur and zinc. Sulfur aids in improving nitrogen use efficiency, indirectly benefiting phosphorus and zinc utilization. Zinc promotes better enzyme function and protein synthesis, further complementing the effects of P and S. This needs to be confirmed with soils of the Guinea Savanna ecological zone.

1.4 Main objective

The overall objective of this experiment was to improve maize yield among smallholder farmer

1.5 Specific objectives

- To establish the effects of Zinc, Sulphur and Phosphorus on the growth parameters of maize
- To establish the best form Zinc and Sulphur must be applied,
- To determine if Phosphorus need of the crop can be supplemented through foliar application
- To determine which of the nutrients impact yield.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin of maize

Maize (*Zea mays L.*), is a widely cultivated crop in the world. It is planted on all continents except the Antarctic continent (Gálvez-Durán *et al*.,2020). The origin and domestication of maize have sparked controversy in the areas of evolutionary biology, taxonomy, and domestication. It was first cultivated in Mexico 7,000 years ago and has been recorded as a forage crop. Pollen fossils and cave corn cobs found in ancient ruins support the theory that corn originated in Mexico ((Gálvez-Durán *et al*.,2020: Uzun *et al*., 2021)). Maize was brought to Africa around 1500 AD after being discovered around 1500 BC. It was domesticated in central Mexico and is currently the most significant grain crop in Africa, having spread over the continent in about 500 years. (Uzun *et al*., 2021). Maize is believed to have been domesticated in the highlands of Mexico 6,000 to 7,500 years ago, probably by the wild Teosinte species (*Euchlaena Mexicana*). The genus Zea belongs to the herbaceous family, also commonly known as grass. Domestication of teosinte maize has also been demonstrated by anthropological discoveries of fossil maize in Mexico (Gálvez-Durán *et al*.,2020). Corn was first introduced to Africa by Portuguese and Arab traders in West and East Africa and then expanded inland via the slave trade route and eventually to Asia. Maize cultivation in Africa dates back to the 16th century (Gálvez-Durán *et al.*,2020) and was transported from the United States along the west and east coasts and gradually spread inland as a slave trade ration.

2.2 Biology of Maize

Maize (*Zea mays L*.) belongs to the Maydeae family of the Gramineae family. Maize is a versatile crop grown in various agricultural climatic zones (Doebley *et al*., 1990). It is a large, definitive, monoecious plant whose height varies from 1 meter to 4 meters. It produces large, narrow contralateral leaves that are alternately carried along the length of the stiff stem. The lower corn leaves are like wide flags, 50-100 cm long and 5-10 cm wide. The stem consists nodes and internodes. The internodes are wide at the bottom and gradually reduces toward the inflorescences at the top. The leaf blades are alternately supported along the stem. The main stem ends with a tassel with spikelets. This usually occurs 35-45 days after appearance. When the tassel opens, the filaments are stretched to extrude spikelets (with anthers), emptying pollen grains from the extruded anthers(Becker *et al*., 2015). The reproductive stage starts when buds present in the axillae of the leaves develop and form pistil inflorescences or female flowers. The axillary buds deform and form leaf masses called ears at the joints of the flowering stems. From each flower, the style stars to grow towards the top of the spadix in to make way for fertilization. These styles form threads called silk that appears in different colours depending on the genotype. The appearance of silk can be affected by temperature, soil moisture and soil fertility. Severe droughts, can also slow or even stop the rise of silk altogether. As a pollen receptor, individual silk is pollinated to produce crops. Pollen counts occur over 14 days and peak in the first 5 days of flight. Silk is receptive immediately after its appearance and remains receptive for up to about 10 days. In general, pollen numbers precede silk budding by about 1-3 days in any plant (Becker *et al*., 2015). Fertilized spikes are always in different shapes and have even rows of nuclei (usually 8 or more rows) arranged in different patterns (regular, irregular, mixed, straight, spiral) depending on the genotype. Maize kernels are composed of embryos, endosperm and pericarp and may vary in colour, structure and chemical composition. The most common core colours are yellow and white, but some native species can use red, purple, and black colours. Often due to different colours on the same ear.

2.3 Importance of maize to humans

There are many health benefits of maize, it contains many different vitamins such as vitamin B-complex which is good for the brain, heart and skin. Other vitamins in maize like vitamins A, C and K boost the immune system. (Huma, 2019; Kumar and Jhariya, 2013) In Countries like China, India and Spain among others, the silk of maize treats diseases like kidney stones, urinary tract infections, jaundice and fluid retention. (Kumar and Jhariya, 2013) It also has the potential to improve blood pressure, support liver functioning and produce bile. (Huma, 2019)

Maize is highly nutritious as it contain 72 per cent starch, 10 per cent protein, 8.5 per cent fibre, 4.8 per cent oil, 3 per cent sugar and 1.7 per cent ash. (Huma, 2019; Kumar and Jhariya, 2013)

Economically, maize is an important source of minerals, vitamins, fibre and oil. The oil is edible and for manufacture soap. Maize is used extensively in the pharmaceutical and cosmetics industries. Grains of maize are used in alcohol production as the stems are used in manufacturing paper. (Kumar and Jhariya, 2013) Smallholder farmers are involved in production due to their high nutritive value.

2.4 Maize production in Ghana

Maize was introduced to Ghana towards the 16th century. Maize is a versatile crop, which grows in almost all parts of Ghana. It grows in the country's northern Savannah, transitional, forest and coastal Savannah zones. Almost every part of the crop has an important role in Ghana. Maize production provides a significant portion of the food for the majority of Ghanaians, it is crucial to maintaining Ghana's household food security. (Wongnaa and Mensah, 2018)

Maize is cultivated twice and once in the southern part and northern of Ghana respectively In Ghana, resource-poor smallholders mainly produce maize under rainfed agricultural conditions. White maize is a common type of corn in Ghana, but imported yellow corn is primarily used as feed for poultry. Although maize has attracted the attention of commercial farmers, it has never reached the economic significance of traditional plantation crops such as oil palm and cocoa. According to Akramov and Malek (2012), the decline in profitability of many plantation crops has helped to increase interest in commercial food crops, including maize. Maize is Ghana's most important staple food and accounts for more than 50% of total grain production. Maize is a major grain in Ghana's domestic market and is the seventh largest agricultural product in terms of production value between 2005 and 2010, accounting for 3.3% of the world's total agricultural production value (FAO, 2012). Most of the corn produced is nutritious and is the most important crop for food security. Since maize is an important component of poultry and livestock feed, the development and productivity of the livestock and poultry sector also depended on the maize value chain. Akramov and Malek (2012) discovered that maize is the country's second most important commercial crop after cocoa. Maize is the main grain produced in Ghana and is also the most commonly consumed staple food in

Ghana,(Abdulai *et al*., 2018; Uzun *et al*., 2021). The average yield of maize registered by the Ministry of Agriculture in 2010 was 1.9 Mt / ha, while the estimated achievable yield was about 2.5-4 Mt/ha (MoFA, 2010). Under traditional production methods and rain conditions, yields are well below achievable levels. In general, the average yield of corn in Ghana is about 1.5 Mt / ha. However, with improved seeds, fertilizers, mechanization, and irrigation, farmers can achieve yields of up to 5.0-5.5 Mt / ha.

2.5 Maize in Northern Ghana

Northern Ghana has been traditionally accustomed to cereals like millet and sorghum. This has been so because of the ability of these crops to withstand low fertility and poor moisture retention. In the 1980's maize was introduced to northern Ghana. (MacCarthy *et al*., 2018) Maize production in northern Ghana makes up about 55 percent of the total output of the crop in Ghana. The crop is grown under a unimodal rainfall pattern which is depended on by more than half of rural families. The rainy season in northern Ghana is between April and September. The wettest months are generally late August and early September. Agriculture is the major source of jobs for the people here and maize is the main crop grown.(Abdulai *et al* 2018) Despite great efforts, maize yield in northern Ghana is below the national average of 1.7 tons/ha. (MacCarthy *et al*., 2018)

2.6 Challenges of maize production in Ghana

The availability of sufficient rainfall is the most limiting factor in maize production in sub-Saharan Africa. MacCarthy *et al*., (2018) added that intermittent droughts are one of the major constraints on maize production in the Guinean forest-savanna of West Africa. Lowlands Fertility is also a major limitation of maize production in the Guinean forests of West Africa (Kamara *et al*., 2014). Although maize is economically important in Ghana, its production is hampered by many factors. Some of the key limiting factors for maize production in Ghana includes inherent low soil fertility, low capital, price volatility, disease and pest epidemics, poor storage facilities and resource utilization in Ghana. In Ghana, the response of plants to nitrogen in continuously cultivated depleted soils can be double that of naturally fertile soils that have been fallowed for several years (Uzun *et al*., 2021).

2.7 Soil fertility management

Soil fertility means a farm site can support plant growth and produce good crops at a particular period. Soil fertility is important for crop cultivation. However, in Guinea's savanna soils, soil fertility is rapidly declining. Decreased soil fertility in this area can be blamed no increased population growth (pressure) and intensive agriculture, which leads to the over-cultivation of soil without replenishment. The decline in soil fertility in sub-Saharan Africa has hampered the improvement of agricultural productivity. Previously, people depended on natural soil fertility to grow their crops, and there was no commercial production. As population growth and commercial production begin, soil's natural nutrient capital is gradually depleted, forcing farmers to adequately compensate for losses by returning nutrients to the soil via fertilizers, especially mineral fertilizers. Smallholders are poor and lack technical know-how, so they cannot afford the recommended amount of fertilizer to increase crop yields, well below the recommended amount to improve yields. Increasing pressure on agriculture has led to much higher nutrient flows and the subsequent collapse of many traditional soil fertility conservation strategies. In smallholders, poor soil fertility is of the main constraints affecting agriculture, particularly nitrogen and phosphorus deficiencies. The use of mineral fertilizers is the most effective and convenient way to improve soil fertility. The main impact of lower soil fertility in Ghana is the observation of reduced food production leading to food insecurity, hunger, and poverty.

2.8 The role of Nitrogen (N) in maize production

Nitrogen has an essential role in determining the yield of maize (Onasanya *et al*., 2009). It is the most frequently deficient of all nutrients and it makes up 2- 4 per cent of the dry matter. The supply of it is related to the of carbohydrate. When nitrogen supply is limited, carbohydrates are deposited in vegetative cells. Nitrogen contains protein, nucleic acids and a major component of essential compounds for plant growth. It also helps in the use of phosphorus, potassium and other plant nutrients. The major use of these elements depends on the availability of nitrogen in the soil. Nitrogen is also very important for the potential yield of maize. There is a direct correlation between N rate and days to tasseling, silking and maturity(Asif *et al*., 2013)

Nitrogen is mainly absorbed in the form of the nitrate ion (NO_3) or ammonium ion (NH_4) Nitrogen is a major nutrient that is needed by plants in larger quantities. Many crops demand more and more of this element; however, the soil alone is not able to meet the needs of plants because they were not well supplied or lost due to the mobility of nitrogen. The role of nitrogen in plants is enormous. Nitrogen occurs as proteins and nucleoproteins with varying amounts of amines, amino acids, polypeptides and others. Plants deficient in nitrogen become stunted which is a result of lack of nitrogen from chloroplasts in older leaves which leads to chlorosis- the main indicator of nitrogen deficiency. Under severe nitrogen deficiency, lower leaves turn brown and necrotic and subsequently die.

2.9 Nitrogen Use Efficiency

Nitrogen use efficiency (NUE) is an indicator for measuring the efficiency of plant nitrogen uptake, assimilation and utilization. Nitrogen use efficiency is the amount of nitrogen absorbed by plants that is used for growth and development (Han *et al.*, 2015; Ravali *et al*., 2020) Increasing NUE is essential for achieving higher crop yields and for reducing environmental pollution caused by nitrogen-based fertilizers. Over the last few decades, improvements in NUE has been a major focus of research and development in the agricultural sector.(Han *et al.*, 2015).Many techniques have been developed to increase NUE, including the use of more efficient nitrogen fertilizer forms and improved cultural practices.(Hirel *et al*., 2011) Additionally, genetic engineering has been used to increase the ability of plants to absorb and utilize nitrogen more efficiently. For example, genetic engineering has been used to introduce genes that increase the uptake of nitrogen from the soil, increase the efficiency of nitrogen assimilation and utilization, and increase the efficiency of nitrogen translocation to growing points in the plant. In addition, a variety of approaches have been developed to improve NUE through improved agronomic practices, such as timing of nitrogen application, split nitrogen applications, and optimized nitrogen rates.(Doebley *et al*., 1990) These approaches have been shown to reduce nitrogen losses and improve NUE. Overall, it is clear that NUE is an important metric Indices for measuring NUE include (i) agronomic efficiency (AE), the increase in grain yield per unit N applied and (ii) recovery efficiency (RE), the increase in above ground N biomass per unit N applied (Wortmann et al., 2011)

2.10 Agronomic Efficiency of Nitrogen

Agronomic efficiency is an important aspect of agriculture, aimed at maximizing yields while minimizing the use of natural resources. Agronomic efficiency closely reflects the production impact of an applied fertilizer and relates directly to economic return making it a good short-term indicator. Typical AE levels of N for cereals ranges from 15–30 kg grain kg^{-1} N, with lower levels suggesting that changes in management could increase crop response or reduce input costs (Fixen *et al*.,2014)

One of the key factors in agricultural efficiency is nutritional management. A study by Yuan *et al.* (2020) studied the impact of nitrogen (N) and phosphorus (P) fertilization rates on maize yield and agricultural efficiency. The results showed that the optimal N and P ratios were 210 kg ha-1 and 80 kg ha-1, respectively, indicating that agricultural efficiency decreased with higher fertilization rates.

In addition to nutrient management, crop rotation and tillage practices can also affect agricultural efficiency. A study by Fan *et al.* (2020) studied the role of crop rotation and tillage on maize yield and agricultural efficiency in a dryland cropping system. The results showed that maize yield and agricultural efficiency were higher in maize–cowpea rotation than in continuous maize, indicating that reducing tillage improved agricultural efficiency. Water management is another important factor affecting agricultural efficiency. A study by Zhang *et al*. (2021) examined the impact of water management practices on rice yield and agricultural efficiency. The results show that alternating wet and dry irrigation improves rice yield and agricultural efficiency compared to continuous irrigation, and that his alternating wet and dry irrigation combined with nitrogen fertilizer achieves the highest agricultural efficiency. was shown.

Additionally, precision farming techniques such as remote sensing and variable rate applications can improve agricultural efficiency by optimizing input use. A study by Huang *et al.* (2020) studied the effects of variable rate nitrogen application on maize yield and agricultural efficiency. Results showed that variable rate nitrogen application increased maize yield and agricultural efficiency compared to constant rate of nitrogen application.

2.11 The role of Phosphorus(P) in maize production

Phosphorus (P) is a plant element which is required by plants in large quantities. Phosphorus used has become very common in recent times due to its depletion in the soil (Wood *et al*., 2010). Phosphorus has many important roles in the growth of plants. One major function is to store and transport energy through the plant. High-energy phosphatic compounds like Adenosine diphosphate (ADP) and Adenosine triphosphate (ATP) control photosynthesis, respiration, protein synthesis and transport of nutrients through plant cells. (Wood *et al*., 2010) Phosphorus is also recognized to be necessary for the generation of seeds and to promote a variety of other traits such as stronger stalks, early plant maturity, better root growth, and resistance to root rot diseases. It is also reported that proper maintenance of Phosphorus fertility leads to increase grain, fibre and forage yield. (Wood *et al*., 2010)

2.12 The role of Potassium (K) in maize production

Potassium ions are absorbed by plant roots. The concentration of potassium ions in vegetative tissues is 1-4 per cent on a dry matter basis, therefore plant reaction to available K is high. Potassium exists solely as a K^+ ion either in soil solution or bonded to negative charges on organic compounds.

Potassium is involved in enzyme activation. Over 80 plant enzymes require K for their activation which is the most important function of potassium. These enzymes are abundant in meristematic tissue where cell division takes place rapidly and where primary or new tissues are formed. Potassium is also required for the synthesis of high-energy molecules (ATP), which are produced during photosynthesis and respiration. Nitrogen uptake and protein synthesis are also influenced by the presence of K and also help in grain filling and increased grain yield because of its association with increased photosynthesis. When K is limiting, there is a chlorotic and necrotic appearance on the leaf edges of maize. Lodging and stalk breakage also occur in maize as a deficiency symptom of K. Potassium stress also increases crop damage due to bacterial, viral nematodes and insect infestation.

2.13 The role of Sulphur(S) in maize production

Sulphur is becoming the next major nutrient after nitrogen, phosphorus and potassium. Cereals, in general, have low Sulphur requirements (Sutar, 2017a). Sulphur is essential for all organisms due to the role it plays in a variety of processes. Sulphur is gaining attention throughout the world due to its frequent deficiencies. The deficiency of Sulphur in the soil is caused by a variety of factors including the use of Sulphur-deficient fertilizers, leaching and erosion, restricted use of organic manure and crop removal. Sutar, (2017b) reported that Sulphur deficient conditions and the efficient use of applied NPK may be seriously affected and yield may also be seriously affected. So, the complete yield potential cannot be achieved in soils where Sulphur is deficient. The impact of Sulphur in plant nutrition is documented.

Many high-yielding varieties of maize quickly use up Sulphur reserves in the soil. the deficiency of Sulphur is becoming a serious issue (Rahman *et al* 2011). Sulphur fertilizers are comparatively inexpensive but lead to substantial increases in the yield and quality of crops. (Rahman *et al* 2011) Sulphur can also be used in the amendment of soils, this because Sulphur compounds neutralize Calcium Carbonate with acids and those leads to the reduction of pH levels in the soil and improve nutrient availability (Rahman *et al* 2011) the combined effects of Sulphur and nitrogen increase maize dry matter content (Rahman *et al* 2011)

Besharati (1999), reports that the application of Sulphur had an important effect on maize root and shoot dry matter. Sulphur is important in plant growth and metabolism. it is required for the synthesis of S- containing amino acids like cysteine, cysteine and methionine which are important components in protein. about 90% of Sulphur in plants is found in those amino acids. Sulphur is also needed in the synthesis of other metabolites like co-enzymes A, biotin, thiamin and glutathione. Co-enzyme A is involved with the oxidation and synthesis of fatty acids and the synthesis of amino acids. Sulphur is a very important component of ferredoxin (Fe-S protein) occurring in chlorophyll. Ferredoxins take part in the transfer of electrons and have a significant role in nitrate reduction, sulphate reduction and assimilation of nitrogen gas by root nodule bacteria. Sulphur also occurs in volatile compounds and is responsible for the characteristic taste and smell of plants like an onion. Additionally, Sulphur enhances oil formation in crops such as soybean. Sulphur is not a constituent of chlorophyll; however, it is needed for chlorophyll synthesis and therefore photosynthesis.

Sulphur deficiency retards crop growth and plants are uniformly chlorotic, stunted, thin-stemmed and spindly. In crops like maize, S deficiency resembles those of N, but Sulphur does not normally move from older to younger leaves because S deficiency symptoms first occur in younger leaves.

1.14 The role of Zinc (Zn) in maize production

Of the micronutrients, zinc deficiency is probably the most common. Zn can be applied via a variety of inorganic and chelated compounds. Zinc sulphate is the most commonly used Zn source. The dose of Zn in the soil is typically in the form of zinc sulphate in the range of 4.5-34 kg Zn / ha (applied or sprayed in an aqueous solution in the nursery). Higher doses are often used for sensitive crops such as alkaline and or calcareous soil corn, as opposed to non-calcareous soil corn (Allowey, 2004). In India, where zinc deficiency is widespread, it is recommended to spray 5 kg Zn / ha on coarse-grained soils and 10 kg Zn / ha on fine-grained soils. One spray is sufficient for three to six harvests.

2.15 Site-selection

Maize does well to varied soil types with a pH about of 5.0-7.0. High yields are obtained from corn planted in organic-rich, deep, fine-grained, well-ventilated, well-drained loamy soils. Shallow sandy or loamy soils are more susceptible to drought and are less responsive to fertilization and should be avoided as much as possible.(Adu *et al* 2014) Proper drainage allows for early cultivation, better weed control, and reduced potential for nutrient leaching. Lowlands usually have poor drainage, and flooding reduces yields. Corn needs to be grown in full sun for efficient photosynthesis.(Adu *et al*, 2014)

2.16 Foliar fertilization

Foliar fertilization involves supplying liquid fertilizer directly to the leaves (Patil and Chetan, 2016). Several terms are used in describing the technique, which includes foliar feeding, foliar application and foliar nutrition (Alshaal and El-Ramady, 2017). Plants are capable of absorbing soluble nutrients through the stomata and epidermis of leaves. Patil and Chetan, (2016) reported that foliar fertilization is ideal for applying smaller quantities of micro-nutrients. However, macro nutrients can also be supplied when there is no much water in the top layer of the leave. Foliar fertilization is to supplement soil application but not as a substitute. Alshaal and El-Ramady, (2017) documented that foliar application is recommended for applying additional Nitrogen, Phosphorus, Potassium, Magnesium and Sulphur as well as the micro-nutrients.

2.16.1 History of foliar fertilization

The history of foliar fertilization has been documented since 1844 (Alshaal and El-Ramady, 2017). Since then, research efforts have been carried out to study the physical and chemical nature of foliar cuticles. By the middle of the 20th Century, fluorescence and radio labelling technology made it possible to create a more precise technology to investigate this mechanism of cuticular penetration and translocation in plants(IFA, 2013) Since the start of the 20th Century, there has been interest in the role of stomata in the absorption process. However, in 1972 it was proposed that unless a surface-active substance is added to drop surface tension is provided with the solution, pure water may not spontaneously penetrate the stomata(IFA, 2013) As a result, the majority of studies were afterwards conducted on cuticular membranes that had been isolated from adaxial (upper) leaf surfaces of species where enzymatic isolation processes could be carried out, such as from poplar or pear leaves. Using this method, it was discovered that cuticles are permeable to polar chemicals, water, and ions (Fernandez and Eichert, 2009). Additionally, it has been hypothesized that the cuticle contains two separate penetration channels, one for hydrophilic chemicals and the other for lipophilic ones(Fernandez and Eichert, 2009; IFA, 2013). Eichert and colleagues reexamined and then confirmed the hypothesis that stomata may also contribute to the foliar penetration process at the end of the 1990s (Brown *et al*., 2012; Fernandez and Eichert, 2009). There is currently a lack of knowledge on the quantitative importance of this pathway and the contribution of other surface features, such as lenticels, to the uptake of foliar-applied solutions(Fernández and Brown, 2013)

2.16.2 Mechanism for foliar fertilization

For foliar fertilization to be effective, the nutrients to be used by crops must enter the cytoplasm of a cell through the leaf (Alshaal and El-Ramady, 2017). To be able to do this, the nutrient must enter the outer cuticle and the wall of the epidermal cell that is beneath it(IFA, 2013; Patil and Chetan, 2016). According to Patil and Chetan, (2016), foliar application is good for the supply of secondary nutrients and micro nutrients and can also be used to supplement the needs of N-P-K. Foliar fertilization helps in the translocation of nutrients to other parts of the plants (Alshaal and El-Ramady, 2017). Foliar feeding targets growth stages where slowing photosynthesis and levelling root growth and nutrient uptake occur**.** Foliar fertilization favourably impacts growth stages by compensating for environmental pressures from adverse growth conditions and inadequate nutrient availability. Early foliar application of plant nutrients can fortify already healthy crops by stimulating more active regrowth or maximizing the period of potential growth stages of yield.

2.16.3 Timing of Foliar fertilization

According to Alshaal and El-Ramady (2017) and Patil and Chetan (2016), The timing of foliar applications, particularly in connection to the growth stage, might be deemed runabout to the optimum efficacy of the foliar spray, and greater attention should be paid to it. Many factors influence foliar feeding efficacy these include the time of the day, temperature, and humidity. wind speed and rainfall (Alshaal and El-Ramady, 2017; Patil and Chetan, 2016).application

Table 1: shows the ideal requirements of the various factors necessary for foliar nutrient application

S*ource:* ***Environmental Biodiversity Soil Security Vol.,1 20***

Time of Day:	After 6:00 p.m. and before 9:00 a.m.
Temperature:	18-19 ºC (Ideal 21ºC)
Humidity:	Greater than 70 %
Wind speed:	Less than 5 mph
Rainfall:	Within 24 to 48 hours after a foliar application may reduce the application’s effectiveness, as not all nutrients are immediately absorbed into the plant tissue.

Table 2: Time required for 50% absorption of foliar applied nutrients

Nutrients	Time for 50% absorption
Nitrogen (as urea)	1/2 – 2 hours
Phosphorus	5 – 10 days
Potassium	10 – 24 hours
Calcium	1 – 2 days
Magnesium	2 – 5 hours
Sulfur	8 days
Zinc	1 – 2 days
Manganese	1 – 2 days
Iron	10 – 20 days
Molybdenum	10 – 20 days

Source: Environmental Biodiversity Soil Security Vol.,1 2017

2.16.4 The role of foliar application of fertilizer

Foliar nutrition can increase the efficiency and speedy use of a nutrient that is required for growth and development (Alshaal and El-Ramady, 2017). Foliar fertilization provides a quick correction of observed nutrient deficiencies in less time compared to soil application. A key advantage of the foliar application is the quick utilization of nutrients applied. An essential use of foliar fertilization is the application of micronutrients in minute quantities and macronutrients without causing phytotoxicity. According to Alshaal and El-Ramady (2017), the foliar application could be used for farming conditions as (1) a quick correction for unsuspected deficiencies, (2) for the late supply of nitrogen at the advanced growth stage, (3) to prevent unsuspected deficiency, and (4) to overcome nutrient fixation in soils like iron and zinc.

For effective application to leaves, a significant amount of deficient nutrients must be added, but not cause plant damage, leaf burning, and adverse effects of osmotic pressure. The solution should be diluted (1-2 per cent), especially if it contains nutrients. Foliar feeding is at best an aid to soil applications and is not a substitute for it (Uzun *et al*., 2021). Plants have a little osmotic effect and are therefore less sensitive to organic compounds. Except for N, the foliar applied ion can only provide a very limited amount of major nutrients such as P and K, compared to the total requirement of plants. For Ca, Mg, and S, the situation is a little better, but even these s can only be added in limited amounts, often not enough for a single application. The best results are obtained with micronutrients, as a relatively large proportion of the total requirements can be met with a single spray. Repeated spraying of micronutrients is essential if there is a marked deficiency or mobility problem in the leaves(Roy and FAO, 2006).

2.16.5 Soil fertilization versus foliar fertilization

The application of fertilizer in the soil is mainly based on soil tests, while the foliar application of nutrients is mainly based on visual leaf symptoms or plant tissue tests. Therefore, a correct diagnosis of malnutrition is the basis for successful foliar application. Alshaal and El-Ramady, (2017), has documented several advantages of foliar fertilization over soil fertilization and these include: (1) Leaf nutrition has been shown to give better results when planted in soils with optimum pH and mineral content. (2) foliar supply of mineral nutrients is considered cost-effective performed to obtain trace and bioaccumulated plants that are deficient in the human diet in certain environments, (3) foliar application will replenish faster-lost nutrients than soil fertilization and (4) incorporation of mineral nutrients into leaves is 8 to 20 times more efficient than application to soil. However, such high efficiencies are often not achieved in agricultural practice.

2.16.6 The role of Adjuvants in foliar fertilization

The surface area of plants depends on the species, variety, organs, and growth conditions of the plant. The presence, chemistry, and topography of epidermal structures such as epicuticular wax and trichomes can make surface wetting difficult. In these situations, proper wetting, distribution and penetration of foliar fertilizers may require the addition of ingredients such as adjuvants that alter the properties of the spray solution. An adjuvant can be defined as any substance that is included in the formulation or added to the spray tank to alter the activity of the active nutrient or the properties of the spray solution (IFA, 2013). They are generally categorized as follows: (I) an active agent adjuvant (e.g., a surfactant) that increases the active, penetration, diffusion and retention of the active substance, or; (ii) alters the properties of the solution without directly affecting the efficacy of the pharmaceutical product. Numerous leaf and cuticle uptake studies work by enhancing the moisturizing, diffusing, retaining, and penetrating properties of leaf sprays compared to pure mineral element solutions applied alone(Brown *et al*., 2012; IFA, 2013). The formulation of mineral solutions containing adjuvants can have a significant impact on the uptake and bioactivity of nutrients supplied to the leaves, which carries the risk of plant toxicity associated with the nutrient-active ingredients applied.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental site

The study was conducted during the 2021 farming season at two locations, Nyankpala and Kpalga. Nyankpala is located on 9.41127, -0.98315 coordinate in Tolon district while Kpalga is located on 9.44509, -0.9658 coordinate in the Kumbungu District of the Northern Region of Ghana. These areas have unimodal rainfall which occurs between May and October but is irregular with dry spells during the rainy season. Peak rainfall occurs in August or September. The dry season lasts from November to March, with daytime temperatures ranging from 33 to 39 degrees Celsius and nighttime temperatures ranging from 20 to 26 degrees Celsius. (Kugbe *et al*., 2019).Soils from the experimental sites are sandy loam and require fertilization for good crop yield. The bulk density of the soil at both locations are generally low (1.5kg/cm3) The soil has a field capacity and permanent wilting point of not greater than 18.6% and 7.4% respectively. The experimental sites for both Nyankpala and Kpalga have history of being used for maize production. The site is located within the Guinea Savanna-agro-ecological zone. The area had been used in the 2020 cropping season for FERARI trials for maize production.

3.2 Treatments and experimental design

The experiment was a single-factor experiment laid out in a randomized complete block design (RCBD) with four replications at two different locations. Plot size of 5 m × 5 m was used with 1 m alley between plots and 2 m between blocks.

The treatments sought to investigate the role of Sulphur and Zinc applied to maize through soil and foliar on growth and yield. Furthermore, the study looked at improving phosphorus availability to maize through foliar application. NPK (23-10-

5) was used as primary nutrient source and different chemicals were added to supply S, Zn and P in the form of soil or foliar application. Basal N was reduced and top dressing with relatively higher amount of N using urea was to make up for the low basal N. Foliar P was also introduced to make up for low basal NPK. *Table 3* below shows the treatment composition used in the study.

Table 3: Nutrient composition used as treatment

Maize - Rice	Rate (kg/ha)	Amount product to apply (g per plot of 25m^2)						
Treatment	NPK	NPK 23-10-5	ZnSO4 (Soil and foliar)	Ammonium Sulphate (Soil)	Potassium Sulphate (foliar)	TSP	Urea	MOP
Control (No Fertilization)								
NPK (No Micronutrients)	120-40-40	1000.0					152.2	100.4
NPK Zn + S	120-40-40	1000.0	27.5	90.4			110.5	100.4
NPK + Zn	120-40-40	1000.0	27.5				152.2	100.4
NPK + S	120-40-40	1000.0		103.0			104.7	100.4
NPK+ [Zn + S]	120-40-40	1000.0	11.0		61.3		152.2	45.2
NPK+ [Zn]	120-40-40	1000.0	11.0				152.2	100.4
NPK+ [S]	120-40-40	1000.0			67.9		152.2	39.2
NPK+ [P]	120-40-40	250.0				124.5	402.2	150.6
NPK + [P + S]	120-40-40	166.7			67.9	124.5	402.2	89.4

Nutrients in parenthesis [ ] represent foliar application while those not in the parenthesis represent soil application.

3.3 Cultural Practices

3.3.1 Planting

Planting was done on the 7th and 8th of July, 2021 at Nyankpala and Kpalga respectively at a planting distance of 75 cm by 40 cm giving seven roles per plot. Two seeds per hole were sown which gave thirteen planting spots per role. The number of planted seeds on a plot was 182. On the 12th of July, 2021, 50% emergence was noticed. The variety used was Wandata, which is early maturing with potential yield of 4 to/ha

3.3.2 Fertilizer Application

NPK Yara Milla 23-10-5, Triple Superphosphate (TSP), Potassium Sulphate (K_2SO_4), and Zinc Sulphate ($ZnSO_4$) were used in the treatment. NPK and Muriate of Potash (MOP) were applied to the soil as basal application 2 WAP. At 6 WAP, urea was applied as top dressing. Spraying of P in the form of triple superphosphate (TSP), S in the form of potassium sulphate (K_2SO_4), and Z also in the form of zinc sulphate ($ZnSO_4$) was applied during the top-dressing stage. For the foliar formulation, 1.5 litters of water was used to dissolve each quantity of the chemicals measured and an adjuvant (Spreader sticker) was added and applied to each experimental plot that required foliar fertilization.

3.3.3 Pest control

Weeding was done by both chemical and cultural means. Glyphosate was used immediately after planting. Hoeing was done 3 WAP and Pendimenthaline was used six weeks after planting.

Spraying against the fall armyworm (*Spodoptera frugiperda*) was done during the third week after planting with Ema Star 112 EC (17 ml per 15 L knapsack). Five weeks after planting a second control was done with Dean (17/ml per 15 L knapsack).

3.4 Data collection

3.4.1 Plant height

Plant height of five tagged plants per plot were measured at two weeks interval starting from two weeks after planting until tasseling. This was done using a graduated measuring ruler from the bottom to the tip end of the last leaf and the average for each plot was computed and recorded.

3.4.2 Leaf area and leaf area index

In each plot five tagged plants were used to determine leaf area using non-destructive method. Three leaves were taken from bottom, middle and upper part of a plant and their lengths and widths measured. The width was taken from the middle where maximum width can be obtained. In all, a total of 15 leaves were used and the average length (L) and width (W) were computed the leaf area of individual leaf was calculated using the formula $Area = L\ xB\ xA$ where L is the mean leaf length, B is the mean leaf breadth and A is a constant, 0.75 (Stewart 1964). In order to obtain the leaf area of a plant the individual leaf area computed was multiplied by 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) The leaf area index was taken at two weeks intervals starting from 3 WAP.

3.4.3 Leaf chlorophyll content

Minolta chlorophyll meter (SPAD 502 Plus) was calibrated before using for measuring the greenery of the leaves. The SPAD reading correlates with the chlorophyll content of the leaves. The five tagged plants in each plot were used to take three SPAD readings each on the 5th and on the 6th leaves counted from the bottom. The average of 3 reading was recorded.

3.4.4 Days to 50% flowering

The number of days from the emergence of seedlings to the day at which 50% of the plants in a plot flowered, were counted and the average was recorded.

3.4.5 Days to 50% maturity

The average number of days from the emergence of seedlings to the day at which 50% of the cobs per plot took to attain physiological maturity was monitored on daily basis and recorded.

3.4.6 Days to maturity

The average number of days for all plants on the plot to reach maturity was taken and recorded.

3.4.7 100 Seed weight

The 100 seed weight was determined by counting 100 seeds from the threshed and oven-dried seeds from each plot. These were weighed to represent the average seed weight.

3.4.8 Biomass and Grain yield

An inner area of 14.7 m^2 was marked from the 25 m^2 plot for harvesting. Plants from this area were harvested from the base. Total biomass was measured from all plants harvested from the marked 14.7 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. The data was converted into g/plant. The cobs of the five selected plants were de-husked and de-grained and placed in a labelled bag for weighing. The grains were dried for three days to a moisture content of 14% before weighing with electronic weighing scale. The figures were recorded in grams (g) and the grains were finally kept in sacks to be used for the protein content analysis. The cobs of the rest of the harvested plants from 14.7 m^2 were removed and were de-husked. The grains were removed from the cobs manually. Grains from a plot were sun-dried for three days. The weight of the grains from each plot was measured in kilogram and the weight of the grains from the five cobs were added. The grain weight was subsequently converted into kilograms per hectare (kg/ha).

3.4.9 Nitrogen Use efficiency

This was assessed by measuring Agronomic efficiency of the nitrogen applied. Agronomic Efficiency (AE) was calculated by subtracting the crop yield (kg/ha) in a control treatment with no N from the crop yield with applied N and then dividing by the amount of kilogram N applied (kg/ha). (Adu *et al*, 2018)

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

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

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

FN- amount of N applied (kg/ha).

3.4.9 Data analysis

Data collected were subjected to analysis of variance (ANOVA) using GenStat Statistical software Edition 12. Treatment differences were determine using Least Significant Difference (LSD) at 5% probability level. Results are presented in Tables and Figures.

CHAPTER FOUR

RESULTS

4.1 Rainfall distribution at Nyankpala experimental site

The rainfall distribution at the Nyankpala experimental site during the 2021 cropping season is shown in **figure 1.** The highest rainfall of 244 mm was recorded in August, which was followed by 121 mm rainfall in September. In October, a total of 82 mm of rainfall was experienced. The least amount of 27 mm rainfall was recorded in July (Figure 1).

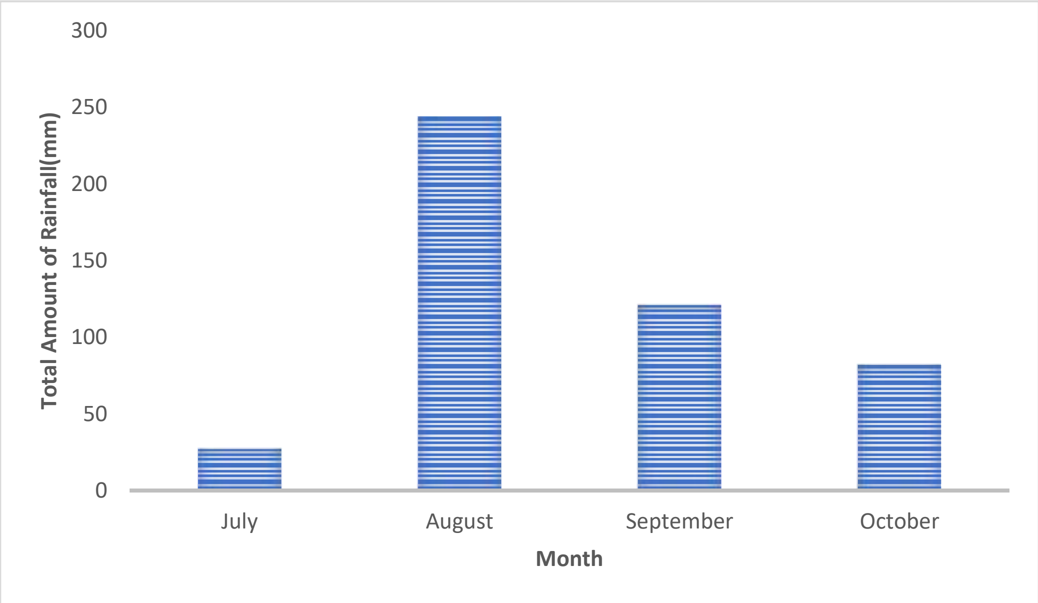

Figure 1: Average Rainfall distribution at experimental sites during 2022 farming season

4.2 Soil Physical properties at experimental sites

Analysis of the soils from the experimental sites shows that the soil at the site is sandy loam. The bulk density of the soil is generally low (1.5kg/cm3) The analysis also indicated that the soil has a field capacity and a permanent wilting point of not greater than 18.6% and 7.4% respectively as shown in **Table 4.**

Table 4: Soil Physical properties

PHYSICAL PROPERTIES OF SOILS AT TRIAL FIELDS

SAMPLE ID	SAND (%)	SILT (%)	CLAY (%)	BULK DENSITY (Kg/cm3)	FC (% VOL)	PWP (%VOL)	TEXTURE
EXP 1 (R4T4)	63.84	29.6	6.56	1.44	16.7	6.4	Sandy Loam
EXP 1 (R4T5)	59.84	31.6	8.56	1.45	18.6	7.5	Sandy Loam
EXP 2 (R2T1)	64.84	30.6	4.56	1.43	15.5	5.2	Sandy Loam
EXP 2 (R4T5)	67.84	27.64	4.52	1.43	14.8	5.2	Sandy Loam
EXP 3 (R1T5)	65.92	31.56	2.52	1.42	14.3	4.1	Sandy Loam
EXP 3 (R3T1)	65.84	31.64	2.52	1.42	14.3	4.1	Sandy Loam
EXP 4 (R2T3)	69.92	25.56	4.52	1.43	14.3	5.2	Sandy Loam
EXP 4 (R3T1)	71.92	23.56	4.52	1.43	13.8	5.2	Sandy Loam

NOTE: FC= Moisture at Field Capacity PWP= Moisture at Permanent Wilting Point

4.2 Effect of fertilizer treatment on plant height

The fertilizer treatments did not show significant differences (*P> 0.05*) in plant height from 4-6 weeks after planting (WAP). Nonetheless, significant difference (*P= 0.005*) was observed among the treatments at 8 WAP. The fertilizer treatments were significantly taller than the absolute control but among the fertilizer treatments there were no significant difference (Figure 2). Though not significantly different when Zn was applied in the soil, the plants grew an average of 14.1 cm taller than when the Zn was applied by foliar means, this was however not different from sole NPK (Figure 2). The top performing treatment was S delivered through foliar though its effect was not statistically different from the other fertilizer treatments.

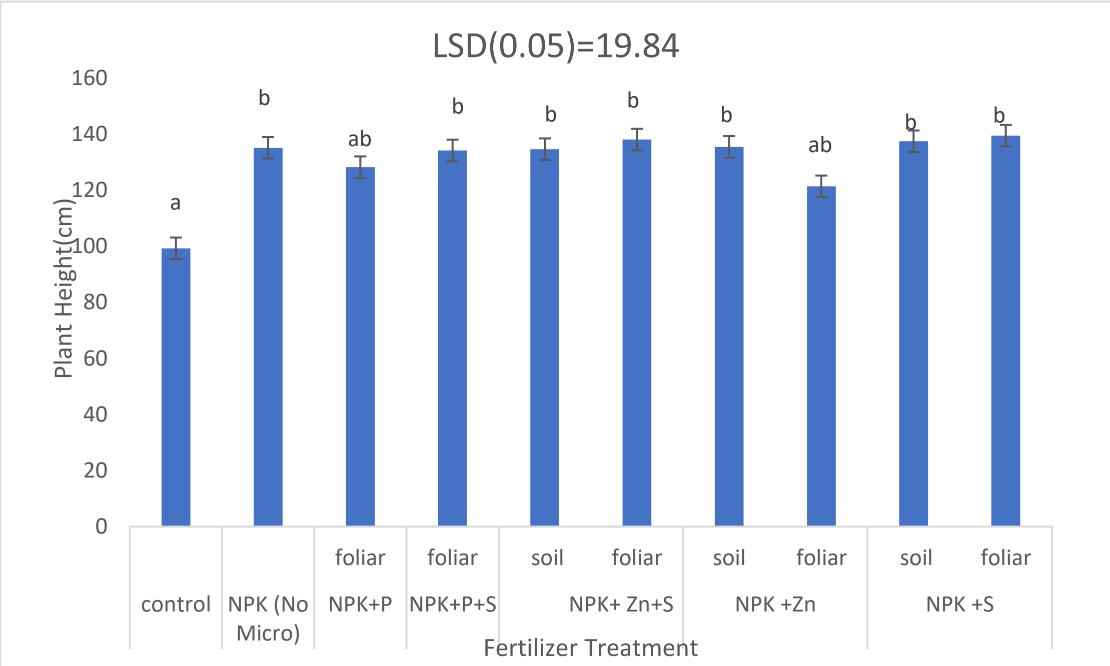

Figure:2 Effect of fertilizer treatment on plant height at 8 WAP. Error bars represent Standard Error of Means (SEM).

4.3 Effect of fertilizer treatment on Leaf Area Index (LAI)

The fertilizer treatments did not show significant difference at 6 WAP (*P=0.052*) in leaf area index, however, there were significant differences at week 4 (*P=0.001*) and week 8 (*P=0.002*) after planting. At 8 WAP, Zn applied in the soil (NPK+Zn) did far better than when it was applied by foliar means, this was however lower than sole NPK. Sulphur applied through foliar (NPK+[S]) was not statistically different from soil applied S (NPK+S), they however outperformed sole NPK. The combination of Zn with S and applied by foliar means produced more leaves than when the two were applied to the soil even though they were not statistically different. They however performed better than sole NPK. Comparing the results of NPK+P and NPK+P+S both by foliar spraying (Figure 3), it was realized that they were not statically different, nonetheless they outperformed sole NPK.

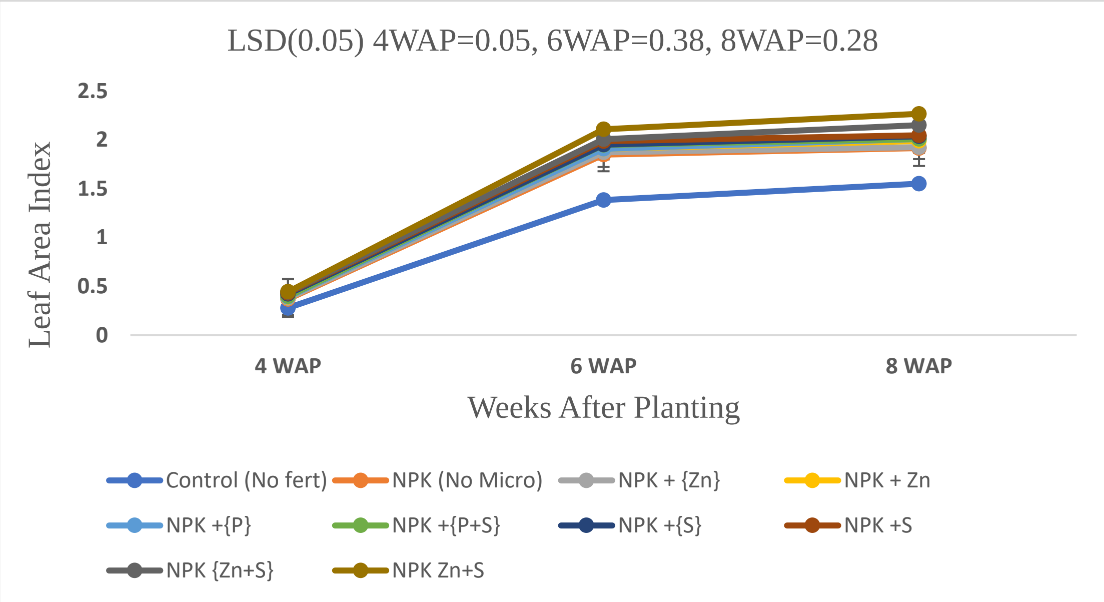

Figure 3: Effects of fertilizer treatments on Leaf Area index. Error bars represent SEM. Nutrients in parenthesis [ ] were foliar applied.

4.4 Effect of fertilizer treatment on leaf Chlorophyll based on SPAD reading

There were significant differences at 4 WAP (*P=0.021*), 6 WAP (*P< 0.001*) and 8th WAP (*P=0.009*) among treatments. The fertilizer treatments showed similar values in SPAD reading but significantly different from the control. From the 6th week after planting P+S applied by foliar lagged behind the other fertilizer treatments (Figure 4).

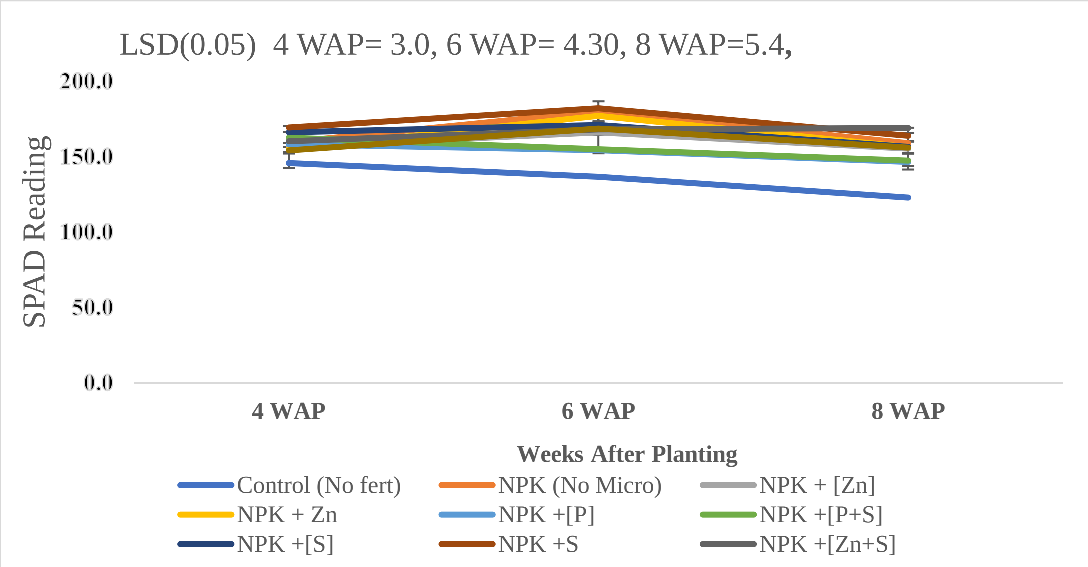

Figure 4: Effects of fertilizer treatments on maize leaf SPAD reading. Error bars represent the SEM

4.5 Effect of Fertilizer treatment on 50% tasseling

The fertilizer treatments recorded significantly different days to tasseling (*P=0.001*) However the two locations did not show differences in earliness to tasseling (*P=0.579*). When S was applied it was seen that delivery through soil at Kpalga tasseled earlier than foliar at Nyankpala (Figure 5). When Zn was applied, foliar delivery caused earlier tasseling than soil delivery at Kpalga but at Nyankpala no significant difference was seen. The combination of Zn and S shows that soil delivery at Kpalga and foliar application at Nyankpala tasseled at similar time. It is interesting to note that for the application of the Zn+S through soil, Kpalga crops tasseled earlier than Nyankpala. However, when it was delivered through foliar, Nyankpala crops tasseled earlier than Kpalga (Figure 5). The application of P by foliar did not lead to early days to 50% tasseling. When P was combined with S the days to 50% tasseling did not alter. Crops that received sole NPK was the last to tassel. However, the control that did not receive any fertilizer tasseled relatively early.

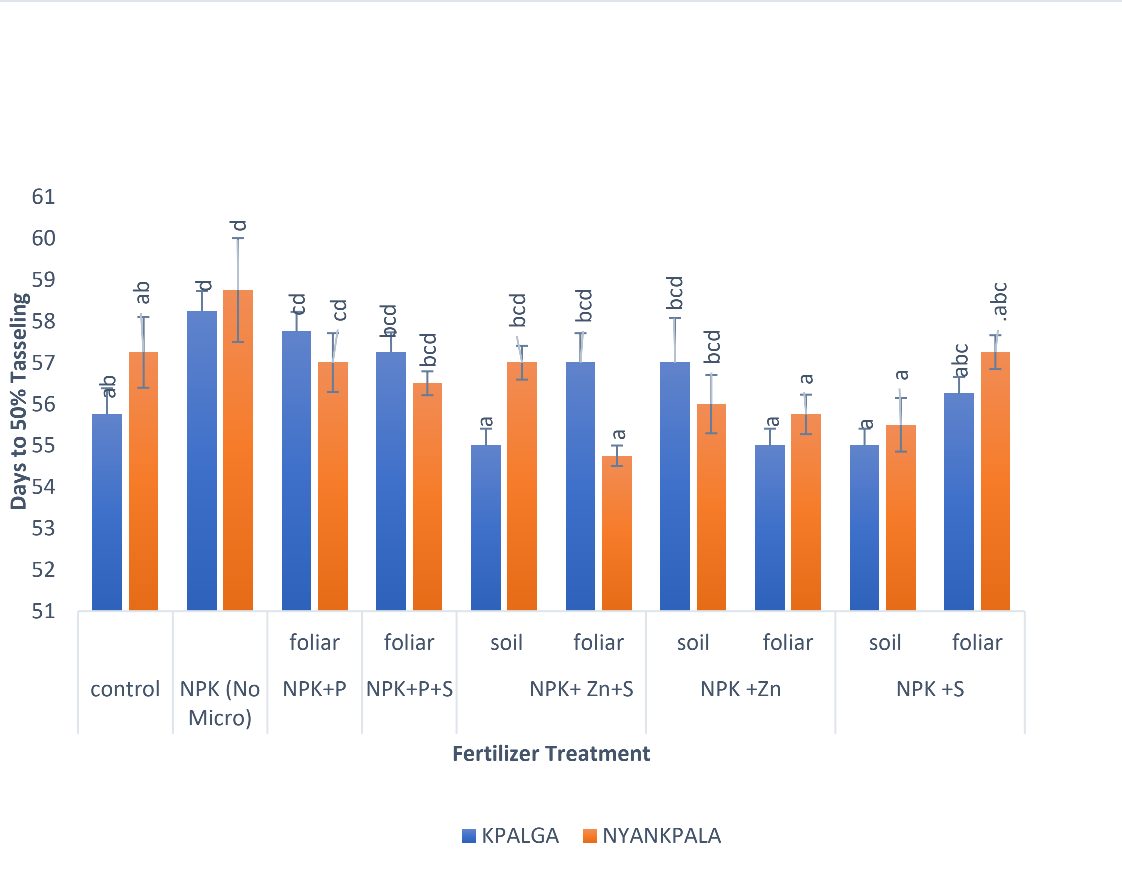

Figure 5: Interactive effects of fertilizer treatments and location on Days to 50% tasseling. Error bars represent SEM

4.6 Effect of Fertilizer treatment on days to 50% Silking

The fertilizer treatments showed significant difference (P=0.001) in relation to days to 50% silking. It was observed that Zn delivered to the plants through foliar application stimulated earlier silking than soil application. (Figure 6). The use of S in both foliar and soil applications did not show any difference between them, and were also statistically similar to the absolute control. When Zn+S was applied through the soil and by foliar means, it was observed that the soil application of the nutrients significantly hastened days to 50% silking compared to the foliar applications. NPK+ [P], and NPK +[P+S] applied by spraying as well as sole NPK did not show any differences in days to 50% silking and were the last to produce silk. The locations did not show significant differences in days to 50% silking (*P=0.571*).

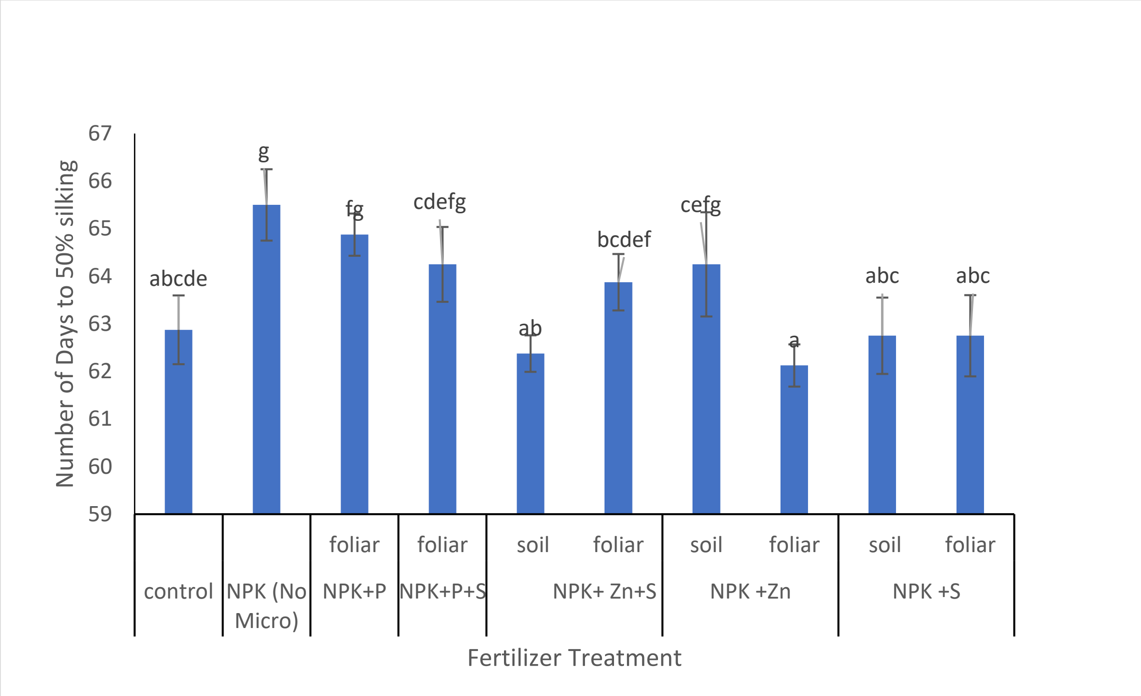

Figure 6a: Effect of fertilizer treatments on Days to 50% silking. Error Bars represent SEM

4.7 Effect of Fertilizer treatment on days to silking

The fertilizer and location interaction did not significantly influence days to full silking (*P=0.921*). The fertilizer treatments showed significant difference in days to full silking (*P=0.001*). The two locations also showed significant differences in the number of days it took to achieve full silking (*P=0.043*). When Zn+S were added to NPK either through the soil or the leaves, there were no differences among them, which was similar to sole NPK, but were statistically different from absolute control. (Figure 7a). Plots that were treated with Zn through the soil and as foliar feeding did not show any differences between them and were also similar to sole NPK, however they were statistically different from absolute control in earliness to full silking at both locations (Figure 7a) Plots that were treated with S in both foliar and soil applications did not show any difference between them, and were also statistically similar to sole NPK however it was different from the absolute control in attaining full silking (Figure 7a). NPK+ [P], and NPK +[P+S] applied by spraying as well as sole NPK did not show any differences in days to silking at both locations (Figure 7b).

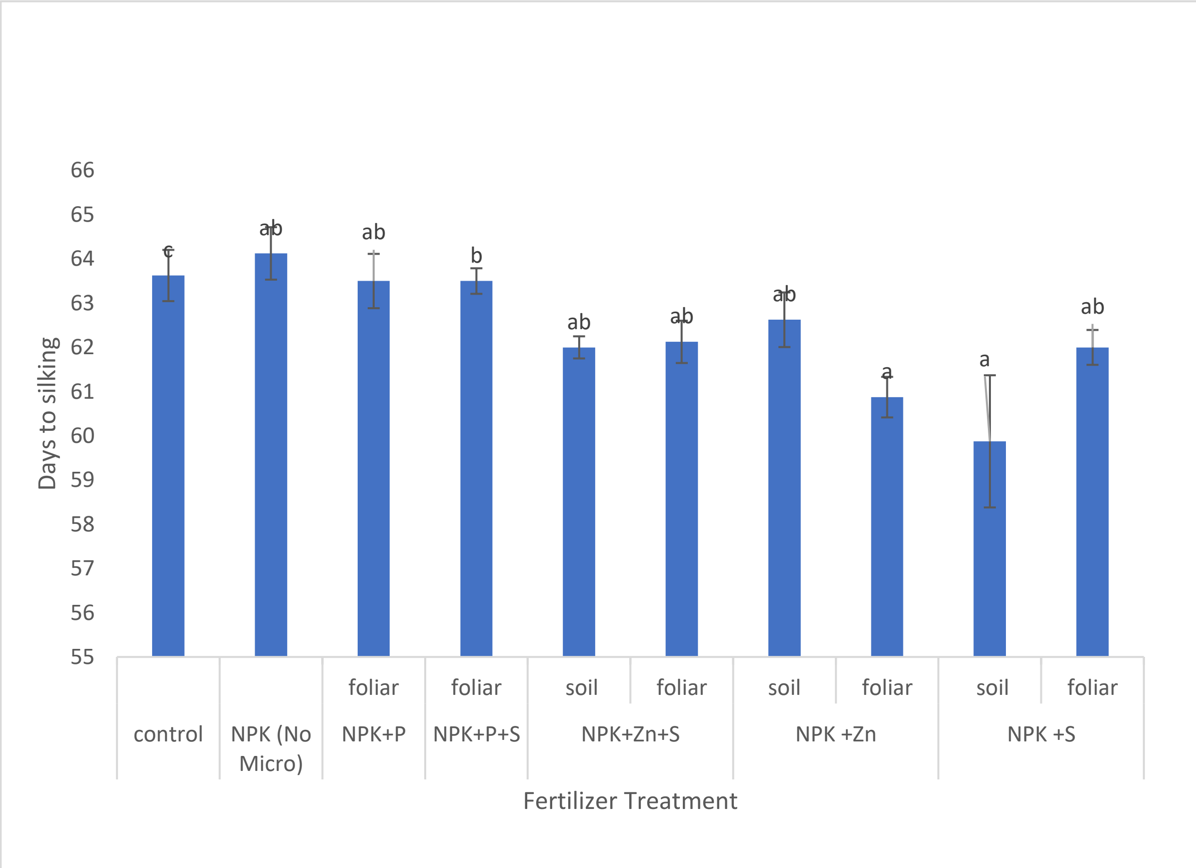

Figure 6b: Effect of fertilizer treatments on days to silking. Error bars represent the SEM

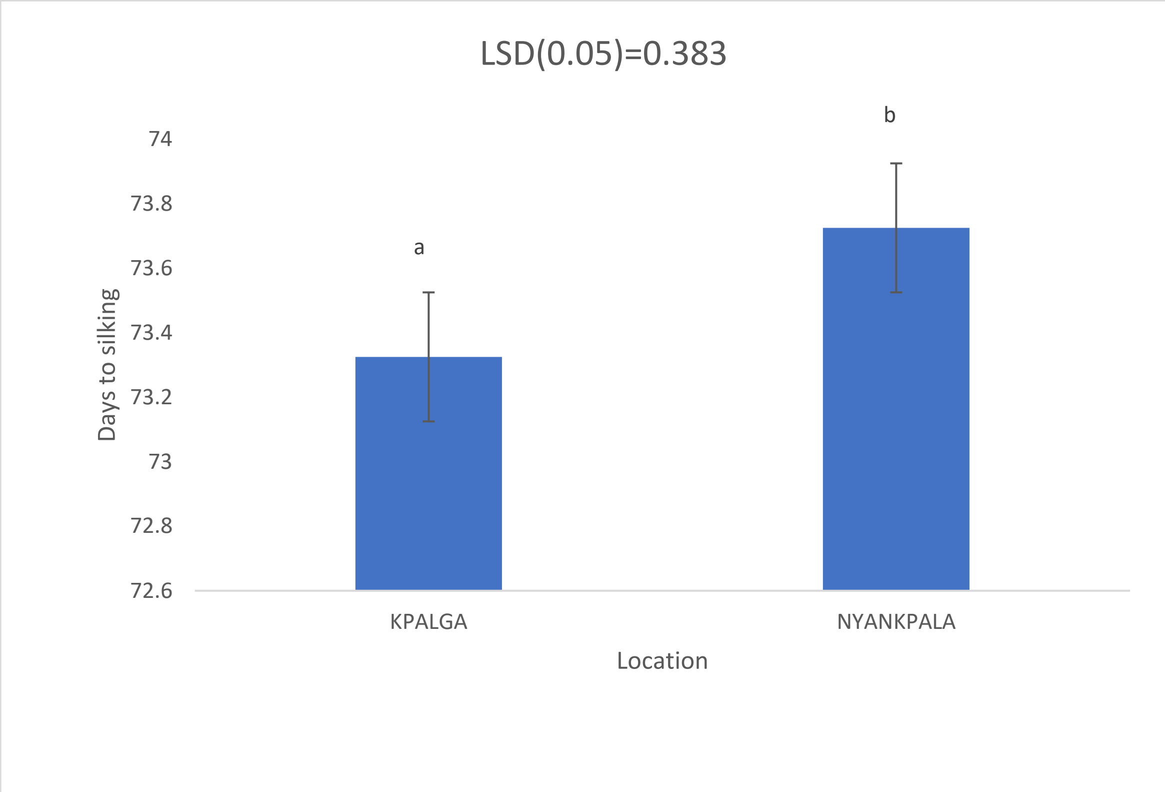

Figure 7: Effect of fertilizer treatment on days to silking. Error bars represent SEM

4.8 Effect of Fertilizer treatment on days to maturity

The fertilizer treatments recorded significantly different days to maturity (*P=0.030*) Location also showed significant differences in days to maturity (*P=0.001*). The fertilizer and location interaction however did not significantly affect maturity (*P=0.141*). All treatments compared to sole NPK did not show any statistical difference. However, treatments were statistically different from the absolute control. The comparison of soil and foliar applications did not show differences as can be observed from **f**igure 8a**.** Nevertheless, the location had significant effect (*P= 0.001*) on the treatments (Figure 8b),

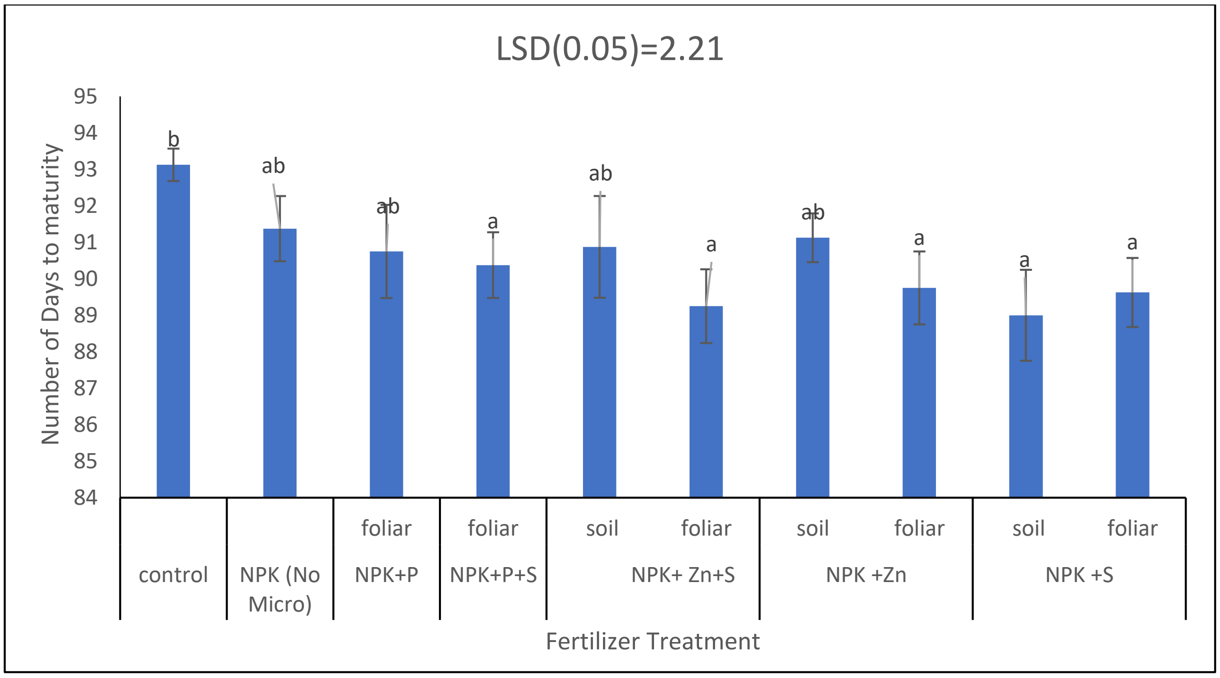

Figure 8a: Effects of fertilizer treatment on days to maturity. Error bars represent SEM

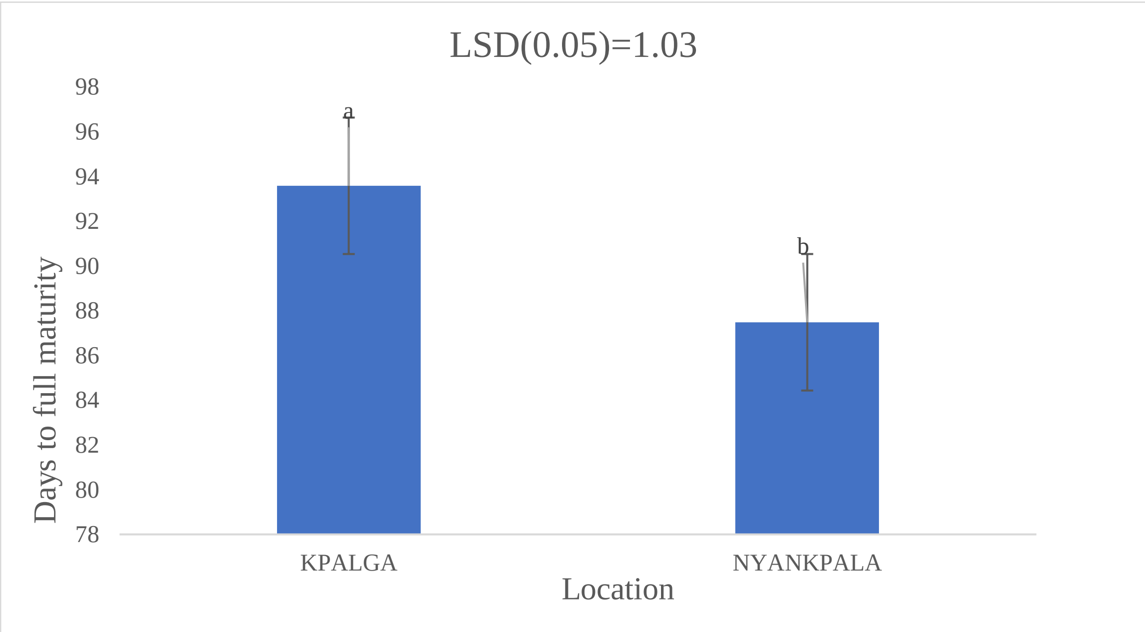

Figure 8b: Effects of location on days to maturity. Error bars represent standard error of means

4.9 Effect of fertilizer treatment on 100 seed weight

The fertilizer treatments did not show any significant difference in 100 seed weight (*P=0.190*). The two locations showed significant differences in 100 seed weight in response to the treatment (*P=0.001*) (Figure 9). Seeds obtained in Nyankpala were relatively larger than that obtained at Kpalga. The fertilizer and location interaction did not significantly influence the weight of 100 seed selected (*P=0.139*).

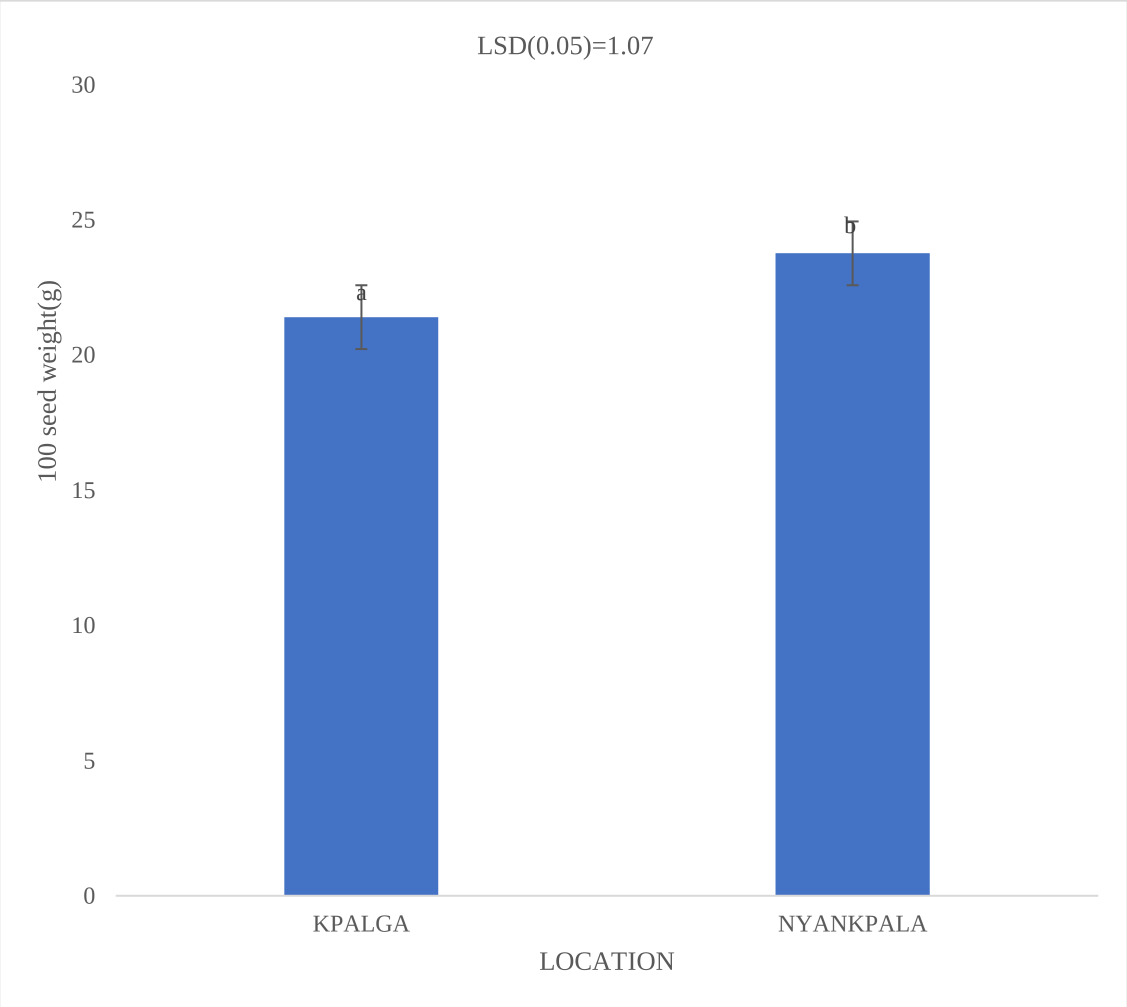

Figure 9 Effect of fertilizer treatment on 100 seed weight. Error bars represent SEM

4.10 Effect of fertilizer treatment on Dry biomass

The location and fertilizer interaction on dry biomass did not significantly affect dry biomass (P=*0.171*). The fertilizer treatment had significant effect (*P=0.009*) on dry biomass. When NPK fertilizer alone was applied it yielded drier biomass as compared to the absolute control. When Zn was applied by foliar means and through the soil, it was realized that their results were not different from the sole NPK. When S was also applied, both the foliar and soil form, did not show any differences between them and they performed similarly to sole NPK (Figure 10). The foliar and soil forms of Zn+S produced similar results, however, the foliar form produced 1628 kg drier biomass than the soil form and 1473 kg more biomass than the sole NPK (Figure 10). The result of foliar form of P and combination of P and S also applied through spraying did not show any differences between them and were similar to the sole NPK.

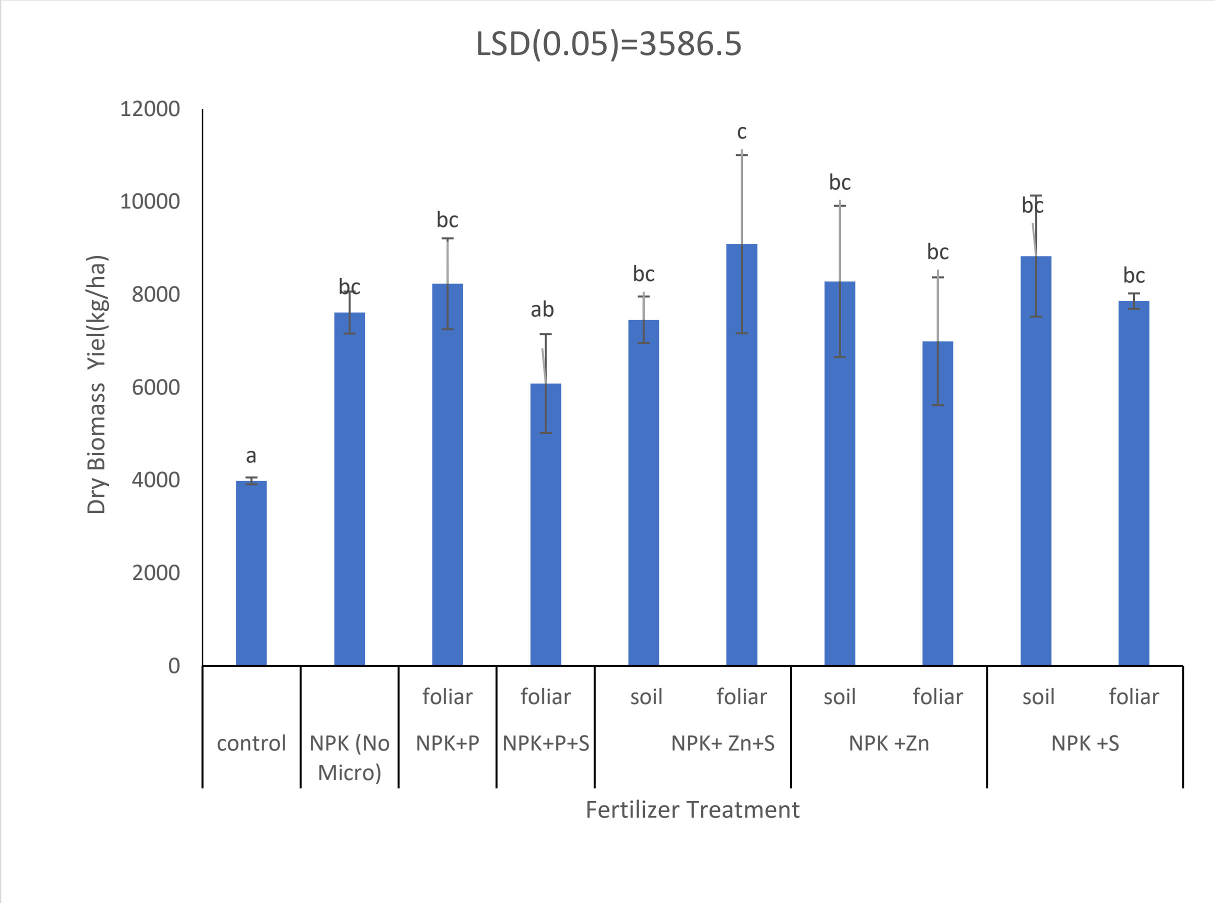

Figure 10: Effect of fertilizer treatments on Dry Biomass. Error bars represent SEM

4.11 Effect of Fertilizer treatment on grain yield

The fertilizer treatments had significant (*P = 0.003*) effect on grain yield. When NPK fertilizer was applied it produced more grain as compared to the absolute control (Figure 11). However, the additional nutrients added to NPK did not lead to significant change from the sole NPK in grain yield. When Zn was applied by foliar means and through the soil, it was realized that their results were not different from the sole NPK. When S was applied, it did not lead to any significant difference from the sole NPK, however, the soil form yielded 406.5 kg/ha more than when it was it applied in the foliar form and 751kg/ha more than sole NPK. The foliar form of

Zn+S did not produce significantly different grain yield from the soil applied Zn+S, however, the foliar form produced 715 kg/ha more grain compared to when the nutrients were applied to the soil. The foliar form of Zn+S in combination with the NPK produced 804 kg more grain than that obtained from sole NPK (**Figure 11).** The result of foliar form of P and a combination of P and S also applied through spraying showed that, foliar P out performed P+S by 332 kg and was 771kg more than sole NPK.

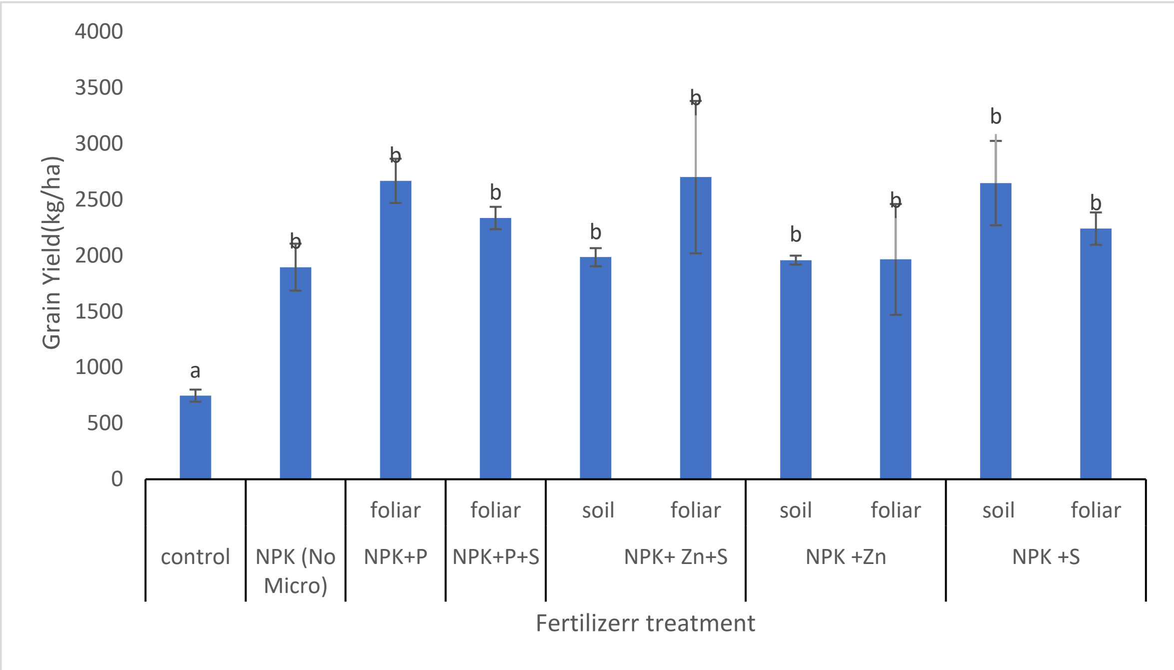

Figure 11: Effect of fertilizer treatment on grain yield. Error bars represent SEM

4.12 Effects of fertilizer treatments on Agronomic Efficiency of Nitrogen (AEN)

Based on the agronomic efficiency values (Table 5), foliar delivery of Zn, S and P nutrients improved Agronomic efficiency of applied nitrogen. The application of S in the soil led to a much higher AEN than when it was applied by foliar (Table 5). Zn+S delivered to maize through foliar ensured the most efficient use of applied N.

P delivered to the leaves gave a higher AEN as compared to S and P also applied by foliar means (Table 5).

Table 5: Agronomic Efficiency of Nitrogen

	AGRONOMIC EFFICIENCY OF NITROGEN (AEN)	
TREATMENT	**Soil**	**Foliar**
Control (No fert)		
NPK (No Micro)	9.566	
NPK Zn+S	10.306	16.267
NPK + Zn	10.092	10.137
NPK +S	15.823	12.434
NPK +P		15.988
NPK +P+S		13.222
Mean	12.07	13.61

4.13 Correlation between yield and growth parameters of maize

It was observed that significant positive correlation existed between grain yield and many growth and yield indicators (Table 6). 64.6% and 71.1% of the variation in the mean grain yield was accounted for by the linear function of Cob weight and 100 seed weight respectively. Dry biomass yields also accounted for 70.7% of the variation seen in grain yield. There was strong association between plant height and cob weight and also 100 seed weight

Table 6: Simple Correlation Coefficient(r) among yield and yield components of maize

	GY	CW	100 SW	DBY	PH	LAI	SR
GY							
CW	0.804**						
100 SW	0.843**	0.893**					
SBY	0.841**	0.783**	0.757**				
PH	0.755**	0.880**	0.825**	0.682**			
LAI	0.764**	0.721**	0.526**	0.754**	0.687**		
SR	0.495*	0.867**	0.734**	0.466*	0.715**	0.456*	

*** Significant at P < 0.05 and ** Highly significant at P < 0.001.**

G Y= Grain yield, C W=Cob weight, 100 SW=100 Seed weight, DBY=Dry Biomass yield, PH= Plant height, LAI=Leaf area index, SR= SPAD reading

4.14 Regression between yield components and grain yield of maize

The linear regression model indicates a significant relationship between 100 seed weight and grain yield. Approximately 71% of the variability in grain yield can be explained by changes in 100 seed weight (Figure 13a). A unit increase in 100 seed weight corresponds to an increase of 949.6 units in grain yield (Figure 13a). About 70.7% of the variability in grain yield is explained by changes in dry biomass yield (Figure 13b). The linear regression model suggests a moderate association between cob weight and grain yield. Approximately 64.95% of the variability in grain yield can be accounted for by changes in cob weight. Despite the robust relationship, there might be additional factors influencing grain yield fluctuations.

Regression analysis showed that 100 seed weight, Dry biomass yield, cob weight and plant height accounted for 71.05%, 70. 72% 64.59% and 57.02% of the total variations in grain yield of maize (Figures 13 a, b, c and d)

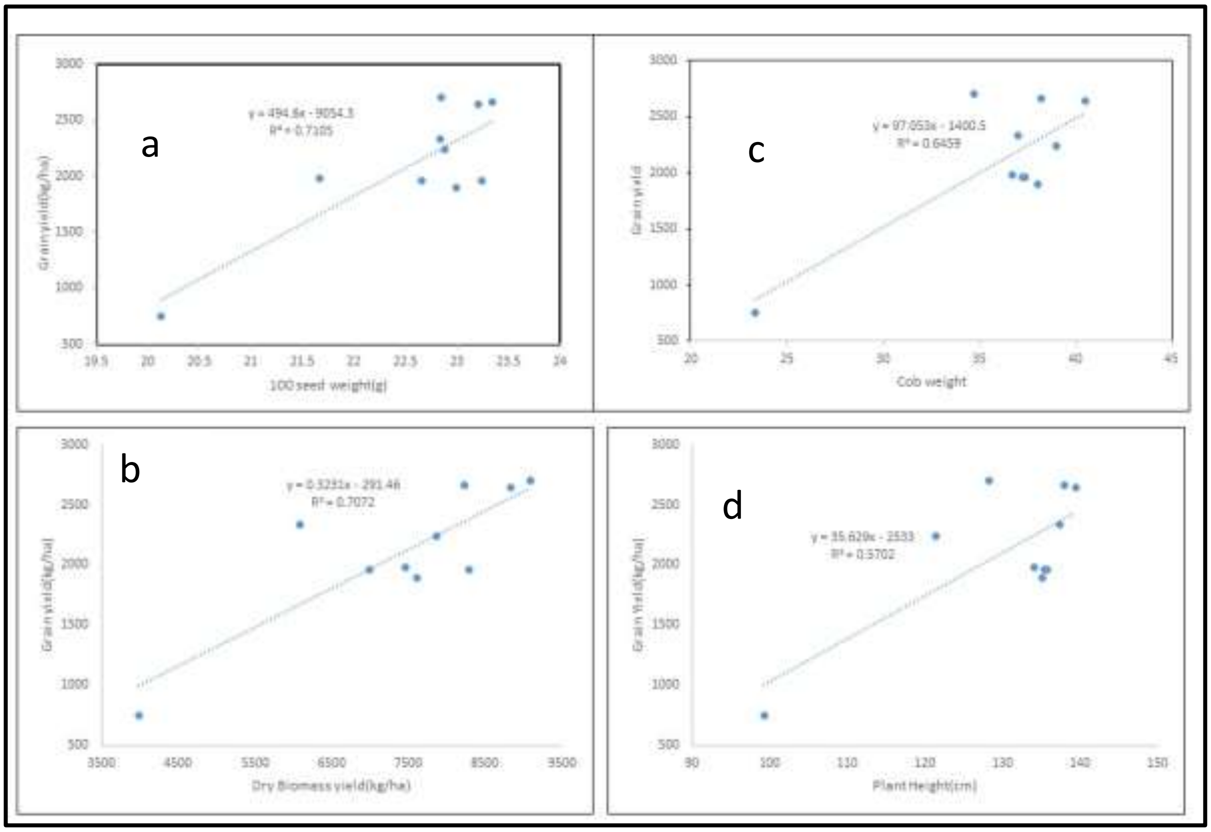

Figure 13: Regression between grain yield and (a) 100 seed weight (b) dry biomass (c) Cob weight and (d) plant height.

CHAPTER FIVE

DISCUSSION

5.1 Effect of fertilizer treatments on growth parameters

The discussion is made in the context that NPK was used for basal application for all treatments except the absolute control. The addition of Zn and S to NPK did not bring any significant change over the sole NPK application in plant height. Though S application through foliar was the best treatment its effect was not significant over the sole NPK. While there is evidence that Zn has an influence on plant height (Shahab *et al*., 2016) there are other studies that have shown that application of Zn to plant through soil did not influence plant height (Ehsanullah *et al*., 2015; Shahab *et al*., 2016; Karim 2020). Foliar application of Zn+S to rice crop led to higher plant height (Kumar Singh *et al*., 2012). Kanjor (2022) in a similar study in 2021 cropping season reported that among the fertilizer treatments significant difference was not evident, however on the numerical strength the combined application of S and Zn applied in the soil or by foliar recorded higher plant height. In our study Zn and S and foliar P did not influence plant height significantly. It appears that Zn and S may contribute to the vertical growth but its effect is not significant.

Leaf Area Index (LAI) is a dimensionless metric that quantifies the leaf area per unit ground area in a plant canopy, typically expressed as m^2 leaf area per m^2 ground area (Boateng *et al*., 2006; Hassan *et al*., 2007; Kumar Singh *et al*., 2012) It is used to describe the foliage density and structure of vegetation, and is an important indicator of ecosystem productivity and carbon and water cycling. According to Lukeba *et al*. (2013) LAI is essential for the correct estimation of crop light interception, transpiration and the accumulation of dry matter and therefore has a greater effect on the yield of crops. In our study it was observed that Zn applied either as foliar or through soil did not lead to any advantage over sole NPK. The same observation was made of S as its performance in LAI was not different from that of sole NPK. However, the combination of the two showed additive effect as their combined effect was better than sole NPK. Phosphorus application, either solely or in combination with S, was better than sole NPK. Mohsin *et al*. (2014) reported that application of foliar Zn and seed priming with Zn improves LAI of maize in Pakistan. Zinc application is reported to have increased LAI in crops like wheat, rice, and maize (Wu *et al*., 2009).

Chlorophyll is the pigment that absorbs light which is transformed into carbohydrates during the process of photosynthesis,(Monteoliva *et al*., 2021; Raza *et al*., 2021) Monteoliva *et al*. (2021) further stated that, chlorophyll content contributes to the efficiency and the conversion of light interception which increases crop yield under stress conditions. The SPAD reading, which correlates with Chlorophyll, increased up to 6th week after planting and then declined. The analysis shows that the addition of Zn, S and extra P by foliar to the NPK did not bring about higher chlorophyll development.

5.2 Influence of fertilizer treatment on earliness to maturity

Flowering marks the start of the reproductive phase in the growth of maize. It is at this stage that the female flowers (silks) emerge and are pollinated by the male flowers (tassels) to produce kernels. The number of kernels produced on each ear of maize is directly proportional to the number of flowers that are pollinated and develop into kernels.(Grzebisz *et al*., 2008) If the flowering process is disrupted, the yield of maize can be significantly reduced.(Skudra and Ruza, 2017).

In the context of this study, the treatment effects on flowering, was significantly influenced by the fertilizer treatments. Plots subjected to the soil treatment of NPK+S and foliar application of Zn (NPK+[Zn]) exhibited earliness in flowering, recording 72.8 and 72.9 days, respectively. Soil application of Zn+S was also one of the treatments that hastened days to 50% silking. These observations prompt further exploration into the role of Sulphur in promoting early flowering, likely attributed to its influence on various plant hormones, including auxin and ethylene. Auxin, a critical hormone governing plant growth and development, is also associated with the initiation of flowering in maize. Moreover, Sulphur's role in enhancing photosynthetic efficiency could contribute to the observed early flowering. Surprisingly, the foliar application of Sulphur did not result in earlier flowering, potentially due to the timing of application, as soluble foliar was administered during the top-dressing stage at 6 weeks after planting (WAP), while soil Sulphur was applied 2 WAP. Future investigations could delve into the possibility of expediting maize flowering through the earlier application of soluble foliar nutrients, warranting additional research in this area which is in line with Alshaal *et al*, (2017) findings that timing of foliar application affects the quality of food crops.

Findings of Foliar application of zinc has shown to have positive influence on the flowering of maize. Foliar application of Zn was observed to have stimulated early silking in this study. This agrees with Aref (2011) that reported that foliar application of Zinc has a significant influence on flowering of maize.

The study demonstrated a considerable impact of fertilizer application on maize. It took 89.0 and 89.3 days, respectively, for NPK + S applied to the soil and NPK + Zn+S applied by foliar, to reach maturity as compared to 93.1 days for the control.

Sulphur is a micro nutrient that is important for the growth plants, and its deficiency can result in slower growth and reduced yields. However, the use of Sulphur in agriculture has often been overlooked due to the belief that Sulphur is readily available in soil. Result of the effect of Sulphur on maturity of maize is in line with the finding of Smith *et al*. (2018). Their findings showed that plants grown in soil amended with Sulphur had significantly shorter days to maturity compared to the control group. The authors attributed the reduced days to maturity to the improved overall growth and development of the plants due to the adequate supply of Sulphur. Another study by Jones *et al*. (2020) analyzed the effect of Sulphur application on the growth and yield of wheat plants. The results showed that Sulphur application reduced the days to maturity by an average of 3-5 days, compared to the control group, which is absolutely in consistent with this study.

The findings of this study support those of Yadav *et al.* (2019), who examined the effects of Zinc and Sulphur application on the development and yield of maize plants and also that of Singh *et al*. (2017), who indicated that the use of Zinc and Sulphur significantly shortened the time it took for maize plants to reach maturity. The application of Zinc and Sulphur resulted in a significant decrease in the number of days needed for the maize plants to reach maturity and an improvement in the overall yield of the plants. These results suggest that soil application of Sulphur and foliar application of Zinc and Sulphur may be useful to farmers seeking to improve the growth and development of their crops.

5.3 Effect of fertilizer treatments on yield parameters

Treatment had a significant effect on Dry biomass yield of maize however differences among the fertilizer treatments were not significant. Zinc whether soil or foliar applied did not have any significant influence on the dry biomass yield, this was also similar for the application of S in either soil or foliar form, they did not increase dry biomass yield over sole NPK. Comparatively, S applied through the soil did much better than foliar, about 969 kg/ha better. This agrees with that reported by Szule *et al*., (2012) in a research involving maize in which yield levels were increased significantly with Sulphur. This therefore confirms that which was earlier registered by Karimizarchi *et al*., (2016) about the role of Sulphur in biomass production

Zn+S foliar applied gave the highest biomass yield. The foliar form of these two elements yielded 408 kg/ha more maize dry biomass than when they were soil applied. So, for biomass production, it can be said that Zn+S foliar applied is the best option. Foliar supplementation of P was among the treatments that produced substantial amount of biomass.

Grain yield is a standard measure of the amount of produce harvested per unit of land area. Yield obtained from application of Zinc by both soil and foliar was very low, less than half of the potential yield of the variety used. Alloway, (2008) has, indicated that to achieve maximum grain yield, foliar form of Zn should be applied several times before flowering. This could be the reason for the low yield since Zn either the foliar or the soil form was applied once in the research. Future research should be looking at varying the rates and increasing the number of applications during the growing season.

Sulphur fertilization increased crop yield for both soil and foliar applied S though not significantly over the sole NPK. Soil applied Sulphur increased crop yield by 406.5 kg/ha over the foliar applied and 751 kg/ha over the sole NPK. This could be due to the fact that Sulphur uptake by the crop is more efficient in the soil than through the stomata. The seemingly low performance of foliar Sulphur could be due to the time of applications since it was only applied at the topdressing stage. From this result it can be said that, the best form to apply S for increased crop yield is through the soil. This finding agrees with the findings of Ramamoorthy *et al*., (2021) and that of Pujar *et al*. (2018) that Sulphur nutrition influences crop yield and quality. Use of Zinc and Sulphur in combination though did not lead to significant change over the sole NPK the yield improvement due to the two nutrients is appreciable. The results showed that when Zn+S was applied by foliar means, it produced the highest grain yield among the treatments. It was better than the counterpart soil applied Zn+S by 715 kg/ha and 804 kg/ha better than the sole NPK. The application of these two nutrients in combination makes them synergistic over their individual application. The foliar application of these nutrients may make them more accessible and efficiently utilized by the crop. Rashid *et al* (2016) has also reported the beneficial effect of combining Zinc and Sulphur leading to higher grain yield. Phosphorus supplementation using foliar application of Triple Supper Phosphate also brought interesting results. The performance of foliar P was the second best in terms of crop yield producing 771 kg/ha more than yield obtained from Sole NPK plot. The combination of S with P and delivered by foliar did not show any superiority over foliar P alone. Foliar P supplied with Zn and Fe recorded higher grain yield of about 4 ton/ha at the same locality (Asare, 2021). There is the need for further research on timing of foliar P.

Dry Biomass is the weight of organic matter remaining after drying the crop. Dry biomass is a key factor in determining how much organic matter plants can use and how much carbon dioxide is released during decomposition.(State and State, 2016) Dry biomass also affects crop yield as the dry matter content of the crop can affect overall quality, yield and storage capacity.

Strong evidence to support the claim that 100 seed weight, dry biomass yields, plant height and grain yield are interdependent and contribute collectively to overall grain productivity is presented by a positive correlation between 100 seed weight, dry biomass yields, plant height and grain yield. Furthermore, 100 seed weight, Dry biomass yield, cob weight and plant height accounted for 71.1%, 70. 7% 64.6% and 57.0% of the total variations in grain yield of maize

5.4 Utilization of applied nitrogen

Nitrogen use efficiency (NUE) refers to the amount of nitrogen taken up by plants and used for growth and development relative to the amount of nitrogen applied as fertilizer. It can be assessed as Agronomic efficiency of applied Nitrogen and recovery efficiency among other methods (Wortmann et al., 2011). Global maize nitrogen use efficiency (NUE) is in the region of 33 %, as a result of loss of fertilizer N from leaching below the root zone, denitrification, and soil- and plant-derived volatilization (Raunand Johnson, 1999; Sindelar et al., 2015).

Agronomic efficiency reflects the effects of an applied fertilizer and relates directly to economic return making it a good short-term indicator. Typical AE levels of N for cereals ranges from 15–30 kg grain kg^{-1} N, with lower levels suggesting that changes in management could increase crop response or reduce input costs (Fixen *et al.,* 2014). The Agronomic efficiency (AE) values was the highest when Zn+S were applied by foliar Two other treatments (foliar applied P and soil applied S) added to the Foliar applied Zn+S was found to be within the normal range for Agronomic Efficiency of applied N (Wortmann *et al*., 2011). Zn, S and P uptake enhanced the efficiency of nitrogen. The general low levels of AEN may be due to the nature of the soil, sandy loam which is not able to hold nutrients applied. Foliar applied of Zn+S and P reduced loss of the applied nutrients making them available for physiological processes they are needed for. This result is consistent with previous studies that reported increased AEs with the application of balanced fertilizers containing all essential nutrients (Adu *et al.*, 2018; Li *et al.*, 2018). On the other hand, the lowest AE values were observed in NPK (No micro nutrient) treatment. This result indicates that the addition of micro and secondary nutrients to NPK fertilizers can help improve AE of nitrogen.

These findings are consistent with earlier findings that have shown the importance of using combined nutrient applications to enhance crop yield and fertilizer use efficiency (Chen *et al.,* 2017; Li *et al.,* 2018; Ojiem et al., 2019). The results also highlight the need for farmers to adopt efficient fertilizer management practices, such as selecting the appropriate fertilizer type and application rate, to maximize crop yield and minimize environmental pollution (Kaur *et al.*, 2020; Zhang *et al.*, 2021).

In conclusion, the results of this study show the essence of using combined nutrient applications to enhance crop yield and fertilizer use efficiency. The findings provide valuable insights into the optimization of fertilizer management practices for sustainable crop production.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusions

The study discovered that;

- In terms of plant height, the two nutrients Zn and S, and their combination were not significantly difference from Sole NPK. In nominal terms S delivered through foliar enhanced height growth.
- Sulphur applied by both pathways produced denser leaves than sole NPK. The combination of Zn with S and applied by foliar produced better leaf area index than when applied through soil. The use of the two nutrients outperformed sole NPK in LAI. Phosphorus supplementation through foliar application was also superior to sole NPK in LAI.
- Soil application of S and foliar application of Zn promoted earliness in tasseling. Soil application of Zn+S was also one of the treatments that hastened days to 50% silking.
- Soil applied S and foliar applied Zn+S promoted earliness to maturity.
- Foliar supplementation of Phosphorus (NPK+[P], Soil application of Sulphur (NPK+S) and foliar supply of Zinc and Sulphur combined (NPK+[Zn+S]) though not significantly different from the sole NPK they produced appreciable grain yield.
- Nitrogen use efficiency, assessed as Agronomic efficiency of applied N was generally low due to coarse nature of the soil. The results revealed that soil application of Sulphur (NPK+S) treatment and supplementation of phosphorus by foliar means (NPK+[P]) promoted the most efficient utilization of nitrogen.

6.2 Recommendation

- Application of NPK formulated with Sulphur, foliar application of Zinc and Sulphur in combination and supplementation of Phosphorus to NPK using the leaves are promising nutrient application that needs further assessment in different ecologies.
- It is advised that additional research be done to examine the effects of altering the rate and time of application of zinc, Sulphur, and phosphorus on crop growth and yield.

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APPENDICES

Appendix 1: Effect of fertilizer treatments on Plant Height 4 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	84.97	28.32	0.69	
REPLICATION.*Units* stratum					
FERTILIZER	9	672.44	74.72	1.82	0.084
LOCATION	1	2299.98	2299.98	56.03	<.001
FERTILIZER.LOCATION	9	612.54	68.06	1.66	0.121
Residual	57	2339.95	41.05		
Total	**79**	**6009.88**			

Appendix 2:Effect of fertilizer treatments on Plant Height 6 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	1258.3	419.4	1.21	
REPLICATION.*Units* stratum					
FERTILIZER	9	2874.1	319.3	0.92	0.515
LOCATION	1	10577.7	10577.7	30.48	<.001
FERTILIZER.LOCATION	9	3167.8	352	1.01	0.44
Residual	57	19778.3	347		
Total	**79**	**37656.1**			

Appendix 3: Effect of fertilizer treatments on Plant Height 8 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	551.5	183.8	0.46	
REPLICATION.*Units* stratum					
FERTILIZER	9	10687.5	1187.5	3	0.005
LOCATION	1	9517.9	9517.9	24.01	<.001
FERTILIZER.LOCATION	9	5897.3	655.3	1.65	0.122
Residual	57	22598.6	396.5		
Total	**79**	**49252.8**			

Appendix 4: Effect of fertilizer treatments on LAI 4 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	0.024601	0.0082	3.07	
REPLICATION.*Units* stratum					
FERTILIZER	9	0.167818	0.018646	6.98	<.001
LOCATION	1	0.021692	0.021692	8.11	0.006
FERTILIZER.LOCATION	9	0.027073	0.003008	1.13	0.36
Residual	57	0.152367	0.002673		
Total	79	0.393551			

Appendix 5: Effect of fertilizer treatments on LAI 6 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	0.2091	0.0697	0.47	
REPLICATION.*Units* stratum					
FERTILIZER	9	2.6906	0.299	2.03	0.052
LOCATION	1	2.582	2.582	17.52	<.001
FERTILIZER.LOCATION	9	1.1274	0.1253	0.85	0.574
Residual	57	8.3992	0.1474		
Total	79	15.0083			

Appendix 6: Effect of fertilizer treatments on LAI 8 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	0.50641	0.1688	2.15	
REPLICATION.*Units* stratum					
FERTILIZER	9	2.48652	0.27628	3.51	0.002
LOCATION	1	1.63832	1.63832	20.82	<.001
FERTILIZER.LOCATION	9	0.55958	0.06218	0.79	0.626
Residual	57	4.48524	0.07869		
Total	79	9.67607			

Appendix 7: Effect of fertilizer treatments on leave SPAD reading 4 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	3	38.353	12.784	1.42	
Replication.*Units* stratum					
FERTILIZER	9	196.547	21.839	2.43	0.021
LOCATION	1	0.025	0.025	0	0.958
FERTILIZER.LOCATION	9	106.156	11.795	1.31	0.251
Residual	57	512.287	8.987		
Total	**79**	**853.368**			

Appendix 8: Effect of fertilizer treatments on leave SPAD reading 6 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	83.04	27.68	1.5	
REPLICATION.*Units* stratum					
FERTILIZER	9	865.86	96.21	5.22	<.001
LOCATION	1	628.99	628.99	34.16	<.001
FERTILIZER.LOCATION	9	100.06	11.12	0.6	0.789
Residual	57	1049.64	18.41		
Total	**79**	**2727.59**			

Appendix 9: Effect of fertilizer treatments on leave SPAD reading 8 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	246.11	82.04	2.86	
REPLICATION.*Units* stratum					
FERTILIZER	9	714.82	79.42	2.77	0.009
LOCATION	1	267.11	267.11	9.32	0.003
FERTILIZER.LOCATION	9	120.49	13.39	0.47	0.891
Residual	57	1633.3	28.65		
Total	**79**	**2982**			

Appendix 10: Effect of fertilizer treatments on days to 50% tasseling

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	15.3	5.1	3.54	
REPLICATION.*Units* stratum					
FERTILIZER	9	67.5	7.5	5.2	<.001
LOCATION	1	0.45	0.45	0.31	0.579
FERTILIZER.LOCATION	9	30.55	3.394	2.35	0.025
Residual	57	82.2	1.442		
Total	**79**	**196**			

Appendix 11: Effect of fertilizer treatments on days to 50% flowering(silking)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	17.737	5.912	3.13	
REPLICATION.*Units* stratum					
FERTILIZER	9	94.312	10.479	5.56	<.001
LOCATION	1	0.613	0.613	0.32	0.571
FERTILIZER.LOCATION	9	1.512	0.168	0.09	1
Residual	57	107.513	1.886		
Total	**79**	**221.688**			

Appendix 12: Effect of fertilizer treatments on days to 50% maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	24.7	8.233	1.38	
REPLICATION.*Units* stratum					
FERTILIZER	9	91.5	10.167	1.7	0.11
LOCATION	1	627.2	627.2	105.06	<.001
FERTILIZER.LOCATION	9	104.3	11.589	1.94	0.064
Residual	57	340.3	5.97		
Total	**79**	**1188**			

Appendix 13: Effect of fertilizer treatments on days to Silking

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	1.45	0.4833	0.65	
REPLICATION.*Units* stratum					
FERTILIZER	9	29.95	3.3278	4.46	<.001
LOCATION	1	3.2	3.2	4.29	0.043
FERTILIZER.LOCATION	9	2.8	0.3111	0.42	0.921
Residual	57	42.55	0.7465		
Total	**79**	**79.95**			

Appendix 14: Effect of fertilizer treatments on days to tasseling

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	10.55	3.517	1.44	
REPLICATION.*Units* stratum					
FERTILIZER	9	128.3	14.256	5.85	<.001
LOCATION	1	0.05	0.05	0.02	0.887
FERTILIZER.LOCATION	9	21.7	2.411	0.99	0.459
Residual	57	138.95	2.438		
Total	**79**	**299.55**			

Appendix 15: Effect of fertilizer treatments on days to maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	9.85	3.283	0.62	
REPLICATION.*Units* stratum					
FERTILIZER	9	107.2	11.911	2.27	0.03
LOCATION	1	744.2	744.2	141.56	<.001
FERTILIZER.LOCATION	9	75.05	8.339	1.59	0.141
Residual	57	299.65	5.257		
Total	**79**	**1235.95**			

Appendix 16: Effect of fertilizer treatments on 100 Seed weight g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	41.01	13.67	2.58	
REPLICATION.*Units* stratum					
FERTILIZER	9	69.131	7.681	1.45	0.19
LOCATION	1	111.156	111.156	20.97	<.001
FERTILIZER.LOCATION	9	76.049	8.45	1.59	0.139
Residual	57	302.151	5.301		
Total	**79**	**599.497**			

Appendix 17: Effect of fertilizer treatments on five plants cob weight g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	788.2	262.7	0.89	
REPLICATION.*Units* stratum					
FERTILIZER	9	5633.2	625.9	2.11	0.043
LOCATION	1	2025.1	2025.1	6.83	0.011
FERTILIZER.LOCATION	9	5292.5	588.1	1.98	0.058
Residual	57	16912.4	296.7		
Total	**79**	**30651.4**			

Appendix 18: Effect of fertilizer treatments on five plants dry weight g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	1499	500	0.05	
REPLICATION.*Units* stratum					
FERTILIZER	9	160367	17819	1.82	0.083
LOCATION	1	155250	155250	15.89	<.001
FERTILIZER.LOCATION	9	152817	16980	1.74	0.101
Residual	57	556735	9767		
Total	**79**	**1026667**			

Appendix 19: Effect of fertilizer treatments on five plants dry root weight g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	1022.4	340.8	1.92	
REPLICATION.*Units* stratum					
FERTILIZER	9	5678.7	631	3.56	0.001
LOCATION	1	80.8	80.8	0.46	0.502
FERTILIZER.LOCATION	9	2652	294.7	1.66	0.119
Residual	57	10094.8	177.1		
Total	**79**	**19528.7**			

Appendix 20: Effect of fertilizer treatments on five plants dry shoot weight g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	2196	732	0.51	
REPLICATION.*Units* stratum					
FERTILIZER	9	27002	3000	2.1	0.044
LOCATION	1	43529	43529	30.46	<.001
FERTILIZER.LOCATION	9	33348	3705	2.59	0.014
Residual	57	81455	1429		
Total	**79**	**187531**			

Appendix 21: Effect of fertilizer treatments on grain yield kg/ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	2792348	930783	1.15	
REPLICATION.*Units* stratum					
FERTILIZER	9	23789790	2643310	3.26	0.003
LOCATION	1	1091480	1091480	1.35	0.251
FERTILIZER. LOCATION	9	6722210	746912	0.92	0.514
Residual	57	46206012	810632		
Total	**79**	**80601840**			

Appendix 22: Effect of fertilizer treatments on Weight of entire harvest g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	3	3.17E+07	1.06E+07	0.76	
REPLICATION.*Units* stratum					
FERTILIZER	9	3.48E+08	3.87E+07	2.79	0.009
LOCATION	1	2.97E+07	2.97E+07	2.14	0.149
FERTILIZER.LOCATION	9	1.87E+08	2.08E+07	1.5	0.171
Residual	57	7.90E+08	1.39E+07		
Total	**79**	**1.39E+09**			