UNIVERSITY FOR DEVELOPMENT STUDIES

AGRONOMIC RESPONSE OF MAIZE (*Zea mays* L.) TO SULPHUR AND THE PRIMARY NUTRIENTS IN THE GUINEA SAVANNA ZONE OF GHANA

AYAMBA MICHAEL MBAWUNI

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BY

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

APRIL, 2023

DECLARATION

Student

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

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

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DEDICATION

This Thesis is dedicated to the Almighty God, and to my lovely wife madam Priscilla Adoliyinepoore Adelwine who played a great role in the success of my life. God blesses her.

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ABSTRACT

Maize is an important cereal crop that requires a high dose of fertilizer for optimum growth and productivity. While primary nutrients and sulphur are known to impact on the crop's growth, data remains relatively scanty on the comparative productivity of these four nutrients. A field experiment was conducted at Bolgatanga municipality and Bongo district of Ghana during the 2020 cropping season to assess the relative agronomic productivity of each primary nutrient (N, P and K) and of sulphur (S) on growth and yield of Wang-dataa maize variety. Eighteen treatments, made up of four nutrient combinations {(N(PR)KS, N(P+PR) KS), NPKS}, three {NPK, NPS, NKS, PKS}, two {PS, PK, PN, KN, KS, NS}, sole nutrient {N, P, K and S} and control (no fertilization) were used. At each site, four replications were used. Data were collected on maize growth and yield and treatment means were separated at probability of 95% using LSD. The results also showed a significant interaction effect of fertilizer combinations. The application of at least one nutrient element improved growth and yield than non application of nutrient elements. Increasing the number of nutrient elements resulted in better growth and yield which were dependent on the type of nutrient combinations. NP and NS were found to be the best performng treatmernts among the binary combinations while N, NPK and N (P+PR) KS treatments were observed to be the best performing among the sole, tertiary and quaternary combinatons. Significantly, higher grain yield and percentage increase in yield were obtained in response to the application of N (P+PR) KS and NPKS. This confirms the need for inclusion of all four elements in fertilizer formulation for increasing maize growth and yield. Apllication of NPK and S to maize production is recommended for fertilizer formulation for maize growth and production. Also, the research further recommends that

smallholder farmers who cannot afford compound fertilisers may apply NP or N fertilisers at lower cost for yield enhancement. This research finally recommends an investigation concerning the agronomic productivity in growth and yield parameters of other crops like soya bean and yam.

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LIST OF ACRONYMS

ADP………………Adenosine Diphosphate

ANOVA…………Analysis of Variance

ATP………………Adenosine Triphosphate

CRI………………Crops Research Institute

CSIR………….. ...Council for Scientific and Industrial Research's

CV………………..Coefficients of Variation

DAP………………Day of Planting

DWOB……………Dry weight of Biomass

FAO………………Food and Agriculture Organization

FWOB……………Fresh Weight of Biomass

G…………………Gram

HA^{-1}………………Per Hectare

K………………….Potassium

Kg………………..Kilogram

Kg/ha……………Kilogram per hectare

LAI……………….Leaf area index

LSD………………Least Significant Difference

MCS………………MPhil Crop Science

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

MG…………………Milligram

N..………………….Nitrogen

P……………………Phosphorus

S……………………Sulphur

CO_2…………………Carborn dioxide

CH_4…………………Methane

CFCs………………Chlorofluorocarbons

N_2O………………Nitrous oxide

O_3…………………Ozone

KCL………………Potassium chloride

K_2NO_3…………….Potassium nitrate

K_2SO_4…………….Potassium sulfate

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

SSA………………Sub-Saharan Africa

SOM………………Soil Organic Matter

SRID………………Statistical Research and information Department

T……………………Treatment

t/ ha…………………ton/hectare

TSP…………………Triple-Superphosphate

UAE………………..United Arab Emirates

WA…………………West Africa

WAP………………..Weeks After Planting

WRC………………..Water Resource Commission

WASCAL…………..West Africa Science Center on Climate Change and Adapted Land Use

CHAPTER ONE

INTRODUCTION

1.1 Background

Maize (*Zea mays* L.) has been identified as having a high potential for genetic yield relative to other cereal crops. It is therefore labeled a "miracle crop" and also a "cereal queen". As a C_4 plant, it is very efficient at transforming solar energy into dry matter (Gong *et al.*, 2015). Globally, it is cultivated as one of the most important cereal crops. Maize is also recognized as a basic component of livestock fodder and a raw material used in the manufacture of a variety of commercial goods. Other products derived from maize comprise of corn sucrose, maltodextrins, maize oil, corn syrup, plus beverages and distillery products. Maize has recently been adopted for biogas production (García-Lara and Serna-Saldivar, 2019). Maize has been listed as the next predominant essential staple product after cassava within Africa and is cultivated within an extensive scope of terrain extending from the northern Sahel of Niger into the highlands of Ethiopia, including an adapted vegetation zone in Sierra Leone (Nhantumbo, 2016).

Maize acceptance across African growers increased steadily until a precursory quota in the 20th century, when it was rapidly boosted. The crop has exceptional production potential as a cereal crop, following wheat and rice. The crop has been reported to be the third most important grain crop, accounting for 4.8 percent of total harvest recorded and 3.5 percent of overall agronomical productivity (Wedajo, 2019). In Ghana, maize is said to be the most consumed and produced cereal crop. It is mainly cultivated by farmers for subsistence purposes either alone or intercropped with cassava. As a result of the ready market offered by urban centers, maize cultivation has increased in recent years (Kassam *et al.*, 2019). The Council for Scientific and Industrial Research (CSIR) through the Crops Research Institute

(CRI) of Ghana has released numerous improved maize varieties that vary over the span of maturity periods to address a range of challenges including climate change. Obatanpa is one of the maize varieties listed as having high potential for grain yield and improved nutritional status. Obatanpa is a white dent form with high levels of lysine and tryptophan, a flinty endosperm, and with excellent protein content in the maize (Obeng-Bio, 2018). In 1992, Obatanpa was first released by the CRI to help recover the protein nutritional status of large low-income families who depend on maize as the primary commodity of food intake (Sonko, 2016). Described as a heavy feeder of nutrients, the production of maize depends primarily on management of soil nutrients. The variety requires high-fertility soil to express its productive potential. In nature, ideal soils are seldom found with the adequate nutrient combinations. Where fertility is low, organic inputs have been used by resource-poor farmers. However, the quantity of organic input remains largely low. Organic manures are not only known for supplying plant nutrients, but also for improving soil quality (Hashim *et al.*, 2015). Furthermore, the micronutrient content of organic manures may be sufficient to meet crop production requirements (Ye *et al.*, 2016).

The application of only deficient nutrients to the soil has been considered to be much more cost effective. The application of single nutrient fertilisers has been used a lot, especially for nitrogen due to its high demand by plant and its extreme volatility; the other applied nutrients do not experience such demand. The application of sulphate of ammonia as well as urea has been common ways of supplementing soil nitrogen levels. With regards to legumes, the application of phosphorus fertilisers such as triple super phosphate (TSP) has also been a good fertility booster. Per the observations of Olowoboko *et al.* (2017) and Baiyeri and Aba (2015), the application of fertilisers with a high number of nutrients improves the fertility status of soils compared to soils amended with lesser number of nutients. However, the use of high number of nutrients is often associated with high fertilizer prices and uneconomical losses to the already resource-constrained farmer. Currently, soil fertility situations have mismatched in recent years, and the old fertilizer references are not the most accurate today. Therefore, in the northern savanna agro-ecological zone of Ghana, updating fertilizer recommendations for maize has become relevant (Saïdou *et al.*, 2018). For several years, nitrogen, phosphorus, and potassium (NPK) fertilizers have been the principal nutrient replacement tools used by farmers (Chukwuka *et al.*, 2015). Aplication of sole NPKs have helped to increase the yield of maize (Afreh *et al.*, 2022). However, there is still room for further yield improvement, especially in northern Ghana, which has an average yield of 1.5 t/ha, a yield level which is much lower than the global average of 4.9 t/ha (Yigermal *et al.*, 2019).

1.2 Statement of the problem

The main mitigating issues facing maize cultivation have been erratic rainfall patterns and low soil fertility, especially in the savanna agro-ecological zone. The inadequate application of chemical and organic fertilizers, limited land productivity control, constant cultivation on a portion of soil over a lengthy period of time, and poor soil nature are the main causes of low soil fertility. The use of fertilizer nutrients recorded in Ghana is roughly 8kgha^{-1}. Food and Agriculture Organization (FAO) estimates indicate pessimistic sustainability balance in the provision of nutrients for every plant in Ghana. The rising rates of mining for land nutrients are key threats to agriculture's sustainability (Food and Agricultural Organization, 2015).

However, due to the poor nature of the input system, the productivity of crops, especially cereals, is hindered by low soil nitrogen (N) and phosphorus (P) concentrations, as well as by unreliable and inadequate precipitation levels. Poor soil N, together with P concentrations, is a threat to food security in the nation unless actions to increase fertility of farmlands are taken. Maize is only one of the abundant essential cereals that could be multiplied as the population of the country grows to provide the much needed nutrition (Pulighe *et al*., 2020). In many agricultural regions, unsustainable farming operations have severely depleted soil nutrients. Although fertilizer consumption in SSA has steadily increased within the recent years (Ariga *et al*., 2019), overall fertilizer usage levels are fixed and unproductive pertaining to sustainable mass production of crops and maintenance of soil fertility (Dolker *et al*., 2017; Sharma *et al*., 2019). In the Upper East Region of Ghana, maize is an essential foodstuff due to the large number of individuals who continuously rely on it for nutrition. Maize farming has rapidly outstripped the indigenous millet and sorghum as the main staples, which were the ones mainly consumed in the province prior to the middle of 2000. Nonetheless, agronomists in the country have frequently identified low soil fertility as a major constraint to maize yield and to the yield of other cereal crops (Kanton *et al*., 2016).

Despite the higher number of farmers involved in maize production, productivity remains low as knowledge on the relative productivity of the individual elements (N, P and K) remain relatively low to inform fertilization. What is missing in the literature is the response of maize to the application of these nutrient elements, particularly sulphur and the primary nutrients (N, P and K).

1.3 Justification/Significance of the study

The issue of low yields and sustainable production of maize has not been solved by the introduction of only high-yielding varieties. In recent times, old and unspecific fertilizer recommendations in the guinea savanna agro-ecological region have not been updated. As such, growth on those new maize varieties with the old recommendations for fertilizers did not yield the maximum potential. Ghana still needs to increase maize productivity, despite all these efforts, in a way that preserves the natural resources as well as prevents additional environmental degradaton, which affects several of the nation's soils. The main way to curb reduction in land productivity by fertility removal as well as curb the observed decreasing plant yield is through application of inorganic fertilizer. The use of inorganic fertilizers is adopted by smallholder resource-poor farmers, yet there is difficulty associated with the utilization of this fertilizer with regards to the unsuited amounts they apply. To increase yield, the low nutrient content of the land requires a demand for external nutrient supply. Increasing maize productivity by improving land productivity can be accomplished by the use of mineral, natural, or bio-fertilizers. Organic and bio-fertilizers are scarce in these resource-scarce populations, a reason why such nutrient supplies are used sparingly. Commercialized inorganic fertilizers, which crop producers can simply obtain in the open market, are the key sources of inorganic fertilizers.

According to Vanlauwe *et al.* (2015), the overall increase in maize yield after introducing specific abundant as well as trace elements beyond the benchmark N, P and K fertilizers demonstrates that the application of the three primary nutrients alone is not enough to solve maize productivity problems in delicate soils. N, P, K and S are elements that are very important to maize production and thus need regular replacement in order for production to be sustainable. Sole, binary, tertiary and quartenary combinations of these elements could have varying influences on the growth and development of maize. While this has generally been known to be the case, literature on the comparative performances of these elements on growth and yield of most crops remain limited. Also, phosphate rock is a rarely used P fertiliser source in Ghana. Phosphate rock has the potential to be a cheaper source of P than triple super phosphate. The comparative performance of rock phosphate with triple superphosphate remains relatively unreported necessitating a study to compare and document their relative effects on maize growth and yield. While sulphur has been taunted in numerous studies to help in maize growth and development, information on the sole contribution of S, as well as the contribution of inclusion of S in NPK formulation to the growth and yield of maize needs further understanding. In order to increase maize production, there is therefore a need to quantify the relative impact of each primary and secondary fertilizer nutrient element on maize production, which has received little attention over the years. This information is critical to inform on the best fertilizer nutrient combinations that would maximize maize productivity and guide fertilizer formulators on the appropriate combination of elemental levels in fertilizer formulas to invest scarce resources for optimum results. Again, performance of of N, P, K, as well as S nutrients as sole, binary, tertiary, and quaternary combination allow us to quantify the various contributions of each of the individual nutrient elements to maize growth and yield, which is also essential information for farmers, agronomists, and plant nutritionists to make the right choice on the best fertilizer combination to optimize maize productivity. According to Vanlauwe *et al.* (2015), yield increases after the addition of secondary nutrients to N, P and K fertilizers, which confirms the need for both primary and secondary nutrient formulation in maize production.

1.4 Research objective

The general objective of the study is to quantify the relative agronomic contribution of each primary nutrient (N, P and K) and Sulphur (S) or their combinations to maize growth and yield in the guninea savannah zone of Ghana

1.4.1 Specific objectives

1. To investigate the agronomic productivity in growth and yield parameters of maize attributable to the single-nutrient applicaton of N, P, K and S.
2. To evaluate the agronomic productivity in growth and yield parameters of maize attributable to the applicaton of binary, tertiary and quaternary combinations of N, P, K and S.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and distribution of maize

For Americans, the word "maize" can be used alternately in place of "corn". The explanation given is that all cereals were referred to as maize in the early British and American business trade. The term "maize" had been preserved since it was the most widespread and widely used cereal crop in trade. While the term "corn" is still disputable, Maize is the most widely recognized crop and is believed to have originated from the Arawac tribes of the Caribbean indigenous people. Based on its common name, Linnaeus used the name *Zea* as its botanical classification (Tefera, 2017).

It is assumed that cultivated maize was obtained from teosinte (*Z. mexicana*). Maize was also known to be established in the ancient world of the sixteenth century and believed to be among the early cultivated crops by farmers between 7,000 and 10,000 years ago as a staple food crop and was first believed to have been discovered in Mexico approximately 5,000 years ago as confirmed by archaeologists according to Kassa, (2017).

2.2 Biology of maize

Maize (*Zea mays* L.) is an annual, high, monoecious crop with an imbricate cover as well as wide, visibly dystichous edges. It belongs to the Graminae (Poaceae) family. In maize, it is frequently recognized as Zea in the plant genealogy. Maize is a wind-pollinated crop, which normally experiences both self and cross-pollination. In a healthy environment, maize pollen shedding is typically viable for 10 to 30 minutes but can be viable for a very long time (Bob, 2018). Maize globally has high adaptation capability and constitutes the major source of food for a large percentage of the world population (Ranum *et al.*, 2014).

Maize is typically planted in early to mid-May, when soil temperatures reach 10°C or higher. It requires good soil management as well as good agronomic practices such as proper fertilizer application, pest and disease control, weed prevention, erosion prevention, and zero-tillage for maximum growth and high productivity (Baum *et al*., 2019). Hybridization of maize (*Zea mays* L.) seeds is achieved by using pure-line male and female inbred parents (e.g., one line of male to four female lines). In the production of hybrid seeds, segregation is needed in comparison to the foundation seeds. The female parent's self-pollination is prevented by detasseling before shedding pollen or using male-impotent technology. In genealogical compliance, inbreds as well as cross-breeds are controlled using parameters such as isozyme profiles through the growth of representative seed lots and laboratory screening (Desta *et al*., 2020).

2.3 Effect of climatic conditions on maize production

Climate conditions have been the primary cause of global vulnerability in most food crop production in the developing countries. Climate change is the rise in global temperature caused by the release of gases such as CO_2, CH_4, CFCs, N_2O, and O_3 into the atmosphere. In recent times, it has become one of the most important limiting factors for maize and other cereal crop production in the tropics. Maize's response to environmental or climatic conditions depends on the physiological composition of the variety being grown. Maize variations in yield also depend on other environmental or climatic conditions under which it is being cultivated and its hybrid's genetic makeup (Zhang *et al*., 2021).

2.4 Water requirements for maize production

Maize (*Zea mays* L.*)* water requirement is an interesting area for agronomists and scientists. It helps plan on nutritional management of the crop (maize). Water deficiency decreases maize yield. At its critical growth stages, maize needs a large amount of water for its maximum growth and productivity. Water has become an essential component in crops production such as maize, and in recent times it has received environmental and global attention with regard to food crop production (Moreno-Pizani, 2021). According to Fang and Su, (2019), recently, competition for water among urban, municipal, industrial, and agricultural users has increased. It is therefore important for good crop planning and management to boost maize productivity through adequate water supply (de Wit *et al.*, 2019). The crop water requirement has been defined as the measure of the amount of water required for evapotranspiration during the period in which adequate soil water is retained by precipitation and/or irrigation so that plant growth and yield are not restricted (Djaman *et al.*, 2018).

The length of the growing and developing stages of the crop, the evaporative demand of the environment, and the density of the canopy, crop species, and planting density expansion are subject to the amount of water required for maize (or any other crop) to grow and develop (Magagula *et al.*, 2019). In the maize reproductive stage, the optimum maize yield could be damaged by moisture stress, resulting in the formation of empty cobs or poor grain formation. The plant's water requirement is therefore important for the plant during its active growth phase and reproductive stage. In order to calculate the amount of water supplied effectively by rainfall and/or irrigation, the amount used by the crop for evapotranspiration, the adjustment in soil moisture storage, and the amount lost by deep percolation should be taken into account (Udom *et al.*, 2019).

Maize is grown over a broad range of climatic parameters, varying in distribution and amount of seasonal rainfall. The crop is also grown under conditions that are irrigated and rain-fed. Approximately 75% of agricultural activities rely on rainfall, particularly in areas where crops are the main source of people's food and income (Nyunza, 2018). Maize responds to waterlogging, particularly during its early growth phases (Jaiswal and Srivastava, 2018). Nevertheless, maize does best during the growing season on soils with adequate moisture. The crop could tolerate dry periods, particularly in the first three to four weeks of development. The amount of rainfall is not only the key limiting factor for the development of rain-fed maize but also the unreliable existence of rainfall, considering the semi-arid and dry sub-humid areas, including the coastal savannahh climate (Bagula *et al.*, 2022). However, water stress occurring at various stages of crop development may potentially limit the accumulation of biomass and consequently reduce the maize crop's grain yield. The degree of decrease in maize productivity depends not only on the intensity of water stress or drought but also on the resistance of the crop to water stress or drought and the efficiency of the maize crop using available soil water for growth, accumulation of biomass, and yield production at the stage of crop development (Sheoran *et al.*, 2022)

2.5 Importance of maize production

Maize (*Zea mays* L.*)* is one of the most significant grain crops used in the human diet in large parts of the world and feed component for animals. Improvement in cereals crops such as maize in terms of nutritional quality is significant as the advantages and benefits can easily be rapidly and effectively be disseminated to the populace without altering the traditional food habits of the consumer. Every part of it is valuable including the grain, the cob, tassel, leaves and stalk which are used to produce a large variety of food and non-food products (Mamudu *et al.*, 2017).

2.5.1 Nutritional benefits of maize

In Ghana depending upon your locality, Akple, Banku, Kenkey and TuoZaafi are some of dishes prepared from maize grain (Mamudu *et al.*, 2017). Maize serves as staple food and source of carbohydrates and the grains has greater nutritional value as it contains averagely

72% starch, 10% protein,10.2% moisture8.5% fibre, and many other vital nutrients (Nirere *et al.*, 2021). Again, maize grains contain fat soluble vitamins such as provitamin A, vitamin B1 (thiamine), vitamin B2 (niacin), vitamin B3 (riboflavin), vitamin B5 (pantothenic acid), vitamin B6 (pyridoxine), vitamin C, vitamin E, vitamin K, folic acid, selenium (Ghete *et al.*, 2018) and various bioactive compounds such as carotenoids, tocopherols, lutein, ergocalciferols and zeaxanthins (Bathla *et al.*, 2020).

2.5.2 Economic benefits of maize

Maize (*Zea mays* L.*)* significantly contributes to global economy especially in the developed world where it is considered as industrial raw materials for biofuel products (Awata *et al.*, 2019). It is reported that, maize is known as mother grain of United State of America as its economy mostly depends on the maize crop (Saeed and Saeed, 2020). Also, serves as source of income and foreign exchange as the maize starch is used in many industries such as pharmaceutical and cosmetics as diluents, the maize oil obtained is used for cooking and soap making, maize as a source of raw material such as sticky gum which contains dextrin for development of envelope sealants, source of alcohol and stem fibres for making of paper (Kumar *et al.*, 2016). Additional source income is through the cash obtained from the sale of livestock and its products that feed on maize. Also, the maize husk used for making door mats and kenkey sellers used it locally to wrap kenkey which generate more income for the populace (Mamudu *et al.*, 2017).

2.5.3 Health benefits of maize

Maize (*Zea mays* L.) is used for pharmaceutical purposes, serve as a significant source of phytochemical compounds and it has been reported that these compounds provide health benefits to human and have the potential of minimizing the major risk of chronic diseases (Huma *et al.*, 2019). The maize plant often used as traditional medicine in countries such as China, France, India, Turkey and the United States because of the qualities it possesses, potential source of antioxidant, diuretic agent, reducing hyperglycemia and used as antidepressants or anti-fatigue (Ghete *et al.*, 2018). Again, pharmacological studies have shown its remarkable medicinal properties such as anti-fatigue, hypoglycemic, antioxidant and effective diuretic agent (Rouf Shah *et al.*, 2016).

Maize grains contain fat soluble vitamins which act as anti-oxidants and help in protection and prevention of various kinds of cancer diseases and ageing, Phylloquinone (Vitamin K) aids blood clotting when accident occurs. Ergocalciferol presents in maize aids bone formation, presents of essential fatty acids aid in maintaining healthy skin and vision, strengthening immune systems for growth and development (Bathla *et al.*, 2020). Again, maize silk serves as a source of medicinal compounds in many countries. It is utilized as medicine in renal problems in both children and adults, due to its anti-inflammatory property. It is used to minimize edema, gout, cystitis and rheumatism and also aid blood pressure improvement and support liver functioning (Huma *et al.*, 2019).

2.6 Major areas of maize cultivation in Ghana

In Ghana, the major areas for maize cultivation cut across the various agro-ecological zones; these agro-ecological zones have different maize production systems. The coastal grassland area is a small strip of grassland that stretches along the coastal savannah and stretches to the eastern coast of Ghana. Farmers cultivate maize, which is usually intercropped with cassava in this area. The annual rainfall in this belt is bimodal. Maize cultivation usually commences at the start of the major rainy season (March or April) in this area (Benjamin and David, 2020).

The majority of Ghana's woodland is semi-deciduous, with a small sector of heavy rain forest near the Côte d'Ivoire border in the south-western part of the country. Cassava, plantain, and cocoyam are commonly intercropped with cultivated maize. The annual rainfall is around 1,500 mm, and maize is sown during both the major and minor rainy seasons (March and September, respectively). As one travels north of Ghana, the forest zone gives way bit by bit to the transition zone. This zone, which is characterized by deep, crumbly soils and scanty bush shelter, allows for continued farming and is an essential zone for commercial cereal cultivation. The annual rainfall, which averages around 1,300 mm, is distributed bimodally. Maize is grown as a monocrop or intercrop during both the major and minor rainy seasons. The savannah zone, which covers the majority of the land in Ghana's northern regions, has only one rainy season per year, with an average rainfall of 1,100 mm. Sorghum, millet, and maize are the most common cereal crops cultivated in the zone. In general, maize is grown in almost every part of Ghana, but three agro-ecological zones produce more than 70% of the country's maize (guinea savannah, forest savannah, and transitional zones). The Northern, Brong Ahafo, Ashanti, Central, and Eastern regions are the five main maize-cropping zones (Dzubey, 2019).

2.7 Nutrient requirements for maize growth and yield

Maize (*Zea mays* L.) cultivation requires a lot of nutrients, especially NPK, to grow (Aliyu *et al.*, 2021). However, maize seedlings cannot withstand high levels of fertilizer at such a young stage and therefore, in fertilizer application, 5 cm holes should be used during seedling application (Rop *et al.*, 2019). In acidic soils, maize takes longer to absorb moisture and nutrients, which is necessary for proper establishment (Mwende, 2019). Maize production in Ghana is low because of its inability to utilize readily available resources (Wongnaa *et al.*, 2021). During the vegetative stage of its growth, maize requires more nitrogen (Shrestha *et al*., 2018). Maize growth and yield improvement are dependent on the nutrient composition of the soil. Crop growth and development are affected by soil nutrient deficiencies (Ayamwego, 2018).

Maize needs nutrients such as nitrogen for growth and development to be at its maximum. In maize crop production, nitrogen is the most limiting nutrient element, and as a result, leaf chlorosis occurs when N levels are insufficient (Anas *et al*., 2020). Plants with deficiencies may grow slowly, become stunted, and weak. With adequate nitrogen levels in the soil, both maize grain quality and quantity improve. Although phosphorus is required in the cultivation of maize, it is not needed in the same quantities as nitrogen (Dhlamini *et al*., 2020). Phosphorus deficiency symptoms in maize include stunted growth and plants are occasionally dark green in color. Purple pigmentation can also be seen on older leaves. Its absence during maize kernel formation can lead to poor kernel set and poor grain formation (Ngure, 2020). After nitrogen, potassium is the second most relevant nutrient needed for maize production. The burning of leaf margins is a common symptom of potassium deficiency in maize. It may also cause weak and lodging in plants as well as poor kernel formation, resulting in less grain quality and quantity.

2.8 The effect of inorganic fertilizer applications

The mineral fertilizers inputs contribution accounts for over 40% to 60% of worldwide food production, however, in the Sub-Sahara Africa the quantities of inorganic fertilizers applied by farmers are still below the recommended quantities set by the African Head of State (Njoroge *et al.*, 2018).

Over the past decades the Nitrogen, Phosphorus and Potassium (NPK) based fertilizers has been the most common available and accessible to farmers for soil nutrients replenishment globally especially developing countries (Nirere *et al.*, 2021). It has been revealed that the NPK elements deficiencies in most poor soil as well as micronutrients constituted a major constraints for maize crop production, where depletion of soil micronutrients is increasing in most developing countries especially under continuous cropping without nutrients replenish (Otieno *et al.*, 2018). Combined effects of macronutrients such as Nitrogen, Phosphorus, and Potassium, known as primary nutrients (Kugbe *et al.*, 2019), with small amount of secondary nutrients such as Calcium [Ca], Magnesium [Mg] and Sulphur [S], and micronutrients such as Boron [B], Chlorine [Cl], Copper [Cu], Iron [Fe], Manganese [Mn], Molybdenum [Mo], Nickel [Ni] And Zinc [Zn] (Bua *et al.*, 2020), have been reported to have the largest influence on maize plants growth and development, increased maize grain yields and nutrients quality of maize grain seeds (Tiwari *et al.*, 2022). Application of macronutrients and micronutrients improve activation of enzymes, photosynthesis regulation, protein build up and resultantly boost the general production (Yasin *et al.*, 2017). Inorganic fertiliser have strong influence on crop growth, development and yield, this implies that the application of NPK inorganic fertilizers serve as good source of crop macronutrients requirements coupled with microelements such as Fe, Mg, Zn and Cu for crop growth, development, grain yield and quality (Prayogo *et al.*, 2021).

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

Over the years, the sole application of macronutrients such as Nitrogen (N), Phosphorus (P) and Potassium (K) fertilizers has been the primary means of nutrient replenishment in the modern agricultural schemes (Kulcheski *et al.*, 2015) and its application has increased maize yield and contributed to food security (Kugbe *et al.*, 2019). NPK fertiliser nutrients remain the most supreme macronutrients required for crop productivity and quality of agricultural production (Chukwuka *et al.*, 2015). However, further maize yield increment is required particularly for northern Ghana (Yigermal *et al.*, 2019). The life cycle of crops is affected by the mineral nutrients that are taken up by crop roots. Klikocka and Marks, (2018) reported that, there is a tight association between maize productivity, both whole-plant and grain N, P, and K uptake. The appropriate content of macronutrients is needed for the normal growth in crops because the deprivation of macronutrients such as nitrogen, phosphorus, potassium strongly affects crop metabolism (Samborska *et al.*, 2018). Crops, like all other living things, need nutrients for their vegetative and agronomic growth. Therefore, they require nitrogen (N), phosphorus (P), potassium (K) elements for their development, growth and food production. These are primary elements that are supplied to the crops either from soil minerals and soil organic matter or by organic or inorganic fertilizers (Asibi *et al.*, 2019). Uptake and accessibility of these primary elements are very significant for the advancement of the crop growth and development especially in the Sub-Saharan Africa where soil nutrients depletion is common. According to Sharif *et al.* (2014), the uptakes of nutrients by crops or plants largely depend on the quantity, concentration, and activities in the rhizosphere as well as the capacity of soil replenishment in the soil solution.

2.9.1 Nitrogen and it effect on growth and yield parameters of maize

Nitrogen is one the major nutrients and the most limiting nutrients in the soil needed for higher yield in cereals production worldwide especially maize (Majid *et al.*, 2017). Nitrogen is considered as an important plant nutrient and its contents significantly influenced the growth, development and yield attributes of plants and final grain yields as it is reported to constitutes about 40% – 50% of dry matter content of protoplasm in plant cell (Tiwari *et al.*, 2022). Nitrogen plays a pivotal role as well as serves as primary nutrient element in the growth and development of maize crops as it is an integral component for increasing maize productivity (Rhezali and Aissaoui, 2021). Nitrogen forms an important component of various enzymes, nucleic acid, proteins as well as an essential part of chlorophyll (Bawa, 2021). Nitrogen management in cereals such as maize production system is a concern to maximum its production via application of Ammonium Nitrate and NPK fertilizer (Klikocka and Marks, 2018). Plants absorb Nitrogen in the soil in the form of Ammonia (NH_3)/Ammonium (NH_4^+), Nitrate (NO_3^-) or urea [$CO(NH_2)_2$] and also as organic N through microbial symbiosis or amino acids (Kulcheski *et al.*, 2015).

Nitrogen, neither organic nor inorganic forms are generally recognised as a main constituent to high yield in maize cultivation and generally, nitrogen uptake and utilization is the most important components of nitrogen use efficiency (Adu *et al.*, 2018). Nitrogen as a macro-element is involved in metabolic activities and protein which increased vegetative and reproductive growth and final yield of the crops (Kulcheski *et al.*, 2015). Nitrogen aid in several physiological developments in maize and establishing the plant's photosynthetic capacity (Asibi *et al.*, 2019). Among the major nutrients needed for plants, Nitrogen application improved maize development in various experiments as it extends the leaf area effectively, delaying senescence and initiation of ear and kernel, thereby affecting the number of developed kernels and final size of kernel (Majid *et al.*, 2017). Nitrogen deficit helps in the decline of growth rate in maize crop and then reduces grain yield, and it is indicated by yellowing of mature leaves, delayed flowering, stunted plants and poorly filled ears (Tiwari *et al.*, 2022). Over application of nitrogen leads to excess vegetative growth and with slightest wind the plant lodges whereas deficiency of nitrogen nutrients decrease grain yield, leaf area index, leaf area duration and rate of photosynthesis (Khan *et al.*, 2014). Aside the deficiency effects of nitrogen on the maize plant and its development, extensive application of nitrogen has contrary environmental effects due to its losses in the form of volatilised ammonia, nitrous oxide, nitrate, leaching into water bodies as water pollutant as a result in low nitrogen use efficiency in cereal crops (Paponov *et al.*, 2020).

2.9.2 Phosphorus and it effect on growth and yield parameters of maize

Phosphorus (P) is documented to be a key element in molecular molecules such as DNA, RNA as well as ATP and phospholipids is critical for the growth and development, functioning and reproduction of all life on earth (Alewell *et al.*, 2020). Phosphorus is the eleventh most abundant naturally occurring element in the earth's crust, water and all living organisms (Sharif *et al.*, 2014) and in the modern agriculture is one of the 16 elements essentially for plant growth and development (Krishnaraj and Dahale, 2014). It is reported that after nitrogen, phosphorus nutrition plays an essential role in plant metabolism and transformation, recycling and availability of nutrients to the crop, it ensures transfer and storage of energy as adenosine diphosphate (ADP) and adenosine triphosphate (ATP) as well as increase soil microbial activities (Wahid *et al.*, 2015). Phosphorus is fundamental mineral nutrients for crop development and agricultural activities which is known for its impact in seed production, rapid plant development, promote development of roots, water use efficiency, early maturity, improves the quality of vegetative growth and resistance to disease infections (Bargaz *et al.*, 2018). It is reported that during vegetative growth plants absorb most of the phosphorus, which biofortified the grains during grain filling stage and enhances early growth and root development (Din and Khalil, 2016; Sharif *et al.*, 2014). Aside being macronutrient for agriculture purposes, Phosphate obtained from rocks with high amount of phosphate minerals is used as anti-corrosion agents, used in ceramics, cosmetics, food preservatives, in animal feed supplements, water treatment and metallurgy (Wahid *et al.*, 2015).

Maize is an exhaustive crop with higher nutrient demand compared to other cereals and it absorbs large quantity of nutrients from the soil at different growth stages of the plant (Nirere *et al.*, 2021). In maize plant, phosphorus is needed for growth, cell division, essential for inflorescence, nuclear formation, photosynthesis, utilisation of starch and sugar, grains formation, ripening and reproductive part of the plant (Ogunsola and Adetunji, 2016). Phosphorus is another essential nutrients required to increase maize yield in higher quantity and control mainly the reproductive growth of the plant (Orebo *et al.*, 2021). According to Adjei-Nsiah *et al.* (2018) findings, it is revealed that substantial increase in grain legume yield may be attainable by application of phosphorus fertilizers in the northern Ghana. Khan *et al.* (2014) reported on the significant effect of phosphorus on plant height, number of cobs per plant, number of grains per plant, thousand grains weight, biological yield and grain yield at a specific application rate and geographical location. Also, it is reported in Pakistan that, application of phosphorus had significant effects on grain yield, dry matter yield, number of leaves and leaf area (Muhammad *et al.*, 2015).

In the tropical and sub-tropical zones, deficiency in phosphorus has become one of the main limiting factors for crop growth and development due to the loss of phosphorus nutrient caused by high temperature, land degradation and heavy rains (Alewell *et al.*, 2020). It is estimated that, approximately 30% to 40% of the world's cultivated land lacks phosphorus (Meng *et al.*, 2021). Soil phosphorus availability in sub-Saharan Africa (SSA) is declining due to soil degradation and insufficient quantity of plant available phosphorus not only produce economically unacceptable yields but also reduce the efficiency of other essential inputs such as nitrogen (Margenot *et al.*, 2016). It is reported that, phosphorus is the second major nutrient next to nitrogen essential for plant growth (Wahid *et al.*, 2015) and one the most limiting plant nutrient in crop production, in most agricultural soils in

Nigeria (Mohammed *et al.*, 2020). Also, in the East Africa it was revealed that most of agricultural soils are estimated to have phosphorus deficiency, over 50% in Tanzania soils and 80% in the Kenya soils (Margenot *et al.*, 2016). According to Muhammad *et al.* (2015), 90% of the soils in Pakistan are deficient in phosphorus which are amended with the application of phosphorus fertilizer essential for crop production. Small ears in maize is as results of phosphorus deficiency (Ogunsola and Adetunji, 2016), though sole application of phosphorus in higher quantity does not increase yield in maize, but combination of phosphorus with other nutrients increased maize yields significantly (Khan *et al.*, 2014).

2.9.3 Potassium and it effect on growth and yield parameters of maize

Potassium (K) element is an essential macronutrient for many physiological processes in plant growth and development such as quality, stress resistance and increase the branches of the crop hence influence yield (Hussain *et al.*, 2020; Xu *et al.*, 2020). Also, potassium fertilizer is reported to enhance the formation and change of sugar and energy needed by crops development and growth through photosynthesis process which plays a critical role in improving the crop yields and grains quality (Xu *et al.*, 2020; Yang *et al.*, 2021). Potassium element is non-structural component of the plant body and important for the growth of plants (Shah *et al.*, 2018). Potassium is estimated to be about 2.1% to 2.3% of the earth's crust and known to be the seventh or eighth most abundant element (Hartati *et al.*, 2018).The soil available potassium pool is easily leached by runoff (Sardans and Peñuelas, 2015), however, in contrast to nitrogen (N) and phosphorus (P) that is given higher attention (Du *et al.*, 2017). Potassium (K) fertilizers are applied at a much lower rate, and less than 50% of the K removed by crops is being replaced, thus decreasing the amount of K in the soil (Jiang *et al.*, 2018).

The current literature shows that potassium is deficient as nitrogen and phosphorus for plants and crops productivity globally (Gu *et al.*, 2021). Lack of attention for a long period of time is the main cause of potassium deficiency in the soils (Ali *et al.*, 2019) and generally, growers believe that K fertilizer does not efficiently increase yields as compared to N and P fertilizers (Du *et al.*, 2017). Most the cultivated lands in Europe, Asia and Africa suffer from soil potassium deficiencies (Jiang *et al.*, 2018), however, potassium nutrients replenish has been through application of potassium fertilizer in the form of KCL, K_2SO_4 and KNO_3 (Hussain et al., 2020). Potassium fertilizer is the primary source of macronutrient in the soil for modern agricultural systems (Anees *et al.*, 2016).

Potassium activates number of enzymes, improves the utilization, efficiency and efficacy of nitrogen and phosphorous as well as plays an vital role in the reproductive growth of plants (Kumar *et al.*, 2017). Potassium involved in the maintenance of water status, energy balance, and cell turgor pressure which is essential in the processes of osmoregulation and activation of enzymes, cell extension, photosynthesis, stomatal movement, protein synthesis and phloem loading (Gu *et al.*, 2021). The potassium application on plants have been reported to increased plants tolerance level to heat and frost injuries, droughts, improves plants resistance to diseases and keeps anion balance in plants.

Losses occur in agriculture production due to the effects of biotic and abiotic factors. It is estimated that in maize production biotic stress cause about 31.2% of maize loss while abiotic stress cause about 65.8% yield losses of maize. It is suggested that inorganic nutrients play a critical role in plant stress resistance, however, among the minerals nutrients potassium (K) plays a role in plant growth and metabolism, and it contributes greatly to the survival of plants under various stresses. Potassium deficiency in the soil reduced the activity of enzymes and nitrogen metabolism related enzymes (Du et al., 2017). Again, a soil deficient in potassium leads to reduction in plant photosynthesis which is the main cause of low yields in maize (Shah *et al.*, 2018). An optimum potassium nutrient level is essential for plant resistance to environmental stress and efficient potassium usage in combination with other nutrients not only contribute to sustainable crop's development and growth, yield and quality but affect plant health and lessen the environmental dangers (Jiang *et al.*, 2018) .

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

Sulphur (S) is an important nutrient for animal life and plants development (Juhász *et al.*, 2021) and is considered as the fourth major nutrient elements for plant growth and development (Dawson and Maseeh, 2021). Sulphur element plays a significant role in plant nitrogen metabolism, protein formation, oil synthesis and enzyme activity (Jeet *et al.*, 2014). Calcium sulfate is most abundant and easily accessible form of Sulphur and its deficiency affect the efficiency of nitrogen assimilation in plants and phosphorus. It is therefore used in fertilizer formulation (Rebi *et al.*, 2020). Sulphur is essential for chlorophyll accumulation (Kumar *et al.*, 2016) and proteins synthesis in crops, as it is a component of the amino acids cysteine, cystine and methionine. Globally, Sulphur deficiency is reported over 70 countries which affects crop yield and grain quality in crops and has become a major constraints in crops production (Imran *et al.*, 2014).

2.11 The effect of micronutrients and secondary nutrients in maize production

Micronutrients and secondary nutrients are trace elements which are needed by the maize crop in small amounts with consistent supply (Ahmad Hisham *et al.*, 2021) and play direct or indirect active role in the plant metabolic functions, photosynthesis, vital processes in plant such as respiration, protein synthesis, and reproduction phase (Roohi *et al.*, 2021). Micronutrients are essential elements for plants growth that are required in very little amounts compared to the macronutrients such as nitrogen (N), phosphorus (P) and potassium (K) (Mugenzi *et al.*, 2018). Micronutrients such as Zinc (Zn), Boron (B), Cupper (Cu), Mn, Mo, Ni and Iron (Fe) are vital for plant growth and development as it improves the quality and yield increment of the maize crop (Dhakal *et al.*, 2021). Zinc deficiencies have become more prominent in the past year, however zinc application has been reported for increasing maize yield globally (Ahmad and Tahir, 2017). Micronutrients are not only enhancing grain yields, however involved in the improvement of the quality of the grains in terms of nutrition (Ehsanullah *et al.*, 2015).

Secondary nutrients such as Magnesium (Mg), Calcium (Ca), and Sulphur (S) are significant in the development of quality and higher grain yield in maize (Stewart *et al.*, 2021), especially sulphur which is the fourth major nutrient after the primary nutrients N, P, and K (Ariraman *et al.*, 2020). The effects of deficiencies in secondary nutrients and micronutrients in Sub-Sahara Africa due to leaching, erosion and continuous cropping without nutrient replenishment limiting crop productivity has been documented (Vanlauwe *et al.*, 2015). The use of agricultural tools such as plant breeding or genetic biofortification and agronomic biofortification (Stangoulis and Knez, 2022) of staple crops with micronutrients and secondary nutrients is a cost-effective and sustainable approach to address nutrient deficiency (Zaman *et al.,* 2018). However, Agronomic biofortification through fertilizers is a well-thought-out method to increase mineral concentrations in the grains as well as increase yield of staple crops on infertile soils (Zaman *et al.*, 2017).

2.12 The effect of applying different levels of nutrient combinations

Though the application of fertilizers has been an age-old method of replenishing soil fertility, its application tends to increase the cost of production astronomically, especially in recent years. As such, the application of only deficient nutrients to the soil has been considered to be much more cost-effective. This could be determined with the use of soil tests. But this is an unaffordable and sometimes inaccessible option for smallholder farmers. Thus, a fertilizer rate that contains only the nutrients required by the soil will be readily adopted by smallholder farmers (Zaroual *et al.*, 2021).

The application of single nutrient fertilizers has been used a lot, especially for nitrogen due to its high demand by plants and its extreme volatility. The other applied nutrients do not experience such demand. The application of sulphate of ammonia as well as urea has been a common way of supplementing soil nitrogen levels. With regards to legumes, the application of phosphorus fertiliser such as triple super phosphate (TSP) has also been a good fertility booster. Per the observations of Olowoboko *et al.* (2017) the application of fertilisers with a high number of nutrients improves the fertility status of soils compared to soils amended with a lower number of nutrients. Sulphur was observed to increase the availability of NPK in the soil for plant use as well as the NPK content in plants (Waleed *et al.*, 2020). However, the application of all nutrients is expensive, thus the need for a reduced combination of nutrients that provides good yield to the smallholder farmer. Baiyeri and Aba (2015) reported superior growth and higher dry matter yield in plants which received combined doses of nitrogen and potassium fertilizer than those grown with single doses of either nutrients (N or K), while the least dry matter yield was recorded from control (no fertilizer) plots. Ogunsola and Adetunji (2016) identified that the application of S fertilizer appears not to be critical to the production of maize on the soils of their study areas. However, responses to P applications were observed. In their study, a higher level of P with a lower S rate synergistically enhanced maize yield. Waleed *et al.* (2020) also observed that, the application of S increased the availability of NPK when applied 60 days before planting. This research has shown that a combination of different nutrients at different levels could influence the growth and development of crops. However, there was no clearcut comparison concerning nutrient combinations of N, P, K and S, especially in maize. Thus, comparison of the effects of applying a single nutrient, two nutrients, and so on with regards to N, P, K and S has not been clearly investigated.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental site

The research was conducted in Bolgatanga municipality and Bongo district, both in the Upper East Region of Ghana. The area lies within the interior Guinea Savannahh agro-ecological zone, between latitude 9°-25' N and longitude 0°-58' W. The climate of the region is semi-arid, with an average annual rainfall (between May and September) of 1200 mm, accompanied by a dry windy season (harmattan) between October and April. The region has an average monthly minimum temperature value of 21.9°C and a maximum temperature value of 43.1°C with a monthly minimum of 50 percent and an overall value of 80 percent during the rainy season. The relative humidity varies considerably during the wet season. The soil is brown, moderately drained, and concrete-free sandy loam.

3.2 Experimental design

The experiment was a 2 (sites) by 18 (fertilizer treatment) factorial experiment with four replications per site. The experiment was laid out in a randomized complete block design (RCBD) with four replications at each location. The two sites were located in Bolgatanga municipality and Bongo district.

3.3 Treatments combinations

The experiment consisted of the following 18 treatment combinations of primary nutrients and sulphur; CONTROL (0-0-0-0 kg/ha), N(PR)KS (120-50-50-15 kg/ha), N(P+PR)KS (120-50-50-15 kg/ha), NPKS (120-50-50-15 kg/ha), NPK (120-50-50 kg/ha), NPS (120-50-15 kg/ha), NKS (120-50-15 kg/ha), PKS (50-50-15 kg/ha), PS (50-15 kg/ha), PK (50-50 kg/ha), PN (120-50kg/ha), NK (120-50 kg/ha), KS (50-15 kg/ha), NS (120-15 kg/h), N (120 kg/ha), P (50kg/ha), K (50 kg/ha) and S (15 kg/ha). Phosphorus was applied at the above rates based on the amount of P_2O_5 contained in both sources, i.e., 50 kg/ha P_2O_5. For treatment N (P+PR) KS, 25 kg/ha of P_2O_5 was supplied in the form of inorganic P while 25 kg/ha of P_2O_5 was supplied in the form of phosphate rock (PR). Soil chemical analysis was carried out to find the initial physicochemical characterstics of the soil before planting.

3.4 Field preparations and agronomic practices

The land was ploughed using a tractor and leveled. The experimental lay-out or demarcation was done using a tape measure, garden-lines, and pegs. At each location, the plot size was 5 m × 5 m with a planting distance of 60 cm inter-row spacing and 40 cm intra-row spacing. Four seeds were planted per hole and thinned to two plants per hole.

Planting was done at Bolgatanga location on June 22, 2020 and Bongo location on June 23, 2020. Basal fertilization with N, P, K, and S was applied 10 days after planting, while top dressing with the half of the N rate was done 20 days after the first application.

3.5 Data collection

3.5.1 Growth parameters

Name of variety: Wang-daataa maize variety was used at both locations for the field experiment.

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

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

Leaf area: This was measured in centimeters two weeks after emergence and was reported on a continuous basis every two weeks until maturity. In the middle rows from each plot, five plants were randomly sampled and tagged and used for this purpose. The leaf area was then determined by measuring the width and length of each plant's three leaves and calculating using the formula: $Leaf\ area\ (cm^2) = LL \times LW \times CF$ (Francis *et al.*, 1969; Montgomery, 1911),

Where LL = length of the leaf, LW = leaf width, and CF = crop factor (0.75 for maize).

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

3.5.2 Harvest data

Number of plants or plant stands at harvest time: This was estimated by counting the number of plants or plant stands on each net plot prior to harvest time.

Total fresh biomass (above- ground biomass: This was documented at a time when maize plants were fully ripe and ready for harvest. All of the plants were cut at ground level and weighed for fresh weight from each net plot.

Total dry biomass: This was estimated after all the above ground plants were dried and weighed for each net plot.

3.5.3 Yield and yield components (yield data)

Total weight of fresh cobs): This was recorded at the time the cobs were harvested from the maize plant. All the maize cobs were weighed for their fresh weight in each net plot.

Dry weight of cobs: This was recorded after drying all the maize cobs harvested from each net plot and weighing them for their dry weight.

Total grain yield: This was calculated by weighing the threshed grains from each harvested plot of 5 m x 5 m to obtain the total grain weight. The harvests were then expressed in t/ha.

Five cob weight: This was calculated by selecting five cobs from each net plot and measuring and recording the weight of the cobs with grains attached.

Length of cob: This was recorded by selecting from each net plot five cobs and measuring their length with the attached grains. The averages of the five cobs were then recorded for the respective plot.

Number of grains/seeds per cob: This was recorded by counting the number of seeds/grains per cob.

Thousand seeds/weight of grain: This was calculated by weighing thousand of seed or grains and recording the weight of the 1000 seeds in grams.

3.6 Soil data

Available Nitrogen (N), Phosphorus (P), Potassium (K) and Sulphur (S): Fifty-four (54) initial samples of composite soils were taken from four (4) replications at each location and analyzed for available status.

3.7 Data analysis

The data collected were subjected to analysis of variance (ANOVA) using the GENSTAT Statistical package 4th edition and the means were separated using Least Significant Difference (LSD) at 5% probability level. Results are presented in tables and graphs.

CHAPTER FOUR

RESULTS

4.1 Soil physical and chemical properties

The table shows the physical and chemical attributes of the soil collected from the Bolgatanga and Bongo experimental sites. In general, Nitrogen (N), Phosphorus (P), Potassium (K), and Sulfur (S) levels in the soil were higher in Bongo than in Bolgatanga.

Table 4.1: Soil nutrient levels for the four plant nutrients used for the study (mg/kg)

	Method/units	Bolgatanga			Bongo		
Soil Nutrients	(mg/kg)	**Limits**	**Grade**	**Results**	**Limits**	**Grade**	**Results**
Nitrogen	Alkaline Permanganate ($KMnO_4$) method (Subbiah and Asija, 1956)	< 151 152-281 281-560 562-701 > 701	Very low Low Normal High Very high	**204.9**	< 152 153-282 282-561 563-702 > 702	Very low Low Normal High Very high	**209.9**
Phosphorus	Olsen mthod ($NaHCO_3$ extraction) (Olsen and Sommers, 1982)	< 7.01 8-13.5 8-18.5 13.5-26 26-36 > 36	Very low Low Normal High High Very high	**12.04**	< 7.02 9-13.5 9-18.5 14.5-26 27-36 > 37	Very low Low Normal High High Very high	**12.09**
Potassium	Neutral ammonium acetate (NH_4OAc) extraction method (Metson, 1956)	< 101 102-136 135-336 336-401 > 401	Very low Low Normal High Very high	**109**	< 102 103-137 136-337 337-402 > 402	Very low Low Normal High Very high	**113**
Sulphur	Neutral ammonium acetate (NH_4OAc) extraction method (Metson, 1956)	< 23.00 23.00-36.00 36-51 > 51	Low Normal High Very high	**13.37**	< 24.00 24.00-37.00 37-52 > 52	Low Normal High Very high	**13.42**

4.2 Effect of nutrient combination on the plant height

Figure 4.1 and Figure 4.2 represent the main effects of the nutrient combination and location on plant height of maize at 2, 4, 6, 8 and 10 weeks after planting (WAP). Plant height differed (*P < 0.001*) significantly among the nutrient combinations for a given week (Figure 4.1). Single-applied fertilizers had minimal differences as compared to the control. Also, the two most performed nutrient combinations were N (P+PR) KS and NPKS. For treatment N (P+PR) KS, values were at least 54% better at 2, 4, 6, 8, and 10 WAP respectively, when compared to the control. Similarly, the nutrient combination NPKS had values which were at least 40% higher than the control at 2, 4, 6, 8 and 10 WAP respectively.

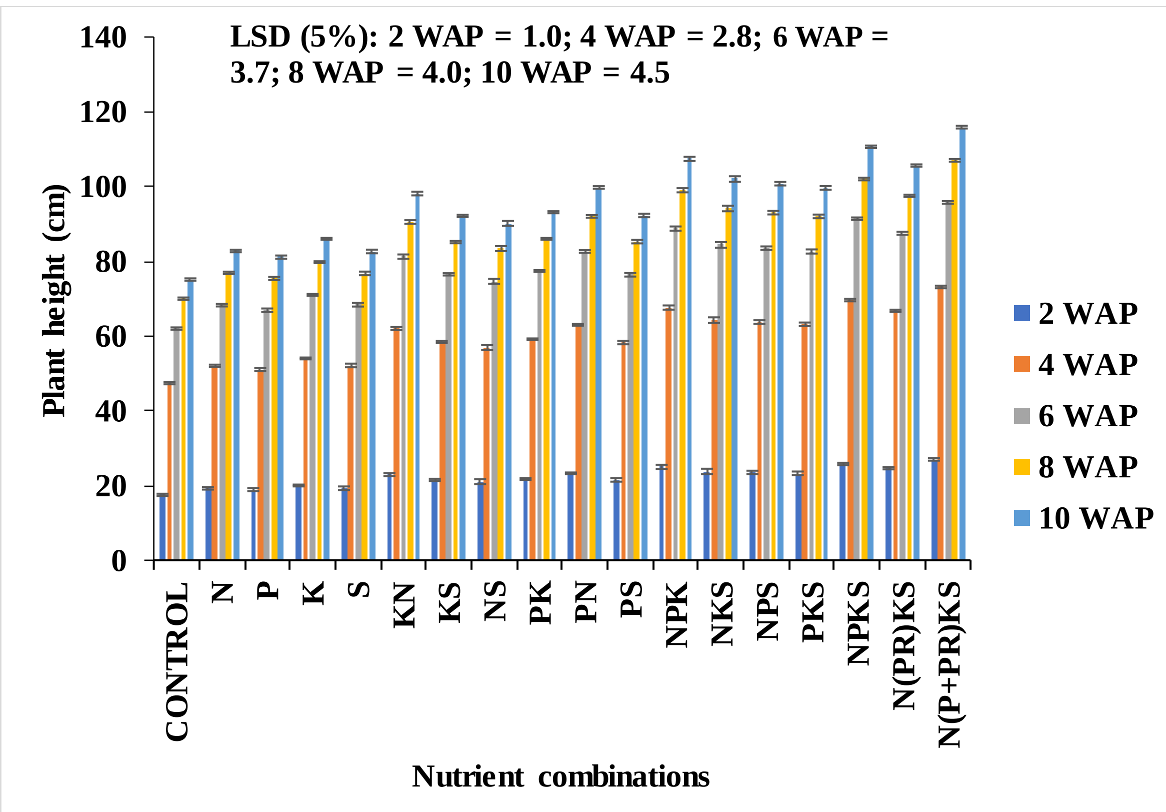

Figure 4.1: Effect of combination of primary nutrients and sulphur on plant height of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Errors bars represent standard error of mean (SEM).

The environment/location significantly ($P < 0.001$) influenced plant height (Figure 4.2). The location considerably improved the plant heights at the Bongo site at 2, 4, 6, 8 and 10 WAP by at least 4% compared to the Bolgatanga site. The maize plants at the Bongo site were relatively uniform without insects or disease infestations on the plants.

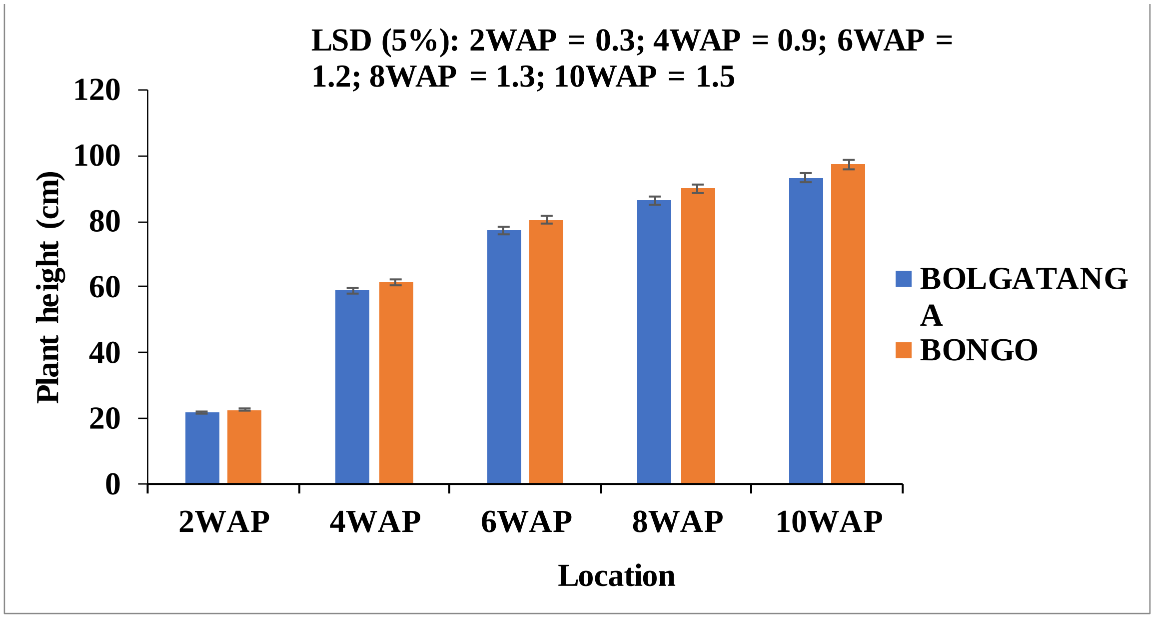

Figure 4.2: Effect of location on plant height of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

4.3 Effect of nutrient combination on the leaf number

There was no interactive effect of location and nutrient combinations on leaf number of maize in all the weeks. The leaf number on plants increased significantly ($P < 0.001$) between nutrient combinations (Figure 4.3). Steadily, the leaf number was noted to increase across all the nutrient combinations, but among the combined applied treatments observed, leaf numbers were in multiples as compared to either the single-nutrient treatment or the control. Combined treatments such as N (P+PR) KS, NPKS and N (PR) KS recorded the highest leaf number compared to all treatments within the periods of 2, 4, 6, 8 and10 WAP.

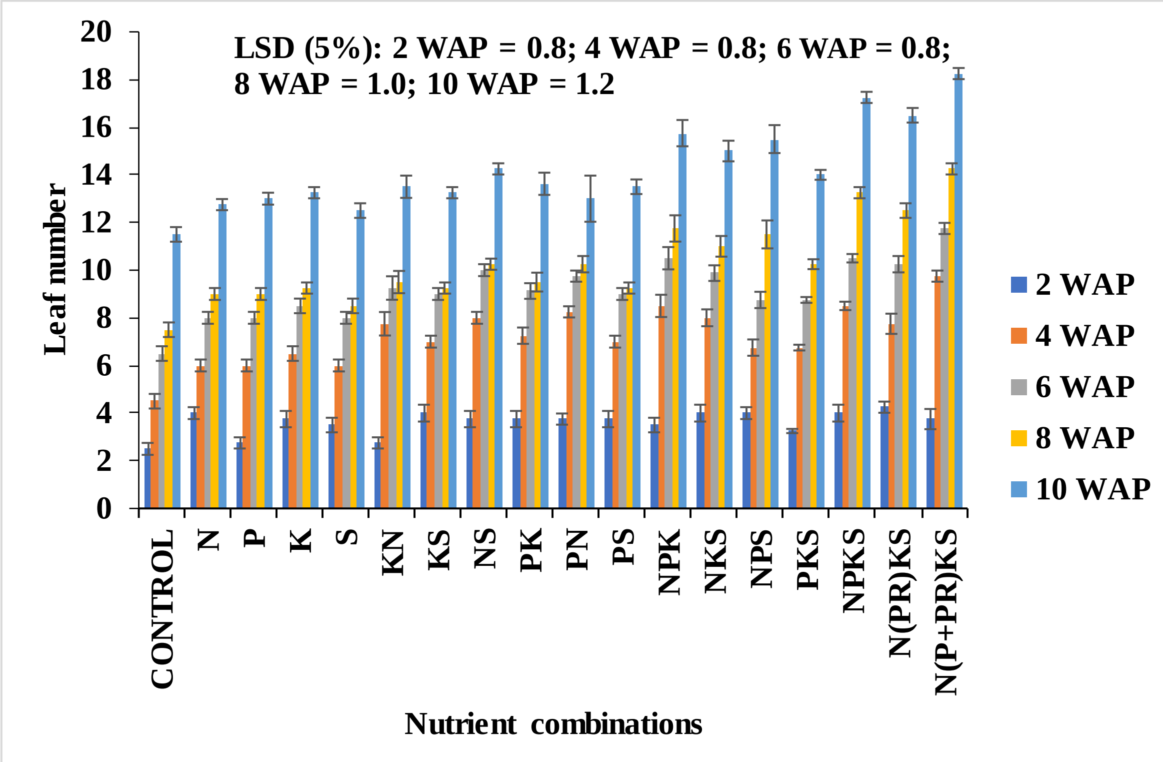

Figure 4.3: Effect of combination of primary nutrients and sulphur on leaf number of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

The leaf number on plants differed significantly (*P < 0.001*) between the two locations. Between the two localities; maize plants from the Bongo site had higher number of leaves compared to those from the Bolgatanga site in all weeks (

Figure 4.4).

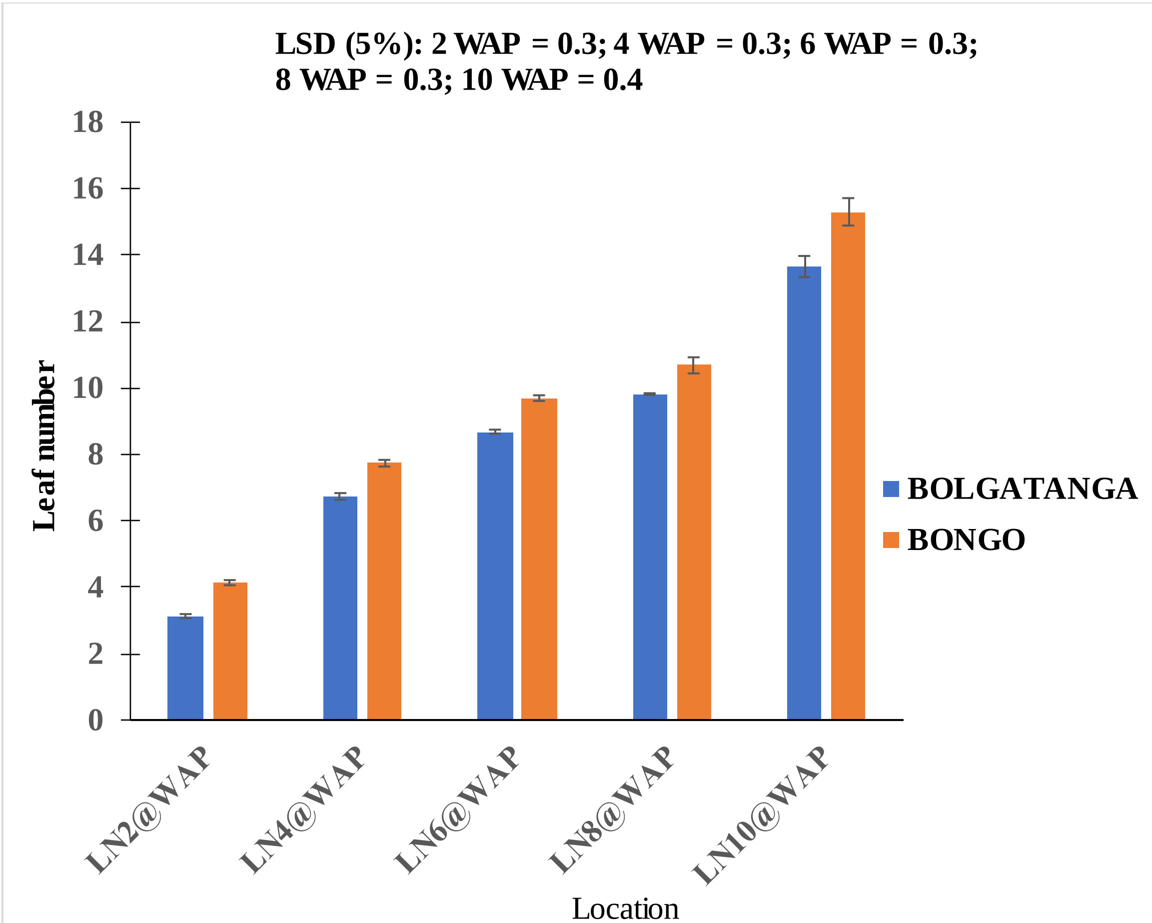

Figure 4.4: Effect of location on leaf number (LN) of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

4.4 Effect of nutrient combination on leaf area

The lowest leaf area of maize plant was recorded from the control plots and this differed significantly (*P < 0.001*) from all the other nutrient combinations.

Though the effect of nutrient combinations was relatively low in all the single-nutrient treatments, they performed better compared to the control (

Figure 4.5). Similarly, tertiary nutrient combinations caused higher leaf areas than either single or binary combinations. For all the weeks considered, nutrient combinations N

(P+PR) KS and NPKS recorded the highest leaf areas compared to other nutrient combinations.

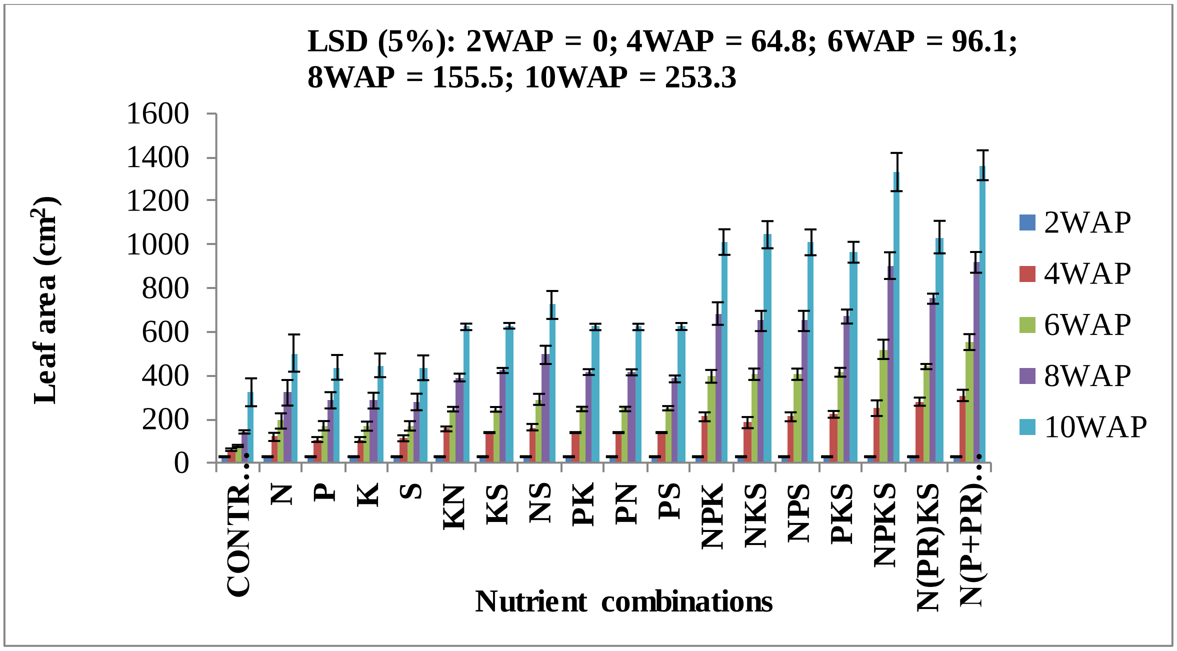

Figure 4.5: Effect of combination of primary nutrients and sulphur on leaf area of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEMs.

4.5 Effect of nutrient combination on leaf chlorophyll content

Figure 4.6 indicates the effect of nutrient combinations on the chlorophyll content of maize leaves at 2, 4, 6, 8, and 10 WAP. The chlorophyll content of maize leaves significantly (*P < 0.001*) differed with the nutrient combinations. The sole-nutrient applications caused a better performance when compared to the control by close to 41%. With the applied N (P+PR) KS treatment, the chlorophyll content improved much better than the control by 392%, 243%, 124%,129% and 119% at 2, 4, 6, 8 and 10 WAP respectively. Also, the applied combined treatment such as NPK, NPKS, PKS and others had higher chlorophyll than the control.

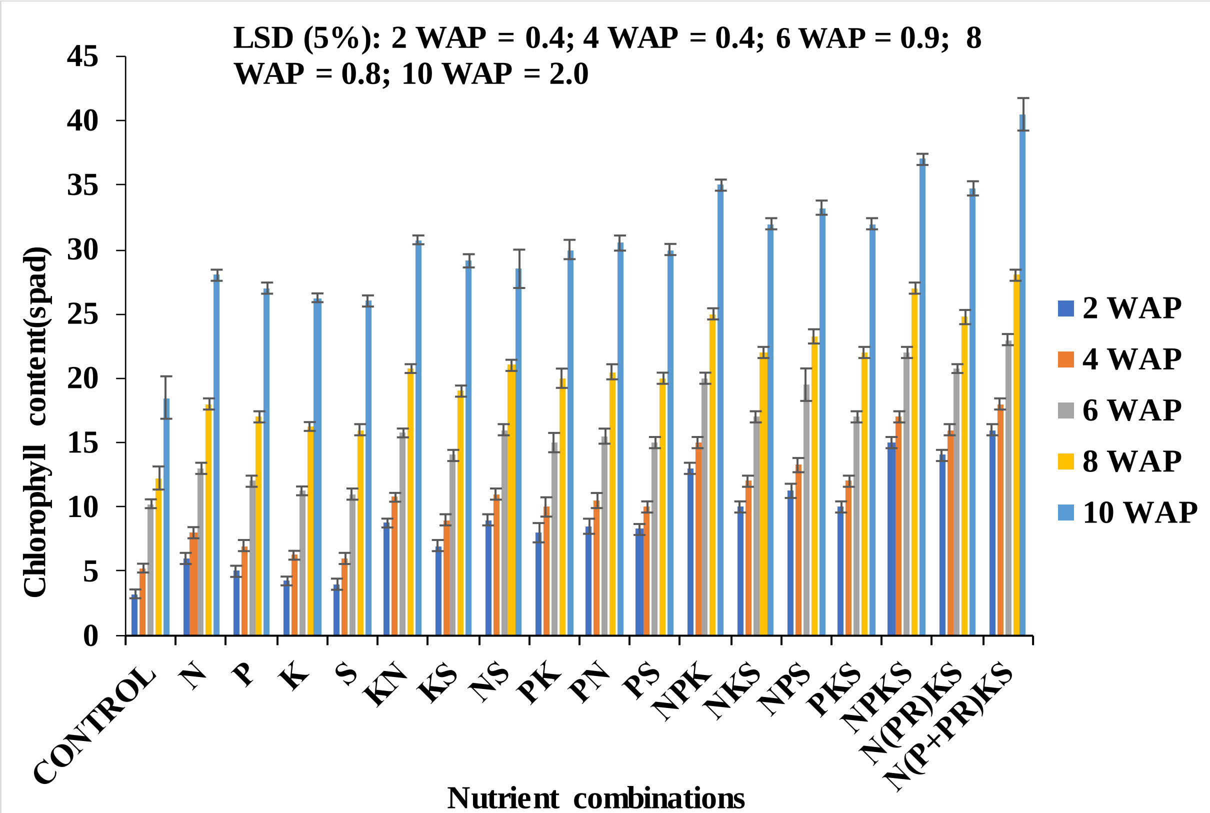

Figure 4.6: Effect of combination of primary nutrients and sulphur on leaf chlorophyll content of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

From figure 4.7 there was significant (*P < 0.001*) difference in chlorophyll content from 2 WAP to 10 WAP with respect to location. At the Bongo site, the maize plants had at least 3% higher leaf chlorophyll content than those in Bolgatanga.

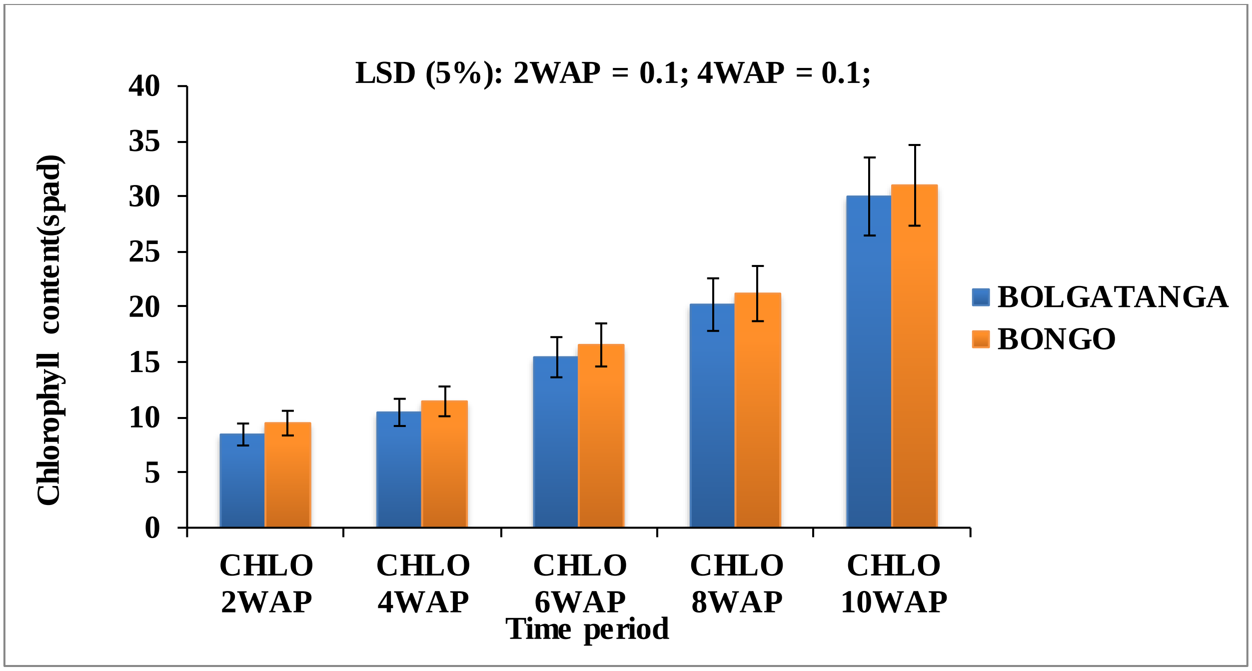

Figure 4.7: Effect of location on leaf chlorophyll content of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

4.6 Effect of nutrient combination on fresh and dry biomass yield

There was a significant (*P < 0.001*) difference in fresh biomass yield under the interaction between the mode of combined treatment and location (Figure 4.8). The applied combined treatment with three or two elements underperformed when compared with the applied treatments consisting of four nutrient elements. The three treatments that enhanced biomass yield better were the applied N (P+PR) KS, NPKS and NPK in both Bolgatanga and Bongo sites.

The mode of combined treatments such as N (P+PR) KS, NPKS and NPK enhanced fresh biomass yield in Bolgatanga by 291%, 275% and 259% respectively higher than the control (Figure 4.8). At Bongo, treatment N (P+PR) KS had a significant increase in fresh biomass yield by 235% better than the control. On the other hand, both NPK and NPKS recorded a similar increase in fresh biomass yield by 222% each as compared to the control. Even though all single applied treatments underperformed when compared to the soil amended with two types of fertilizers, they were also better than the control in both locations.

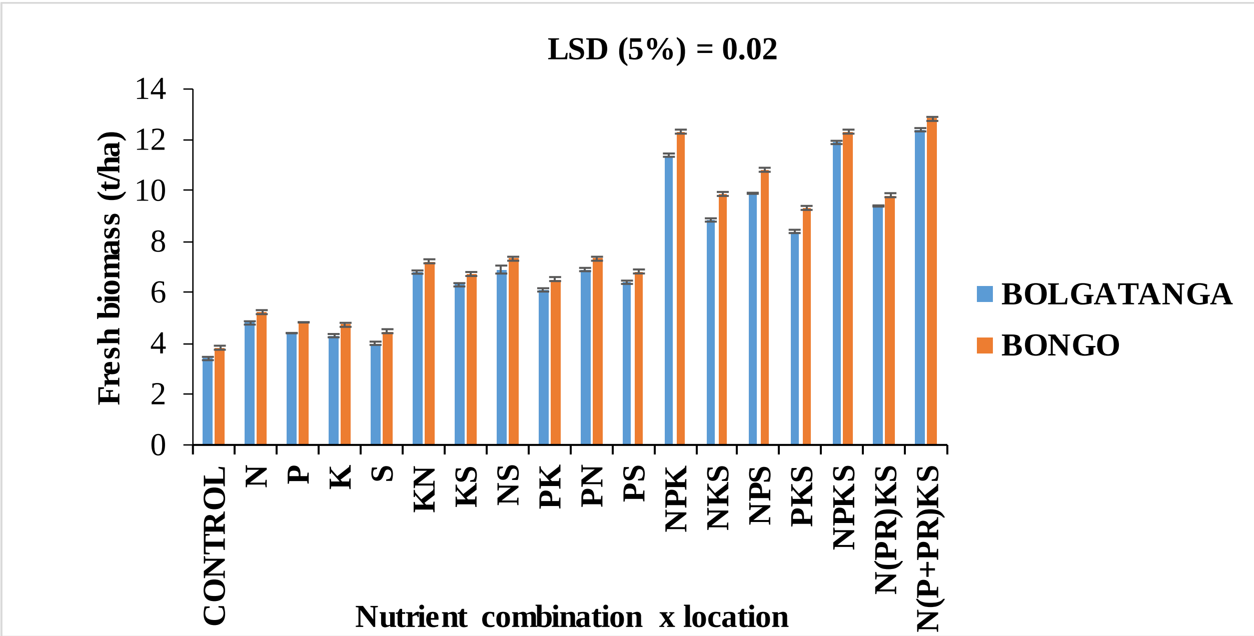

Figure 4.8: The interaction effect of nutrient combination and location on fresh biomass yield of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

Dry biomass yield was however influenced ($P < 0.001$) by main effects of the nutrient combinations only; it was not affected ($P > 0.05$) by location nor the interaction between nutrient combinations and location. Even though all single nutrient treatments underperformed when compared to the plots amended with two or more elements, they were also better than the control (Figure 4.9). The nutrient combinations of N (P+PR) KS, NPKS and NPK were able to increase dry biomass yield by 214%, 196% and 195% respectively compared to control.

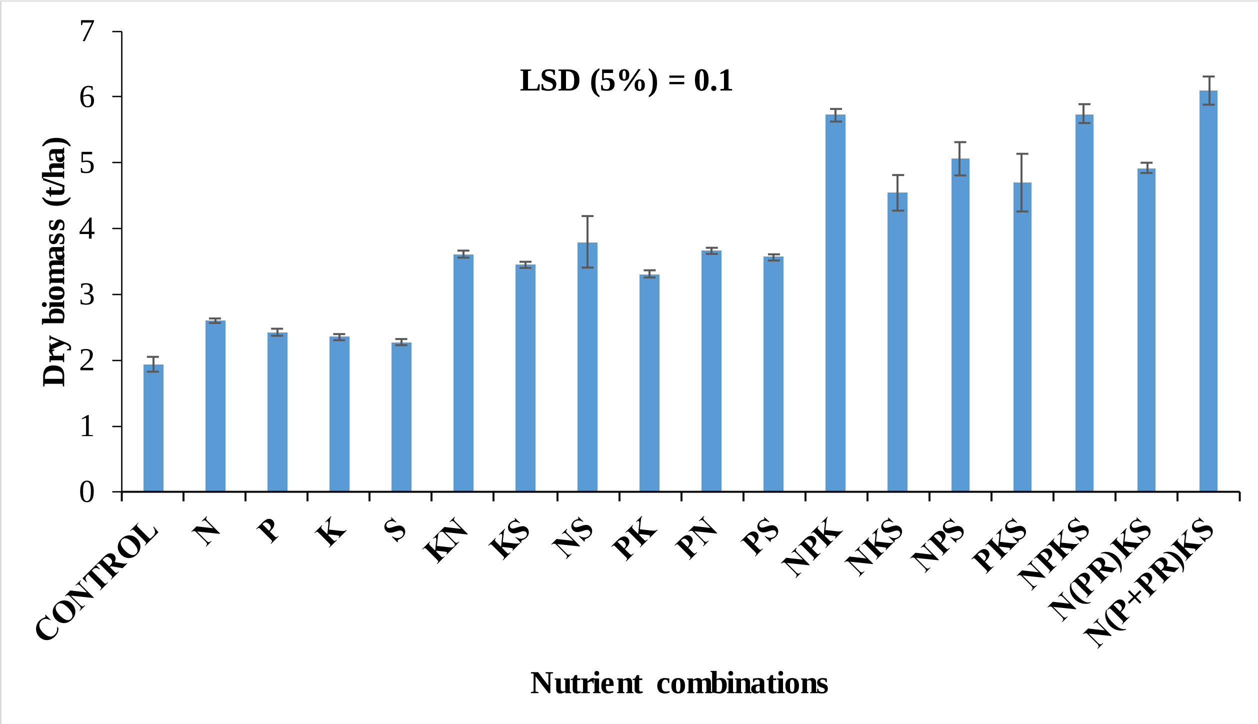

Figure 4.9: Effect of combination of primary nutrients and sulphur on dry biomass yield of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

4.7 Effect of nutrient combination and location on fresh and dry cob weight

Figure 4.10 and Figure 4.11 show the fresh and dry cob weights respectively measured at the two locations. Fresh dry cob weights were highly affected (*P < 0.001*) by the interaction effect of the nutrient combinations and location. It was also observed that applied N (P+PR) KS, NPKS and NPK recorded the highest fresh cob weight which was at least 3.68, 3.48 and 3.38 times higher in both locations compared to that recorded in control. In addition, applied treatment with at least three combined fertilizers improved the fresh cob weight as compared to treatments with double or single fertilizers from the two localities. Again, it was observed that the combination of more than two fertilizers increases fresh cob weights over the single nutrient application and control yields.

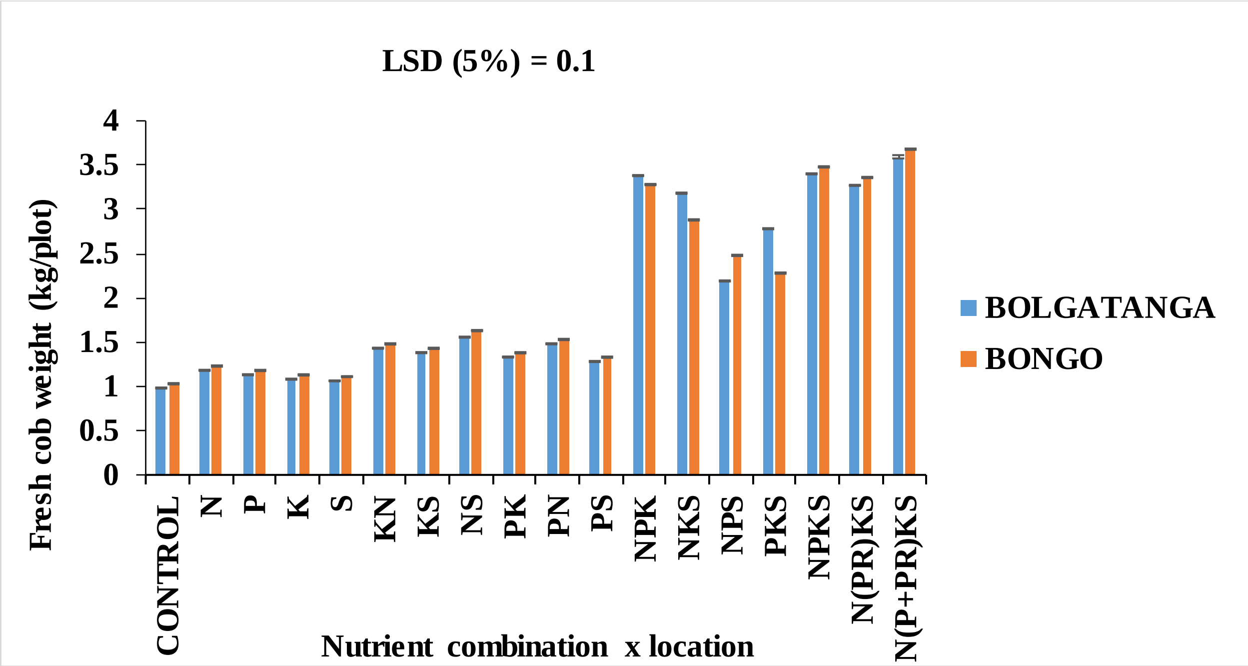

Figure 4.10: The interaction effect of nutrient combination and location on fresh cob weight of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

Statistically, dry biomass weight had appreciable variations in favor of the combined mode of treatments among the two localities (Figure 4.11). The applied combined treatments N (P+PR) KS, and NPKS had extensively higher dry cob weight than the control in the two localities. The trend was same for treatments such as NPK, N (PR) KS, and NKS. Sole N produced the highest dry cob weight among the sole-nutrient applications in both locations. All single nutrient applications caused higher dry cob weights compared to the control.

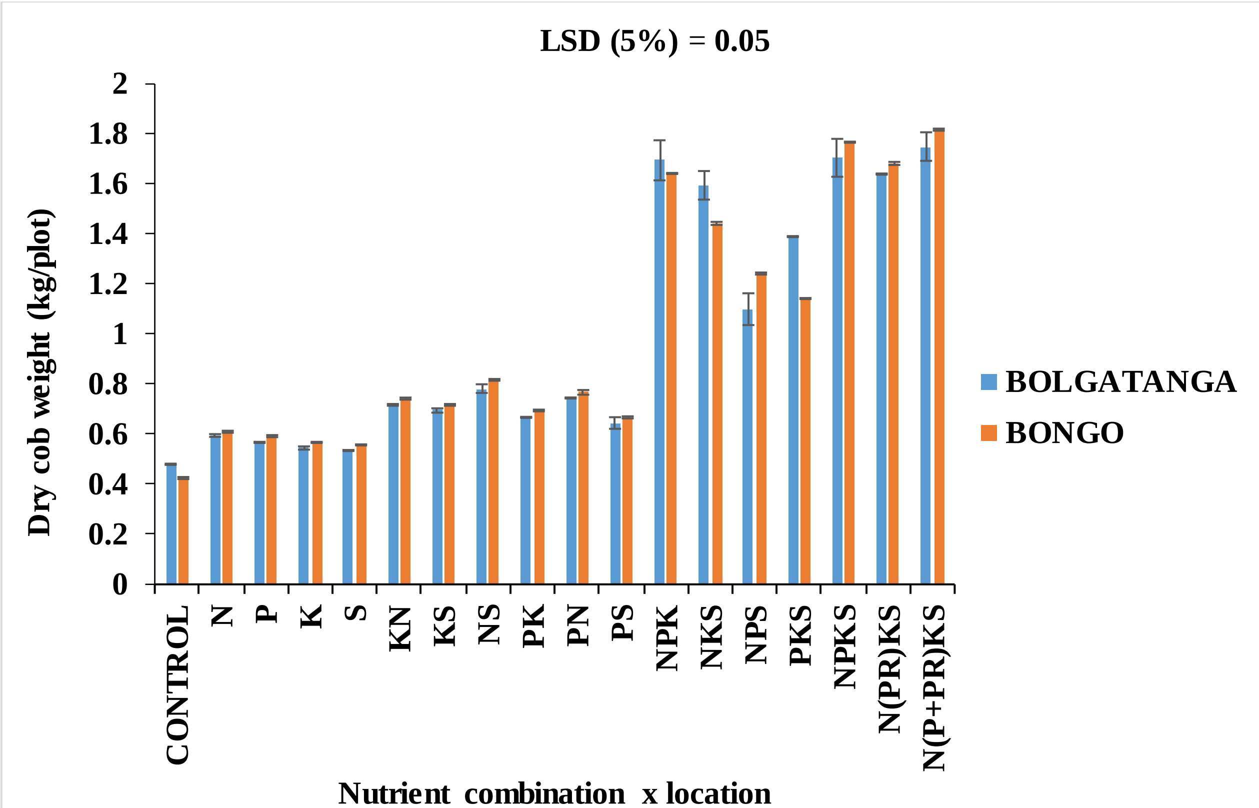

Figure 4.11: The interaction effect of nutrient combination and location on dry cob weight of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

4.8 Effect of nutrient combination and location on yield components

Cob length of the maize plant was significantly (*P < 0.001*) influenced by either single or more of N, P, K, PR, and S fertilizers combinations. Cob length ranged from a minimum of 10.3 cm (control) to 21.5 cm (N (P+PR) KS) (Figure 4.12).

The treatments N (P+PR) KS and NPKS enhanced cob length by 109% and 90% respectively higher than the control (Figure 4.12). The combined treatments like NPK, NPS, PKS, and N (PR) KS improved cob length by a range of 56% to 66%.

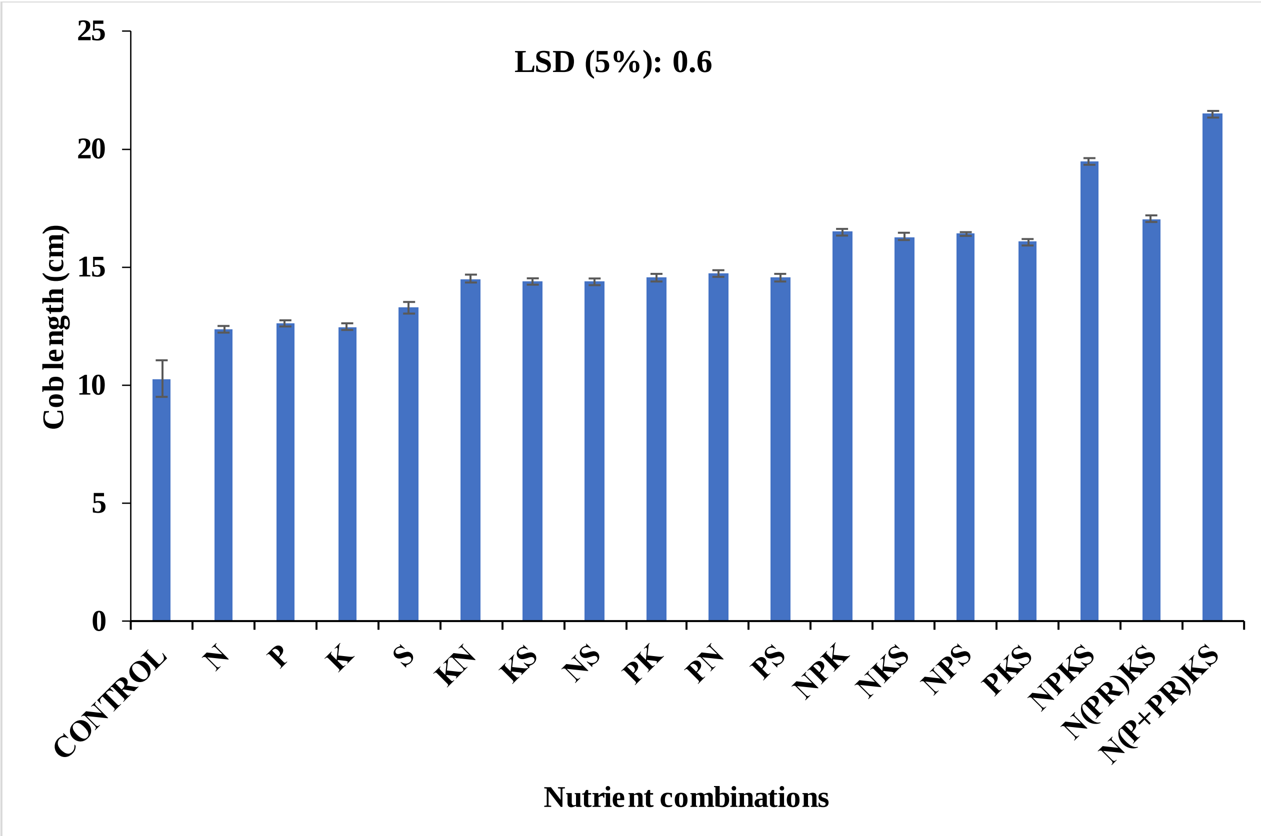

Figure 4.12: Effect of nutrient combination on cob length of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

Cob length was also highly affected (*P* < *0.001*) by location. From Figure 4.13, plants cultivated at Bongo had higher cob length compared to those from Bolgatanga.

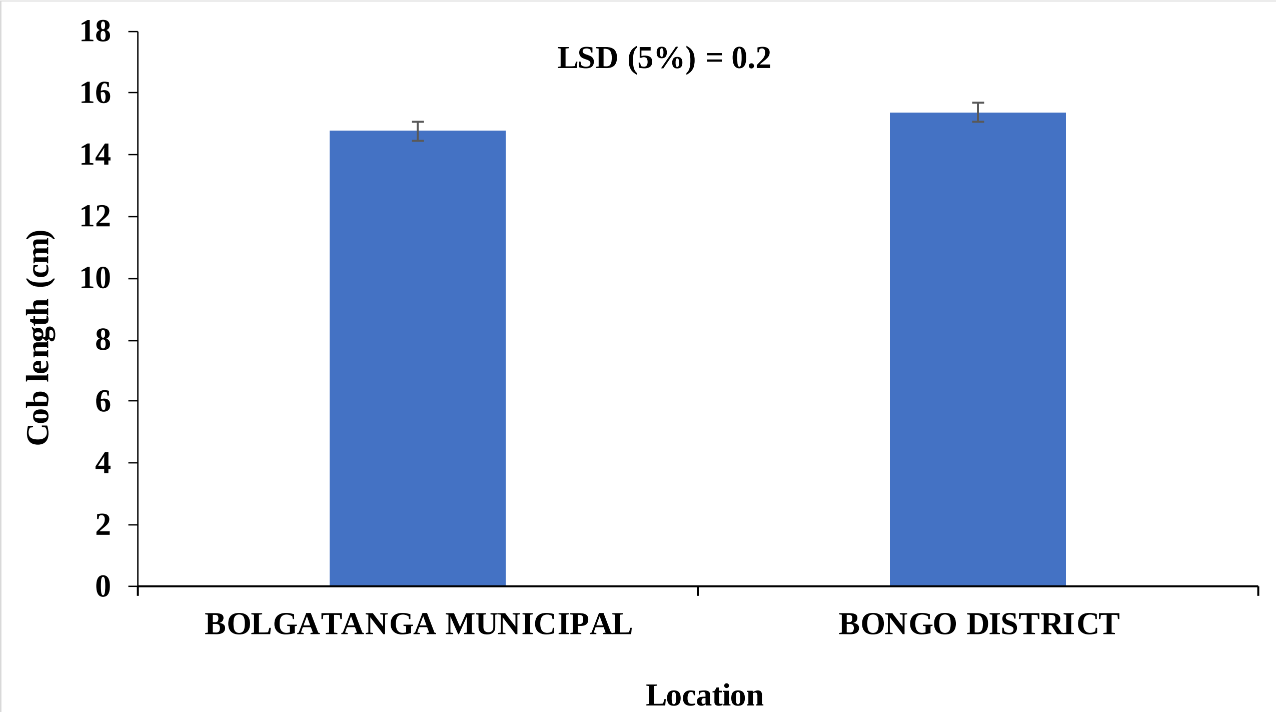

Figure 4.13: Effect of location on cob length of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

Cob grains differed (*P < 0.001*) significantly among the applied treatments. The application of quarternary nutrient elements such as N(P+PR) KS and N(PR)KS significantly increased cob grains weight by 490% and 458%, respectively, compared to the control (Figure 4.14). Also, tertiary combination of nutrient treatments like NPKS and NPK were better compared to the control by 422% and 338% respectively.

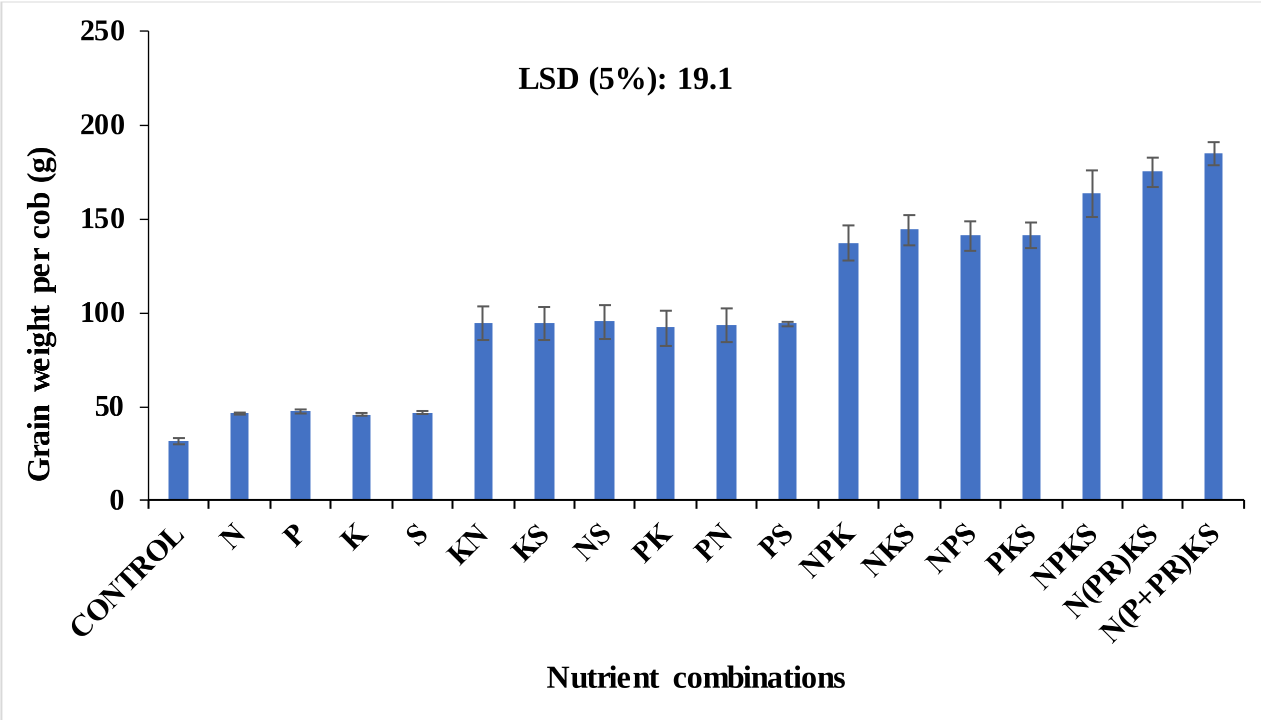

Figure 4.14: Effect of nutrient combination on grain weight per cob of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

The cob grain weight of maize plants were influenced (*P < 0.001*) by location in this study. Unexpectedly, the cob grain weights in plants from Bolgatanga were 18% higher than those from Bongo (Figure 4.15).

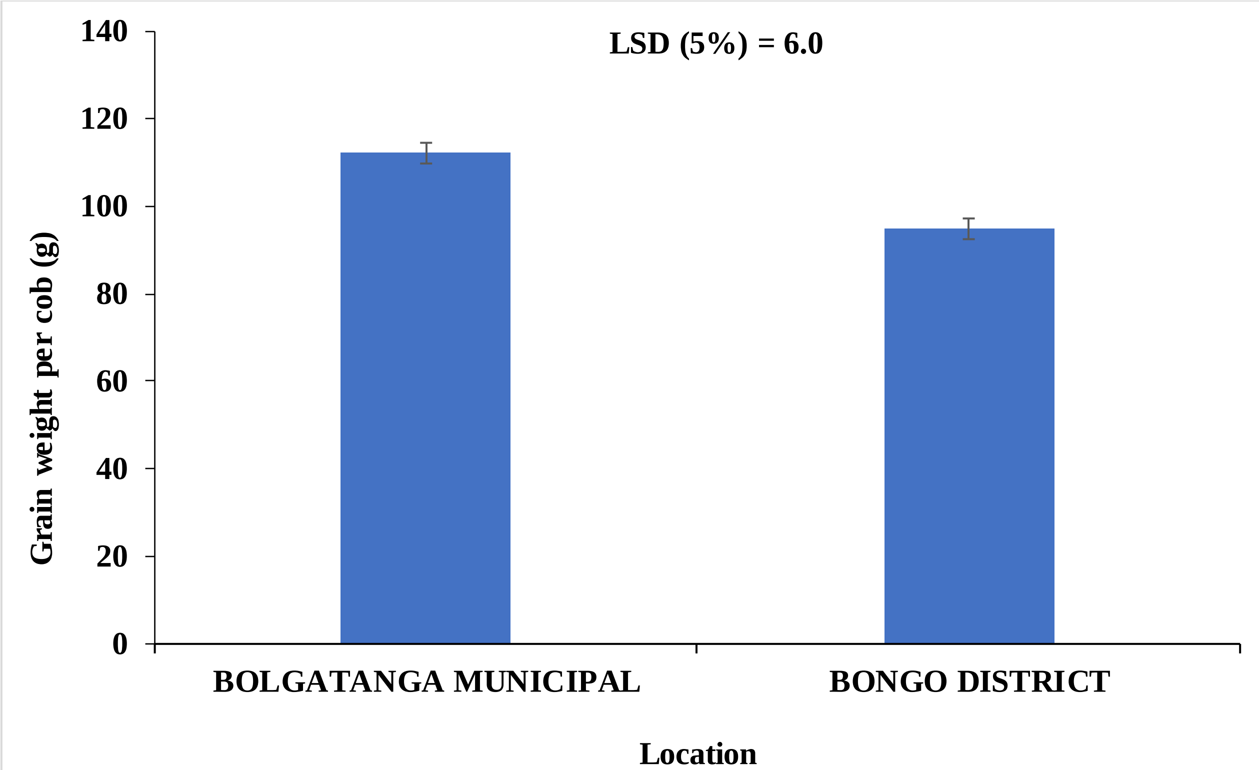

Figure 4.15: Effect of location on grain weight per cob of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

The weight of one maize cob was significantly (*P < 0.001*) affected by either single or more of N, P, K, PR, and S fertilizers. The range was from 87.5 g (control) to 277.2 g (N (P+PR) KS) (Figure 4.16). Quarternary combination of nutrient treatments such as N (P+PR) KS, N (PR) KS and NPKS produced cob weights at least 212% higher than the control. Tertiary combinatoion of nutrient treatments (NPK, NPS, and PKS) increased cob weight by at least 175% when compared to control.

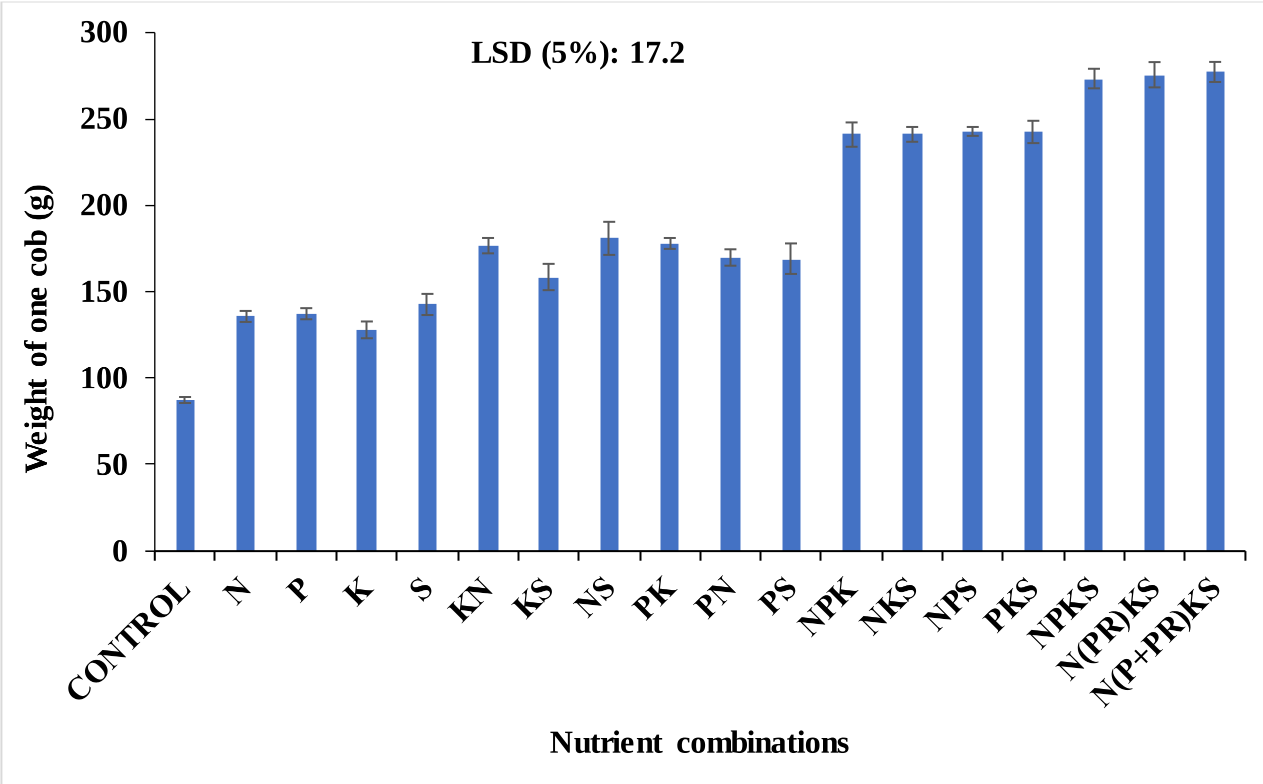

Figure 4.16: Effect of nutrient combination on weight of one cob of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

The number of grains per cob was significantly (*P < 0.001*) influenced by nutrient combinations. All nutrient combinations performed better than the control (Figure 4.17). Minimal variations were noted under the application of N (P+PR) KS, N (PR) KS and NPKS with at least a 279% increase in the number of grains per cob comparable to the control. It was further observed that the higher the number of nutrient elements combined the higher the number of grains per cob recorded.

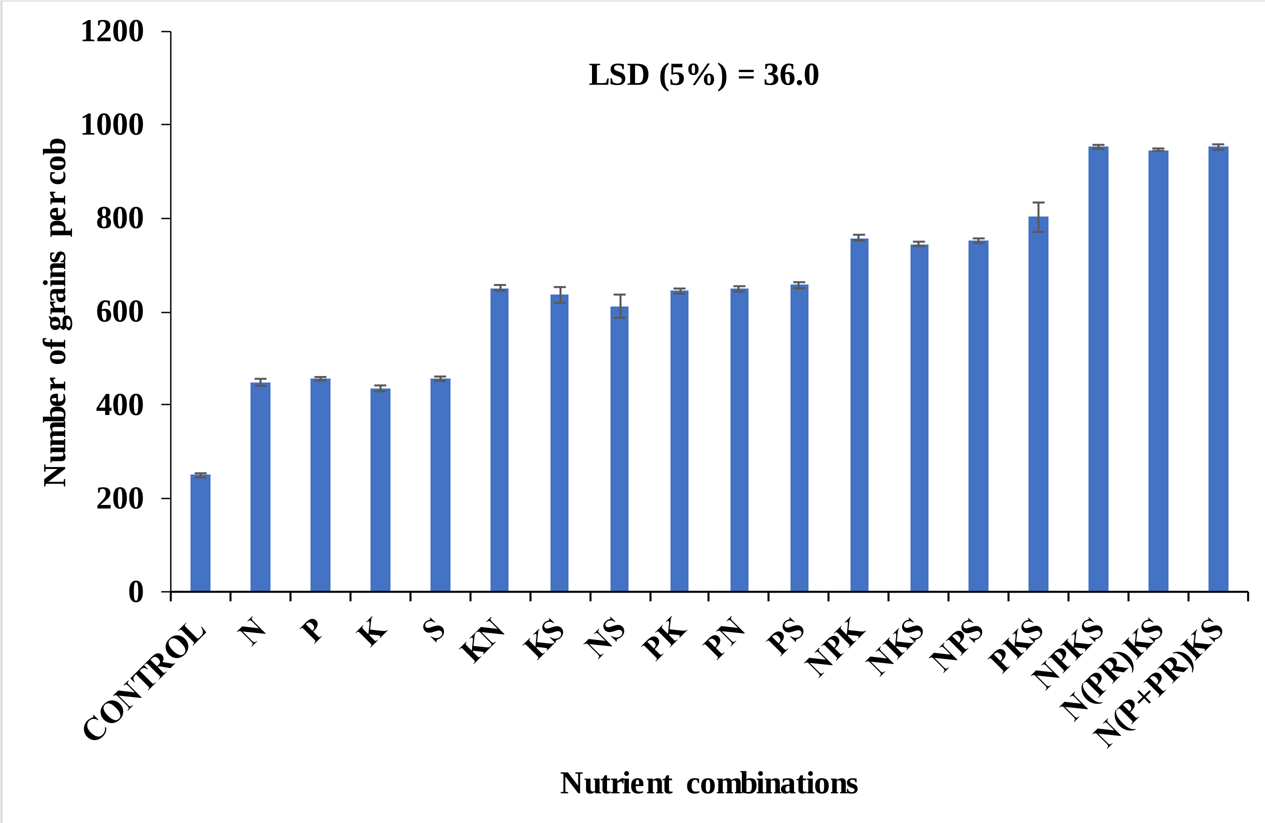

Figure 4.17: Effect of nutrient combination on number of grains per cob of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

4.9 Effect of nutrient combination and location on thousand grain weight and grain yield

All treatments had a significant (*P < 0.001*) influence on thousand grain weight of maize. Thousand grain weights ranged from a minimum of 243.8 g (control) to a maximum of 659.7 g (NPKS) (Figure 4.18). Application of NPKS and N(P+PR) KS enriched thousand grain weight by 171% and 168%, respectively, higher than the control (Figure 4.18). To increase thousand grain weights, the difference between treatments NPK and PKS was only 2% in favor of NPK.

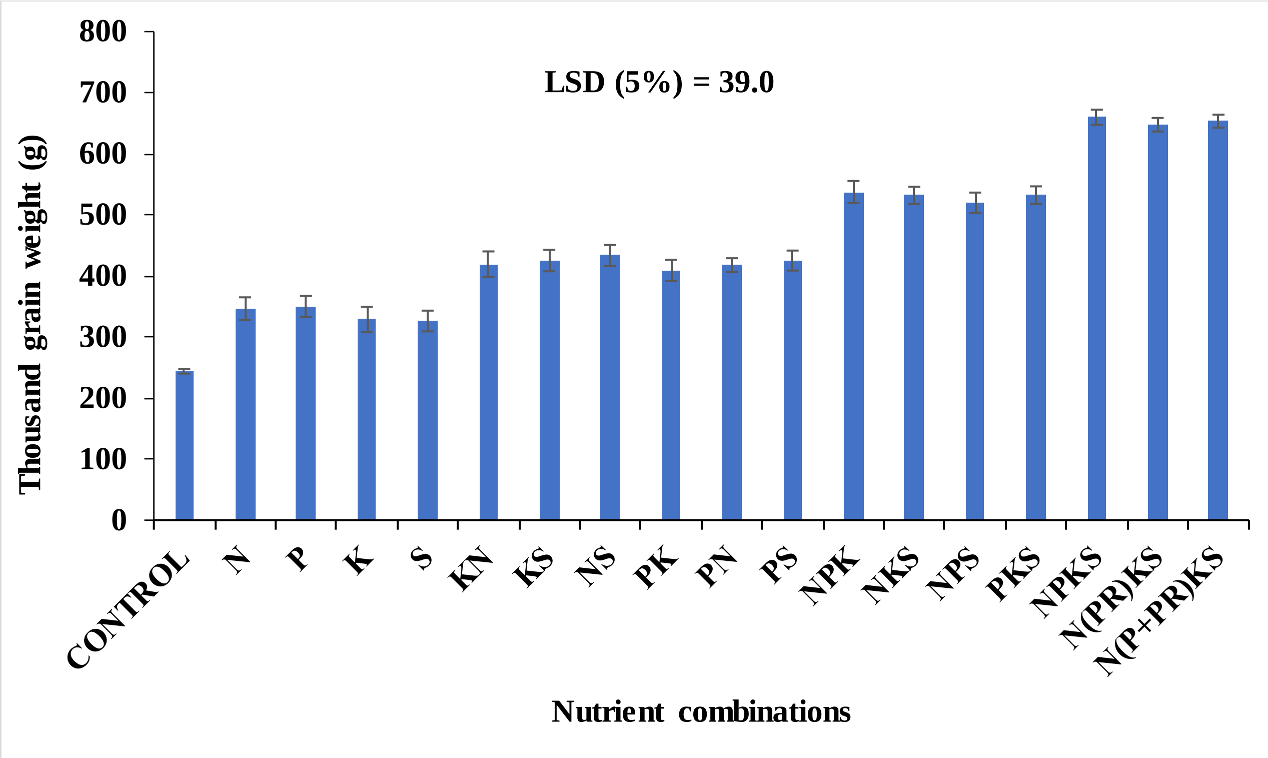

Figure 4.18: Effect of combination of primary nutrients and sulphur on thousand grain weight of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

From Figure 4.19, there was significant (*P* < *0.001*) difference in thousand grain weight with respect to location. At Bongo, the maize plants had at least 8% higher thousand grain weight than those in Bolgatanga sites.

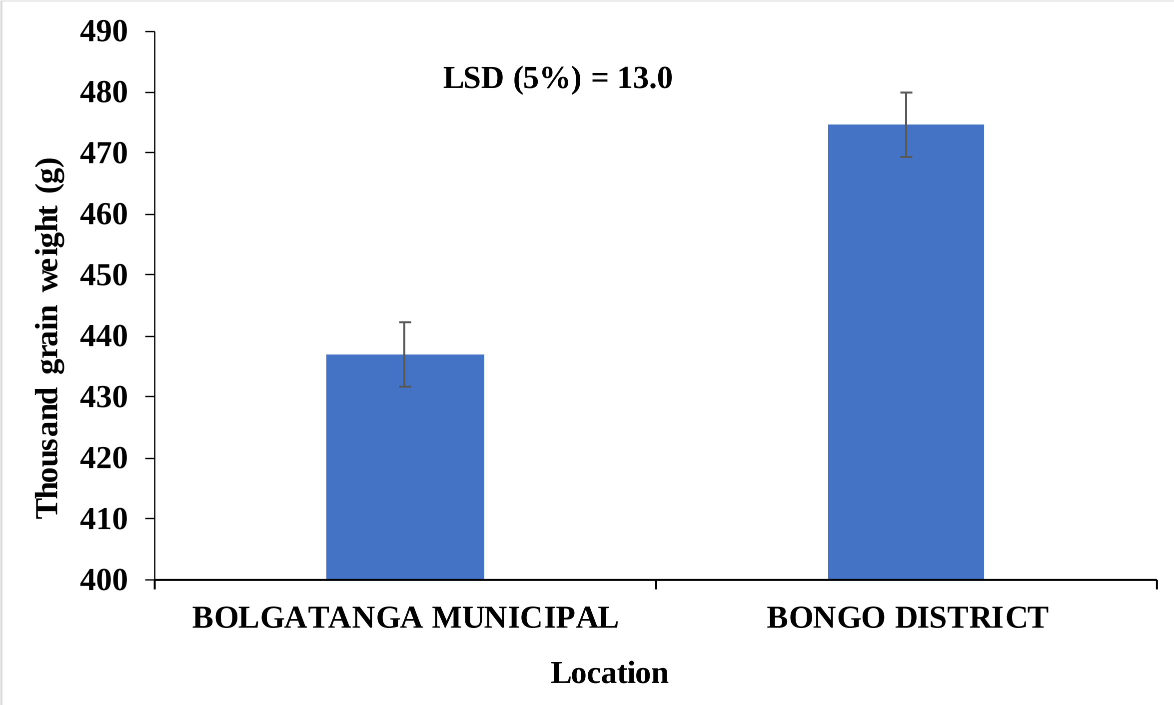

Figure 4.19: Effect of location on thousand grain weight of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

Figure 4.20 shows the interaction effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur with location on the grain yield of maize. The grain yield differed (*P < 0.001*) significantly among the factor combinations due to their interaction effect. The effects of treatments such as N(P+PR) KS and NPKS greatly enhanced grain yield.

Other combined treatments (NPK, N(PR)KS, NPS, PKS, and NKS) had marginal variations as compared to other combined treatments (KN, KS, NS, PK, PN, and PS), but all performed better than the control with no treatment. In addition, the grain yield was relatively higher in the N (P+PR) KS applied plots, followed by N (PR) KS, NPKS and then NPK for both localities (

Figure 4.20). In Bongo, the grain yield was better under the treatments; N (P+PR) KS (868%), NPK (389%), N (PR) KS (313%) and NPKS (313%) when compared to the control. Furthermore, at the Bolgatanga site, total grains yield was higher under the treatments; N (P+PR) KS (1162%), NPKS (935%), NPK (524%) and N (PR) KS (313%) as compared to the control.

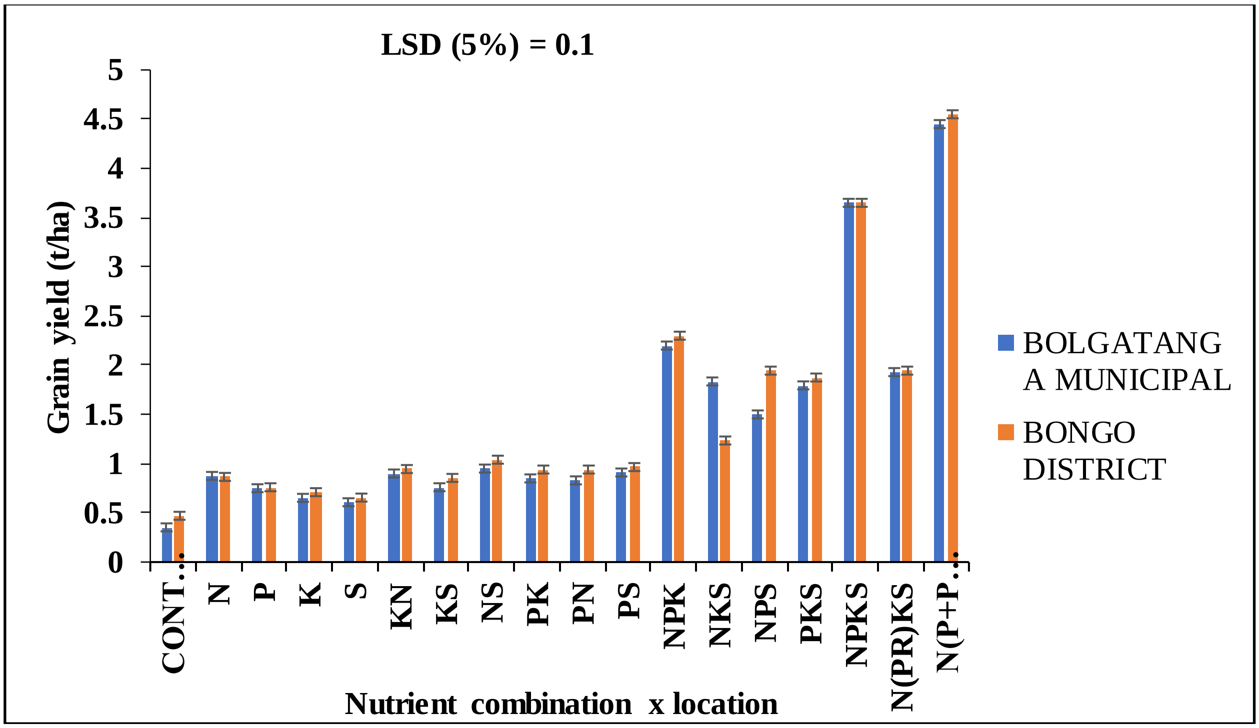

Figure 4.20: The interaction effect of nutrient combination and location on grain yield of Wang dataa maize variety in the Guinea Savannah zone of Ghana during the 2020 growing season. Error bars represent SEM.

4.10 Phenotypic correlation coefficients among selected parameters

Total grain yield was found to be positively related to cob length (r = 0.90; $P < 0.001$), plant height (r = 0.83; $P < 0.001$), number of grains per cob (r = 0.77; $P < 0.001$), cob weight (r = 0.70; $P < 0.001$), and cob grain weight (r = 0.74; $P < 0.001$) (Table 4.2). Also, the correlation between chlorophyll content and plant height was highly significant (r = 0.88; $P < 0.001$)

Cob length was found to be highly correlated with plant height (r = 0.89; $P < 0.001$), thausand seed weight (r = 0.85; $P < 0.001$), and the number of grains per cob (r = 0.75; $P < 0.001$

Table 4.2: Correlation between growth and yield parameters of maize

Parameter	TGY	TSW	PH	TSW	NOGPC	CL	CW	CGW
TGY								
TSW	0.8052**							
PH	0.8311**	0.8406**						
TSW	0.8430**	0.6689**						
NOGPC	0.7741**	0.8458**	0.8152**					
CW	0.7033**	0.7240**	0.7221**	0.6689**				
CL	0.9018**	0.8664**	0.8924**	0.8497**	0.7573**			
CGW	0.7428**	0.8430**	0.8192**	0.8117**	0.7325**	0.8094**	0.7741**	
CHL	0.8370**	0.8698**	0.8778**	0.8262**	0.7359**	0.9241**	0.7741**	0.8458**

*** (Highly Significant P < 0.001) * (significant P < 0.05) NS: Not significant. CCI: Chlorophyll content Index, CGW: cob grain weight, CW: cob weight, TGY: total grain yield, NOGPC; Number of grain per cob, TSW: Thousand seed weight, PH: Plant height, CHL: Chlorophyll content, CL: Cob length*

4.11 Percentage Increase in Yield due to the effect of nutrient combination

There was a significant difference ($P < 0.05$) in the interactions between the fertilizer combination and locations on the percentage increase in yield attributable to the fertilizer combinations. The crops applied with N(P+PR) KS fertilizer combination in both locations recorded the highest average and percentage increase in yield, followed by crops applied with the NPKS fertilizer combination (Table 4.3).

Table 4.3: Percentage Increase in Yield due to the application of combination of primary nutrients and sulphur

Treatment	Average yield (t/ha)	% increase in yield attributable to fertilization	Average yield (t/ha)	% increase in yield attributable to fertilization
CONTROL	0.35	0.00	0.47	0.00
N	0.88	148.40	0.87	84.10
P	0.75	112.90	0.76	61.70
K	0.65	85.10	0.71	51.10
S	0.61	72.40	0.66	39.40
NS	0.95	169.50	1.04	121.20
PS	0.91	158.20	0.97	105.30
PK	0.85	141.10	0.94	99.90
PN	0.83	135.50	0.94	100.00
KS	0.76	115.60	0.86	81.90
KN	0.90	155.40	0.95	101.00
N(P+PR) KS	4.45	1162.90	4.55	868.30
N(PR)KS	1.93	447.60	1.95	313.90
NKS	1.84	420.60	1.24	162.80
NPK	2.20	524.40	2.30	389.10
NPKS	3.65	935.90	3.65	676.70
NPS	1.50	325.00	1.95	313.80
PKS	1.80	409.30	1.88	299.00
LSD	**0.11**	**32.65**		
%CV	**5.5**	**8.9**		

CHAPTER FIVE

DISCUSSION

5.1 Soil Nutrients Analysis

Notwithstanding the initial levels of N (>702 mg kg^{-1}), K (>402 mg kg^{-1}), S (< 52 mg kg^{-1}) and P (>37 mg kg^{-1}) in soil samples at Bolgatanga and the initial levels of N (>701 mg kg^{-1}), K (>401 mg kg^{-1}), S (< 401mg kg^{-1}) and P (>36 mg kg^{-1}) (Table 4.1) for soil samples in Bongo field, the application of S with N, P, K fertilizer did influence the results significantly with increase in maize growth and yield characteristics. The observation might be attributed to adequate supply of the required elements for crop growth especially with regards to S (Omara *et al.*, 2020). Different investigations have found a similar impact of S (Baker *et al.*, 2018; Lollato *et al.*, 2019). Furthermore, it was observed that in sandy soils with more than 1% soil organic matter, a response to S was unlikely (Lollato *et al.*, 2019). Jaliya *et al.* (2015), on the other hand, found a contradictory study in which 5-15 S (kg ha^{-1}) generated high maize grain production in Nigeria. A similar discovery was made in Malawi, where the use of S rates of 5-10 kg ha^{-1} resulted in optimum maize grain yields (Alkharabsheh *et al.*, 2021). Bongo soil had the best growth and development qualities.

5.2 Nutrient combination and plant height

It was observed from the results that increasing the number of elements in a formulation improved plant height. This supports the observations of Olowoboko *et al.* (2017) which showed that maize plants treated with two elements did not perform well as compared to those treated with three elements at optimum rates. Elimination of some elements from the fertilizer formulation must be the reason for such observations. The applications of a full regiment of nutrients have been observed to trigger increase in height of maize plants (Kugbe *et al.*, 2019; Sun *et al.*, 2020). The application of the sole nutrients, such as N, P, K and S, enhanced plant height similarly but all performed better than the control. The application of one nutrient, though not ideal, might have increased the nutrient status of the soil, making plants perform better than those in the control treatment with no fertrilization. Furthermore, the presence of some nutrients enabled the absorption, uptake and utilization of other nutrients. Ogunsola and Adetunji (2016) observed a synergistic relationship between P and S which relied on the concentrations of each. Oladele *et al.* (2019) observed that plant height had been influenced by sole application of N, P, K and S in a similar way as observed in this experiment. As previously stated, the application of two nutrients had better effect on the height of maize plants compared to sole nutrients and treatments with not fertilization, except for NS. Treatment NS caused similar performance as treatment K. This could be due to the enhanced potassium levels in the soil causing a higher absorption of other major nutrients by the crop. The application of NP caused the highest performance in plant height among the binary combinations, indicating the need for N and P nutrient incoporatrion for maize production in the soils of the study area. The application of NK caused statistically similar performance as NP. The combination of N with a primary major nutrient could have boosted the growth of plants because the high plant growth noted for NP and NK was not observed in NS. However, in the study of Olowoboko *et al.* (2017), PK also triggered a similar performance to that of NP and NK.

For the tertiary combination of primary nutrients, treatment NPK caused the highest plant height among the combinations. Presence of the full complement of the primary nutrients might have been the cause for the observed higher plant height as compared to NPS, PKS and NKS treatments. Though S is an important element, its application could not mask the absence of the other primary nutrients investigated. Ajeng *et al.* (2020) observed that the application of NPK improved the height of maize plants better than S application but they didn't investigate the effect of other tertiary combinations. With regards to the quaternary combination, the N(P+PR) KS produced the highest plant height for all the weeks observed. The combination of rock phosphate and TSP, which have different levels of P availability, could have caused the higher growth in height compared to the other treatments. As rock phosphate release phosphorus much slowly into the soil, TSP can provide readily available phosphorus for immediate plant use, followed by the slow release of P from rock phosphate as growth progresses. These might have resulted in relatively available P, released from the rock phosphate at later stages of growth for uptake by the plant. The application of S to the rock phosphate in the treatment might have also resulted in increased acidity around the banded N(P+PR)KS fertilizers, causing activation of the applied rock phosphate and making the relatively unavailable P nutrients more available to the plants at later stages of growth as also observed by Waleed *et al.* (2020). Dhruw *et al.* (2017) also made similar observations with respect to the effect of NPKS on the height of maize when compared to NPK.

5.3 Impact of nutrient combination on leaf number

The nonsignificant differences observed among P, N, K and S treatments for leaf number of maize indicate that sole elemental applications might not be enough to statistically influence the number of maize leaves produced. The control caused the least leaf number among the treatments. A similar observation was made by Baiyeri and Aba (2015) when investigating fertiliser nutrient effects on two plantain and maize genotypes. Though PK produced the highest mean observed for number of leaves among the binary combinations, the application of NP, PK, NK, NS, PS and KS also did not significantly differ from that observed for the control. The application of NP in the research by Olowoboko *et al.* (2017) however produced higher number of leaves compared to PK and NK. Potassium (K) is considered to be the second most abundant among the three primary nutrients (Sardans and Peñuelas, 2015) and thus applying NP could have been enough to enhance bud initiation and consequently leaf formation, better than the other combinations where either N or P was absent. This was expected but was contrary to the findings of this research probably due to other soil characteristics like pH which might have affected nutrient availability and subsequent uptake.

NPK and NPS had 37% and 35% more leaves respectively than the control. NKS and PKS however caused a similar performance in leave number compared to the control. The common denominator for the two treatments that caused a better performance than control is the presence of N and P. Olowoboko *et al.* (2017) identified that N applied together with P and K influenced the number of leaves of maize in their study. This might have been the cause as NP alone, as observed, did not cause significant differences in leaf number but was able to do so in combination with one other element- K or S. The result also shows a likely synergistic effect of either K or S with NP fertilization for leaf formation. With regards to the quaternary combination of the elements, all three treatments caused higher number of leaves compared to the control. A full complement of the nutrients might have been met, thereby enhancing the metabolic reactions within the maize plant and causing the production of tissues that are necessary for better growth and development. This is in consonance with the findings of Dhruw *et al.* (2017).

5.4 Impact of nutrient combination on leaf area

Among the elements solely applied, K alone caused a similar performance as that of the control. From the study N, P and S caused higher leaf areas compared to the control by 53%, 48% and 48% respectively. Leaf area is very important as the amount of light absorbed by plants for photosynthesis is affected by the leaf area (Hu *et al.*, 2020). The findings of Baiyeri and Aba (2015) differed in this respect as application of single nutrients did not cause significant differences in leaf area when compared to each other and to the control. Considering the combination of two elements, KS had the highest mean leaf area but was statistical similar in performance to all the other binary combinations. All treatments enhanced leaf area compared to the control by at least 110%. The combination of at least two elements might have enhanced the rate of metabolic activities necessary for increase in leaf area compared to the control which might have had less concentration of these elements. Other soil related factors may be involved because NP was observed to cause better performance compared to NK and PK by at least 322% (Olowoboko *et al.*, 2017).

The combination of three elements was also observed to have better performance compared to control by at least 154%. They also caused a better performance compared to the sole-nutrient and binary nutrient applications. The NPK caused the highest leaf area among this group though NPS caused a similar performance as NPK. With regards to NPK, the presence of full complement of the primary nutrients might be the cause for this response. As the ample concentrations of the nutrients were made available, plants fertilized with NPK might have responded favorably by developing broader leaves to absorb more light to keep up with the energy requirement of the plant. Oladele, (2019) observed that, NPK triggered a 96% increase in leaf area compared to control. Elka and Laekemariam (2020) also identified the effectiveness of NPS in improving the leaf area of haricot bean. Observing the quaternary combinations, N(P+PR) KS treatment caused the highest leaf area among all the treatments except for NPKS. N(PR)KS caused a similar performance to NPK only. As P is more available in the inorganic form, this could be the reason for N(P+PR) KS and NPKS performing best among the treatments. The growth of plants can be affected by the period of growth at which nutrients are made available to them. Inorganic sources make nutrients readily available for ready uptake of P to boost the enlargement of their leaves. The phosphate rock in N(P+PR)KS might have gradually released P into the soil to allow plants to absorb P during later stages of growth, resulting in the highest mean leaf area observed. Havlin *et al.* (2014) and Waleed *et al.* (2020) also observed that addition of sulphur improved the leaf area by increasing the absorption of NPK applied to maize.

5.5 Impact of nutrient combination on the chlorophyll content

Among all the nutrient combinations, the control had the least leaf chlorophyll content for maize. Figure 4.6The sole-nutrient applications caused a better performance (41%) when compared to the control. However, they performed similarly when compared to each other in all the weeks of observation. The application of one element might have not been sufficient enough to cause different performances among the treatments with regards to leaf chlorophyll content. Guo *et al.* (2020) observed similarly that the application of one element was not sufficient to trigger differences in vegetation index for chlorophyll estimation in maize.

NP caused the highest mean chlorophyll among the binary combinations but its performance did not differ from that of the other binary combinations. Also, NS and KS performed similarly to sole-N application. All binary combinations caused higher leaf chlorophyll content than the control with no fertilization. The higher production of chlorophyll in the sole-nutrient application as compared to the control might be due to availability of nutrients that complement each other when taken up by plants. The N and P for example have been observed to have such a trend with crop growth parameters (Olowoboko *et al.*, 2017; Ray *et al.*, 2019). It was however observed by Zhang *et al.* (2021) that NP produced higher chlorophyll content in maize plants than NS and KS.

NPK caused the highest performance among the three-element combinations. NKS and PKS caused similar performance to NP application but all of the tertiary nutrient combinations performed better than the control by at least 73%. An observed trend was that the higher the number of nutrients available, the higher the leaf chlorophyll content. NPK application might have enhanced the production of leaf chlorophyll by enabling the plant to increase the absorption of other nutrients, like Mg which is an important component of the chlorophyll molecule. Van Nguyen *et al.* (2022) observed that NPK application increased the performance of leaf chlorophyll content in maize plants when compared to the control. When observing the quaternary combinations, N(P+PR) KS treatment caused the highest leaf chlorophyll content among all the treatments. As P is known to be important for energy production, transfer and storage, the combined use of TSP and phosphate rock might have increased the availability of P during the growth of the crop. Also, the application of S in addition to the primary nutrients could have enhanced nutrient availability to plants and consequently increased the rate of leaf chlorophyll production. Dhlamini *et al.* (2020) bserved similarly that NPKS application triggered higher chlorophyll content compared to the control.

5.6 Impact of nutrient combination on biomass yield

The influence of sole-nutrient application was realized as the application of N, P, K and S solely enhanced both fresh and dry biomass yield of maize when compared to the control with no fertilization. The sole application of N, in particular, caused the highest fresh and dry biomass of maize among the single-nutrient combinations. It performed 39% and 34% better than control with regards to fresh and dry biomass yields respectively. N is an important component of amino acids which serve as structural building blocks for living organisms and the higher biomass of plants fertilized with N solely, might be attributed to the higher production of these acids than in the sole-application of the other elements. Sole application of S caused the least fresh and dry biomass yield among the solely applied nutrients which might be as a result of the lesser contribution of S in structural composition of the plant compared to N and P. Qahar and Ahmad (2016) observed that the biological yield of maize plants was affected by N application and lesser impact was observed for S application, but they both performed better than a control with no fertilization. Baiyeri and Aba (2015) however did not observe significant differences among single-nutrient applications and control with regards to dry matter yield per plant for plantain.

All the binary combinations of the nutrients did better than the sole-nutrient applications and control. NP, NS and NK performed better than the other binary combinations, and performed statistical similar among themselves. The presence of N in each of the combinations could be the reason for their higher performance compared to PK, PS and KS. The combination of N with another nutrient might have boosted the effect of N, the other nutrient or both. It was however observed by Olowoboko *et al.* (2017) that NP produced higher shoot and root weight in maize plants than NK and PK. Treatment NPK produced higher fresh and dry biomass yield than the other tertiary combinations of the elements. It also produced at least 190% more biomass yield than the control with no fertilization. The application of NPK might have enhanced cell metabolism due to the presence of readily available primary nutrients for better growth and development. Thuriès *et al.* (2019) observed that NPK application increased the shoot and root weight of maize plants by up to 888% when compared to a control with no fertilization. Elka and Laekemariam (2020) also observed higher fresh weight of maize and haricot bean with NPS application in comparison to a control treatment with no fertilization.

Observing the quaternary combinations, treatment N(P+PR) KS caused the highest fresh and dry biomass of maize among the treatments. NPKS caused a similar performance as N(P+PR) KS but only for the dry biomass. This observation may support the need for combining both organic and inorganic sources of nutrients in fertilization schemes.

Phosphate rock releases P slowly into the soil which may not be favorable for immediate uptake by the crop. This might be the reason for N(PR)KS treatment producing the least biomass among the four-element combinations. N(P+PR)KS treatment production of the highest biomass might be attributed to the ready availability of inorganic P needed by the plants; thus causing the luxurious growth and development of maize plants. Dhlamini *et al.* (2020) observed a similar outcome comparing NPKS and control.

5.7 Impact of nutrient combination on cob weight

Sole N produced the highest fresh and dry cob weight among the sole-nutrient applications. However, sole P and sole K performed similarly. Sole N and sole P performed better than the control for both parameters while sole K performed better than control for dry cob weight. As observed with the biomass yield, the high performance of sole N shows the relevance of N in increasing the dry matter content of plants. The plants fertilized with N could have produced bigger cobs due to the higher availability of N. The grains of those plants could have also been well filled as a result. The application of N caused a 42 % increase in 1000 grain weight. A similar observation was made by Yuniwati and Lestari (2021) who investigated fertiliser nutritional effects on corn cob.

For the binary combinations, the application of NS was found to have the highest fresh and dry cob weight but NP application also showed a statistical similar result. It was observed that N was common among high performing binary combinations. This observation could have been that the N assisted the other nutrients or vice versa to enhance cob size and grain filling, thereby increasing the weight of the maize cobs. Admas *et al.* (2015) had similar findings where NP performed better than PS. Observing the tertiary combinations, with regards to the fresh cob weight, NPK, NPS, NKS and PKS had similar performances. When it came to the dry weight of cobs, NPK had the highest dry weight of maize cobs, showing the importance of the primary nutrients in increasing maize productivity. The similarity in fresh weight could have been due to the moisture in the grains at harvest. The differences in dry weight however could be due to the enhanced dry matter accumulation assisted by the availability of N, P and K which are essential for maize growth and reproduction. Enhanced nutrient uptake could also be the reason for heavier cobs as this brings about heavier grain filling (Ray *et al.*, 2019). A similar observation was made by Kareem *et al.* (2020) where NPK was observed to perform better than control by 37%. The N(P+PR) KS treatment caused the highest cob weights among the quaternary treatments. When compared to control, N(P+PR) KS treatment had 260% and 294% more fresh and dry cob weight respectively. This could be as a result of a higher amount of N absorbed with the application of S. Cellular enlargement and differentiation requires energy and nutrients which could have been supplied by N(P+PR) KS treatment, resulting in the observed higher cob weight. The research of Jazaeri *et al.* (2016) indicated that S application increased P availability and P uptake. This indicates that S application could have further enhanced the availability of P in phosphate rock at faster rate than that which occurs without S, thereby increasing productivity of maize.

5.8 Impact of nutrient combination on cob length

The sole application of S produced the highest cob length among the single-nutrient applications. The N, P and K had similar influence on cob length when compared to each other and all treatments caused better performance than the control. The result for S could be due to its ability to aid in N absorption in adequate levels to influence cob lenght. This observation is uncommon for this experiment as sole N application has been the main factor of influence on most growth and yield parameters. The synergistic relationship between N and S might have improved cob length rather than the availability of S alone. Jassim and Rahim-Hariz (2019) observed that S application influenced the length of maize ears which was better than not applying fertilizer at all. Treatment NP triggered the highest mean cob length recorded, but its influence was not significantly different from that of the other binary combinations. Improved photosynthetic ability and cellular metabolism due to application of two nutrients could have influenced the increase in cob length. However, NS and KS caused similar performance as sole S application. It appears likely, that the application of S with either N or K could not sufficiently influence intracellular activities to enhance cob length than sole S application. The highest mean cob length was caused by the application of NPK but a statistical similar performance was observed for the other tertiary combinations. This observation could be due to the availability of more complementary nutrients. It could be that the application of three nutrients had a synergistic effect in enhancing the cob length of maize. Jassim and Rahim-Hariz (2019) and Kareem *et al.* (2020) also found that NPK application enhanced maize cob length better than the control.

N(P+PR) KS treatment caused the highest cob length among the quaternary combinations. It was followed by the performance of NPKS treatment. The combined application of both organic and inorganic sources of P could have been the cause of the enhanced cob length. There was a 10% increment when N(P+PR) KS was applied compared to NPKS which likely means that the inorganic P and rock phosphate combination influenced cob length better than sole application from either sources of P. Jassim and Rahim-Hariz (2019) also found that NPKS application recorded the highest maize cob length among NPK and S treatment combinations.

5.9 Impact of nutrient combination on one-cob weight and grain weight per cob

As observed with cob length, the sole application of S caused the highest one-cob weight but in this case, the other sole nutrient applications caused similar performances. All treatments performed better than the control. The application of S might have caused better grain filling as a result of higher absorption of N. With regards to grain weight per cob, P had the highest mean value but also performed statistically similar to the other sole applications. Sole nutrient applications could have been able to enhance the weight of the grains as well as the cob better than control but performed similarly with each other. Keteku *et al.* (2021) observed that N application rates enhance the weight of the grains as well as the cob better than control. Among the binary combinations, NS produced the highest one-cob weight and grain weight per cob, but as observed with the sole-nutrient applications, the other combinations also performed similarly to NS. The N-S synergistica relationship might be a contributory factor to the higher mean value of NS applied treatments. However, since the other binary combinations expressed similar results in their effect on grain weight per cob, the N-S relationship may not be the only factor. Probably, the application of two nutrients was sufficient enough to cause increase in the amount of grain filling and cob biomass compared to single-nutrient applications. Furthermore, the number of grains could have also contributed to this result, as the higher the number of well filled grains, the higher the resultant grain weight per cob and one-cob weight. Artyszak and Gozdowski (2020) observed that NS dose in maize significantly produced high cob weight as well as grain weight per cob compared to sole nutrient applications and controls with no fertilization. NKS triggered the highest one-cob weight and grain weight per cob. The NPK, NPS and PKS also produced statistical similar results with that of NKS. Furthermore, they performed better than the single and binary combinations of the elements which can be attributed to the higher nutrient availability that a tertiary combination contributes compared to the lower levels. This enhanced nutrient availability might have improved cellular metabolism and reproductive activities of the plants contributing to more and heavier grains. Jassim and Rahim-Hariz (2019) and Kareem *et al.* (2020) also found that NPK and other tertiary applications enhanced maize cob weight as well as grains weight per cob better than the control treatment. The highest grain weight per cob was produced by the N(P+PR) KS treatment among the quaternary combinations. The other combinations performed less than N(P+PR) KS but caused similar performances when compared to the tertiary combinations with respect to grain weight per cob. However, with regards to one-cob weight, N(P+PR) KS and N(PR)KS produced statistical similar results. The better performance of N(P+PR) KS could be be attributed to combined application of inorganic P and phosphate rock. As observed in the results, NPKS and N(PR)KS could only trigger results similar to those of tertiary combinations with respect to grain weight per cob which could imply that the inorganic and organic sources of P alone would not contribute significantly in quaternary combinations. Looking into the cob weight, phosphate rock may have contributed to heavier cobs probably due to its slow release of P, making P available even during the silking stage when cob formation can be affected by nutrient availability. Jassim and Rahim-Hariz (2019) also found that NPKS application recorded the highest maize cob length and weight as well as grain weight per cob among NPK and S treatment combinations.

5.10 Impact of nutrient combination on number of grains per cob

All sole nutrient treatments performed significantly better than control by at least 75% which shows that application of a nutrient can have an influence on plant development during silking. The sole application might have enhanced cellular activities and improved upon cell division in plants in comparison with those in control plots. Hasan *et al.* (2018) found that the application of one element is sufficient enough to trigger higher number of grains per cob in maize than the control. The insignificant differences observed among the binary treatments show some level of complimentarity between the nutrient elements. Treatment PS and the other binary treatments performed significantly better than the single-nutrient applications. Binary nutrient application might have had a better influence on the silking process probably by increasing the number of silks and enhancing cob size to accommodate more grains. The findings contradicts that of Admas *et al.* (2015) where NP was observed to produce significantly higher number of maize grains per cob compared to PS. Tertiary PKS treatment triggered the highest number of grains per cob but performed statistically similar with the other tertiary combinations. The application of two and three elements did not show significant differences for some of the combinations. The higher value for PKS might be as a result of S allowing for more absorption of N from the soil by the plant which in combination with the other elements, not available in the other tertiary combinations, improved the number of viable embryos. This could have resulted in a higher grain count in cobs unlike those from control plots. NPK was found by another study to produce higher number of rows per cob and number of kernels per row compared to control (Kareem *et al.*, 2020). Considering the quaternary combination of the nutrients, N(P+PR) KS treatment produced the highest number of grains per cob. The other two treatments performed similarly but could not catch up with N(P+PR) KS. The different sources of P could be the reason for the differences observed, as they all had same quantity and source of N, K and S applied. An increased P availability in phosphate rock by the application of S (Jazaeri *et al.*, 2016) might have also contributed to this finding.

5.11 Impact of nutrient combination on thousand grain weight and grain yield

The sole application of P produced the highest value for 1000 seed weight among the single nutrient applications with the others also showing similar performances. The control had the least 1000 seed weight and grain yield among the treatments in this study. The highest grain yield was however produced by sole N application which caused a 112% increment in yield unlike P application which triggered an 84% increment in yield over the control. The application of N might have had a higher impact on the reproductive development of the maize plants. It was expected that at least P would have performed similarly with N with respect to grain yield as observed in most of the other growth and yield parameters. There might be underlying intrinsic factors within the maize, like phenotypic expression that could account for the observed differences. Nurudeen *et al.* (2015) observed that N rates affected the grain yield of maize significantly but application of P or K did not. The binary combinations of the nutrients performed statistically similar with regard to 1000 seed weight, though NS produced the highest mean. NS also produced the highest grain yield which was 142% higher than the grain yield for control. The NP, PK and PS performed statistically similar to the NS. The application of N and S might have been sufficient enough to enhance growth and development resulting in increased grain yield. It was observed that NS treatment produced high values for fresh and dry cob weight, one-cob weight and grain weight per cob. Since there was a significant relationship between grain yield and these parameters, this implies that NS application was able to influence grain yield among the binary combinations tested. In the study of Essel *et al.* (2020), the PK, NK and NP treatments influenced maize grain yield in a similar manner which partially supports the findings of this research where NK and NP produced similar grain yield. In the research of Bua *et al.* (2020), a dissimilar outcome was observed where NP, NK and PK had triggered average grain yields of 3.2, 2.5 and 2.0 t/ha respectively. The NPK triggered the best performance with respect to 1000 seed weight. The 500-grain yield was enhanced by the application of NPK in a research by Jassim and Rahim-Hariz (2019). Regarding grain yield, NPK caused the highest grain yield. When compared to control, the increment in yield observed was 447% which was similar to the observations made by Ray *et al.* (2019). The application of N, P and K at the rate of 60-90 kg, 60 kg and 60 kg per ha respectively improved yield of maize significantly in the semi-deciduous zone of Ghana (Essel *et al.*, 2020). The PKS treatment had the second-best performance followed by NPS. The NPK contained the three primary nutrients that need supplementation when deficiency is observed. The S is among the secondary nutrients and thus, the effect of its absence was not observed in grain yield. Maize growth and development might have been boosted by the presence of N, P and K which resulted in better maize yield. A similar observation was made in the study of Ajeng *et al.* (2020) with regards to lowbush blueberry and maize. It was further observed by Ray *et al.* (2019) that grain yield of NP, NK and PK treated plots were lesser than that of full dose of NPK by 27, 17 and 44% respectively.

The best performance with regards to grain yield was influenced by N(P+PR) KS with grain yield increment of 994%. The NPKS followed with an increment of 788% when compared to control. All the quaternary combinations performed statistically similar with regards to 1000 seed weight. The results of grain yield for N(P+PR) KS treatment was to be expected due to the treatments influence on the other measured parameters. The result in table 4.4 further supports this trend. In the research of Waleed *et al.* (2020), the application of NPK with S resulted in a 24.4% higher 500-grain weight than the control. It also triggered a better 500-grain weight compared to control in the study of Jassim and Rahim-Hariz (2019). This supports another observation in this study that NPK applied with S triggered a better performance than NPK without S. Dry matter increase in grains which was found in the enhanced plant height and higher cob weights might be due to higher production of photosynthetic assimilates which could have been stored in the grains. Waleed *et al.* (2020), also made a similar observation with grain yield. Furthermore, Bua *et al.* (2020) observed an average grain yield of 4.0 t/ha for sites treated with NPKS which was the highest compared to the other treatments.

5.12 Correlation among growth and yield parameters

Correlation coefficients were computed for plant height, number of grains per cob, thousand seed weight, cob length, one cob weight, cob grain weight, chlorophyll content and grain yield. The correlation coefficients reveal that as the plant grows taller, it has a better chance of generating more leaves, which improves photosynthetic activities and might lead to larger grain yields (Kuntoji *et al.*, 2021). This is in line with research by Ezeagu *et al.* (2017), who found that plant height is an important yield determinant. This is because as the plant grows taller, more leaves are produced resulting in increased chlorphyll production, contributing to photosynthetic activity and final grain yield. A study by Yigermal *et al.* (2019) also reveals that these growth parameters are important determinants of grain yield in maize, since higher plants and larger values of the other parameters results in more cobs and yield.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

From this study, the application of at least one of the nutrients (N, P, K or S) is better than not applying any fertilizer amendment. The results have showed that the application of at least one element can significantly affect maize growth and yield parameters. Also, increasing the number of nutrients applied caused a corresponding enhancement in maize growth and yield parameters but tended to depend on the types of nutrients combined. Sulphur application can improve the performance of maize plants in combination with NPK; the inability to apply S drastically reduced yield by at least 62%.

From the study, the application of N caused the highest maize grain yield among the single nutrient applications. Its application enhanced yield of maize better than the other nutrients. In resource constrained situations where only one nutrient type can be afforded, the results show that application of N had the best agronomic productivity in growth and yield parameters among the single nutrient applications. The application of NS among the binary combinations proved to influence most of the yield parameters than the other treatments. The NP and NS applications were the best among the binary combinations of N, P, K and S in relation to their effect on the agronomic productivity in growth and yield parameters of maize.

The application of NPK treatment at the tertiary level had the highest influence on the yield of maize due to the presence of the three primary nutrients. Therefore, NPK application can cause the best agronomic productivity in growth and yield parameters of maize among the tertiary combinations of N, P, K and S.

The application of N(P+PR) KS treatment was observed to cause the best performance for most growth and yield parameters of maize and thus is the best performing quaternary combination of N, P, K and S. The application of N(P+PR) KS treatment can improve the yield of maize as that is the issue of highest concern to smallholder and commercial farmers.

6.2 Recommendation

Apllication of NPK and S to maize production resulted in the best growth and yield parameters. As such, the four elements are recommended for fertilizer formulation for maize growth and production. This research recommends an investigation concerning the agronomic productivity in growth and yield parameters of other crops like soya bean and yam due to the applicaton of sole, binary, tertiary and quaternary combinations of N, P, K and S. There is also limited literature on some of the parameters investigated on maize in this study which subsequent research can be done in order to confirm or contradict the findings of this research. The research further recommends that smallholder farmers having nutrient-deficient lands who cannot afford compound fertilisers may apply NP or N fertilisers at lower cost for yield enhancement.

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APPENDICES

Appendix 1: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on plant height of maize 2 week after planting.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	93.521	31.174	28.65	
REP.*Units* stratum					
LOCATION	1	31.174	31.174	28.65	<.001
Treatment	17	913.035	53.708	49.37	<.001
LOCATION.Treatment	17	3.201	0.188	0.17	1.000
Residual	105	114.229	1.088		
Total	143	1155.160			

Appendix 2: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on plant height of maize 4 week after planting.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	682.076	227.359	28.81	
REP.*Units* stratum					
LOCATION	1	232.562	232.562	29.47	<.001
Treatment	17	6734.618	396.154	50.20	<.001
LOCATION.Treatment	17	20.563	1.210	0.15	1.000
Residual	105	828.674	7.892		
Total	143	8498.493			

Appendix 3: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on plant height of maize 6 week after planting.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1168.74	389.58	27.96	
REP.*Units* stratum					
LOCATION	1	390.06	390.06	27.99	<.001
Treatment	17	11555.45	679.73	48.78	<.001
LOCATION.Treatment	17	34.06	2.00	0.14	1.000
Residual	105	1463.01	13.93		
Total	143	14611.33			

Appendix 4: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on plant height of maize 8 week after planting.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1434.52	478.17	28.96	
REP.*Units* stratum					
LOCATION	1	465.84	465.84	28.21	<.001
Treatment	17	13694.95	805.59	48.79	<.001
LOCATION.Treatment	17	52.78	3.10	0.19	1.000

Residual	105	1733.73	16.51		
Total	143	17381.83			

Appendix 5: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on plant height of maize 10 week after planting.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REP stratum	3	1728.72	576.24	28.28	
REP.*Units* stratum					
LOCATION	1	568.03	568.03	27.88	<.001
Treatment	17	16761.39	985.96	48.39	<.001
LOCATION.Treatment	17	67.47	3.97	0.19	1.000
Residual	105	2139.28	20.37		
Total	143	21264.89			

Appendix 6: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on leaf number of maize 2 week after planting.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REP stratum	3	1.3889	0.4630	0.65	
REP.*Units* stratum					
LOCATION	1	34.0278	34.0278	47.57	<.001
Treatment	17	33.2222	1.9542	2.73	<.001
LOCATION.Treatment	17	0.4722	0.0278	0.04	1.000
Residual	105	75.1111	0.7153		
Total	143	144.2222			

Appendix 7: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on leaf number of maize 4 week after planting.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REP stratum	3	4.3056	1.4352	1.98	
REP.*Units* stratum					
LOCATION	1	36.0000	36.0000	49.61	<.001
Treatment	17	203.4722	11.9690	16.49	<.001
LOCATION.Treatment	17	0.0000	0.0000	0.00	1.000
Residual	105	76.1944	0.7257		
Total	143	319.9722			

Appendix 8: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on leaf number of maize 6 week after planting.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REP stratum	3	2.7222	0.9074	1.33	
REP.*Units* stratum					
LOCATION	1	36.0000	36.0000	52.66	<.001
Treatment	17	199.8056	11.7533	17.19	<.001
LOCATION.Treatment	17	0.2500	0.0147	0.02	1.000
Residual	105	71.7778	0.6836		

Total	143	310.5556			

Appendix 9: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on leaf number of maize 8 week after planting.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REP stratum	3	0.3056	0.1019	0.10	
REP.*Units* stratum					
LOCATION	1	36.0000	36.0000	36.63	<.001
Treatment	17	417.8056	24.5768	25.01	<.001
LOCATION.Treatment	17	0.0000	0.0000	0.00	1.000
Residual	105	103.1944	0.9828		
Total	143	557.3056			

Appendix 10: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on leaf number of maize 10 week after planting.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REP stratum	3	1.299	0.433	0.30	
REP.*Units* stratum					
LOCATION	1	27.563	27.563	18.86	<.001
Treatment	17	432.118	25.419	17.39	<.001
LOCATION.Treatment	17	12.063	0.710	0.49	0.955
Residual	105	153.451	1.461		
Total	143	626.493			

Appendix 11: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on leaf area of maize 2 week after planting.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.000	0.000		
REP.*Units* stratum					
Treatment	17	0.000	0.000		
LOCATION	1	5852.250	5852.250		
Treatment.LOCATION	17	0.000	0.000		
Residual	105	0.000	0.000		
Total	143	5852.250			

Appendix 12: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on leaf area of maize 4 week after planting.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	8174.	2725.	0.64	
REP.*Units* stratum					
Treatment	17	594681.	34981.	8.19	<.001

LOCATION	1	9712.	9712.	2.27	0.135
Treatment.LOCATION	17	48576.	2857.	0.67	0.827
Residual	105	448715.	4273.		
Total	143	1109859.			

Appendix 13: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on leaf area of maize 6 week after planting.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1528.	509.	0.05	
REP.*Units* stratum					
Treatment	17	2434725.	143219.	15.23	<.001
LOCATION	1	92066.	92066.	9.79	0.002
Treatment.LOCATION	17	180151.	10597.	1.13	0.339
Residual	105	987269.	9403.		
Total	143	3695738.			

Appendix 14: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on leaf area of maize 8 week after planting.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	14109.	4703.	0.19	
REP.*Units* stratum					
Treatment	17	6851875.	403051.	16.38	<.001
LOCATION	1	138750.	138750.	5.64	0.019
Treatment.LOCATION	17	627371.	36904.	1.50	0.109
Residual	105	2583486.	24605.		
Total 143 10215592.					

Appendix 15: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on leaf area of maize 10 week after planting

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	3183.	1061.	0.02	
REP.*Units* stratum					
Treatment	17	13400847.	788285.	12.08	<.001
LOCATION	1	136524.	136524.	2.09	0.151
Treatment.LOCATION	17	1332078.	78358.	1.20	0.277
Residual	105	6853240.	65269.		
Total	143	21725872.			

Appendix 16: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on chlorophyll content of maize 2 week after planting.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REP stratum	3	186.7500	62.2500	358.15	

REP.*Units* stratum					
LOCATION	1	38.0278	38.0278	218.79	<.001
Treatment	17	1956.2500	115.0735	662.07	<.001
LOCATION.Treatment	17	0.4722	0.0278	0.16	1.000
Residual	105	18.2500	0.1738		
Total	143	2199.7500			

Appendix 17: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on chlorophyll content of maize 4 week after planting.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REP stratum	3	192.6667	64.2222	439.78	
REP.*Units* stratum					
LOCATION	1	36.0000	36.0000	246.52	<.001
Treatment	17	1959.5556	115.2680	789.34	<.001
LOCATION.Treatment	17	0.0000	0.0000	0.00	1.000
Residual	105	15.3333	0.1460		
Total	143	2203.5556			

Appendix 18: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on chlorophyll content of maize 6 week after planting.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REP stratum	3	176.6667	58.8889	70.00	
REP.*Units* stratum					
LOCATION	1	44.4444	44.4444	52.83	<.001
Treatment	17	1998.0000	117.5294	139.70	<.001
LOCATION.Treatment	17	12.5556	0.7386	0.88	0.601
Residual	105	88.3333	0.8413		
Total	143	2320.0000			

Appendix 19: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on chlorophyll content of maize 8 week after planting.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REP stratum	3	186.5278	62.1759	89.47	
REP.*Units* stratum					
LOCATION	1	36.0000	36.0000	51.80	<.001
Treatment	17	2208.2500	129.8971	186.91	<.001
LOCATION.Treatment	17	0.0000	0.0000	0.00	1.000
Residual	105	72.9722	0.6950		
Total	143	2503.7500			

Appendix 20: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on chlorophyll content of maize 10 week after planting.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REP stratum	3	162.354	54.118	12.82	
REP.*Units* stratum					

LOCATION	1	37.007	37.007	8.76	0.004
Treatment	17	3199.118	188.183	44.56	<.001
LOCATION.Treatment	17	0.118	0.007	0.00	1.000
Residual	105	443.396	4.223		
Total	143	3841.993			

Appendix 21: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on fresh biomass weight of maize at harvest.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REP stratum	3	0.0125351	0.0041784	27.90	
REP.*Units* stratum					
LOCATION	1	0.1067031	0.1067031	712.61	<.001
Treatment	17	10.9607966	0.6447527	4305.94	<.001
LOCATION.Treatment	17	0.0171068	0.0010063	6.72	<.001
Residual	105	0.0157222	0.0001497		
Total	143	11.1128639			

Appendix 22: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on dry biomass weight of maize at harvest.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REP stratum	3	0.038021	0.012674	3.76	
REP.*Units* stratum					
LOCATION	1	0.009598	0.009598	2.85	0.095
Treatment	17	2.288983	0.134646	39.93	<.001
LOCATION.Treatment	17	0.048890	0.002876	0.85	0.629
Residual	105	0.354023	0.003372		
Total	143	2.739516			

Appendix 23: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on fresh cob weight (t/ha) of maize at harvest.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REP stratum	3	0.010850	0.003617	0.94	
REP.*Units* stratum					
LOCATION	1	0.004046	0.004046	1.05	0.308
Treatment	17	124.931195	7.348894	1909.32	<.001
LOCATION.Treatment	17	0.971268	0.057133	14.84	<.001
Residual	105	0.404140	0.003849		
Total	143	126.321500			

Appendix 24: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on dry cob weight (t/ha) of maize at harvest.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**

REP stratum	3	0.003100	0.001033	0.87	
REP.*Units* stratum					
LOCATION	1	0.000254	0.000254	0.21	0.644
Treatment	17	31.398073	1.846945	1554.57	<.001
LOCATION.Treatment	17	0.253242	0.014897	12.54	<.001
Residual	105	0.124748	0.001188		
Total	143	31.779416			

Appendix 25: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on cob length of maize.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	12.4725	4.1575	13.34	
REP.*Units* stratum					
LOCATION	1	13.8136	13.8136	44.33	<.001
Treatment	17	950.4147	55.9067	179.39	<.001
LOCATION.Treatment	17	3.9164	0.2304	0.74	0.756
Residual	105	32.7225	0.3116		
Total	143	1013.3397			

Appendix 26: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on grain weight per cob of maize.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	4922.6	1640.9	4.43	
REP.*Units* stratum					
LOCATION	1	10751.6	10751.6	29.03	<.001
Treatment	17	316973.3	18645.5	50.35	<.001
LOCATION.Treatment	17	4866.9	286.3	0.77	0.720
Residual	105	38884.1	370.3		
Total	143	376398.5			

Appendix 27: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on weight of one cob in maize.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	417.5	139.2	0.46	
REP.*Units* stratum					
LOCATION	1	1677.0	1677.0	5.59	0.020
Treatment	17	456716.9	26865.7	89.48	<.001
LOCATION.Treatment	17	4848.2	285.2	0.95	0.519
Residual	105	31525.3	300.2		
Total	143	495184.9			

Appendix 28: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on number of grains per cob of maize.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1256.	419.	0.32	
REP.*Units* stratum					
LOCATION	1	528.	528.	0.40	0.528
Treatment	17	5190590.	305329.	232.10	<.001
LOCATION.Treatment	17	8905.	524.	0.40	0.983
Residual	105	138130.	1316.		
Total	143	5339409.			

Appendix 29: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on thousand grain weight of maize

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	51694.	17231.	10.90	
REP.*Units* stratum					
LOCATION	1	51155.	51155.	32.37	<.001
Treatment	17	1985517.	116795.	73.90	<.001
LOCATION.Treatment	17	19417.	1142.	0.72	0.773
Residual	105	165937.	1580.		
Total	143	2273721.			

Appendix 30: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on grain yield of maize.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.031619	0.010540	1.62	
REP.*Units* stratum					
LOCATION	1	0.079806	0.079806	12.25	<.001
Treatment	17	161.574353	9.504374	1459.42	<.001
LOCATION.Treatment	17	1.213381	0.071375	10.96	<.001
Residual	105	0.683806	0.006512		
Total	143	163.582966			

Appendix 31: ANOVA Table for the effect of sole, binary, tertiary and quarternary combination of primary nutrients and sulphur as well as location on percentage yield increment of maize.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1146.0	382.0	0.70	
REP.*Units* stratum					
LOCATION	1	302640.6	302640.6	558.22	<.001
Treatment	17	9962545.5	586032.1	1080.94	<.001
LOCATION.Treatment	17	277499.3	16323.5	30.11	<.001
Residual	105	56926.0	542.2		
Total	143	10600757.5			

Appendix 32: ANOVA Table for regression analysis of growth and yield parameters of maize

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	6	1880.3	313.381	12.21	<.001
Residual	137	382.6	2.793		
Total	143	2262.9	15.824		