

**AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING  
AND ENTREPRENEURIAL DEVELOPMENT**

**GROWTH AND YIELD RESPONSE OF MAIZE (*Zea mays* L.) TO GRANULE NPK  
BLENDED WITH SULPHUR, UREA AND AMMONIUM SULPHATE FERTILIZER**

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**AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING  
AND ENTREPRENEURIAL DEVELOPMENT  
FACULTY OF AGRICULTURE EDUCATION  
ASANTE MAMPONG**



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a Master of Philosophy degree in Crop Science**

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## DECLARATION

### **Candidate's Declaration**

I hereby declare that this thesis, with the exception of quotations and references contained in published works which have been duly acknowledged; is the result of my own original work and that no part of it has been presented for another degree at this university or elsewhere.

**Candidate Name:** Charles Yaw Adu-Frimpong

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### **Supervisors' Declaration**

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development.

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## **DEDICATION**

This thesis is dedicated to my wife, Priscilla Ayi and my family.

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## LIST OF ABBREVIATIONS/ACRONYMS

BB	Bulb blended
CGR	Crop Growth rate
CP knapsack	Cooper Pegler Knapsack
CSIR	Council for Scientific and Industrial Research
CV	Coefficient of variation
DAP	Days after planting
EC	Electrical conductivity
FERARI	Fertilizer Research and Responsible Implementation
IFDC	International Fertilizer Development Centre
GB	<i>Gliricidia sepium</i> biochar
KNUST	Kwame Nkrumah University of Science and Technology
HSD	Tukey's Honestly Significant Difference
MRR	Marginal rate of returns
NB	Net benefit
OPV	Open Pollinated Variety
QPM	Quality protein maize
RGR	Relative Growth Rate
SSA	sub-Saharan Africa
TVC	Total variable cost
WAS	West African savannas
WAP	Weeks after planting

## ABSTRACT

The main objective of the study was to determine the effect of granule NPK fertilizer blended with S, Urea and  $(\text{NH}_4)_2\text{SO}_4$  fertilizer to improve the growth and yield performance of maize. The field research was carried out at two different sites in 2023 during the major and minor cropping seasons from March to July and August to December, 2023 respectively at the Research field of the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED), Mampong Campus. The experimental design used for the two field studies was a Randomized Complete Block Design (RCBD), with five (5) treatments and each treatment was replicated four times. The treatments were; (i) Control (No fertilizer), (ii) Granule (70-50-50 kg/ha NPK) + Urea Granules, (iii) Granule (70-50-50 kg/ha NPK) + S +  $(\text{NH}_4)_2\text{SO}_4$  Granules, (iv) Granule (90-60-60 kg/ha NPK) + Urea Granules and (v) Granule (90-60-60 kg/ha NPK) + S +  $(\text{NH}_4)_2\text{SO}_4$  Granules. The results showed that Granule (90-60-60 kg/ha NPK) + 20S +  $(\text{NH}_4)_2\text{SO}_4$  Granules, Granule (70-50-50 kg/ha NPK) + 20S +  $(\text{NH}_4)_2\text{SO}_4$  Granules and Granule (70-50-50 kg/ha NPK) + Urea Granules enhanced the chemical properties of the soil as compared to the control plot. Granule (70-50-50 kg/ha NPK) + Urea Granules had fewer days to 50% silking, days to physiological maturity and days to 100% maturity. Granule (90-60-60 kg/ha NPK) + 20S +  $(\text{NH}_4)_2\text{SO}_4$  Granules significantly enhanced vegetative growth of maize. Granule (90-60-60 kg/ha NPK) + 20S +  $(\text{NH}_4)_2\text{SO}_4$  Granules and Granule (90-60-60 kg/ha NPK) + Urea Granules recorded significantly heavier grain weight per plot and higher grain yield than the control and the other rates of granule NPK fertilizer. Apart from the control treatment (no fertilizer), all the other four treatments produced a significant benefit to cost ratio. It is therefore recommended that farmers should use Granule (90-60-60 kg/ha NPK) + 20S +  $(\text{NH}_4)_2\text{SO}_4$  Granules and Granule (90-60-60 kg/ha NPK) + Urea Granules for heavier grains and more yield and benefit over the control.

## CHAPTER ONE: INTRODUCTION

### 1.1 Background of the Study

Maize is an important staple crop in Africa and the foremost commercial cereal in Ghana. As a food crop, it is produced to meet increasing urban and rural consumer demand in food-deficit areas of the country. According to Galani *et al.* (2022) about twenty-four food items are prepared from maize, and maize-based food accounts for 10.8% of total food expenditures by all households. Maize (*Zea mays* L.) also known as, corn is a widely cultivated cereal grain that holds significant importance in Ghana's agricultural sector (Adu *et al.*, 2021). It serves as a staple food for a large portion of the population and plays a crucial role in the country's food security (Tacoli, 2020). Ghana's maize production has experienced notable growth over the past few decades, driven by several factors (Amponsah *et al.*, 2021). Favourable climatic conditions, particularly in the northern regions of Ghana, provide suitable environments for maize cultivation (Ahmad *et al.*, 2020). Additionally, government initiatives aimed at promoting agriculture, such as the provision of improved seeds and fertilizers, have contributed to increased yields (Prah *et al.*, 2023). Maize production in Ghana primarily involves smallholder farmers who cultivate the crop on relatively small landholdings (Appiah-Twumasi *et al.*, 2020). However, commercial maize farming is also practised on a larger scale, particularly by agribusinesses and large-scale farmers (Htoo, 2023).

To ensure sustainable maize production, farmers in Ghana employ various practices, including crop rotation, intercropping, and the use of organic fertilizers (Marfo *et al.*, 2021). These practices help maintain soil fertility, reduce pest and disease incidence, and enhance overall crop productivity (Saha and Baudhdh, 2020). Maize (*Zea mays* L.) is the principal staple crop, produced and consumed by most farming households in Ghana (Atiah *et al.*, 2022). Smallholder resource-poor farmers under rain-fed conditions produce it predominantly (Bekuma *et al.*, 2022). The crop is well-adapted and grows in most of the ecological zones of Ghana including the northern savannah. It provides a major source of calories in many parts

of Ghana (Derbile *et al.*, 2022). It has nearly replaced traditional staple crops like sorghum and pearl millet in northern Ghana. An average maize grain yield on farmers' fields is about 1.7 t/ha as against an estimated achievable yield of about 6.0 t/ha (Ajayi *et al.*, 2021). The major limiting factors to maize production in Ghana include drought during critical early stages of crop growth, low soil nutrient levels (particularly nitrogen and phosphorus), striga, and pest and disease infestations (Marfo-Ahenkora, 2020). According to Obour *et al.* (2022), other limitations to maize production include poor management practices such as low plant populations, inappropriate planting time, inadequate control of weeds, lack of credit, limited use of inputs (especially, fertilizer and improved seeds) as well as untimely application of adequate quantities of fertilizers, inadequate drying and storage facilities leading to high post-harvest losses and poor market access.

One of the major steps towards improving maize productivity in Ghana is the provision of extension advice by agricultural extension agents to farmers on good agronomic practices of maize during production, hence the need to compile a production guide for the crop (Tembo *et al.*, 2023). This production guide therefore provides simplified good agricultural practices for maize production in more diverse areas of the country (Santpoort, 2020). Maize therefore has a high potential to address critical food security problems and could play a key role in any future strategy to reverse Africa's declining trend in per capita food production (Hossain *et al.*, 2020). The strong dependence on maize as a food and cash crop in Ghana is however of great concern and requires considering effective adaptation options to reduce potential negative impacts of climate change since much of the maize production is rain fed and its output is directly influenced by weather patterns. In addition, the savanna and forest-savanna transitional zones of Ghana, where most of the maize is produced, fall under the agro-climate regimes, that will likely be most impacted by climate change (Ankrah *et al.*, 2023). According to Awunyo & Sackey (2018), the agricultural sector drives the social and economic development of Ghana and climate variability and climate change could pose a significant

challenge to food security. Maize (*Zea mays* L.) is the most important cereal crop in sub-Saharan Africa (Food and Agriculture Organizations [FAO], 2005). Maize has been cultivated in Ghana since it was introduced in the late 16th century and attracted the attention of commercial farmers (Marfo-Ahenkora, 2020). However, it never achieved the economic importance attained by traditional plantation crops, such as oil palm and cocoa (Parveez *et al.*, 2020).

According to Lu *et al.* (2022), over time, the eroding profitability of many plantation crops served to strengthen interest in commercial food crops. on smallholder farms, the use of organic inputs has great potential for improving soil productivity and crop yield, but their bulkiness, low nutrient content and slow nutrient release make their use less convenient (Biramo, 2018). At high levels of maize grain yield, organic inputs are likely to be insufficient and must be supplemented with inorganic fertilizers (Miner *et al.*, 2020).

Ghana is a major exporter of maize in Africa. In 2021, the country exported around 1.2 million metric tons of maize, making it the second-largest exporter of grain on the continent after South Africa (Agyei-Sasu, 2023). The main export markets for Ghanaian maize include neighbouring countries such as Burkina Faso, Togo, and Benin, as well as more distant markets such as Nigeria, Senegal, and Côte d'Ivoire (Pitigala and Lopez-Calix, 2021). Ghana's maize exports have been growing steadily in recent years, driven by increased production and demand from neighbouring countries. The country has also benefited from favourable weather conditions, improved infrastructure and reduced transportation costs, which have helped to increase the competitiveness of Ghanaian maize in regional markets (Abokyi *et al.*, 2020).

## 1.2 Problem Statement and Justification

Fertilizer application is a crucial aspect of maize cultivation, as it provides essential nutrients for optimal growth and yield (Itelima *et al.*, 2018). However, according to Gao *et al.* (2020), several challenges can arise during the application process, affecting the effectiveness and efficiency of fertilization. One primary challenge lies in determining the appropriate fertilizer type and dosage. Maize requires a balanced supply of nutrients, including nitrogen, phosphorus, potassium, and other micronutrients (Sinha & Tandon, 2020). Selecting the right fertilizer blend and calculating the optimal application rate based on soil conditions, crop growth stage, and environmental factors is essential to avoid nutrient deficiencies or imbalances (Nawar *et al.*, 2017; Wortmann *et al.*, 2017)

Another challenge is related to the timing and method of fertilizer application. Split application, where fertilizers are applied in multiple doses throughout the growing season, is often recommended to synchronize nutrient availability with crop demand and minimize nutrient losses. However, determining the optimal timing and frequency of application requires careful consideration of weather conditions, soil moisture, and crop growth stages (Davies *et al.*, 2020).

Furthermore, the reports of Tyagi *et al.* (2022) and Shanmugavel *et al.* (2023) suggest that the application method itself can pose challenges. Broadcasting, where fertilizers are spread over the field, is a common practice, but it can result in uneven distribution and nutrient losses due to factors like wind and water runoff. Localized application methods, such as banding or side-dressing, can improve nutrient uptake efficiency, but they require specialized equipment and increased labour.

In addition, the management of fertilizer application about other agronomic practices is crucial (Shah *et al.*, 2021). Factors such as irrigation, crop rotation, and pest control can influence nutrient availability and utilization. Integrated nutrient management approaches, which

combine organic and inorganic fertilizers with other sustainable practices, can help optimize fertilizer use and minimize environmental impacts.

Blended basal fertilizer is a type of fertilizer that combines multiple essential plant nutrients in a single product. It is designed to provide a balanced and comprehensive nutrient supply to crops during the early stages of growth, particularly at the time of planting or transplanting (Qin *et al.*, 2018; Xu *et al.*, 2020).

Blended basal fertilizers typically contain a combination of macronutrients, such as nitrogen (N), phosphorus (P), and potassium (K), along with secondary nutrients like calcium (Ca), magnesium (Mg), and sulphur (S). The proportions of these nutrients vary depending on the specific formulation and crop requirements (Gebeyehu, 2024; Kihara *et al.*, 2017). The primary advantage of using blended basal fertilizers is their convenience and efficiency (He *et al.*, 2023). By combining multiple nutrients in one product, farmers can apply all the necessary nutrients in a single application, reducing the need for multiple fertilizer applications and saving time and labour. Blended basal fertilizers are commonly used in various agricultural practices, including field crops, horticulture, and turf management (Yilmaz, 2019). They provide a controlled and balanced release of nutrients, ensuring that plants have access to the essential elements they need for healthy growth and development. It is important to note that the specific composition of blended basal fertilizers can vary based on regional soil conditions, crop types, and specific nutrient requirements (Gebeyehu, 2024). Therefore, it is always advisable to consult with local agricultural experts or soil testing results to determine the most appropriate blended basal fertilizer for your specific needs. Blended basal fertilizers, on the other hand, are less prone to leaching and runoff, reducing the risk of environmental contamination.

### **1.3 Objective of the Study**

The main objective of the study was to determine the effect of granule NPK fertilizer blended with Sulphur (S), Urea and Ammonium sulphate  $[(\text{NH}_4)_2\text{SO}_4]$  fertilizers on the growth and yield performance of maize.

### **1.3.1 Specific Objectives**

The specific objectives were to:

- 1 Evaluate the effect of granule NPK fertilizer blended with S, Urea and  $(\text{NH}_4)_2\text{SO}_4$  fertilizer on soil physical and chemical properties.
- 2 Assess the effect of granule NPK fertilizer blended with S, Urea and  $(\text{NH}_4)_2\text{SO}_4$  fertilizer on growth and yield of maize.
- 3 Determine the profitability of combined use of granule NPK with S, Urea and  $(\text{NH}_4)_2\text{SO}_4$  fertilizer on yield of maize.

## CHAPTER TWO: LITERATURE REVIEW

### 2.1 Origin and Distribution

Maize (*Zea mays* L.) belongs to the family Gramineae and it is believed to have originated from Central/Southern America, from where it spread to the Tropics. Maize was domesticated in Southern Mexico around 4000 BC. It was first introduced into Africa in the 16th Century and was reported for the first time in West Africa in 1498 by the Portuguese (Bonavia, 2013). Maize has an extremely wide distribution. It is grown from latitude 58<sup>0</sup> N in Canada and Russia, throughout the tropics, to latitude 42<sup>0</sup> S in New Zealand and South America, and in areas below sea level in the Caspian Plain up to areas as high as 3800 m in Bolivia and Peru. It is grown in all countries of Africa, and from sea-level to the mid and high altitudes of East and Central Africa (Wang *et al.*, 2020).

Archaeological and botanical evidence indicates that maize was domesticated and in existence in central Mexico by 5000 BC.

The earliest dated remains are cobs discovered in Puebla state, Mexico (Jaenicke-Després *et al.*, 2016). These cobs were from a very primordial maize race, possibly an intermediate between teosinte and all-encompassing maize races. The plants were more maize-like than teosinte-like, and the cobs were non-shattering and had either four or eight clusters of kernels. These cobs are similar to teosinte cobs. These cobs are also comparable to the majority of primitive stable biotypes or races of maize that are cultivated in western Mexico. Maize culture expanded throughout central and southern Mexico, reaching northern Chile by 2700 BC and New Mexico by 1200 BC. Maize culture was introduced to the Old World by Columbus in 1493 and subsequently spread to the majority of the eastern hemisphere within a century.

Maize's antiquity in India is not confirmed (Kalleswaraswamy *et al.*, 2018). It is generally accepted that the Portuguese introduced it to India from Europe during the early sixteenth century (Carvalho, 2020). In pre-Columbian periods, there is no evidence of its existence on the Indian plains. Watt (Kumari *et al.*, 2022) suggested that the vernacular names for maize

did not provide any insight into the history of maize in India. The most frequently encountered name, makai or Makka, which translates to "Mecca," implies that it was introduced from outside of India.

## 2.2 Botany

Maize (*Zea mays* L.) is classified within the tribe Tripsaceae (Maydeae) of the family Gramineae. It is a tall, determinate annual plant that produces broad, thin, opposite leaves, approximately one-tenth as wide as they are long, arranged alternately along a strong stem. The maize stem is upright, cylindrical, ranging from 50 cm to 3 meters in height, and 2-3 cm in thickness (Bilgili *et al.*, 2023). It has loose parenchyma and features distinct nodes and internodes. The leaves develop alternately on opposing sides of the stalk. They possess diminutive hairs and the leaf count ranges from 10 to 20 (Oguchi, 2018). The top leaves of corn are primarily responsible for light interception and significantly contribute to the production of photosynthate for grain.

The root system is robust and fibrous, extensively infiltrating the soil. The maize caryopsis germinates via a single embryonic root, subsequently producing seedling or seminal roots. The primary role of seminal roots is to provide the maize plant with water and nutrients during the initial 2-3 weeks of growth before the nodal roots mature and become operational. The seminal roots are subsequently supplanted by permanent adventitious (nodal) roots that emerge from the crown located at the end of the mesocotyl. The lateral roots extensively branch, spreading broadly and penetrating deeply (Doll, 2019). The majority of maize roots are contained inside the 30 cm soil layer. In addition to these roots, 'prop or brace roots' often emerge from the lowest aerial nodes of the stem. Upon contacting the soil, they extend their branches and contribute to the nourishment of the maize plants; nonetheless, their primary role is to prevent the plants from lodging (Duque & Villordon, 2021).

The defining characteristic of maize is the sexual differentiation within its floral structures. Maize generates male inflorescences (tassels) that are located at the stem apex, and female inflorescences (cobs or ears) that emerge from the apex of condensed lateral branches in the leaf axils (Rajoo *et al.*, 2021). The male (staminate) inflorescence, characterized as a loose panicle, generates pairs of free spikelets, each containing one fertile and one sterile floret. The

female (pistillate) inflorescence, characterized as a spike, generates pairs of spikelets on the surface of a densely condensed rachis (Yathish *et al.*, 2020). Each female spikelet has two viable florets, one of which will develop into a maize kernel upon successful fertilization by wind-dispersed pollen (Rajoo *et al.*, 2021).

### **2.3 Uses and Nutritional Value**

Maize is a principal crop in Ghana, constituting over 50% of the nation's grain output and serving as a vital food supply. It moreover supplies animal and poultry feed and is used for other non-food goods, including matchsticks and biofuel. Maize serves as a source for the production of starch, syrup, dextrose, oil, gelatin, lactic acid, and other derivatives. Corn flour serves as a thickening ingredient in the creation of various foods, including soups, sauces, and custard powder. Corn syrup serves as an ingredient in confectionery products. Corn sugar (dextrose) is utilized in medicinal formulations as a sweetening component in soft drinks, among other applications. Corn gel, due to its moisture-retaining properties, serves as a bonding ingredient for ice cream cones and a dry dusting agent for baked goods (Helstad, 2019).

The elevated carotene concentration in yellow maize is seen highly beneficial for imparting a yellow hue to egg yolk and a yellow tint to milk. No other concentration has yet been identified as a replacement for maize in this regard. The maize cob, the core rachis to which the grains are affixed, remains as agricultural waste post-threshing; it has several significant agricultural and industrial applications (Mboya, 2020). It constitutes around 15 to 18% of the total ear weight and comprises 35% cellulose, 40% pentose, and 15% lignin. Their applications in agriculture encompass use as poultry litter and as a soil amendment.

AliAkbari *et al.* (2021) indicate that the industrial applications of ground corn cob powder, due to its physical properties, include its use as fillers in the production of explosives, plastics, adhesives, rayon, resin, vinegar, and synthetic leather, as well as diluents and carriers in

insecticide and pesticide formulations. Due to their chemical qualities, processed cobs are utilized in the production of furfural, fermentable sugars, solvents, liquid fuels, charcoal gas, and other chemicals by destructive distillation, as well as in the manufacturing of pulp, paper, and hardboards. The water utilized for soaking maize grains in glucose production is employed for cultivating penicillin molds (Selim *et al.*, 2021).

Approximately 1,400 calories are present in 100 grams of maize on a dry weight basis, which is sufficient to maintain equilibrium. Additionally, this energy is employed to perform a diverse array of physiological functions. Maize or corn can be ingested as a source of energy in the form of breakfast cereals, such as cornflakes, chapattis, and tortillas. Maize is also rich in fat, which facilitates the transportation of fat-soluble vitamins A, D, E, and K. The texture and aroma of food are primarily determined by the fat content of maize or corn. As a result, it enhances the perception of flavor. Subcutaneous fat, also referred to as subcutaneous fat, serves as an efficient heat-insulator for the body. Furthermore, adipose content functions as a body reservoir for energy conservation (Schnetzler, 2018; Rachkeeree *et al.*, 2018; Mordenti *et al.*, 2021) (Table 2.1).

Table 2. 1: Nutritive Value of Proximate Content of Maize, Dried *Zea mays*

Essential amino acids		Conditionally essential amino acids		Non-essential amino acids	
Amino acids	Nutritive value	Amino acids	Nutritive value	Amino acids	Nutritive value
Histidine	2.70±0.21	Arginine	4.20±0.24	Alanine	7.73±0.46
Isoleucine	3.67±0.22	Cysteine	1.55±0.14	Asparagine	
Leucine	12.24±0.57	Glycine	3.27±0.15	Aspartic acid	6.55±0.59
Lysine	2.64±0.18	Proline	7.88±0.71	Glutamic acid	19.39±0.70
Methionine	2.10±0.17	Tyrosine	3.71±0.18	Glutamine	
Phenylalanine	5.14±0.29			Serine	4.58±0.44
Threonine	3.23±0.29			Selenocysteine	
Tryptophan	0.57±0.12			Pyrrolysine	
Valine	5.41±0.71				

Source: Bathla *et al.* (2020)

The human digestive enzyme system is unable to hydrolyze or metabolize the portion of food that is derived from plant cells which is referred to as dietary fiber. Dietary fiber is the second most significant component of maize, following lipids (Raigond *et al.*, 2015; Dhital *et al.*, 2017). However, specific microorganisms in the large intestine have the ability to degrade components of fiber-releasing products, which can be absorbed by the body and utilized as an energy source. Crude fiber is the residue that remains after the treatment with heated sulphuric acid, alkali, and alcohol (Mehta *et al.*, 2018). The polysaccharide cellulose, which is also a constituent of dietary fiber, is the primary constituent of crude fiber. Insoluble fibers are water-insoluble and indigestible, while soluble fibers are water-soluble and indigestible. Total fiber is the sum of soluble and insoluble fibers. Dietary fiber is extracted and isolated from a synthetic fiber that has been scientifically proven to have health benefits. Furthermore, resistant starch serves as dietary fiber. Total fiber is the sum of dietary fiber and functional fiber (Surampudi *et al.*, 2016). The influence of fiber on the gastrointestinal tract is contingent upon the fiber's characteristics, particle size, interaction with other dietary components, and

bacterial flora. Furthermore, the cell wall of the constituent in maize contains a significant quantity of insoluble fiber.

The physiological effect of the insoluble fiber present in maize or corn is to prevent constipation, diverticulitis, and perhaps even cancer of the large intestine. The daily energy requirements of humans are met by maize, which is also regarded as a nutrient booster due to its presence of carbohydrates, lipids, proteins, and insoluble fibers (Risso *et al.*, 2023).

The 8-11% of protein content in maize is composed of proteins such as albumin, globulin, nonnitrogen substance, and prolamin. Additionally, maize's protein quality is influenced by its genotype and agronomic practices. Corn's protein quality is inferior to that of other cereal carbohydrates, including wheat, barley, and rice. Rai *et al.* (2018) have conducted recent research that has shown that genetic modification can improve the protein composition of maize. Zein is the maize protein that is deficient in the essential amino acids tryptophan and lysine. The opaque-2 gene is also beneficial for enhancing the protein quality of maize and reducing the concentration of zein by up to 30%. The protein content of maize is essential for the growth and maintenance of tissues, the formation of essential body compounds, the transport of nutrients, the regulation of water balance, the maintenance of an optimal pH, defense, and detoxification (Dhaliwal *et al.*, 2022).

The primary component of maize grain is starch, which contributes over 70% of the cereal kernel's weight. The starch in maize is primarily composed of two glucose polymers, with amylose accounting for 30% of its starch content. The remaining 70% is composed of amylopectin. According to Bathla (2019), waxy maize is entirely composed of amylopectin. Maize is characterized by a branch-like structure as a result of its pectin content. Glucose and fructose constitute the monosaccharide of maize, while a small amount of sucrose is present in the disaccharide. The sugar and starch contents of maize are illustrated in Table 2.2.

Table 2. 2: Starch and Sugar Content in Maize

<b>S/N Nutrient</b>	<b>Nutritive Value</b>
1.Total available CHO	61.01 ± 0.76
2.Total starch	59.35±0.83
3.Fructose	0.16±0.03
4.Glucose	0.80±0.01
5.Sucrose	0.70±0.03
6. Total free sugars	1.66±0.04

Source: Bathla *et al.* (2020)

## **2.4 Climatic and Soil Requirements**

Maize is adapted to a wide range of environments, but it is a crop of warm regions where moisture is adequate. Maize is generally less suited to semi-arid or equatorial climates, although drought-tolerant cultivars adapted to semi-arid conditions are now available (Prasad *et al.*, 2020). The crop requires an average daily temperature of at least 20<sup>0</sup> C for adequate growth and development; the optimum temperature for growth and development is 25-30<sup>0</sup> C; temperatures of above 35<sup>0</sup> C reduce yields. Frost is not tolerated. Maize requires abundant sunlight for optimum yields. The time of tasselling is influenced by photoperiod and temperature; maize is considered as a quantitative short-day plant. Maize is less drought-resistant than sorghum, pearl millet and finger millet (Prasad *et al.*, 2020).

In the tropics, it does best with 600-900 mm well-distributed rainfall during the growing season (Alameraw, 2020). It is especially, sensitive to drought and high temperatures around the time of tasselling (Waqas *et al.*, 2021).

Maize can be grown on wide range of soils, but performs best on well-drained, well-aerated, deep soils containing adequate organic matter and well supplied with nutrients. The high yield of maize is a heavy drain on soil nutrients and maize is therefore, often grown as a first crop in rotation. It can be grown in a pH of 5-8, but 5.5-7 is optimal. It does not tolerate water logging and is sensitive to salinity (Jaidka *et al.*, 2019; Ndunguru, 2015).

## **2.5 Varieties**

### **2.5.1 Obatanpa**

The type of variety of Obatanpa maize is Open Pollinated Variety (OPV), it has a maturity period of 110 days and its potential yield is estimated at 4.6 t/ha. The seed colour is white and its days to 50% silk is 5, the average plant height is 175 cm, ear height 80 cm, the colour of its tassel is cream purple. The tassel arrangement is open and alternate with purple silk color and green with shade stem color. Obatanpa has an average of 15.2 cm cob length, 4.8 cm cob diameter, 1.3 cm of kernel dent with straight arrangement. It is well known as quality protein maize (QPM). It is also excellent for enhanced nutrition and health of humans, poultry and livestock.

### **2.5.2 Mamaba**

Type of variety is three-way cross hybrid, it has 110 days maturity period and its potential yield is 6.5 t/ha. The seed colour is white, and has 51 days to 50%. The plant height is 187 cm with 89 cm ear height, cream with purple shade tassel colour. The tassel arrangement of Mamapa maize variety is mid-open and alternate with purple silk colour. Stem colour is greenish with about 18.9 cm, and 4.5 cm cob diameter, 1.2 cm kernel depth and flint type and straight arrangement. Excellent for enhanced nutrition and health of humans and it is drought tolerant.

### **2.5.3 Dadaba**

Dadaba is also a three-way cross hybrid type, with 110 days maturity. The potential yield of Dadaba maize is 6.5 t/ha. The seed colour is white with average days 50% silking to be 51 and plant height of 187 cm with 89 cm ear height and cream with purple shade tassel colour. The tassel arrangement is mid-open and alternate, silk colour is purple and with green stem colour, 18.9 cm cob length, 4.5 cm cob diameter, and kernel arrangement: is straight with flint type. It is excellent for enhanced nutrition and health of humans drought tolerant.

#### **2.5.4 CSIR-Abontem**

This variety is OPV, the maturity period ranges from 75 to 80 days with a potential yield of 4.7 t/ha. It yellow seeds, 54 days to 50% silking, 162 cm height, 82 cm ear height and creamy purple shade tassels. The tassel arrangement of CSIR-Abontem maize is open and alternate with purple silks, green with purple shade stem, 15.5 cm cob length, 4.4 cm, 4.4cm cob diameter, 1.1 cm kernel depth with straight arrangement and flint or dent type. This variety is good for feed poultry and livestock.

#### **2.5.5 CSIR-Omankwa**

It is also OPV and has a maturity period of 90 days. Its potential yield is estimated at 5.0 t/ha, with white seeds, 54 days to 50% silking and an average plant height of 182 cm, 91 cm ear height, purple shade tassels, open and alternate tassel arrangement, purple silks, green with purple shade stem, and a cob length of 15.7 cm, 4.5 cm cob diameter, kernel depth of 1.2 cm and kernel arrangement to be straight and flint or dent type.

#### **2.5.6 CSIR-Etubi**

CSIR-Etubi is also a three-ways cross hybrid with a maturity period of 110 days. Its potential yield is estimated at 6.5 t/ha. It has white seeds, 54 days to 50% silking, 188 cm plant height, 95 cm ear height, cream-coloured tassels, open and alternate tassel arrangement silks with purple colour. It has greenish stem and 15.8 cm cob length, 4.0 cm cob diameter and kernel depth of 1.2 cm, kernel arrangement is straight and flint type. CSIR-Etubi is Excellent for enhanced nutrition and health of humans. Drought and Lodging resistant. Good Synchronization between single cross parent and inbred lines.

#### **2.5.7 Opeaburo**

Opeaburo is a maize variety developed in Ghana, known for its resilience and suitability for local farming conditions. Opeaburo is bred to withstand dry spells, making it ideal for regions

with erratic rainfall. It typically matures within 80 to 85 days, allowing for quicker harvests and flexibility in crop rotation. It produces substantial vegetative growth, which can be beneficial for fodder or soil enrichment. While not always the highest-yielding, Opeaburo performs well under both optimal and stressed conditions, it shows strong ear development, which contributes to its overall productivity.

## **2.6 Production Estimates**

The trend suggests that the developing world will require more maize than the industrialized world as a result of population growth and urbanization, despite the fact that the industrialized world still produces and consumes more maize. By 2050, the demand for maize in the developing world will double, and the maximum level of maize production in the developing world will occur in 2025. It is estimated that 140 million hectares of maize are cultivated globally, with 96 million of those hectares situated in developing countries (Erenstein *et al.*, 2022). However, only 46% of the world's maize is produced in developing countries. The considerable disparity between the global share of land and the global share of agricultural output is believed to be a result of the low average yield in the developing world. According to the Food and Agricultural Organization, the global average maize production is 4 t/ha; however, the average yield in Africa is only 1.7 t/ha. The average yield of agricultural fields in Ghana is approximately 1.6 t/ha. The yields of the US agricultural system are 65 percent greater than the global average. The disparity in crop yields between the developed and developing nations is primarily due to the vast differences in agricultural techniques and climatic conditions.

In Ghana, the overwhelming majority of rural households in every region of the country, with the exception of the savannah zone, cultivate maize. It is frequently cultivated in a system that includes other cereals (sorghum, millet) and legumes (groundnut, cowpea) (Macauley & Ramadiita, 2015). In Ghana, as in other African countries, maize is cultivated by both men

and women. Maize is the primary staple meal in agricultural regions of Ghana. The majority of maize is converted into indigenous dishes and ingested directly by humans. It is an essential source of nutrition for infants (Rouf-Shah *et al.*, 2016). It is frequently administered to weaning children in lieu of protein supplements, such as milk, eggs, or legumes, which are more costly. It is also a critical industrial raw material and an ingredient in animal nutrition. It is a significant feed ingredient for livestock and poultry. Maize is ingested in Ghana in a variety of ways. In the northern region, it is typically consumed as a thick porridge, comparable to the way sorghum and millet are consumed. In the southern region, it is frequently used to prepare porridges and other solid foods that are prepared with fermented or unfermented dough.

## **2.7 Crop Propagation**

Maize is propagated by seeds and direct sowing is common. Sowing is preferably done early in the season, as soon as soil conditions and temperature are favourable and rain is well established. Small holders plant maize by hand while mechanical planting is practised on large commercial farms (Santos *et al.*, 2019; Nurk *et al.*, 2017).

Planting may be done on hills or in rows, on flat land or on ridges. The land may also be ploughed and harrowed before planting on commercial farms. The usual depth of ploughing is 8-10 cm and ploughing is done just before or at planting time. The seed rate is up to 25 kg/ha in sole cropping, and 10-15 kg/ha in intercropping. Seed is dropped in the plough furrow or in holes made with a planting stick, cutlass or hoe.

When maize is sown in rows, the spacing is usually 75-90 cm between rows and 25-50 cm within the rows with 1-3 seeds per hole, resulting to a plant density of 40,000-80,000 plants/ha. The sowing depth is commonly 3-8 cm, depending on soil conditions and temperature. Sometimes animal manure or fertilizers are applied at the time of planting (Simachew, 2020). Maize may be grown as a sole crop or an inter-cropping with other food crops such as common bean (De-Ron *et al.*, 2018), cowpea (Biruk *et al.*, 2021), pigeon pea (Saidia *et al.*, 2019),

groundnut (Okpanachi *et al.*, 2022) and yam (Udom *et al.*, 2019). In some parts of tropical Africa maize is planted twice a year. In areas where the rainy season is shorter, the crop is planted only once, although a second planting is possible under irrigation, on residual moisture on heavy soils or on hydromorphic soils.

## **2.8 Cultural Practices**

Maize is very sensitive to weed competition during the first 4-6 weeks after emergence and weed control are very important. Weeding is mostly done by hand, requiring at least 25 man-days/ha. Chemical weed control is gaining importance in tropical Africa, because hand weeding is time-consuming and expensive as a result of increase scarcity of labour (Kumar *et al.*, 2015). Most maize production in tropical Africa is rainfed. Occasionally it is grown on bunds in irrigation schemes. Maize usually responds well to fertilizers. A maize crop yielding 2 t grains and 5 t stover per ha removes 60kg N, 10kg P and 70 kg K per ha from the soil. Nitrogen uptake is slow during the first month after planting, but increases to a maximum during formation of the inflorescences. Maize has high demand for nitrogen, which is often the limiting nutrient and should be applied in 2 doses; the first dose at planting or 2-3 weeks after emergence and the second about 2 weeks to tasselling. is not easily taken up by maize but many tropical soils are deficient in available phosphate. It is advisable to apply organic manure before ploughing to improve upon soil structure and supply nutrients.

Smallholder farmers in tropical Africa apply little or no fertilizer to the maize crop. When they do, it is usually only once, about 4 weeks after planting when the crop is knee high. Maize is grown in rotation with groundnut, common bean, cowpea, cotton and tobacco (Ichami *et al.*, 2019; Baijukya *et al.*, 2020). Rotation with soya bean is gaining popularity (Du *et al.*, 2018), it increases maize yields by providing nitrogen and by reducing insects or pest's attack.

In the United States maize is often grown in rotation with soya bean. The most important fungal diseases of maize in tropical Africa are the rot affecting the female inflorescences, the

stalk and the leaves. While the most important virus disease is the maize streak virus (MSV), which is restricted to Africa and may cause 100% yield loss. Host-plant resistance is the most effective disease control measure. The most serious pests are cutworms, stem borers, cob borers and leaf hoppers. Occasionally termites and locust also infest maize fields. Application of insecticides may be necessary to control these pests. Cultural methods also exist and include early planting and burying or burning crop residues. Biological method using natural enemies can also be used. (Pande *et al.*, 2017; Arif *et al.*, 2018).

## **2.9 Fertilizer Use in Maize Production**

Nutrient concentrations are important to understand plant maintenance and growth, specifically if certain nutrients are limiting in grain or vegetative material. Many crops have a maximum potential yield which is never actually achieved due to limiting factors, often which are nutrients (Liliane *et al.*, 2020). An adequate supply of nutrients should be observed in maize grain as well as in the fodder material not harvested. If nutrient supply is not limiting to yield production, light interception could become a more limiting factor than available nutrients. There are three main processes that plants take up nutrients from the soil via their roots: root extension, mass-flow and diffusion. Mass-flow is the primary mechanism that supplies nitrogen (N) to the roots, whereas diffusion is the primary mechanism that supplies phosphorus (P) and potassium (K) to the roots. Diffusion occurs from lower gradient at the root-soil interface from the uptake of nutrients by the roots. However, diffusion is a slow process, especially for nutrients like phosphorus that may react with the soil along this gradient. Mass flow can be much quicker, but depends on the amount of water taken up by a plant. Roots also grow in the soil and come in direct contact with soil nutrients. Most estimates consider roots to take up only about 1% of soil volume, but even with a generous 3% pore space estimate, maize roots only come in contact with 6 to 10% of the nutrient requirement of N, P, and K for a 7846 kg ha<sup>-1</sup> grain yield. Consequently, over 90% of nutrient uptake is via mass flow for N or diffusion for K and P. Soil N is available to plants as nitrate and ammonium

(Liliane *et al.*, 2020). However, soil nitrate must be reduced to ammonium before being used in the plant. Soil nitrate and ammonium is important in agriculture because high levels could reduce the amount of added fertilizer required for a crop

Muthaura *et al.* (2017) reported that maize has strong exhausting effect on the soil and it is generally observed that maize fails to produce good yield in soils without fertilizer application. The use of synthetic nitrogen fertilizers has increased steadily in the last 50 years, rising almost 20-fold to the current rate of 100 million tonnes of nitrogen per year. Kitonyo *et al.* (2018) reported that nitrogen is the most limiting essential nutrient for maize production in the humid and sub-humid tropics. The need for adequate and balance nutrition for maize is very important. The application of NPK fertilizers significantly increased plant height, stem girth, number of leaves, leaf area index, dry matter accumulation and yield of maize (Achiri *et al.*, 2017).

Maize is fast growing and it has a relatively high demand for nutrients, particularly N, P and K which are necessary for high yield. reported that higher grain yield was obtained by applying 4.5 t/ha of mineral fertilizer which supplies 18 kg N, 1.8kg P and 27 kg K per hectare (Suganya *et al.*, 2020). Agbede *et al.* (2017) reported that the most cultivated soils do not supply more than 20-25 % of the NPK requirements and thus adequate NPK is necessary if high yields are to be realized. Maize usually responds well to fertilizers and the maize crop can yield 2 tonnes grains and 5 tonnes stover per hectare by utilizing about 60 kg N, 10 kg P and 70 kg K per hectare from the soil.

Low soil fertility is a major constraint to maize production in smallholder farms. This is mainly attributed to the mining of nutrients due to cropping without external addition of adequate nutrients (Cairns *et al.*, 2021). Crop yields have been reduced by as much as 50% in sub-Saharan Africa due to low nutrient input and excessive nutrient losses by erosion and crop extraction. An average of 22 kg N (nitrogen), 3 kg P (phosphorus), and 15 kg K (potassium)

ha<sup>-1</sup> is lost annually. In the tropics, water and nitrogen (N) are the major factors that limit the grain yield of maize (*Zea mays* L.). About 50% of tropical lowland maize grown suffer with a substantial reduction in grain yield because of periodic drought stress and low N supply. Nitrogen deficiency stress in maize delays shoot elongation and also leaf growth and the flowering of tropical maize (Tapera, 2017). Grain yield was found to be positively associated with shoot biomass and N content at anthesis under conditions of N deficiency (Liu *et al.*, 2020). According to Rizzo *et al.* (2024), high yielding maize production systems require an adequate supply of potassium (K) to meet production potential. A mature maize crop can contain up to 300 kg K ha<sup>-1</sup> in aboveground plant material.

There are several factors that impact on the ability of a soil to meet the K demands of a growing maize crop, including: the soil solution K concentration, the capacity of the soil to buffer the soil solution K concentration, soil moisture content, soil texture and structure, and the distribution of soil K reserves. In many cases, one or more of these factors may restrict the supply of K to maize crops (Rawat *et al.*, 2016). Phosphorus is one of the most important nutrients for higher yield in larger quantity and controls mainly the reproductive growth of plants. Generally, P is the second most crop-limiting nutrient in most soils. It is second only to nitrogen in fertilizer use. Plant growth behaviour is influenced by the application of phosphorus (Gerenfes & Negasa, 2021). It is needed for growth, utilization of sugar and starch, photosynthesis, nucleus formation and cell division, fat and albumen formation. Fosu-Mensah & Mensah (2016) reported significant effect of P application on grain yield whereas Muthaura *et al.* (2017) observed significant effect of P application on dry matter yield and individual plant characteristics like height, number of leaves and leaf area.

## **2.10 Plant Nutrient Partitioning**

### **2.10.1 Nitrogen**

Nitrogen absorption during maize development often exhibits an S-shaped uptake pattern, characterized by a lag phase between two intervals of accelerated nitrogen uptake. The initial fast buildup of nitrogen transpires between V12 and V18, coinciding with the determination of yield potential. This is succeeded by a lag phase during which nitrogen uptake by the plant diminishes around the period of pollination. A subsequent elevated accumulation rate transpires during the grain-fill phase. Approximately two-thirds, or 50 to 70%, of nitrogen (N) is necessary for pollination (VT/R1), suggesting that the time of N delivery should precede pollination (Bender *et al.*, 2012b). Nitrogen absorption averages around 8.73 kg N/ha per day in certain growth stages (Yue *et al.*, 2022; Battaglia *et al.*, 2019).

Maize fodder (stalk and leaves) is projected to extract 3.40 kg of nitrogen per ton of fodder and 12.5 kg of nitrogen per megagram of grain (AGR-1, 2014). A total of 286.7 kg N/ha was extracted for yields of 12 Mg/ha, with 165.7-kilogram N/ha eliminated via the grain. The N requirement signifies that 13.8 kg of nitrogen was extracted for 1 Mg of maize grain. Nitrogen is transportable within plant tissues, evident in cases of deficit when it is remobilized from older tissues initially. Nitrogen deficit can also be assessed by monitoring nutrient concentration during vegetative development to see if sufficient nitrogen is available for reproductive growth. Nitrogen concentration will decrease during reproductive growth when nitrogen is remobilized from leaves and stalks to the grain. Visual manifestations of nitrogen deprivation include yellowing, resulting from the depletion of nitrogen proteins in chlorophyll inside the leaves. Chlorosis often manifests first in older leaves, located lower on the plant, whereas younger leaves retain their green coloration due to the mobility of nitrogen throughout the plant. Chlorosis may evolve to necrosis in cases of severe deficiency, starting at the leaf tip and advancing throughout the midvein in a distinctive V-shaped pattern (Parveen *et al.*, 2018).

### **2.10.2 Phosphorus**

Phosphorus is initially sequestered in vegetative tissues, such as leaves and stalks, and is then remobilized to the grain post-pollination (Wang & Ning, 2019). Maize fodder is projected to absorb 1.59 kg of  $P_2O_5$  every Mg of fodder and 0.181 kg of  $P_2O_5$  each bushel (25.4 kg) of grain harvested (Mousavi, 2022). P demand is around 50% of total P needs during pollination, equating to roughly 2.35 kg  $P_2O_5$  ha<sup>-1</sup> needed daily, somewhat less than N. A corn production of 12 Mg ha<sup>-1</sup> necessitated 113.7 kg  $P_2O_5$  ha<sup>-1</sup>, with 89.9 kg  $P_2O_5$  ha<sup>-1</sup> extracted by the grain, equating to approximately 7.49 kg  $P_2O_5$  per Mg of grain yield (Hossain, 2022).

### **2.10.3 Potassium**

Potassium absorption resembles nitrogen, exhibiting greater need during vegetative development compared to the grain filling stage. Maize fodder is projected to absorb around 3.63 kg of  $K_2O$  per ton of fodder and to eliminate around 0.159 kg of  $K_2O$  for each bushel (25.4 kg) of grain harvested. During the development stages, maize necessitates around 6.05 kg of  $K_2O$  per hectare daily, with nearly two-thirds of the total potassium required at the time of pollination. Maize yields of 12 Mg ha<sup>-1</sup> necessitated 201.9 kg  $K_2O$  ha<sup>-1</sup>, with 65.7 kg  $K_2O$  ha<sup>-1</sup> extracted in the grain. Thus, the nutrient removal coefficient is 0.26, which is lower than that of nitrogen or phosphorus, indicating that a greater quantity of potassium is returned to the soil with crop residue compared to nitrogen or phosphorus.

### **2.10.4 Sulphur**

Sulfur is a critical nutrient that is necessary for the proper growth and development of plants (Zenda *et al.*, 2021). Protein disulfide bonds, amino acids, vitamins, and cofactors are structurally composed of sulfur. The plants are unable to access the majority of the sulfur in the soil, as it is present in organic matter. The primary source of sulfur for plants is the anionic form of sulfur ( $SO_4^{2-}$ ), which is typically present in minimal quantities in the soil. It is readily leached from the soil due to its water-soluble nature. Sulfur and sulfur-containing compounds

function as signaling molecules in the regulation of stress and in the execution of typical metabolic processes (Miller & Schmidt, 2020). Additionally, they function as mediator molecules in the crosstalk of intricate signaling networks. By employing their specialized sulfate transporters, plants directly absorb sulfate from the soil. Furthermore, plants also utilize the sulfur transporter of a symbiotically associated organism, such as bacteria and fungi, to extract sulfur from the soil, particularly in situations where sulfur levels are low. Therefore, sulfur is a critical element of plant metabolism, and its analysis in various dimensions is essential for the enhancement of the overall health of plants, dependent animals, and humans. Crop quality and yield are adversely affected by sulfur deficiency. Although mild sulfur deficiency may have a negligible impact on yield, it can have a substantial impact on quality (Narayan *et al.*, 2023).

### **2.11 Effect of NPK Fertilizer on Maize Growth and Yield**

one of the primary constraints to agricultural productivity in the cereal-dominated savannas of sub-Saharan Africa (SSA) is nutrient limitation, particularly Nitrogen (N). The risk associated with year-to-year variability in weather and prices is reduced, and net returns are generally increased by moderate additions of N. The application of mineral N fertilizer alone is responsible for approximately 50% of the annual global food harvest (Heffer & Prudhomme, 2016). The N fertilizer requirements for optimal crop production can be estimated by utilizing estimates of internal N requirements (Morris *et al.*, 2018). N and P are the two most prevalent limiting nutrients in Africa, and they respectively serve as significant constraints on food production (Du *et al.*, 2020). The response of maize to starter fertilizer is typically attributed to the presence of N or P in the mixture. Battisti *et al.* (2022) found that NPK starter mixtures increased maize yield in a variety of tillage systems, even in soils with P and K levels that were considered optimum or higher. Nevertheless, it is impossible to accurately predict the total nitrogen requirement of a crop. With no-till, maize yield increases to starter-applied K were greater than those with tillage (Chlingaryan *et al.*, 2018).

## **2.12 Effect of NPK Blended with other Macro or Micronutrients on Maize Growth and Yield**

Bulk Blended NPK compound fertilizer is abbreviated as BB Fertilizer. BB fertilizer is a compound fertilizer that is combined with a single fertilizer or compound fertilizer in a specific proportion. The total nutrient can be produced in accordance with the buyer's specifications, which can satisfy the nutritional and growth requirements of crops, enhance the quality of crop products, and increase income and other attributes (Li *et al.*, 2022). The characteristics of BB fertilizer are as follows: simple to use, low cost, moderate granule intensity, no agglomeration, low moisture, and granule uniformity. The formulation of BB Fertilizer, which includes Nitrogen (N), Phosphate ( $P_2O_5$ ), and Potassium ( $K_2O$ ), can be adjusted to accommodate the needs of the crop, the fertility of the local soil, the growth stage of the crop, and other factors (Uddin *et al.*, 2020).

Consequently, BB Fertilizer is more scientific and specifically designed for balanced fertilization. Medium Element (Ca, Mg, S) and Trace Element (Fe, Zn, Cu, Mn, B, Mo) or (EDTA-Fe, EDTA-Zn, EDTA-Cu, EDTA-Mn) can be applied as special fertilizers.

The NPK bulk blending fertilizer can be employed as a top-dressing fertilizer (Mbhele, 2017). The application of top dressing is adaptable and should be implemented in accordance with the various stages of crop growth, as indicated by the absence of certain nutrients. Water soluble bulk blending fertilizer is a common example of a quick-acting top-dressing fertilizer. In general, the methods include water flushing, burying, distributing, and drip irrigation. NPK bulk blending fertilizer may be implemented as either a base fertilizer or a basal dressing. It is administered to the soil prior to the sowing or transplanting of the plant. The purpose of base fertilizers is to provide the soil with the necessary nutrients for the entire growth stage, thereby enhancing the soil's quality. This approach is more appropriate for the cultivation of commodities that are densely populated. Additionally, NPK bulk blending fertilizer may be employed as seed fertilizer (seed manure). Seed fertilizers are implemented concurrently with

seeding or seed mixtures. It is the most cost-effective fertilization method. Fertilizer is applied to the seed's vicinity or mingled with the seed during sowing or transplanting to provide nutrients for the early growth of crops. It is crucial to rigorously regulate the quantity and selection of fertilizer varieties, as the fertilizer is directly applied to the seed's vicinity (Walia *et al.*, 2024).

Substantial per-hectare losses of N, P, and K in approximately 100 million hectares of cultivated land in Africa over the past 30 years (700, 100, and -450 kg ha<sup>-1</sup> 30 years<sup>-1</sup> for N, P, and K, respectively). In the balances of NPK, the primary plant nutrients, are considered to be valuable indicators of the sustainability of cultivation systems. According to Dagne (2016) the shortest mean days to 50% tasseling (85.25), silking (87.25) and maturity (154.25) of maize were recorded for blended fertilizers, whereas the longest records were obtained from the control. Blended fertilizers had improved grain nutrient uptakes and agronomic efficiency of maize. It was also apparent that much of the nutrients applied were assimilated by the grain than that achieved by the stover.

### **2.13 Effect of Ammonium Sulphate and Urea on Growth and Yield of Maize**

The kind of N-containing inorganic fertilizer is sulphate of ammonia. The fertilizer comprises ammonium (NH<sub>4</sub>) as a 21 percent nitrogen (N) and sulphate (SO<sub>4</sub>) as a 24 percent sulfur (S). The main limiting nutrient in maize productivity in the West African savannas (WAS) is nitrogen (N), which is supplied to the plants by the sulphate of ammonium (NH<sub>4</sub>) levels (Masood *et al.*, 2023). According to estimates, low-N stress causes a 10–50% yearly reduction in maize output (Ertiro *et al.*, 2022).

Numerous factors contribute to nitrogen deficiency in West Africa, such as the application of suboptimal amounts of inorganic fertilizer due to high prices (Kihara *et al.*, 2020) and fertilizer availability, poor weed control in farmers' fields (Rodenburg & Johnson, 2009), and the leaching of soil N below the root zone as a result of torrential rainfall (Osman, 2018). For

maize crops, less than 20 kg N/ha is typically treated. According to Tofa *et al.*, (2022), when nitrogen was not provided, maize yields in Nigerian savannas were severely reduced. As a nitro-positive crop, maize requires comparatively more nitrogen to provide a healthy yield. Therefore, it is essential to employ the most N possible from an appropriate and effective source.

Because it is a crucial component of structural and functional proteins, chlorophyll, and nucleic acids (RNA and DNA), as well as being necessary for the appropriate use of carbohydrates, nitrogen plays a major role in crop growth (Boulter, 2012). As the amount of N increases, so do the leaf area index, leaf area duration, rate of leaf expansion, photosynthetic rate, radiation interception, and radiation usage efficiency. According to Tariq *et al.* (2023), adequate nitrogen delivery also improves the content of crude protein.

The number of leaves and plant height both significantly impacted the pace at which urea was applied. The results demonstrated that the treatment with the greatest urea application (200 kg/ha) at 6WAP, when tassel commencement occurred, had the highest vegetative growth, which declined at the eighth week. According to Wagan *et al.* (2017), this might be explained by the decrease in the rising nitrogen days to silking levels. The days to silking were also shortened by nitrogen levels, according to Ning *et al.* (2017). According to Zhang *et al.* (2021), the plants' vegetative height peaked at 6WAP, which may be explained by improved nitrogen availability and its stimulating influence on vegetative development, which leads to an increase in mutual shading and internodal extension. Wang *et al.* (2024) claim that crops grown on nitrogen-deficient soils display extremely unique N-deficiency symptoms, such as poor growth and produces disruption in physiological/biochemical properties of plants. The control group had the lowest result in all the weeks, which supported their findings.

Two weeks after urea application, there were no significant changes ( $p < 0.05$ ) in the number of leaves across the treatments; however, there were significant differences ( $p < 0.05$ ) when

compared to the control. In the fourth week following application, urea at 100 kg/ha promoted leaf growth, and the quantity of leaves was substantially different from the control and other treatments. When compared to the control, there were similarly significant changes ( $p < 0.05$ ) at the sixth week; however, no significant differences ( $p < 0.05$ ) were seen among the treatments after eight weeks following urea administration.

This rise might also be attributed to the availability of nitrogen, which frequently causes plants to grow taller and produce more nodes and internodes, which in turn causes plants to produce more leaves in their early stages.

Plots treated with 200 kg/ha of treatment had the highest results on the leaf area in every week, followed by those treated with 150 and 100 kg/ha. Out of all the weeks, the control group's performance was the lowest (Ikeh *et al.*, 2023).

## CHAPTER THREE: MATERIALS AND METHODS

### 3.1 Description of Experimental Site/Location

Two field experiments were conducted from March to July 2023 during the major cropping season and from August to December 2023 during the minor cropping season. The research was conducted at the Multi-purpose Crop Nursery of the Akonte Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED), Mampong Campus. Asante Mampong is situated in the Forest Savannah transitional zone of Ghana at an elevation of 435 meters above sea level (Geodatos, 2020). The average annual precipitation of Asante Mampong is around 1270 mm, exhibiting a bimodal distribution. The major rainy season occurs from early April to July, while the minor rainy season spans from September to November. A short dry period occurs in August, but the principal dry season starts in December and ends in March. The experimental area has an average annual temperature of around 27 °C, typically fluctuating between 22 °C and 30 °C (GSS, 2014).

The soil at the experimental site originates from Voltaian sandstone, categorized as Chromic Luvisol according to Asiamah (1987) classification system, and is part of the Bedease Series under the Savannah Ochrosol class. It is a deep red, sandy loam devoid of stones. It possesses excellent drainage, friability, and substantial water retention, along with favourable texture and structure. The pH is around 6.5. The plant cover of Asante Mampong is characterized as transitional, including a dense layer of grass. The experimental location is populated by plant species including giant-star-grass (*Cynodon plectostachyus*), wire weed (*Sida acuta*), centrosema (*Centrosema pubescens*), Guinea grass (*Panicum maximum*), and nutgrass (*Cyperus rotundus*).

### 3.2 Experimental Design and Treatment

The experimental design used for the two field studies was a Randomized Complete Block Design (RCBD), with five (5) treatments and each treatment was replicated four (4) times.

The treatments were as listed below:

T1-Control (No fertilizer)

T2-Granule (70-50-50 kg/ha NPK) + Urea Granules

T3-Granule (70-50-50 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules

T4-Granule (90-60-60 kg/ha NPK) + Urea Granules

T5-Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules

A total field size of 29.0 m × 26.0 m (754 m<sup>2</sup>) was demarcated, ploughed, harrowed, lined and pegged. Each experimental plot measured 5 m x 5 m and 2.0 m was left between blocks and 1m between plots.

Maize seed used as planting material for the experiment was *Obatanpa* and was supplied by the International Fertilizer Development Center on FERRARI project. The *Obatanpa* maize variety is white dent maize seed with maturity period between 120 days, open- pollinated, quality protein maize (QPM) variety, resistant to certain pests and diseases (maize streak virus, rust and blight). *Obatanpa* maize variety has a relatively higher yield (3.2 t/ha) than other maize varieties. (Okai et al., 2015).

### **3.3 Cultural and Management Practices**

#### **3.3.1 Land Preparation and Planting**

The experimental site was ploughed, harrowed, lined and pegged and levelled to obtain the desire germination and growth of crop. The *Obatanpa* maize seed was planted on the flat land after the plots have been prepared. Maize seeds were sown on 15<sup>th</sup> April, 2023 during the major cropping season and on the 2<sup>nd</sup> September 2023 during the minor cropping season at the depth of 4 cm to 6 cm, 3 seeds were sown per hill at a spacing of 75 cm x 40 cm and seedlings were thinned to two (2) plants per hole ten (10) days after emergence. Each experimental plot had six (6) rows with twenty-four (24) plants per row. The total number of plants per experimental plot was one hundred and forty-four (144) plants. Maize seedling emerged at six (6) days after sowing and eight (8) days later vacant holes were refilled.

#### **3.3.2 Weed Control**

Weed control was conducted three (3) times. The first weeding was done manually with a hoe, two weeks after seedling emergence. The second and third weeding were done with a hoe before tasseling and before harvesting. This was to prevent weeds from competing with the maize crop for soil nutrients and water. Weed removal by hand was carried out on weeds close to maize plants during weed control.

#### **3.3.3 Fertilizer Application**

The inorganic fertilizer was administered to each plot in accordance with the treatment at 2 weeks after planting, at a rate determined by the specified ratio of NPK granule fertilizer and other blended fertilizer as top dressing. The fertilizer was administered directly to the crop via the side placement method and incorporated into the soil using a dibber and a hand fork. Urea and ammonium sulphate granule, with Sulphur was administered 6 weeks after planting by the side placement technique, according to treatment.

### **3.3.4 Pest and Disease Control**

The incidence of pests and diseases was frequently monitored by regular visits to the experimental site to inspect for pests, including rats, birds, stem borers, and fall army worms. Insecticide (Porselen 5% SG) was administered at a dosage of 30 g per 15L of water using a CP 15 knapsack sprayer to control fall army worm infestation observed four weeks after planting (4WAP) and biweekly thereafter.

### **3.4 Data Collected**

Data was collected on soil physical and chemical properties, phenology, vegetative growth, yield and yield components of maize. The following records were taken:

#### **3.4.1 Soil Sampling and Analysis**

Soil samples were taken from five randomly selected locations on each experimental plot at a depth of 0-20 cm. Soil samples from each plot were combined and thoroughly mixed in a container, air-dried, and passed through a 2.0 mm sieve to achieve a fine texture, following which sub-samples were placed in labeled plastic bags. The labelled soil samples were subsequently taken to the KNUST Soil Science Laboratory in Kumasi to assess the physical and chemical properties of the soil. This was done for each experimental site before planting and after harvest.

##### **3.4.1.1 Soil pH**

The pH of the soil was determined using a Suntex pH (mv) Sp meter (701) for soil: water ratio of 1:2.5 as was used by Apori & Byalebeka (2021). A 20 g soil sample was weighed into a 100 ml beaker. To this 50 ml distilled water was added and the suspension was stirred continuously for 20 minutes and allowed to stand for 15 minutes. After calibrating the pH meter with buffer solutions of pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension.

### 3.4.1.2 Total Nitrogen

The total nitrogen content of the soil was assessed utilizing the Kjeldahl digestion and distillation method as outlined by Silva (2016). Ten grams of soil and fifty milliliters of runoff were measured into a 500 mL Kjeldahl digestion flask, to which one spatula of a combination including copper sulfate, sodium sulfate, and selenium was added, followed by 30 mL of concentrated H<sub>2</sub>SO<sub>4</sub>. The mixture was heated vigorously to provide a permanent clear green hue in the soil. The digest was cooled and transferred to a 100 mL volumetric flask, then diluted to the mark with distilled water. A 10 mL aliquot of the digest was transferred to a Tecator distillation flask, and 20 mL of 40% NaOH solution was added. Steam from a Foss Tecator device was let to enter the flask. The distilled ammonium was collected in a 250 mL flask containing 10 mL of 4% boric acid with a mixed indicator of bromocresol green and methyl red. The distillate was titrated using 0.1 N HCl solutions. A blank digestion, distillation, and titration were performed without soil to verify the absence of nitrogen residues in the reagents and water utilized.

It was mathematically expressed as:

$$\% N = \frac{(a - b) \times 1.4 \times N \times V}{s \times t}$$

Where; a = mL HCl used for sample titration b = mL HCl used for blank titration 1.4 = 14 x 10<sup>-3</sup> x 100 % (14 = atomic weight of N) N = normality of HCl V = total volume of digest s = mass air-dried soil sample taken for digestion in grams (10.0 g) or volume of runoff sample taken for digestion in mL (50mL) t = volume of aliquot taken for distillation (10.0 mL).

### 3.4.1.3 Available Phosphorus

A 2.0 g soil sample was weighed into a 50 ml shaking bottle and 20 mL of Bray-1 extracting solution was added. The sample was shaken for one minute and then filtered through Whatman filter paper. 10 ml of the filtrate was pipetted into a 25 mL volumetric flask and 1 mL each of molybdate reagent and reducing agent were added for colour development. The percent

transmission was measured at 650 nm wavelength on a spectrophotometer. The concentration of P in the extract was obtained by comparison of the results with a standard curve (Lumbanraja *et al.*, 2017).

#### **3.4.1.4 Soil Exchangeable Potassium**

Potassium in the soil extract was determined by flame photometry (Ullah *et al.*, 2022). Standard solutions of 0, 2, 4, 6, 8 and 10 ppm K<sup>+</sup> and Na<sup>+</sup> were prepared by diluting appropriate volumes of 100 ppm K<sup>+</sup> and Na<sup>+</sup> solution to 100 mL in volumetric flask using distilled water. Photometer readings for the standard solutions were determined and a standard curve constructed. Potassium concentrations were read from the standard curve.

#### **3.4.1.5 Organic Carbon**

Organic carbon content was determined by the dichromate acid oxidation method (Rao *et al.*, 2019). Ten milliliters (10 mL) each of concentrated sulphuric acid, 0.5 N potassium dichromate solution and concentrated orthophosphoric acid were added to 0.05 g of sample in Erlenmeyer flask. The solution was allowed to stand for 30 minutes after addition with distilled water. It was then back titrated with 0.5 N ferrous sulphate solutions with diphenylamine indicator. The organic carbon content was calculated from the equation:

$$\% \text{ Carbon} = \frac{N * (a * b) * 3 * (10)^3 * 100 * 1.3}{w}$$

where: N = normality of ferrous sulphate a = mL ferrous sulphate solution required for sample titration b = mL ferrous sulphate solution required for blank titration w = weight of oven dried sample in gram 0.003 = equivalent weight of carbon 1.3 = compensation factor allowing for incomplete combustion.

### **3.4.2 Phenological Data**

- **Days to 50% Emergence**

This was determined as the number of days required for 50% of the plants within the 3 m × 3 m area from the four central rows per plot to emerge from the planting date.

- **Percentage Crop Establishment**

The percentage plant establishment was calculated by counting the number of plants that had established within the 3 m × 3 m area from the four central rows per plot (harvestable area) at twenty-one days after planting, and the percentage was then estimated.

- **Days to 50% Tasseling**

This was determined as the number of days until 50% of the plants within a 3 m × 3 m area from the four central rows per plot (harvestable area) have tasseled from the planting date.

- **Days to 50 % Silking**

This was determined as the number of days from the planting date until 50% of the plants within the 3 m × 3 m area (harvestable area) to silk.

- **Days to 50% and 100% Maturity**

This was determined as the number of days required for 50% of the plants within the 3 m x 3 m area (harvestable area) to reach full maturity from the planting date. The days to 100% maturity was also determined as the number of days required for 100% of the plants within the 3 m x 3 m area (harvestable area) to reach full maturity from the planting date.

### **3.4.3 Vegetative Growth Data**

- **Plant Height**

Plant height was measured on five randomly selected tagged plants per plot from the harvestable area, from the base to the apical leaf, using a meter rule four weeks after planting (4 WAP), and at two-week intervals until at tasseling stage and the mean recorded.

- **Stem Diameter**

The stem diameter was measured using a vernier caliper at the widest point of five randomly selected tagged plants from the harvestable area per plot, four weeks after planting (4 WAP), and thereafter at 14-day intervals until at tasseling stage and the mean recorded.

- **Number of Leaves Per Plant**

The total leaf count per plant was recorded individually for five (5) randomly selected tagged plants from the harvestable area per plot at four weeks after planting (4 WAP) and thereafter at two-week intervals until tasseling stage and the mean estimated.

- **Dry Matter Accumulation**

Six (6) plants were randomly selected and uprooted from the rows outside the harvestable area and were separated into root and shoot. The dry root and shoot weight were determined using electronic weighing scale and then oven drying at 70°C to constant weight. This was done two weeks before and after tasseling.

- **Leaf Chlorophyll Content**

The leaf chlorophyll content was measured on the fifth and sixth leaf of five (5) randomly selected tagged plants from the 3 m x 3 m area within the four (4) central rows per plot using the calibrated SPAD meter at four (4) weeks after planting and at two (2) weeks interval until eleven weeks after planting and the mean was computed.

- **Leaf Area**

The leaf length was measured from the base (where the leaf blade meets the petiole or stem) to the tip of the leaf and leaf width was measured at the widest part of the leaf using meter rule. Leaf area was measured using the formula  $LA = LW \times 0.75$ , where LA= total leaf area per corn plant modified from Montgomery (1911), W= width of leaf and L is length of leaf and multiplied by a factor (0.75) (Elings, 2000).

- **Internode Length**

The internode length was measured on five randomly selected tagged plants in the harvestable area per plot between the fifth and sixth nodes using a meter stick from 30 DAP at two-week intervals until 72 DAP, and the mean was estimated.

### **3.4.4 Physiological Growth Parameters**

- **Crop Growth Rate**

The crop growth rate was measured using the formula;  $CGR = (1/GA) \times ((W2 - W1)/(T2 - T1))$ , Where CGR= Crop growth rate; W1=total dry matter at first harvest; W2= Total dry matter at second harvest; T1 = Days of observation at first harvest; T2= Days of observation at second harvest and was obtained in  $g\ m^{-2}\ day^{-1}$ .

- **Relative Growth rate**

The relative growth rate was measured using the formula;  $RGR = ((\ln W2 - \ln W1)/(T2 - T1))$ , Where RGR = Relative growth rate; W1=Total dry matter at first harvest; W2= Total dry matter at second harvest; T1= Days of observation at first harvest; T2=Days of observation at second harvest; ln=Natural log and was obtained in  $g\ m^{-2}\ day^{-1}$ .

### **3.4.5 Yield and Yield Components**

- **Number of Plants Harvested**

The total number of plants harvested from the 3 m × 3 m area within the four middle rows of each plot was counted, and the mean was recorded.

- **Number of Lodged Plants Per Plot**

The total count of lodged plants from the harvestable area for each plot on the day of harvest was determined, and the average was recorded.

- **Number of Cobs Per Plot**

The total number of cobs from the 3 m × 3 m area within the four middle rows per plot was counted and the average was recorded.

- **Number of Seeds Per Cob**

The total number of seeds from the five (5) randomly selected cobs from the harvestable per plot was counted and the mean estimated.

- **100-Seed Weight**

The weight of one hundred seeds was determined by randomly selecting seeds from matured shelled cobs in the harvestable area and the weight determined using an electronic weighing scale, and the mean was recorded.

- **Total stover Weight Per Plot**

At harvest, the total number of plants from the 3 m × 3 m rea within the four middle rows of each plot was collected and bundled. The complete bundle was weighed using an electronic weighing scale, and the average was estimated.

- **Dehusked Cob Weight Per Plot**

The total number of unhusked cobs from the 3 m × 3 m area within the four middle rows per plot was dehusked, weighed using an electronic weighing scale, and the average was recorded.

- **Cob Length**

The cob length was measured on the five (5) randomly selected cobs from the harvested area per plot from the base to the tip of the cob using a meter stick and the mean was recorded.

- **Cob Diameter**

The diameter of the cob was measured using a vernier caliper at the widest part of five randomly selected cobs per plot after harvest and dehusking, and the mean was estimated.

- **Grain Weight Per Plot**

The total weight of grain harvested from the 3 m × 3 m area within the four central rows of each plot was weighed using electronic weighing scale after harvest, dehusking and drying and the mean value recorded in kgm<sup>-2</sup>.

- **Grain Yield**

Grain yield was assessed from sixty-four (64) plants within the 3 m x 3 m area within the four central rows of each plot. Grains were extracted from cobs after harvest using a manual grain remover and subsequently sun-dried to achieve uniform moisture content. The dried grains were weighed using an electronic weighing scale, and their yield per plot was estimated in t/ha.

$$\text{Grain yield (t/ha)} = \left( \frac{10000\text{m}^2 \times Q \text{ grain (kg)}}{\text{Harvest area (m}^2\text{)}} \right) / 1000 \text{ (Makarova } et al., 2020\text{)}.$$

- **Harvest Index**

Harvest index is the ratio of grain yield to plant biomass produced at harvest. It was determined by dividing the grain yield by the total biomass yield.

$$HI = GY/TY$$

where: HI = harvest index, GY = grain yield, TY = Total biomass yield

### **3.5 Statistical Analysis/Data Analysis**

The data was analyzed using analysis of variance (ANOVA) with GenStat statistical package (2008) version 11.1 (VSN International Ltd). Significant differences between treatment means were separated using the Tukey's Honestly Significant Difference (HSD) test at a 5% probability level. Correlation matrix analysis was used to determine the relationship between some vegetative growth parameters and yield and yield components of maize.

## **CHAPTER FOUR: RESULTS**

### **4.1 Climatic Conditions at the Experimental Sites**

The climatic conditions at the experimental site during 2023 major and 2023 minor cropping seasons are presented in Appendix 2 and Appendix 3 respectively. In 2023 major cropping season, a total monthly rainfall of 784.00 mm was recorded from March 2023 to July 2023 (Appendix 2). The highest rainfall occurred in April (258.8 mm) and July (198.9 mm). At 6:00 hours and 15:00 hours the mean monthly relative humidity was 90.4% and 63% respectively. The monthly relative humidity ranged between 55% to 92%. The mean monthly minimum and maximum temperatures varied from 22.76°C to 31.72°C (Appendix 2).

During the 2023 minor cropping season, a total of 786.90 mm of rainfall was recorded between August and December, with the highest amounts in October (286.4 mm) and August (213.4 mm) (Appendix 3). The average monthly relative humidity was 88% at 6:00 hours and 61.60% at 15:200 hours, ranging from 44% to 93%. The average monthly temperatures varied from a minimum of 22.4°C to a maximum of 34.5°C during this period (Appendix 3).

### **4.2 Soil Properties**

#### **4.2.1 Initial Soil Chemical and Physical Properties at the Experimental Sites**

The initial chemical and physical properties of the background soil for both cropping seasons are shown in Table 4.1. During the 2023 major cropping season, the soil pH was 5.25, indicating acidity. The levels of available P, N, Ca, Mg, Na, Al, and H were low (Appendix 1). However, the contents of K, organic carbon, and organic matter were moderate (Appendix 1). During the 2023 minor cropping season, the background soil had an acidic pH of 5.36. The levels of available P, Al, H, and Na were low (Appendix 1). However, the contents of K, Ca, Mg, N, organic carbon, and organic matter were moderate. The soil at both experimental sites was classified as sandy loam (Table 4.1).

**Table 4. 1:** Initial chemical and physical properties of the background soils

Soil Samples	pH (H <sub>2</sub> O 1:1)	P mg/kg	N (%)	Exch. Bases (cmol/kg)				Exch. Acidity		% OC	% OM	EC ( $\mu$ S/cm)
				K	Ca	Mg	Na	Al	H			
Major Season	5.25	3.835	0.104	0.345	1.22	0.78	0.059	0.251	0.285	1.246	2.148	205
Minor Season	5.36	4.824	0.113	0.358	2.08	1.12	0.044	0.236	0.258	1.045	1.802	56
Particle size analysis												
		% Sand	% Clay		% Silt		Textural class					
Major Season		74.88	19.44		5.68		Sandy loam					
Minor Season		75.76	19.92		4.32		Sandy loam					
<i>Season 1: 2023 major cropping season</i>				<i>Season 2: 2023 minor cropping season</i>								

#### 4.2.2 Final Soil Chemical and Physical Properties at the Experimental Seasons

The final soil chemical properties after harvesting of maize plant is presented in Table 4.2 and Table 4.3. Generally, there were significant ( $p < 0.05$ ) differences in nutrient status and pH of the soil as affected by the treatments in both major and minor seasons. All the fertilizer treated plots increased the nutrient status and the pH of the soil as compared to the control plot across both cropping seasons. In 2023 major cropping season, the highest soil pH (5.84) and Ca (2.42) content was recorded when Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules was applied followed closely by Granule (70-50-50 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granule and treatments (Table 4.2). The soil applied with Granule (90-60-60 kg/ha NPK) + Urea Granules recorded the highest content of available P and Na. Application of Granule (70-50-50 kg/ha NPK) + S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded the highest total N, K, Mg, EC after harvesting of the maize plants. Application of Granule (70-50-50 kg/ha NPK) + Urea Granules had higher H, Organic carbon and Organic matter as compared to the control and other amended soils (Table 4.2). Highest Al was recorded in the unamended plot.

In 2023 minor cropping season, the highest soil pH as well as Na and Al contents were recorded by Granule (90-60-60 kg/ha NPK) + Urea Granules. The soil applied with Granule (70-50-50 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded the highest available P, total N,

Mg and EC. Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules treated soils produced the highest content of Ca, H, Organic matter and Organic carbon. Highest K content was recorded by Granule (70-50-50 kg/ha NPK) + Urea Granules treated plot (Table 4.3).

### **4.3 Phenology of Maize**

#### **4.3.1 Days to 50% Emergence**

The results on days to 50% emergence as affected by different rates of Granules NPK fertilizer during 2023 major and 2023 minor cropping seasons are presented in Table 4.3. In 2023 major cropping season there were significant ( $P<0.05$ ) differences between treatments in days to 50% emergence. Maize plants that received Granule (90-60-60 kg/ha NPK) + Urea Granules emerged (4.00 days) two days (2) earlier than maize plants grown on unamended plot (6.00 days) (Tables 4.3).

In 2023 minor cropping season there were significant ( $P<0.05$ ) differences between treatments in days to 50% seedling emergence. Maize plants grown on Granule (90-60-60 kg/ha NPK) + Urea Granules recorded the least (4.50 days) number of days to 50% seedling emergence and emerged almost two (2 days) earlier than maize plants grown on unamended plot . Across both cropping seasons the days to 50% seedling emergence ranged from 4.00 – 7.00 days (Tables 4.3). There were no significant ( $P>0.05$ ) differences between season and treatment x season interactions in days to 50% seedling emergence.

**Table 4. 2: Final chemical and physical properties of the soil of treatments after harvesting of maize**

Treatment	pH	Available N (%) P	Exch. Bases (cmol/kg)				Exch. Acidity		% OC	% OM	EC ( $\mu$ S/cm)	
			K	Ca	Mg	Na	Al	H				
<b>2023 Major cropping season</b>												
Control (No fertilizer)	5.25	3.835	0.104	0.345	1.22	0.78	0.059	0.251	0.285	1.246	2.148	205
Granule (70-50-50 kg/ha NPK) + Urea Granules	5.65	4.536	0.115	0.435	2.40	1.80	0.055	0.233	0.295	1.502	2.589	166
Granule (70-50-50 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	5.74	6.512	0.129	0.462	1.64	2.16	0.044	0.241	0.214	1.268	2.185	226
Granule (90-60-60 kg/ha NPK) + Urea Granules	5.62	9.01	0.116	0.448	1.88	0.52	0.059	0.265	0.254	1.385	2.387	180
Granule (90-60-60 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	5.84	8.773	0.119	0.428	2.42	0.18	0.051	0.247	0.231	1.287	2.219	185
<b>HSD (0.05)</b>	<b>0.13</b>	<b>0.08</b>	<b>0.01</b>	<b>0.01</b>	<b>0.13</b>	<b>0.09</b>	<b>0.01</b>	<b>0.01</b>	<b>0.02</b>	<b>0.01</b>	<b>0.01</b>	<b>10.75</b>
<b>CV (%)</b>	<b>0.91</b>	<b>0.46</b>	<b>5.51</b>	<b>1.34</b>	<b>2.65</b>	<b>3.26</b>	<b>11.26</b>	<b>2.69</b>	<b>2.95</b>	<b>0.43</b>	<b>0.25</b>	<b>2.04</b>

*T1: Control (No fertilizer); T2: Granule (70-50-50 kg/ha NPK) + Urea Granules; T3: Granule (70-50-50 kg/ha NPK + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules; T4: Granule (90-60-60 kg/ha NPK) + Urea Granules; T5: Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules*

**Table 4. 3: Final chemical and physical properties of the soil of treatments after harvesting of maize**

Treatment	pH	Available N (%) P	Exch. Bases (cmol/kg)				Exch. Acidity		% OC	% OM	EC ( $\mu$ S/cm)	
			K	Ca	Mg	Na	Al	H				
<b>2023 Minor cropping season</b>												
Control (No fertilizer)	5.36	4.824	0.113	0.358	2.08	1.12	0.044	0.236	0.258	1.045	1.802	56
Granule (70-50-50 kg/ha NPK) + Urea Granules	5.84	5.174	0.118	0.422	2.10	1.30	0.040	0.258	0.247	1.092	1.883	59
Granule (70-50-50 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	5.88	7.33	0.137	0.405	2.20	1.40	0.055	0.261	0.265	1.170	2.017	104
Granule (90-60-60 kg/ha NPK) + Urea Granules	5.99	6.293	0.116	0.418	2.60	1.25	0.063	0.274	0.258	1.112	1.916	82
Granule (90-60-60 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	5.77	7.175	0.122	0.378	2.66	1.10	0.055	0.258	0.274	1.482	2.555	79
<b>HSD (0.05)</b>	<b>0.10</b>	<b>0.08</b>	<b>0.01</b>	<b>0.01</b>	<b>0.08</b>	<b>0.08</b>	<b>0.01</b>	<b>0.01</b>	<b>0.01</b>	<b>0.01</b>	<b>0.01</b>	<b>10.76</b>
<b>CV (%)</b>	<b>0.69</b>	<b>0.48</b>	<b>4.74</b>	<b>1.49</b>	<b>1.27</b>	<b>2.37</b>	<b>10.45</b>	<b>2.28</b>	<b>2.25</b>	<b>0.51</b>	<b>0.29</b>	<b>5.00</b>

*T1: Control (No fertilizer); T2: Granule (70-50-50 kg/ha NPK) + Urea Granules; T3: Granule (70-50-50 kg/ha NPK + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules; T4: Granule (90-60-60 kg/ha NPK) + Urea Granules; T5: Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules*

### 4.3.2 Percentage Crop Establishment

Percentage crop establishment as affected by different rates of Granules NPK fertilizer during 2023 major and 2023 minor cropping seasons is presented in Table 4.3. There were significant ( $P < 0.05$ ) differences between treatments in percentage crop establishment across both cropping seasons. The percentage crop establishment ranged from 73.00 % - 98.25 % during 2023 major and 2023 minor cropping seasons. Maize plants that received Granule (70-50-50 kg/ha NPK) + 20S +  $(\text{NH}_4)_2\text{SO}_4$  Granules recorded significantly higher (98.25% and 97.51%) number of established plants than maize plants grown on unamended plots (73.00% and 74.76%) and Granule (70-50-50 kg/ha NPK) + Urea Granules (85.55% and 80.26%) across both cropping seasons. Treatment x season interactions did not significantly ( $P > 0.05$ ) influence percentage crop establishment. However, percentage crop establishment in 2023 major cropping season was significantly higher than those in 2023 minor cropping season (Table 4.3).

**Table 4. 4 Effect of different rates of Granules NPK fertilizer on days to 50% emergence and percentage crop establishment of maize during 2023 major and 2023 minor cropping seasons**

Treatment	Days to 50% emergence		Percentage plant establishment	
	2023 major season	2023 minor season	2023 major season	2023 minor season
Control (No fertilizer)	6a	7a	73c	75c
Granule (70-50-50 kg/ha NPK) + Urea Granules	5bc	5b	86b	80b
Granule (70-50-50 kg/ha NPK) + 20S + $(\text{NH}_4)_2\text{SO}_4$ Granules	5ab	5b	99a	98a
Granule (90-60-60 kg/ha NPK) + Urea Granules	4c	5b	91ab	84b
Granule (90-60-60 kg/ha NPK) + 20S + $(\text{NH}_4)_2\text{SO}_4$ Granules	6a	5b	90ab	81b
Mean	5	5	88	84
<b>HSD (<math>P \leq 0.05</math>)</b>	<b>1.02</b>	<b>1.52</b>	<b>8.43</b>	<b>4.57</b>
<b>CV (%)</b>	<b>12.78</b>	<b>18.29</b>	<b>6.25</b>	<b>3.55</b>
Treatment (HSD=0.05)	=	0.86**		4.29**
Season (HSD=0.05)	=	NS		2.71**
Treatment x Season (HSD=0.05)	=	NS		NS

### **4.3.3 Days to 50% Tasseling**

From Table 4.4, there were significant ( $P \leq 0.05$ ) differences between the amended and unamended plots in days to 50% tasseling across both cropping seasons. In 2023 major cropping season, the days to 50% tasseling ranged from 49.00 – 61.25 days. Maize plants that received Granule (70-50-50 kg/ha NPK) + Urea Granules recorded significantly lower (49.00 days) number of days to 50% tasseling than plants grown on the unamended plot which tasseled almost twelve (12) days later (61.25 days) (Table 4.4).

In 2023 minor cropping season, maize plants that received Granule (70-50-50 kg/ha NPK) + Urea Granules recorded significantly lower (51 days) number of days to 50% tasseling than plants grown on the unamended plot which tasseled almost thirteen (32) days later (64 days). Maize plants that received Granule (70-50-50 kg/ha NPK) + 20S +  $(\text{NH}_4)_2\text{SO}_4$  Granules and Granule (90-60-60 kg/ha NPK) + 20S +  $(\text{NH}_4)_2\text{SO}_4$  Granules tasseled on the same day (58.50 days) and differed significantly from the control with the highest days to 50% tasseling (Table 4.4). Number of days to 50% tasseling in 2023 major cropping season was significantly lower than those in 2023 minor cropping season (Table 4.3). Treatment x season interactions did not significantly ( $P > 0.05$ ) influence days to 50% tasseling.

### **4.3.4 Days to 50% Silking**

From Table 4.4, there were significant ( $P \leq 0.05$ ) differences between treatments in days to 50% silking across both cropping seasons. In 2023 major cropping season the days ranged from 54.50 -67.75 days. Maize plants that received Granule (70-50-50 kg/ha NPK) + Urea Granules silked (54.50 days) almost thirteen days earlier than plants grown on the unamended plot which (67.75 days) (Table 4.4).

In 2023 minor cropping season, maize plants that received Granule (70-50-50 kg/ha NPK) + Urea Granules silked (56.00 days) fourteen days earlier than maize plants grown on the unamended plot (70.00 days) (Table 4.4). Maize plants grown during the 2023 major cropping

season silked significantly earlier than those in 2023 minor cropping season (Table 4.4). There was no significant ( $P \geq 0.05$ ) difference between treatment x season interactions in days to 50% silking.

**Table 4. 5:** Effect of different rates of Granules NPK fertilizer on days to 50% tasseling and 50% silking of maize during 2023 major and 2023 minor cropping seasons

Treatment	Days 50% Tasseling		Days to 50% Silking	
	major season	minor season	major season	minor season
Control (No fertilizer)	61a	64a	68a	70a
Granule (70-50-50 kg/ha NPK) + Urea Granules	49d	51c	55c	56d
Granule (70-50-50 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	57b	59b	61b	66b
Granule (90-60-60 kg/ha NPK) + Urea Granules	52c	52c	60b	61c
Granule (90-60-60 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	58b	59b	64ab	65b
Mean	55	57	62	64
<b>HSD (<math>P \leq 0.05</math>)</b>	<b>2.72</b>	<b>3.32</b>	<b>4.11</b>	<b>3.02</b>
<b>CV (%)</b>	<b>3.20</b>	<b>3.80</b>	<b>4.34</b>	<b>3.09</b>
	Treatment = 1.93**		2.48**	
	Season = 1.22**		1.57**	
	Treatment x Season = NS		NS	

Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation;

### 4.3.5 Days to Physiological Maturity

The results on days to physiological maturity as affected by different rates of Granule NPK fertilizer during 2023 major and 2023 minor cropping seasons is presented in Table 4.5. There were significant ( $P \leq 0.05$ ) differences between treatments in days to physiological maturity across both cropping seasons. The days to physiological maturity ranged from 78 – 90 days and 74 – 92 days during 2023 major and 2023 minor cropping seasons respectively. In 2023 major cropping season, maize plants that received Granule (70-50-50 kg/ha NPK) + Urea Granules matured thirteen days earlier than maize plants grown on unamended plot and was significant ( $P \leq 0.05$ ) different. Maize plants that received Granule (70-50-5020 kg/ha NPK) +

20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules and Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules matured on the same day (82 days) and differed significantly from the control with the highest days to physiological maturity (Table 4.5).

In 2023 minor cropping season, maize plants that received Granule (70-50-50 kg/ha NPK) + Urea Granules mature almost sixteen days earlier than maize plants grown on the unamended plot. Maize plants that received Granule (70-50-50 kg/ha NPK) + Urea Granules took significantly lesser number of days (about 10- 14 days) to physiological maturity than the other amended plots. Number of days to physiological maturity in 2023 major cropping season was significantly lower than those in 2023 minor cropping season (Table 4.5). There was no significant ( $P \geq 0.05$ ) difference between treatment x season interactions in days to physiological maturity.

#### **4.3.6 Days to Maturity**

The results on days to maturity as affected by different rates of Granule NPK fertilizer during 2023 major and 2023 minor cropping seasons are presented in Table 4.5. There were significant ( $P \leq 0.05$ ) differences between treatments in days to 100% maturity across both cropping seasons. In 2023 major cropping season, maize plants that received Granule (70-50-50 kg/ha NPK) + Urea Granules matured thirteen days earlier than maize plants grown on unamended plot and was significant ( $P \leq 0.05$ ) different. Maize plants grown on unamended plot differed significantly from all the amended plot except Granule (90-60-60 kg/ha NPK) + Urea Granules and Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules in days to maturity (Table 4.5).

In 2023 minor cropping season, maize plants that received Granule (70-50-50 kg/ha NPK) + Urea Granules matured almost twelve days earlier than maize plants grown on the unamended plot. Maize plants that received Granule (70-50-50 kg/ha NPK) + Urea Granules took significantly lesser number of days (about 8- 9days) to maturity than the other amended plots.

Maize plants that received Granule (70-50-50 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules and Granule (90-60-60 kg/ha NPK) + Urea Granules matured on the same day (119.75 days) but did not differ significantly from the control with the highest days to maturity (Table 4.5). Number of days to maturity in 2023 major cropping season was significantly lower than those in 2023 minor cropping season (Table 4.5).

**Table 4. 6:** Effect of different rates of Granules NPK fertilizer on days to physiological maturity and 100% maturity of maize during 2023 major and 2023 minor cropping seasons

Treatment	Days to Physiological Maturity		Days to 100% Maturity	
	major season	minor season	major season	minor season
Control (No fertilizer)	90a	92a	114a	122a
Granule (70-50-50 kg/ha NPK) + Urea Granules	78c	74d	101b	110c
Granule (70-50-50 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	82b	84c	103b	120ab
Granule (90-60-60 kg/ha NPK) + Urea Granules	83b	88b	108ab	120ab
Granule (90-60-60 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	82b	84bc	112a	118b
Mean	83	84	108	118
<b>HSD (P ≤ 0.05)</b>	<b>3.95</b>	<b>3.72</b>	<b>8.29</b>	<b>3.97</b>
<b>CV (%)</b>	<b>3.10</b>	<b>2.86</b>	<b>5.00</b>	<b>2.19</b>
	Treatment = 2.74**		4.33**	
	Season = NS		2.74**	
	Treatment x Season = 3.87**		NS	

Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation

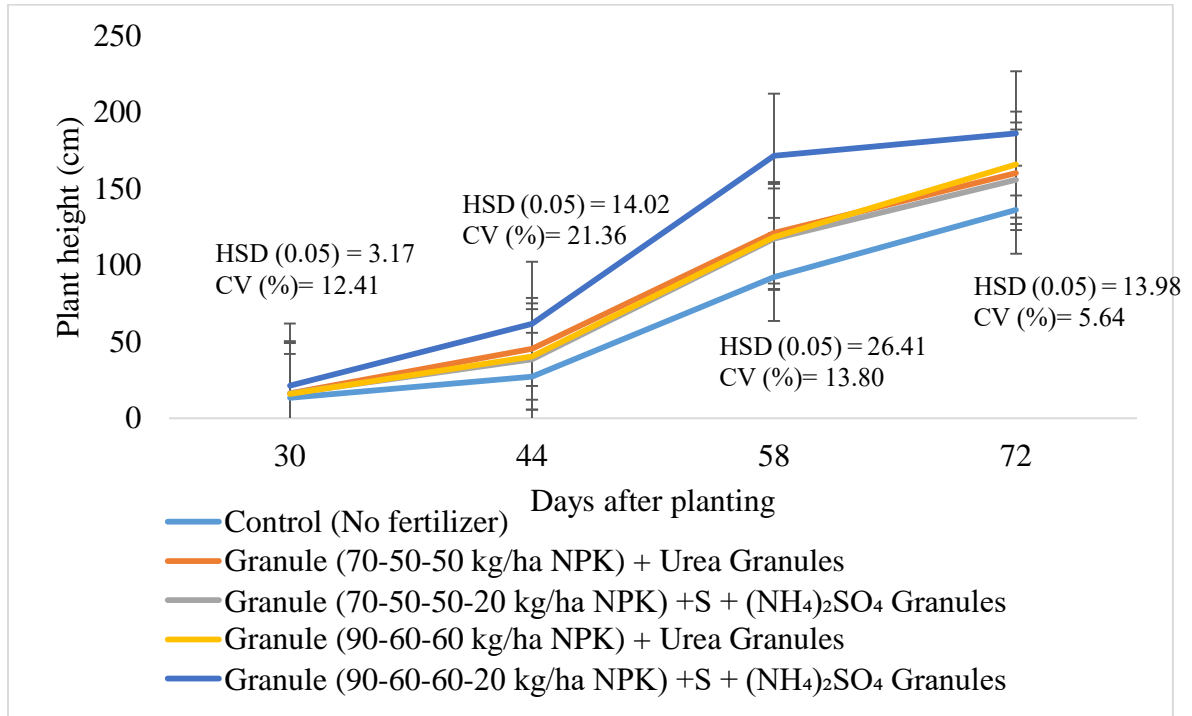
## **4.4 Vegetative Growth of Maize**

### **4.4.1 Plant Height**

The results on plant height as affected by different rates of Granule NPK fertilizer during 2023 major and 2023 minor cropping seasons are presented in Figure 4.1. There were significant ( $P \leq 0.05$ ) differences between treatments in plant height across both cropping seasons. In 2023 major cropping season, maize plants that received Granule (90-60-60 kg/ha NPK) + 20S +  $(\text{NH}_4)_2\text{SO}_4$  Granules recorded significantly taller plants than maize plants that received the other amendments as well as plants grown on unamended plot over the sampling periods (Figure 4.1a).

In 2023 minor cropping season, there were no significant ( $P \geq 0.05$ ) differences between treatments in plant height from 30 DAP to 58 DAP (Figure 4.1b). Maize plants that received Granule (90-60-60 kg/ha NPK) + Urea Granules recorded significantly taller plants than maize plants grown on Granule (90-60-60 kg/ha NPK) + 20S +  $(\text{NH}_4)_2\text{SO}_4$  Granules as well as plants grown on unamended plot at 72 DAP (Figure 4.1b). Generally, maize plants grown on the unamended plot over the sampling periods (Figure 4.1b).

(a) Major Season Cropping, 2023



(b) Minor Cropping Season, 2023

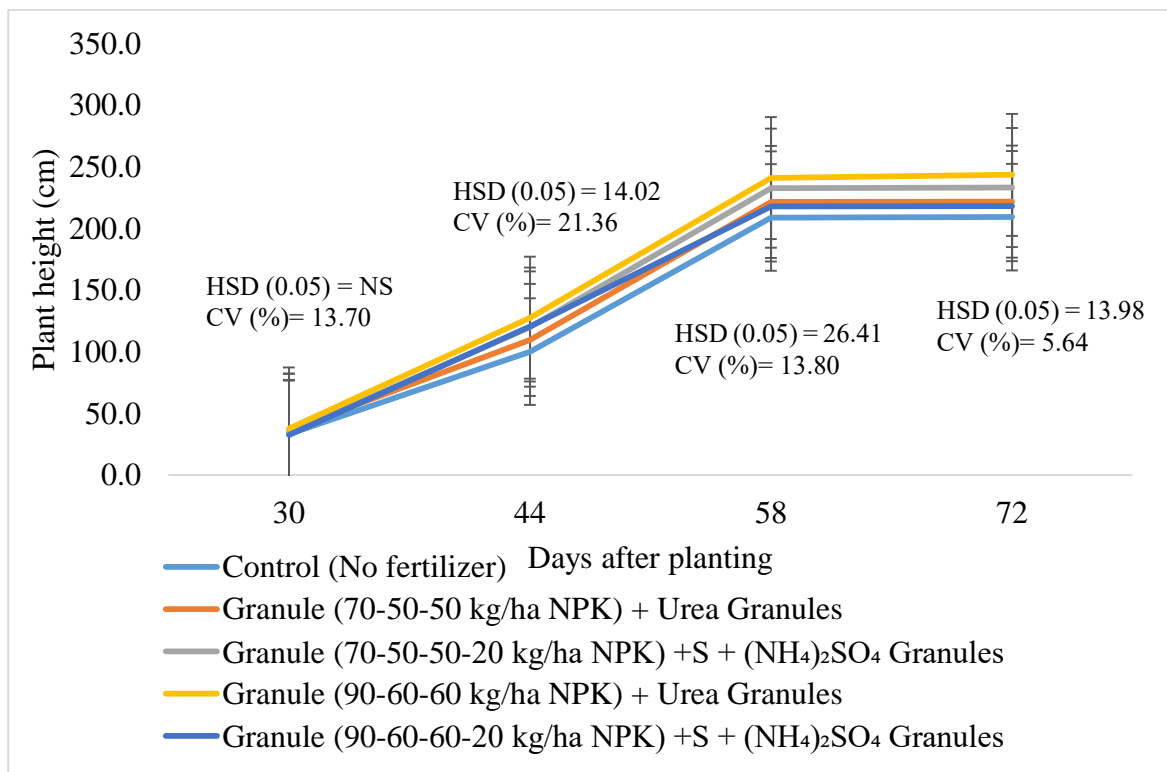


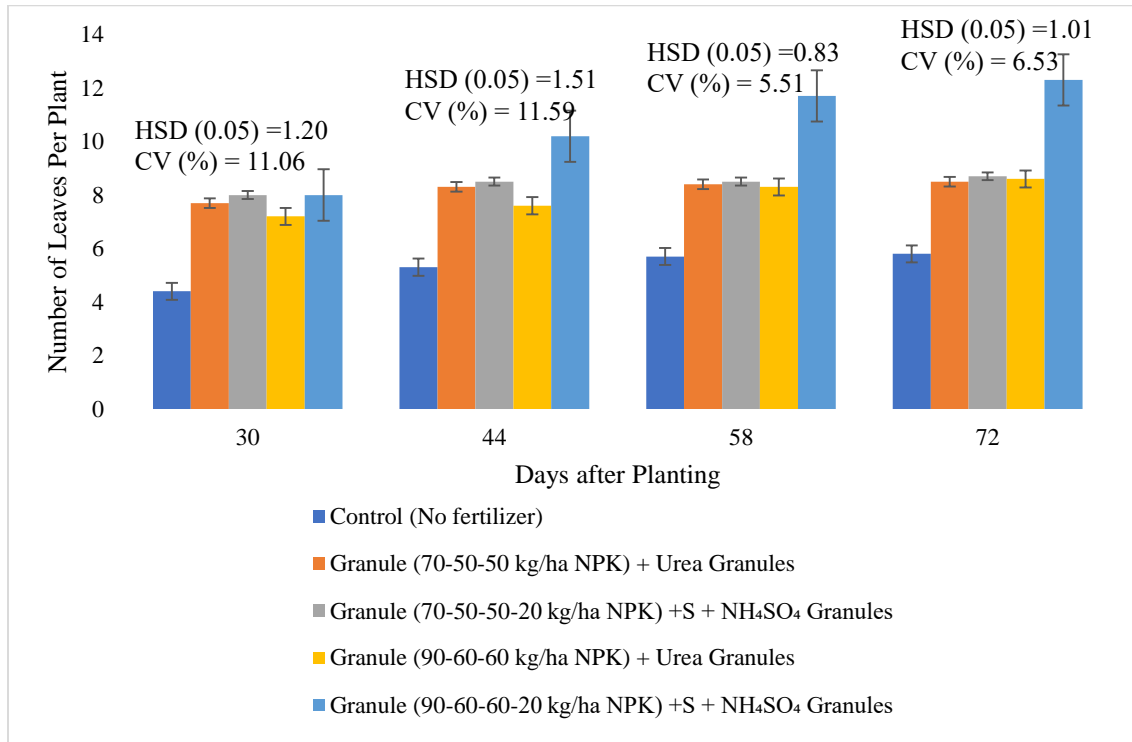
Figure 4. 1: Effect of different rates of granules NPK fertilizer on plant height of maize during 2023 major and minor seasons

#### 4.4.2 Number of Leaves Per Plant

The results on number of leaves per plant as influenced by different rates of Granule NPK fertilizer during 2023 major and 2023 minor cropping seasons is presented in Figure 4.2. In 2023 major cropping season, there were significant ( $P \leq 0.05$ ) differences between treatments in number of leaves per plant from 30 to 86 DAP. From 30 to 72 DAP, maize plants that received Granule (90-60-60 kg/ha NPK) + 20S +  $(\text{NH}_4)_2\text{SO}_4$  Granules recorded significantly higher number of leaves per plant than plants grown on unamended plot (Figure 4.1). Maize plants grown on unamended plots recorded the least number of leaves per plant throughout the entire growing period (Figure 4.2a).

In 2023 minor cropping season, maize plants grown on Granule (90-60-60 kg/ha NPK) + Urea Granules recorded the highest (10.98) number of leaves per plant and was significantly ( $P \leq 0.05$ ) different from maize plants grown on unamended plot (9.68). There was no significant ( $P \geq 0.05$ ) difference between the amended plots in number of leaves per plant at 30 DAP. There were no significant ( $P \geq 0.05$ ) differences between treatments in number of leaves per plant from 44 to 72 DAP (Figure 4.2b).

(a) Major Cropping Season, 2023



(b) Minor Cropping Season, 2023

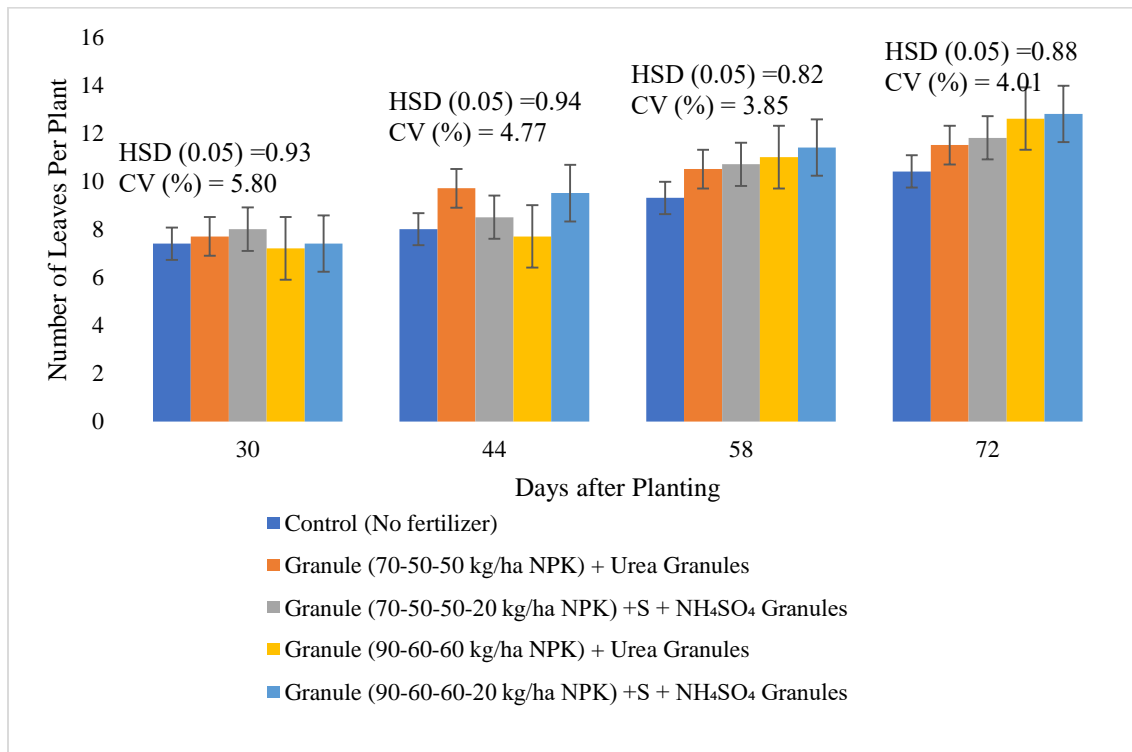


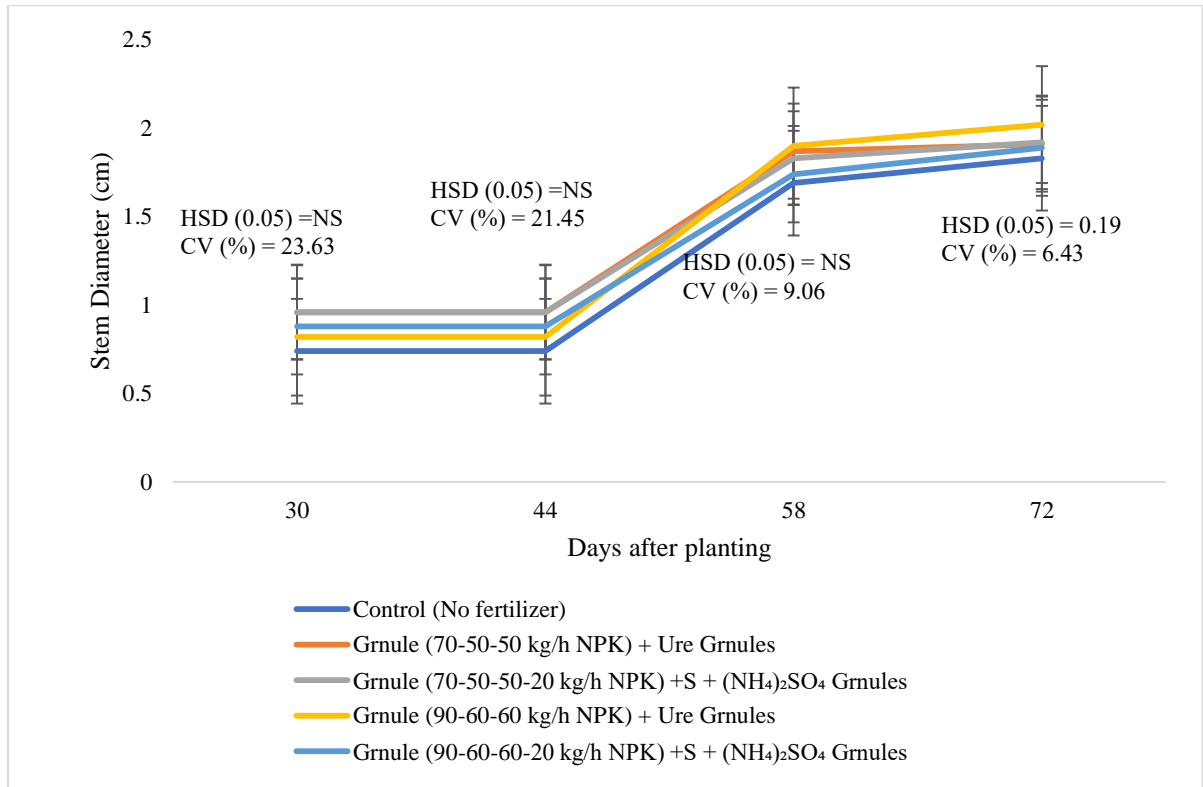
Figure 4. 2: Effect of different rates of granules NPK fertilizer on number of leaves per plant of maize during 2023 major and minor cropping seasons

#### 4.4.3 Stem Diameter

The results on stem diameter as affected by different rates of Granule NPK fertilizer during 2023 major and 2023 minor cropping seasons is presented in Figure 4.3. In the 2023 major cropping season, there were no significant ( $P \geq 0.05$ ) differences between treatments in stem diameter from 30 to 58 DAP (Figure 4.3a). Maize plants that received Granule (90-60-60 kg/ha NPK) + Urea Granules recorded significantly wider stem diameter than maize plants grown on unamended plot from 72 to 86 DAP (Figure 4.3a).

In 2023 minor cropping season, there were no significant ( $P \geq 0.05$ ) differences between treatments in stem diameter at 30 DAP (Figure 4.3b). However, significant differences occurred between the treatments in plant height from 44 to 86 DAP. From 44 to 86 DAP, maize plants grown on Granule (90-60-60 kg/ha NPK) + Urea Granules recorded significantly wider stem diameter than maize plants grown on unamended plot. There were no significant ( $P \geq 0.05$ ) differences between the amended plots in stem diameter from 44 to 72 DAP (Figure 4.3b).

(a) Major Cropping Season, 2023



(b) Minor Cropping Season, 2023

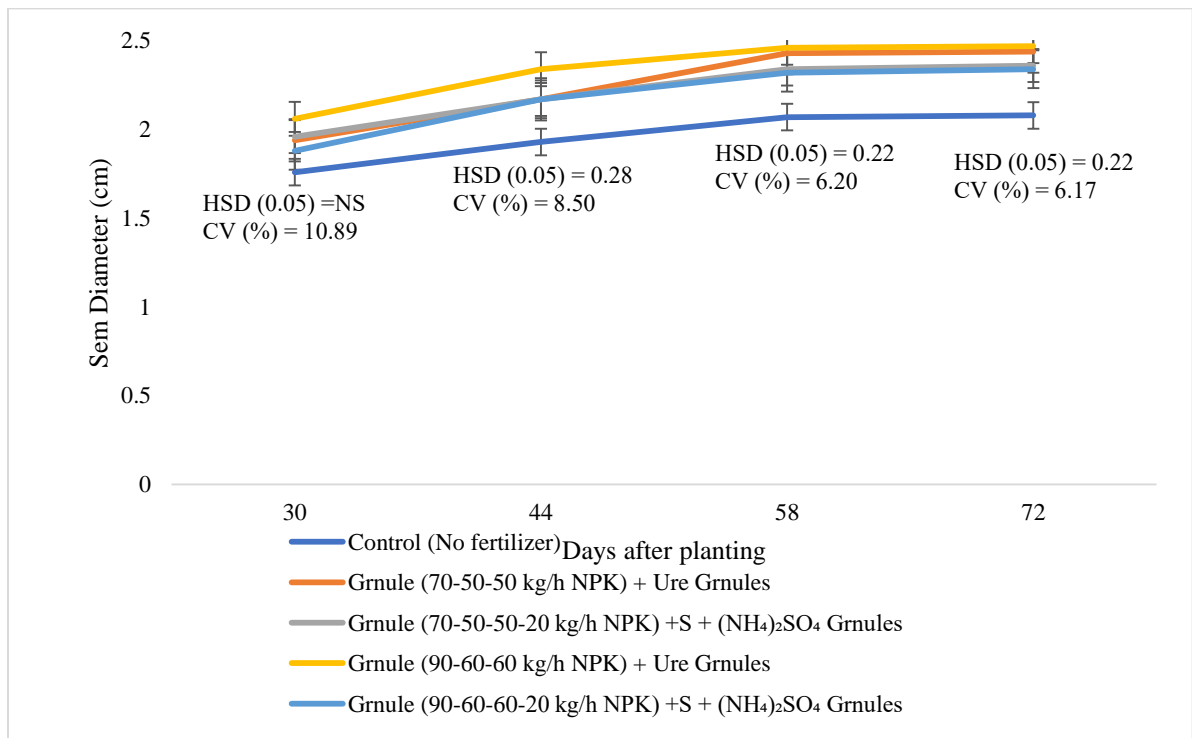


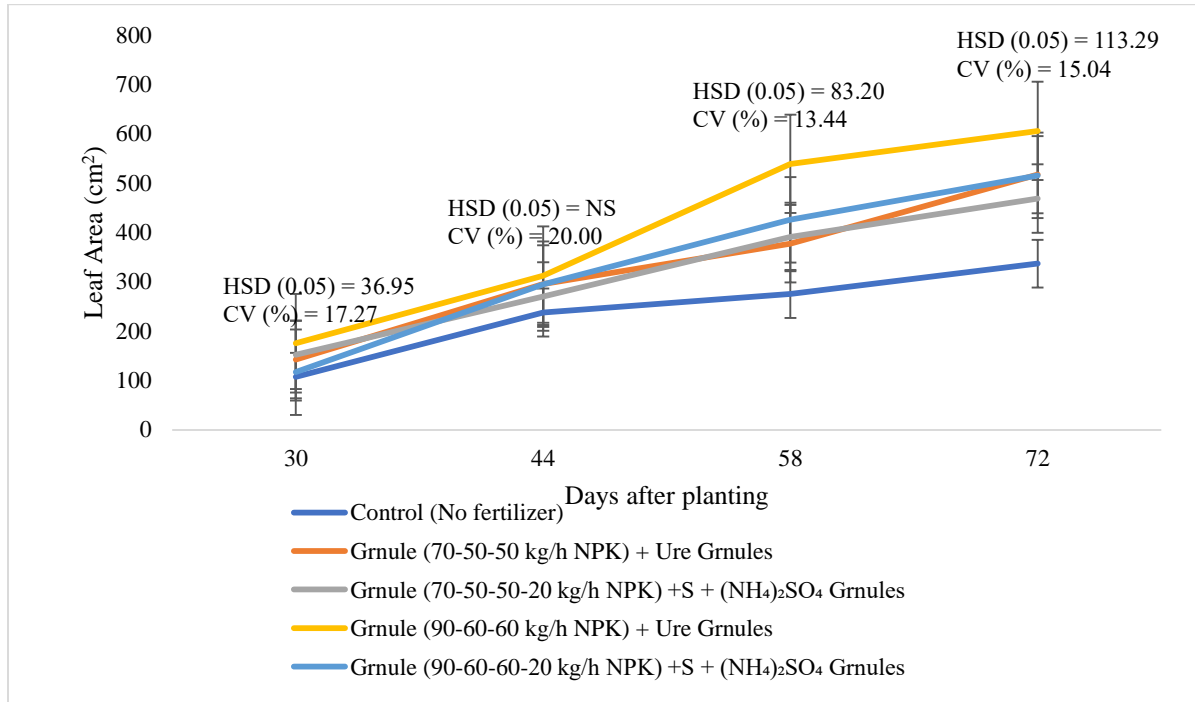
Figure 4. 3: Effect of different rates of granules NPK fertilizer on stem diameter per plant of maize during 2023 major and minor cropping seasons.

#### 4.4.4 Leaf Area

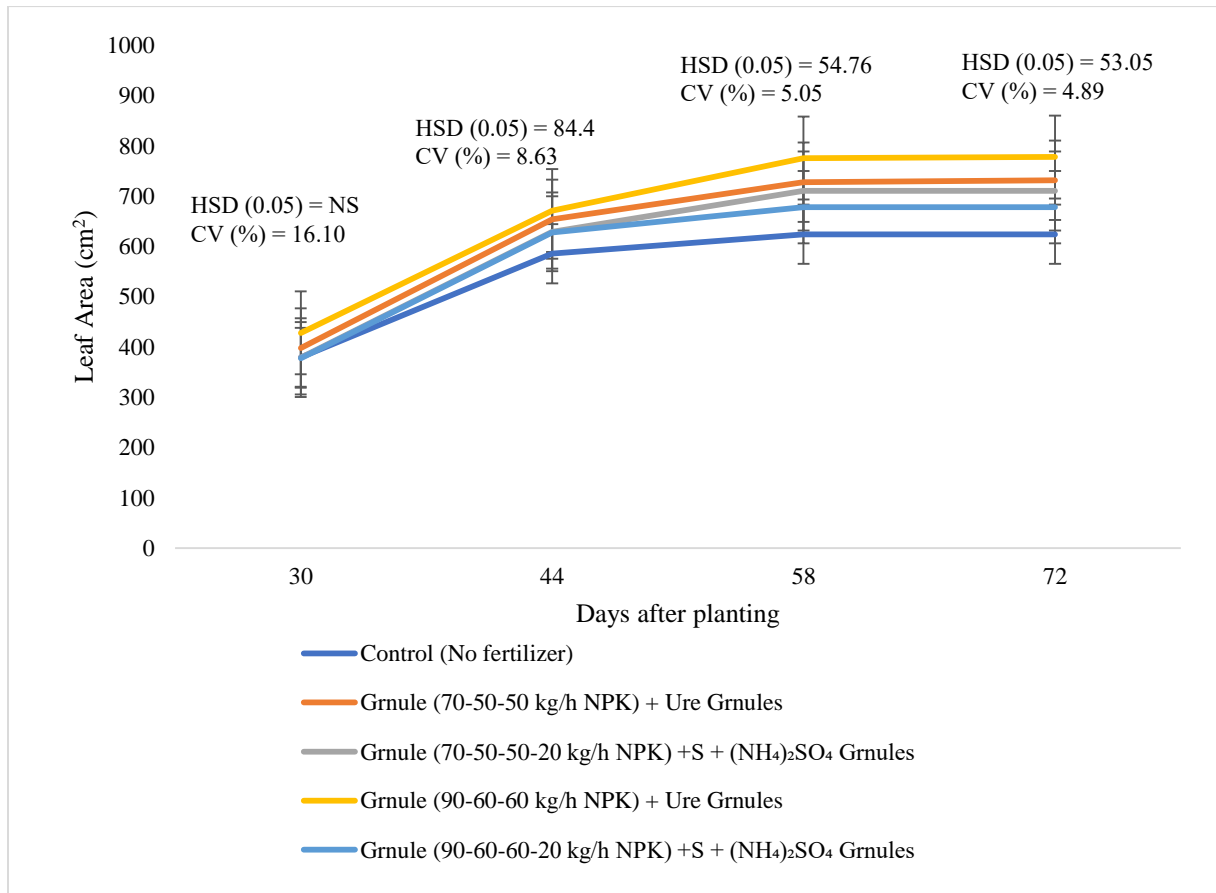
The results on leaf area as influenced by different rates of Granule NPK fertilizer during 2023 major and 2023 minor cropping seasons is presented in Figure 4.4. In 2023 major cropping season, there were significant ( $P \leq 0.05$ ) differences between treatments in leaf area of maize from 30 to 72 DAP except at 44 DAP where the treatments had no significant effect on leaf area. Maize plants that received Granule (90-60-60 kg/ha NPK) + Urea Granules recorded significantly wider leaf area than plants grown on unamended plot from 30 to 86 DAP (Figure 4.4a). Maize plants grown on unamended plots recorded the least leaf area throughout the entire growing period.

In 2023 minor cropping season, there was no significant ( $P \geq 0.05$ ) difference between the treatments in leaf area at 30 DAP. Significant differences occurred between the treatments in leaf area from 44 to 86 DAP. Maize plants grown on Granule (90-60-60 kg/ha NPK) + Urea Granules recorded the widest leaf area and was significantly ( $P \leq 0.05$ ) different from maize plants that received Granule (70-50-50 kg/ha NPK + 20S +  $(\text{NH}_4)_2\text{SO}_4$  Granules as well as maize plants grown on unamended plot from 44 to 86 DAP (Figure 4.4b).

(a) Major Cropping Season, 2023



(b) Minor Cropping Season, 2023



**Figure 4. 4:** Effect of different rates of granules NPK fertilizer on leaf areat of maize during 2023 major and minor cropping seasons.

#### 4.4.5 5<sup>th</sup> Leaf Chlorophyll Content

The results on 5<sup>th</sup> leaf chlorophyll content as influenced by different rates of Granule NPK fertilizer during 2023 major and 2023 minor cropping seasons are presented in Tables 4.7 and Table 4.8. In 2023 major cropping season, there was no significant ( $P \geq 0.05$ ) difference between treatments in 5<sup>th</sup> leaf chlorophyll content at 51 DAPS. From 81 to 104 DAP, maize plants that received Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded significantly wider 5<sup>th</sup> leaf chlorophyll content than plants grown on unamended plot (Table 4.7). The amended plots did not differ significantly in 5<sup>th</sup> leaf chlorophyll content from 81 to 104 DAP. Maize plants grown on unamended plots recorded the least 5<sup>th</sup> leaf chlorophyll content throughout the entire growing period (Table 4.7).

In 2023 minor cropping season, there were significant ( $P \leq 0.05$ ) differences between the treatments in 5<sup>th</sup> leaf chlorophyll content from 51 to 104 DAP. At 51 DAP, maize plants grown with Granule (90-60-60 kg/ha NPK) + Urea Granules recorded the highest 5<sup>th</sup> leaf chlorophyll content and was significantly ( $P \leq 0.05$ ) different from maize plants grown on unamended plot (Table 4.8). From 81 to 104 DAP, maize plants that received Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded the highest 5<sup>th</sup> leaf chlorophyll content and differed significantly from maize plants that received Granule (90-60-60 kg/ha NPK) + Urea Granules as well as maize plants grown on unamended plots (Table 4.8).

**Table 4. 7:** Effect of different rates of Granules NPK fertilizer on 5th leaf chlorophyll content of maize during the 2023 major cropping season

Treatment	5th leaf chlorophyll Content ( $\mu\text{mol}/\text{m}^2$ )		
	51 DAP	81 DAP	111 DAP
Control (No fertilizer)	39.63	41.80b	37.37b
Granule (70-50-50 kg/ha NPK) + Urea Granules	42.08	46.65a	40.63ab
Granule (70-50-50 kg/ha NPK) + 20S + $(\text{NH}_4)_2\text{SO}_4$ Granules	42.02	48.25a	40.32ab
Granule (90-60-60 kg/ha NPK) + Urea Granules	42.42	46.67a	41.11ab
Granule (90-60-60 kg/ha NPK) + 20S + $(\text{NH}_4)_2\text{SO}_4$ Granules	40.53	48.26a	43.04a
<b>HSD (<math>P \leq 0.05</math>)</b>	<b>NS</b>	<b>4.59</b>	<b>5.01</b>
<b>CV (%)</b>	<b>5.85</b>	<b>6.44</b>	<b>8.01</b>

Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation; DAP = Days after planting

**Table 4. 8:** Effect of different rates of Granules NPK fertilizer on 5th leaf chlorophyll content of maize during the 2023 minor cropping season

Treatment	5th leaf chlorophyll Content ( $\mu\text{mol}/\text{m}^2$ )		
	51 DAP	81 DAP	111 DAP
Control (No fertilizer)	43.31b	32.21c	31.50c
Granule (70-50-50 kg/ha NPK) + Urea Granules	47.47a	38.87ab	38.15ab
Granule (70-50-50 kg/ha NPK) + 20S + $(\text{NH}_4)_2\text{SO}_4$ Granules	47.82a	37.25ab	36.92ab
Granule (90-60-60 kg/ha NPK) + Urea Granules	50.31a	34.91bc	34.11bc
Granule (90-60-60 kg/ha NPK) + 20S + $(\text{NH}_4)_2\text{SO}_4$ Granules	48.98a	39.35a	38.69a
<b>HSD (<math>P \leq 0.05</math>)</b>	<b>3.24</b>	<b>4.37</b>	<b>4.37</b>
<b>CV (%)</b>	<b>4.42</b>	<b>7.77</b>	<b>7.89</b>

Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation; DAP = Days after planting

#### 4.4.6 6<sup>th</sup> Leaf Chlorophyll Content

The results on 6<sup>th</sup> leaf chlorophyll content as influenced by different rates of Granule NPK fertilizer during 2023 major and 2023 minor cropping seasons are presented in Tables 4.9 and Table 4.10. In 2023 major cropping season, there were no significant ( $P \geq 0.05$ ) differences between treatments in 6<sup>th</sup> leaf chlorophyll content at 51 and 104 DAP. However, at 81 DAP, maize plants that received Granule (70-50-50 kg/ha NPK) + Urea Granules recorded

significantly higher 6<sup>th</sup> leaf chlorophyll content than plants grown on unamended plot (Table 4.9).

In 2023 minor cropping season, there were significant ( $P \leq 0.05$ ) differences between the treatments in 6<sup>th</sup> leaf chlorophyll content from 51 to 104 DAP. From 51 to 104 DAP, maize plants grown on Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded the highest 6<sup>th</sup> leaf chlorophyll content and was significantly ( $P \leq 0.05$ ) different from maize plants grown on unamended plot (Table 4.10).

**Table 4. 9:** Effect of different rates of Granules NPK fertilizer on 6th leaf chlorophyll content of maize during the 2023 major cropping season

Treatment	6th leaf chlorophyll Content ( $\mu\text{mol}/\text{m}^2$ )		
	51 DAP	81 DAP	111 DAP
Control (No fertilizer)	39.83	41.66b	40.17
Granule (70-50-50 kg/ha NPK) + Urea Granules	42.97	49.14a	41.63
Granule (70-50-50 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	42.99	46.09ab	40.77
Granule (90-60-60 kg/ha NPK) + Urea Granules	41.98	46.59ab	42.93
Granule (90-60-60 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	41.81	48.16a	42.51
<b>HSD (<math>P \leq 0.05</math>)</b>	<b>NS</b>	<b>5.05</b>	<b>NS</b>
<b>CV (%)</b>	<b>7.67</b>	<b>7.08</b>	<b>7.285</b>

*Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation; DAP = Days after planting*

**Table 4. 10:** Effect of different rates of Granules NPK fertilizer on 6th leaf chlorophyll content of maize during the 2023 minor cropping season

Treatment	6th leaf chlorophyll Content ( $\mu\text{mol}/\text{m}^2$ )		
	51 DAP	81 DAP	111 DAP
Control (No fertilizer)	43.31b	32.21c	31.50c
Granule (70-50-50 kg/ha NPK) + Urea Granules	47.47a	38.87ab	38.15ab
Granule (70-50-50 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	47.82a	37.25ab	36.92ab
Granule (90-60-60 kg/ha NPK) + Urea Granules	50.31a	34.91bc	34.11bc
Granule (90-60-60 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	48.98a	39.35a	38.69a
<b>HSD (P ≤ 0.05)</b>	<b>3.24</b>	<b>4.37</b>	<b>4.37</b>
<b>CV (%)</b>	<b>4.42</b>	<b>7.77</b>	<b>7.89</b>

*Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation; DAP = Days after planting*

#### 4.4.7 Internode Length

The results on internode length as affected by different rates of Granule NPK fertilizer during 2023 major and 2023 minor cropping seasons are presented in Tables 4.11 and 4.12.

There were significant ( $P \leq 0.05$ ) differences between treatments in internode length across both cropping seasons. In 2023 major cropping season, maize plants that received Granule (70-50-50 kg/ha NPK) + Urea Granules recorded significantly longer internode length than maize plants that received Granule (90-60-60 kg/ha NPK) + S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules from 44 to 86 DAP (Table 4.11).

In 2023 minor cropping season, maize plants that received Granule (90-60-60 kg/ha NPK) + Urea Granules recorded the highest internode length and was significantly different from maize plants that received Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules as well as plants grown on unamended plot from 44 to 86 DAP. Among amended plots, maize plants that received Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded the shortest internode length (Table 4.12).

**Table 4. 11:** Effect of different rates of Granules NPK fertilizer on internode length of maize during the 2023 major cropping season

Treatment	Internode length (cm)			
	44 DAP	58 DAP	72 DAP	86 DAP
Control (No fertilizer)	9.78ab	12.00ab	14.45ab	15.10ab
Granule (70-50-50 kg/ha NPK) + Urea Granules	11.73a	14.00a	15.35a	16.40a
Granule (70-50-50 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	10.25ab	13.43ab	15.20a	16.05a
Granule (90-60-60 kg/ha NPK) + Urea Granules	10.27ab	12.80ab	15.15a	15.75ab
Granule (90-60-60 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	8.43b	11.20b	12.35b	13.15b
<b>HSD (P ≤ 0.05)</b>	<b>2.80</b>	<b>2.49</b>	<b>2.56</b>	<b>2.63</b>
<b>CV (%)</b>	<b>18.03</b>	<b>12.75</b>	<b>11.46</b>	<b>11.15</b>

Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation; DAP = Days after planting

**Table 4. 12:** Effect of different rates of Granules NPK fertilizer on internode length of maize during the 2023 minor cropping season

Treatment	Internode length (cm)			
	44 DAP	58 DAP	72 DAP	86 DAP
Control (No fertilizer)	7.31c	9.35b	11.38b	12.28c
Granule (70-50-50 kg/ha NPK) + Urea Granules	10.63ab	12.80a	14.08a	15.10ab
Granule (70-50-50 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	8.91bc	12.60a	14.65a	15.75a
Granule (90-60-60 kg/ha NPK) + Urea Granules	11.70a	13.00a	15.45a	16.28a
Granule (90-60-60 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	7.93c	10.05b	11.48b	12.90bc
<b>HSD (P ≤ 0.05)</b>	<b>2.17</b>	<b>1.96</b>	<b>2.26</b>	<b>2.46</b>
<b>CV (%)</b>	<b>15.14</b>	<b>11.01</b>	<b>10.94</b>	<b>11.03</b>

Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation; DAP = Days after planting

#### 4.4.8 Shoot Dry Weight Per Plant

The results on shoot dry weight per plant as affected by different rates of Granule NPK fertilizer during 2023 major and 2023 minor cropping seasons is presented in Tables 4.13 and 4.14. In 2023 major cropping season, at 49 DAP, maize plants that received Granule (70-50-50 kg/ha NPK + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules; recorded significantly heavier shoot dry weight

per plant than maize plants grown on Control (No fertilizer) with the least mean (Table 4.13). There were no significant ( $P \geq 0.05$ ) differences between treatments in shoot dry weight per plant from 63 to 77 DAP (Table 4.13).

In 2023 minor cropping season, maize plants grown on Granule (70-50-50 kg/ha NPK + 20S +  $(\text{NH}_4)_2\text{SO}_4$  Granules recorded the heaviest shoot dry weight per plant and was significantly different from maize plants grown on Granule (90-60-60 kg/ha NPK) + Urea Granules (Table 4.19). There were no significant ( $P \geq 0.05$ ) differences between treatments in shoot dry weight per plant from 63 to 77 DAP (Table 4.14).

**Table 4. 13:** Effect of different rates of Granules NPK fertilizer on shoot dry weight per plant of maize during the 2023 major cropping season Treatment

Treatment	Shoot dry weight per plant (g)		
	49 DAP	63 DAP	77 DAP
Control (No fertilizer)	32.75c	73.00	87.00
Granule (70-50-50 kg/ha NPK) + Urea Granules	49.00bc	88.00	93.50
Granule (70-50-50 kg/ha NPK) + 20S + $(\text{NH}_4)_2\text{SO}_4$ granules	69.50a	79.75	86.60
Granule (90-60-60 kg/ha NPK) + Urea Granules	63.50ab	84.50	90.25
Granule (90-60-60 kg/ha NPK) + 20S + $(\text{NH}_4)_2\text{SO}_4$ Granules	56.75ab	88.25	91.75
<b>HSD (<math>P \leq 0.05</math>)</b>	<b>19.01</b>	<b>NS</b>	<b>NS</b>
<b>CV (%)</b>	<b>22.72</b>	<b>18.48</b>	<b>24.87</b>

*Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation; DAP = Days after planting*

**Table 4. 14:** Effect of different rates of Granules NPK fertilizer on shoot dry weight per plant of maize during the 2023 minor cropping season

Treatment	Shoot dry weight per plant (g)		
	49 DAP	63 DAP	77 DAP
Control (No fertilizer)	43.50	70.00	88.00
Granule (70-50-50 kg/ha NPK) + Urea Granules	46.00	66.50	86.50
Granule (70-50-50 kg/ha NPK) + 20S + $(\text{NH}_4)_2\text{SO}_4$ Granules	48.75	73.50	92.50
Granule (90-60-60 kg/ha NPK) + Urea Granules	44.75	62.00	92.25
Granule (90-60-60 kg/ha NPK) + 20S + $(\text{NH}_4)_2\text{SO}_4$ Granules	48.25	65.00	84.75
<b>HSD (<math>P \leq 0.05</math>)</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>

<b>CV (%)</b>	<b>15.81</b>	<b>11.19</b>	<b>24.87</b>
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*Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation; DAP = Days after planting*

## **4.5 Physiological Growth Parameters**

### **4.5.1 Crop Growth Rate**

Tables 4.22 show the result on Crop Growth Rate (CGR) as influenced by different rates of Granule NPK fertilizer during 2023 major and 2023 minor cropping seasons. There were no significant ( $P \geq 0.05$ ) differences between treatments, seasons and treatment x seasons interactions in crop growth rate from 0-7 WAP to 9-11 WAP (Table 4.15). However, the crop growth rate values recorded in 2023 minor cropping season was higher than those in 2023 major cropping season. Generally, CGR values were increased gradually from 0 - 7 WAP through to 9 – 11 WAP across both cropping seasons across both seasons (Table 4.15).

### **4.6 Relative Growth Rate**

Table 4.23 presents the Relative Growth Rate (RGR) results influenced by different rates of Granule NPK fertilizer during the 2023 major and minor cropping seasons. There were no significant ( $P \geq 0.05$ ) differences between treatments, seasons, or treatment x season interactions in RGR from 0-7 WAP to 9-11 WAP, except at 0-7 during the 2023 minor cropping season (Table 4.16). However, the RGR values recorded in the 2023 minor cropping season were higher than those in the 2023 major cropping season. Generally, RGR values were high from 0-7 WAP and then decreased from 7-9 WAP through to 9-11 WAP across both cropping seasons (Table 4.16).

**Table 4. 15:** Effect of different rates of Granules NPK fertilizer on crop growth rate of maize during the 2023 major and minor cropping seasons

Treatment	Crop growth rate (g m <sup>-2</sup> day <sup>-1</sup> )					
	Major Season			Minor Season		
	0-7 WAP	7-9 WAP	9-11 WAP	0-7 WAP	7-9 WAP	9-11 WAP
Control (No fertilizer)	11.36	23.91	43.29	10.41	16.83	37.10
Granule (70-50-50 kg/ha NPK) + Urea Granules	14.51	17.48	34.11	16.10	22.12	30.86
Granule (70-50-50 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	11.78	16.83	35.09	11.95	20.16	34.19
Granule (90-60-60 kg/ha NPK) + Urea Granules	9.93	17.01	36.87	11.77	26.11	44.54
Granule (90-60-60 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	11.77	26.64	37.88	14.51	25.16	41.21
<b>Mean</b>	<b>11.87</b>	<b>20.73</b>	<b>31.45</b>	<b>12.95</b>	<b>22.07</b>	<b>37.58</b>
<b>HSD (P ≤ 0.05)</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>
<b>CV (%)</b>	<b>27.49</b>	<b>51.74</b>	<b>48.62</b>	<b>35.25</b>	<b>41.02</b>	<b>30.54</b>

Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation; DAP = Days after planting.

**Table 4. 16:** Effect of different rates of Granules NPK fertilizer on relative growth rate of maize during the 2023 major and minor cropping seasons

Treatment	Relative growth rate (g m <sup>-2</sup> day <sup>-1</sup> )					
	Major Season			Minor Season		
	0-7 WAP	7-9 WAP	9-11 WAP	0-7 WAP	7-9 WAP	9-11 WAP
Control (No fertilizer)	0.48	0.35	0.11	0.54a	0.20	0.08
Granule (70-50-50 kg/ha NPK) + Urea Granules	0.48	0.26	0.10	0.54a	0.19	0.11
Granule (70-50-50 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	0.51	0.31	0.11	0.52a	0.22	0.08
Granule (90-60-60 kg/ha NPK) + Urea Granules	0.50	0.23	0.07	0.48b	0.31	0.14
Granule (90-60-60 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	0.47	0.30	0.13	0.52a	0.17	0.18
<b>Mean</b>	0.49	0.29	0.11	0.52	0.22	0.12
<b>HSD (P ≤ 0.05)</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>0.04</b>	<b>NS</b>	<b>NS</b>
<b>CV (%)</b>	<b>6.33</b>	<b>37.18</b>	<b>52.98</b>	<b>4.00</b>	<b>52.35</b>	<b>47.65</b>

Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation; DAP = Days after planting.

## **4.7 Yield and Yield Components of Maize**

### **4.7.1 Number of Plants Harvested**

Table 4.17 shows the result on number of plants harvested as affected by different rates of Granule NPK fertilizer during 2023 major and 2023 minor cropping seasons. In 2023 major cropping season, maize plants that received Granule (70-50-50 kg/ha NPK + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded the highest (55.75) number of plants harvested and was significantly different from maize plants grown on other amended as well as maize plants grown on the unamended plot. The least number of plants harvested (33.50) was recorded by maize plants grown on unamended plots and was significantly lower than all the amended plots (Table 4.17).

In 2023 minor cropping season, maize plants that received Granule (70-50-50 kg/ha NPK + S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded the highest (53.00) number of plants harvested and was significantly different from maize plants grown on the unamended plot which recorded the least mean of 35.25. There were no significant ( $P \geq 0.05$ ) differences between seasons and treatment x season interactions in number of plants harvested (Table 4.17).

### **4.7.2 Number of Lodged Plants Per Plot**

Table 4.17 shows the result on number of lodged plants as affected by different rates of Granule NPK fertilizer during 2023 major and 2023 minor cropping seasons. Across both cropping seasons, maize plants grown on unamended plot recorded the highest (14.50 and 14.50) number of lodged plants and was significantly ( $P \leq 0.05$ ) different from maize plants grown on Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules with least number of lodged plants (7.75 and 9.75). Maize plants that received Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded the least number of lodged plants as compared to the other amended plots during both cropping seasons (Table 4.17). There were no significant ( $P \geq 0.05$ ) differences between season and treatment x season interactions in number of lodged plants per plot (Table 4.17).

**Table 4. 17:** Effect of different rates of Granules NPK fertilizer on number of plants harvested and number of lodged plants per plot of maize during both seasons

Treatment	Number of plants harvested		Number of lodged plants per plot	
	Major season	Minor season	Major season	Minor season
Control (No fertilizer)	34d	35d	15a	15a
Granule (70-50-50 kg/ha NPK) + Urea Granules	41c	43bc	11bc	11b
Granule (70-50-50 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	56a	53a	11bc	13ab
Granule (90-60-60 kg/ha NPK) + Urea Granules	45bc	47b	11ab	12ab
Granule (90-60-60 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	47b	41 cd	8c	10b
Mean	44	44	11	12
<b>HSD (P ≤ 0.05)</b>	<b>6.41</b>	<b>5.54</b>	<b>3.39</b>	<b>3.15</b>
<b>CV (%)</b>	<b>9.41</b>	<b>8.23</b>	<b>20.09</b>	<b>17.20</b>
Treatment	= 4.80**		2.21**	
Season	= NS		NS	
Treatment x Season	= NS		NS	

*Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation; DAP = Days after planting.*

#### 4.7.3 Number of Cobs Per Plot

Table 4.18 shows the result on number of cobs per plot as affected by different rates of Granule NPK fertilizer during 2023 major and 2023 minor cropping seasons. Across both cropping seasons, maize plants grown on unamended plot recorded the least (33.75 and 30.20) number of cobs per plot and was significantly ( $P \leq 0.05$ ) different from maize plants grown on Granule (70-50-50 kg/ha NPK + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules with the highest number of cobs per plot (58.25 and 53.00). Maize plants that received on Granule (70-50-50 kg/ha NPK + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules produced significantly higher number of cobs per plot as compared to the other amended plots during both cropping seasons (Table 4.18). There were no significant ( $P \geq 0.05$ ) differences between season and treatment x season interactions on number of cobs per plot (Table 4.18).

**Table 4. 18:** Effect of different rates of Granules NPK fertilizer on number of cobs per plot of maize during the 2023 major and minor cropping seasons

Treatment	Number of cobs per plot	
	Major season	Minor season
Control (No fertilizer)	34d	34d
Granule (70-50-50 kg/ha NPK) + Urea Granules	44bc	44bc
Granule (70-50-50 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	58a	58a
Granule (90-60-60 kg/ha NPK) + Urea Granules	40cd	40cd
Granule (90-60-60 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	48b	48b
Mean	45	45
<b>HSD (P ≤ 0.05)</b>	<b>6.18</b>	<b>6.18</b>
<b>CV (%)</b>	<b>8.96</b>	<b>8.96</b>
Treatment	= 4.80**	
Season	= NS	
Treatment x Season	= NS	

*Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation; DAP = Days after planting.*

#### 4.7.4 Cob Length

Table 4.19 shows the result on cob length as affected by different rates of Granule NPK fertilizer during 2023 major and 2023 minor cropping seasons. In 2023 major cropping season, maize plants that received Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded the longest cob length (18.55 cm) and was significantly (P ≤ 0.05) different from maize plants grown on unamended plot with the shortest cob length of 16.81 cm (Table 4.19).

In 2023 minor cropping season, maize plants grown on Granule (70-50-50 kg/ha NPK + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded significantly longer (17.10 cm) cob length than plants grown on unamended plot (14.62 cm) (Table 4.19). There were no significant ( $P \geq 0.05$ ) differences between the amended plots in cob length across both cropping seasons (Table 4.19). Cob length recorded in 2023 major cropping season was significantly higher than those in 2023 minor cropping season. There was no significant ( $P \geq 0.05$ ) difference between treatment x season interactions in cob length (Table 4.19).

#### **4.7.5 Cob Diameter**

The result on cob diameter as influenced by different rates of Granule NPK fertilizer during 2023 major and 2023 minor cropping seasons is presented in Table 4.19. There were significant ( $P \leq 0.05$ ) differences between the treatments in cob diameter across both cropping seasons. In 2023 major cropping season, maize plants grown on Granule (70-50-50 kg/ha NPK + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded significantly wider (5.42 cm) cob diameter than plants grown on unamended plot (4.16 cm) (Table 4.19). Maize plants grown on Granule (70-50-50 kg/ha NPK + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded significantly wider cob diameter than plants grown on all other amended plots (Table 4.19).

In 2023 minor cropping season, amending soils with Granule (70-50-50 kg/ha NPK + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded the widest cob diameter (5.01 cm) and was significantly ( $P \leq 0.05$ ) different from plants grown on unamended plot (4.08 cm) and Granule (70- 50-50 kg/ha NPK) + Urea Granules (4.55 cm) (Table 4.19). Cob diameter recorded in 2023 major cropping season was significantly higher than those in 2023 minor cropping season. There was no significant ( $P \geq 0.05$ ) difference between treatment x season interactions in cob diameter (Table 4.19).

**Table 4. 19:** Effect of different rates of Granules NPK fertilizer on cob length, cob diameter and number of seeds per cob of maize during both seasons

Treatment	Cob length (cm)		Cob diameter (cm)	
	Major season	Minor season	Major season	Minor season
Control (No fertilizer)	16.81b	14.62b	4.16d	4.08c
Granule (70-50-50 kg/ha NPK) + Urea Granules	17.36ab	16.82a	4.89c	4.55b
Granule (70-50-50 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	18.05a	17.10a	5.42a	5.01a
Granule (90-60-60 kg/ha NPK) + Urea Granules	17.61ab	16.11ab	5.14b	4.91ab
Granule (90-60-60 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	18.55a	16.98a	4.84c	4.75ab
Control (No fertilizer)	17.67	16.32	4.89	4.66
Mean	17.67	16.32	4.89	4.66
<b>HSD (P ≤ 0.05)</b>	<b>1.22</b>	<b>1.60</b>	<b>0.20</b>	<b>0.46</b>
<b>CV (%)</b>	<b>4.47</b>	<b>6.36</b>	<b>2.71</b>	<b>6.35</b>
Treatment	= 0.99**		0.24**	
Season	= 0.63**		0.15**	
Treatment x Season	= NS		NS	

*Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation; DAP = Days after planting.*

#### 4.7.6 Number of Seeds Per Cob

From Table 4.20, there were significant ( $P \leq 0.05$ ) differences between the treatments in number of seeds per cob across both cropping seasons. In 2023 major cropping season, maize plants grown on Granule (70-50-50 kg/ha NPK + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded significantly higher number (627.80) of seeds per cob than plants grown on unamended plot (486.80) (Table 4.20). However, all the amended plots did not significantly affect the number of seeds per cob.

In 2023 minor cropping season, amending soils with Granule (70- 50-50 kg/ha NPK) + Urea Granules recorded the highest number of seeds per cob (498.70) and was significantly different from maize plants grown on unamended plot (443.15) and Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules (444.35). The unamended plot recorded the least number of seeds per cob (Table 4.27). Number of seeds per cob recorded in 2023 major cropping season was significantly higher than those in 2023 minor cropping season. There was no significant

( $P \geq 0.05$ ) difference between treatment x season interactions on number of seeds per cob (Table 4.20).

**Table 4. 20:** Effect of different rates of Granules NPK fertilizer on number of seeds per cob of maize during the 2023 major and minor cropping seasons

Treatment	Number of seeds per cob	
	Major season	Minor season
Control (No fertilizer)	487b	443b
Granule (70-50-50 kg/ha NPK) + Urea Granules	596a	499a
Granule (70-50-50 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	628a	482ab
Granule (90-60-60 kg/ha NPK) + Urea Granules	577ab	472ab
Granule (90-60-60 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	581ab	444b
Mean	573	468
<b>HSD (<math>P \leq 0.05</math>)</b>	<b>100.37</b>	<b>52.39</b>
<b>CV (%)</b>	<b>11.36</b>	<b>7.27</b>
Treatment	=	0.99**
Season	=	0.63**
Treatment x Season	=	NS

*Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation; DAP = Days after planting.*

#### 4.7.7 100-Seed Weight

From Table 4.21, there were significant ( $P \leq 0.05$ ) differences between the treatments in 100-seed weight across both cropping seasons. Across both cropping seasons, maize plants that received Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded the highest 100-seed weight (46.25 g and 45.50 g) and was significantly different from maize plants grown on unamended plot (30.75 g and 29.75g), Granule (70-50-50 kg/ha NPK) + Urea Granules (38.50 g and 36.75 g) and maize plants grown on Granule (90-60-60 kg/ha NPK) + Urea Granules (36.75 g and 35.50 g). Maize plants grown on all amended plots differed significantly ( $P \leq 0.05$ ) higher 100-seed weight than maize plants grown on the unamended plot (Table 4.21). There was no significant ( $P \geq 0.05$ ) difference between season and treatment x season interactions on 100-seed weight (Table 4.21).

**Table 4. 21** Effect of different rates of Granules NPK fertilizer on 100-seed weight, and Undehusked cob weight per plot of maize during the 2023 major and minor cropping seasons

Treatment	100-seed weight (g)	
	Major season	Minor season
Control (No fertilizer)	30.75d	29.75c
Granule (70-50-50 kg/ha NPK) + Urea Granules	38.50bc	36.75b
Granule (70-50-50 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	41.75ab	40.50ab
Granule (90-60-60 kg/ha NPK) + Urea Granules	36.75c	35.50b
Granule (90-60-60 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	46.25a	45.50a
Mean	38.80	37.60
<b>HSD (P ≤ 0.05)</b>	<b>4.68</b>	<b>5.29</b>
<b>CV (%)</b>	<b>7.83</b>	<b>9.13</b>
Treatment	=	3.24**
Season	=	NS
Treatment x Season	=	NS

*Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation; DAP = Days after planting.*

#### 4.7.8 Dehusked Cob Weight Per Plot

From Table 4.22, there were significant ( $P \leq 0.05$ ) differences between the treatments in dehusked cob weight per plot across both cropping seasons. In 2023 major cropping season, maize plants grown on Granule (70-50-50 kg/ha NPK + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded the heaviest (6.75 kg) dehusked cob weight per plot and was significantly ( $P \leq 0.05$ ) different from plants grown on unamended plot (4.75 kg) (Table 4.22).

In 2023 minor cropping season, amending soils with Granule (70- 50-50 kg/ha NPK) + Urea Granules recorded the heaviest (7.25 kg) dehusked cob weight per plot and was significantly ( $P \leq 0.05$ ) different from maize plants grown on unamended plot (3.75 kg). Maize plants that received Granule (90-60-60 kg/ha NPK) + Urea Granules and Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded the same dehusked cob weight of 6.50 kg and differed significantly from the control (3.75 kg). There were no significant ( $P \geq 0.05$ ) differences between all the amended plots in dehusked cob weight per plot across both cropping seasons.

There were no significant ( $P \geq 0.05$ ) differences between season and treatment x season interactions on undehusked cob weight per plot (Table 4.22).

**Table 4. 22:** Effect of different rates of Granules NPK fertilizer on Dehusked cob weight per plot of maize during the 2023 major and minor cropping seasons

Treatment	Dehusked cob weight per plot (kg)	
	Major season	Minor season
Control (No fertilizer)	4.75b	4.75b
Granule (70-50-50 kg/ha NPK) + Urea Granules	6.25ab	6.25ab
Granule (70-50-50 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	6.75a	6.75a
Granule (90-60-60 kg/ha NPK) + Urea Granules	5.75ab	5.75ab
Granule (90-60-60 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	6.50a	6.50a
Mean	6.00	6.00
<b>HSD (<math>P \leq 0.05</math>)</b>	<b>1.66</b>	<b>1.66</b>
<b>CV (%)</b>	<b>18.00</b>	<b>18.00</b>
Treatment	=	1.30**
Season	=	NS
Treatment x Season	=	NS

*Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation; DAP = Days after planting.*

#### 4.7.9 Stover Weight Per Plot

The result on stover weight per plot as influenced by different rates of granule NPK fertilizer is shown in Table 4.23. There were significant ( $P \leq 0.05$ ) differences between the treatments in stover weight per plot across both cropping seasons. In 2023 major cropping season, maize plants grown on Granule (70-50-50 kg/ha NPK) + Urea Granules recorded the heaviest (16.50 kg) stover weight per plot and was significantly ( $P \leq 0.05$ ) different from plants grown on unamended plot (4.75 kg) (Table 4.23).

In 2023 minor cropping season, amending soils with Granule (90-60-60 kg/ha NPK) + Urea Granules recorded the heaviest (16.25 kg) stover weight per plot and was significantly ( $P \leq 0.05$ ) different from maize plants grown on unamended plot (10.00 kg). There were no significant ( $P \geq 0.05$ ) differences between all the amended plots in stover weight per plot across

both cropping seasons. There were no significant ( $P \geq 0.05$ ) differences between season and treatment x season interactions on stover weight per plot (Table 4.23).

#### **4.7.10 Harvest Index**

The result on harvest index as influenced by different rates of granule NPK fertilizer is shown in Table 4.23. There were significant ( $P \leq 0.05$ ) differences between the treatments in harvest index across both cropping seasons. In 2023 major cropping season, maize plants grown on Granule (70-50-50 kg/ha NPK) + Urea Granules recorded the highest (0.69) harvest index and was significantly ( $P \leq 0.05$ ) different from plants grown on unamended plot (0.30) (Table 4.23). All maize plants grown on the amended plots differed significantly from maize plants grown on unamended plot (Table 4.23).

In 2023 minor cropping season, amending soils with Granule (90-60-60 kg/ha NPK) + S +  $(\text{NH}_4)_2\text{SO}_4$  Granules recorded significantly higher harvest index (0.61) than maize plants grown on unamended plot with recorded the least the mean (0.41) as well as Granule (90-60-60 kg/ha NPK) + Urea Granules with mean value of 0.45. There was no significant ( $P \geq 0.05$ ) difference between season on harvest index (Table 4.23). However, the interaction between treatment and season was significantly different in harvest index.

**Table 4. 23:** Effect of different rates of Granules NPK fertilizer on stover weight per plot and harvest index of maize during 2023 major and minor cropping seasons

Treatment	Stover weight per plot (kg)		Harvest index	
	Major season	Minor season	Major season	Minor season
Control (No fertilizer)	11.00b	10.00b	0.30c	0.41b
Granule (70-50-50 kg/ha NPK) + Urea Granules	16.50a	14.75a	0.69a	0.55ab
Granule (70-50-50 kg/ha NPK) + S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	14.75ab	14.25a	0.57ab	0.47ab
Granule (90-60-60 kg/ha NPK) + Urea Granules	13.75ab	16.25a	0.51b	0.45b
Granule (90-60-60 kg/ha NPK) + S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	15.25a	13.50ab	0.50b	0.61a
Mean	14.25	13.75	0.51	0.50
<b>HSD (P ≤ 0.05)</b>	<b>3.79</b>	<b>4.19</b>	<b>0.17</b>	<b>0.15</b>
<b>CV (%)</b>	<b>17.27</b>	<b>19.77</b>	<b>21.99</b>	<b>18.98</b>
	Treatment = 2.74**		0.10**	
	Season = NS		NS	
	Treatment x Season = NS		0.14**	

*Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation.*

#### 4.7.11 Grain Yield

Table 4.24 shows the result on grain yield affected by different rates of granule NPK fertilizer during 2023 major and 2023 minor cropping seasons. The treatments significantly ( $P \leq 0.05$ ) affected grain yield across both cropping seasons. In 2023 major cropping season, maize plants that received Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded the highest (4.81 t/ha) grain yield which differed significantly ( $P \leq 0.05$ ) from maize plants grown on unamended plot (3.00 t/ha) (Table 4.24). All maize plants grown on the amended plots did not differ significantly from each other but differed significantly ( $P \leq 0.05$ ) from maize plants grown on unamended plot in harvest (Table 4.24).

In 2023 minor cropping season, maize plants that received Granule (90-60-60 kg/ha NPK) + Urea Granules recorded significantly higher (4.72 t/ha) grain yield than maize plants grown on unamended plot which recorded the least the mean (2.92 t/ha). All maize plants grown on the amended plots did not differ significantly from each other but differed significantly ( $P \leq$

0.05) from maize plants grown on unamended plot in grain yield (Table 4.24). There was no significant ( $P \geq 0.05$ ) difference between season, and treatment x season interactions in grain yield (Table 4.24).

**Table 4. 24:** Effect of different rates of Granules NPK fertilizer on grain weight per plot and grain yield of maize during 2023 the major and minor cropping seasons

Treatment	Grain yield (t/ha)	
	Major season	Minor season
Control (No fertilizer)	3.00b	2.92b
Granule (70-50-50 kg/ha NPK) + Urea Granules	4.67a	4.64a
Granule (70-50-50 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	4.70a	4.22a
Granule (90-60-60 kg/ha NPK) + Urea Granules	4.78a	4.72a
Granule (90-60-60 kg/ha NPK) + 20S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	4.81a	4.42a
Mean	4.39	4.18
<b>HSD (<math>P \leq 0.05</math>)</b>	<b>1.22</b>	<b>1.21</b>
<b>CV (%)</b>	<b>18.09</b>	<b>18.74</b>
	Treatment = 0.75**	0.83**
	Season = NS	NS
	Treatment x Season = NS	NS

*Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD= Tukey's Honestly Significant Difference; CV = Coefficient of variation.*

#### **4.7.12 Correlation between Vegetative and Yield and Yield Components**

The results on correlation matrix among vegetative and yield and yield components parameters of maize during 2023 major and 2023 minor cropping seasons are presented in Tables 4.25 and 4.26. In 2023 major cropping season, there was a strong and positive correlation between plant height and number of leaves per plant (0.73\*\*\*). There was a moderate and positive correlation between leaf chlorophyll content and grain yield (0.57\*\*) and cob diameter and grain yield (0.57\*\*). However, plant height and grain yield (0.44\*) as well as number of leaves per plant and cob diameter (0.43\*) had a low and positive correlation during 2023 major cropping season. About 67% of the parameters correlated showed no significant correlation among themselves (Table 4.25).

In 2023 minor cropping season, about 34% of the variables correlated showed a strong and positive correlation. Plant height and leaf chlorophyll content (0.99\*\*\*), plant height and number of leaves per plant (0.81\*\*\*), number of leaves per plant and grain yield (0.74\*\*\*) and leaf chlorophyll content and grain yield (0.69\*\*\*) showed a strong and positive correlation. There was a moderate and positive correlation between plant height and grain yield (0.64\*\*) whereas cob length and cob diameter (0.45\*) showed a low and positive correlation. About 54% of the variables correlated had no significant influence on each other (Table 4.26).

**Table 4. 25:** Correlation matrix among vegetative and yield and yield components parameters of maize during the 2023 major cropping season

	1	2	3	4	5	6
1. Plant height	1	0.73***	0.02ns	0.16ns	0.28ns	0.44*
2. Number of leaves per plant		1	-0.09ns	0.34ns	0.43*	0.28ns
3. Leaf chlorophyll content			1	0.04ns	0.37ns	0.57**
4. Cob length				1	0.42ns	0.15ns
5. Cob diameter					1	0.57**
6. Grain yield (t/ha)						1

Numbers against the parameters in columns correspond with variables in rows; NS – Not significant  
 \* = Significant at  $P \leq 0.05$ ; \*\* = Significant at  $P \leq 0.01$  \*\*\* = Significant at  $P \leq 0.001$

**Table 4. 26:** Correlation matrix among vegetative and yield and yield components parameters of maize during the 2023 minor cropping season

	1	2	3	4	5	6
1. Plant height	1	0.81***	0.99***	0.22ns	0.29ns	0.64**
2. Number of leaves per plant		1	0.82***	0.14ns	0.24ns	0.74***
3. Leaf chlorophyll content			1	0.24ns	0.30ns	0.69***
4. Cob length				1	0.45*	0.36ns
5. Cob diameter					1	0.26ns
6. Grain yield (t/ha)						1

Numbers against the parameters in columns correspond with variables in rows; NS – Not significant  
 \* = Significant at  $P \leq 0.05$ ; \*\* = Significant at  $P \leq 0.01$  \*\*\* = Significant at  $P \leq 0.001$

#### 4.8 Partial Budget Analysis

Partial budget analysis was done for both major and minor cropping seasons and are shown in the Tables 4.27 and 4.28, respectively. The benefit to cost ratio showed that Granule (90-60-60 kg/ha NPK) + Urea Granules recorded the highest ratio of 11.5 and 11.3 for both major and minor seasons, respectively, followed by Granule (70-50-50 kg/ha NPK) + Urea Granules which recorded 11.2 and 11.1 for major and minor seasons respectively. Granule (90-60-60 kg/ha NPK) + S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded 9.5 and 8.7 for major and minor seasons, respectively as the next highest, while Granule (70-50-50 kg/ha NPK) + S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules recorded the least ratio of 9.3 and for 8.2 for major and minor seasons, respectively.

In the dominance analysis, a treatment is dominated if it has a higher cost of production but a lower net benefit than another. The dominance analysis indicated that Granule (70-50-50 kg/ha NPK) + Urea Granules + S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules, and Granule (90-60-60 kg/ha NPK) + S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules were dominated by the Granule (90-60-60 kg/ha NPK) + Urea Granules in both seasons (Table 4.27 and Table 4.28). The Granule (70-50-50 kg/ha NPK) + Urea Granules had an MRR of 3.4 over the no fertilizer (control) treatment in the major season and over 3.3 in the minor season (Table 4.27 and Table 4.28).

Table 4. 27: Partial Budget Analysis for the Major Cropping Season

	No Fertilizer (Control)	Granule (70-50- 50 kg/ha NPK) + Urea Granules	Granule (70-50-50 kg/ha NPK) + S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	Granule (90-60-60 kg/ha NPK) + Urea Granules	Granule (90-60-60 kg/ha NPK) + S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules
<b>GROSS FARM BENEFITS</b>					
Average yield (t/ha)	3	4.67	4.7	4.78	4.81
Adjusted yields (10%)	2.7	4.203	4.23	4.302	4.329
Farm Price/ton of maize (GHS)	7200	7200	7200	7200	7200
<b>Total Gross Benefits (TGB) (GHS/ha)</b>	19440.0	30261.6	30456.0	30974.4	31168.8
Cost of NPK Granule applied (GHS)	0	1.8	1.7	1.8	1.7
Cost of Urea Granule applied (GHS)	0	1.4	0	1.4	0
Cost of (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granule applied (GHS)	0	0	1.5	0	1.5
Cost of S applied (GHS)	0	0	1.2	0	1.2
Total labour cost for fertilizer application	0	150/240	150/240	150/240	150/240
<b>Total Variable Cost per ha</b>	640	3364.8	3840.0	3364.8	3840.0
<b>Net Benefit (GHS)</b>	19440.0	27776.8	27496.0	28489.6	28208.8
<b>Benefit to Cost ratio</b>	0	11.2	9.3	11.5	9.5
<b>MARGINAL RATE OF RETURNS (MRR)</b>					
	No Fertilizer (Control)	Granule (70-50- 50 kg/ha NPK) + Urea Granules	Granule (90-60-60 kg/ha NPK) + Urea Granules	Granule (70-50-50 kg/ha NPK) + S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	Granule (90-60-60 kg/ha NPK) + S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules
Total variable cost (TVC) (GHS/ha)	640	<b>3364.8</b>	<b>3364.8</b>	3840.0	3840.0
Net benefits (GHS/ha)	19440	27776.8	28489.6	27496	28208.8
MRR= (ΔNB/ΔTVC)*100	0	3.4	0	D*	0

Table 4. 28: Partial Budget Analysis for the Minor Cropping Season

	No Fertilizer (Control)	Granule (70-50- 50 kg/ha NPK) + Urea Granules	Granule (70-50-50 kg/ha NPK) + S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	Granule (90-60-60 kg/ha NPK) + Urea Granules	Granule (90-60-60 kg/ha NPK) + S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules
<b>GROSS FARM BENEFITS</b>					
Average yield (t/ha)	2.92	4.64	4.22	4.72	4.42
Adjusted yields (10%)	2.628	4.176	3.798	4.248	3.978
Farm Price/ton of maize (GHS)	7200	7200	7200	7200	7200
<b>Total Gross Benefits (TGB) (GHS/ha)</b>	18921.6	30067.2	27345.6	30585.6	28641.6
Cost of NPK Granule applied (GHS)	0	1.8	1.7	1.8	1.7
Cost of Urea Granule applied (GHS)	0	1.4		1.4	
Cost of (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granule applied (GHS)	0		1.5		1.5
Cost of S applied (GHS)	0		1.2		1.2
Total labour cost for fertilizer application	0	150/240	150/240	150/240	150/240
<b>Total Variable Cost per ha</b>	640	3364.8	3840.0	3364.8	3840.0
<b>Net Benefit (GHS)</b>	18921.6	27582.4	24385.6	28100.8	25681.6
<b>Benefit to Cost ratio</b>	0	11.1	8.2	11.3	8.7
<b>MARGINAL RATE OF RETURNS (MRR)</b>					
	No Fertilizer (Control)	Granule (70-50- 50 kg/ha NPK) + Urea Granules	Granule (90-60-60 kg/ha NPK) + Urea Granules	Granule (70-50-50 kg/ha NPK) + S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules	Granule (90-60-60 kg/ha NPK) + S + (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> Granules
Total variable cost (TVC) (GHS/ha)	0	3364.8	3364.8	2840.0	2840.0
Net benefits (GHS/ha)	19440	27582.4	28100.8	24385.6	25681.6
MRR= (ΔNB/ΔTVC)*100	0	3.3	0	D*	D*

## CHAPTER FIVE: DISCUSSION

### 5.1 Effect of Different Rates of Granules NPK Fertilizer on Soil Physico-chemical Properties

Amending soils with Granule (70-50-50 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules and Granule (70-50-50 kg/ha NPK) + Urea Granules enhanced the chemical properties (pH, total N, available P, K, Mg, EC) of the soil after harvesting of maize across both cropping seasons. The increased chemical properties (pH, total N, available P, K, Mg, EC) under these treatments suggest that the specific combination and rate of NPK effectively improved soil chemical properties, potentially enhancing nutrient availability and uptake by crops. This was in agreement with Niedziński *et al.* (2021) who asserted that the individual physical and chemical properties of granules fertilizer influence the soil characteristics, changing the soil parameters until a new balance is reached. Niedziński *et al.* (2021) further observed that EC value of the soil solution was significantly modified under the influence of mineral granules, it reached a maximum of 1147  $\mu\text{S cm}^{-1}$  on the 10th day, and for organic fertilizers of 944  $\mu\text{S cm}^{-1}$  on the 35th day. This contradicts the findings of Agegnehu *et al.* (2016) who asserted that use of mineral fertilizers led to a reduction in soil pH, rather than improving nutrient availability and uptake as suggested in the previous claim.

In both cropping seasons, Granule (90-60-60 kg/ha NPK) + S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules and Granule (70-50-50 kg/ha NPK) + Urea Granules produced the highest content of calcium (Ca), hydrogen (H), organic matter, and organic carbon in the soil than the unamended and other amended plots. This could be that the application of balanced NPK fertilizers along with sulfur (S) and ammonium sulfate ((NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>) enhanced the availability and uptake of nutrients in the soil. Similarly, Reshma *et al.* (2024) found that soil treated with NPK fertilizer granules on nutrient availability and soil fertility significantly increased compared to the unamended plot.

## 5.2 Effect of Different Rates of Granules NPK Fertilizer on Phenology of Maize

Maize plants that received Granule (90-60-60 kg/ha NPK) + Urea Granules emerged 2-3 days earlier than those grown on the unamended plot across both cropping seasons. This could be that Granule (90-60-60 kg/ha NPK) + Urea Granules provided a readily available source of nitrogen through urea, which is crucial for early seedling vigour and growth, and an optimal supply of phosphorus, vital for energy transfer and root development. According to Bedwal (2023) the balanced NPK formulation in Granule (90-60-60 kg/ha NPK) + Urea Granules ensured enhanced soil fertility and created a conducive environment for seed germination and early growth, unlike the nutrient-deficient in unamended plot.

The combination of Granule (70-50-50 kg/ha NPK) + 20S +  $(\text{NH}_4)_2\text{SO}_4$  Granules significantly improved maize establishment rates compared to unamended plots. The combination of NPK and sulfur (S) plus ammonium sulfate  $(\text{NH}_4)_2\text{SO}_4$  granules likely provided a balanced and sustained supply of essential nutrients, such as nitrogen, phosphorus, and potassium, which are crucial for maize growth and development (Mbangcolo, 2018). This balanced nutrient supply can enhance root growth, leaf development, and overall plant health, leading to higher crop establishment rates. The significant difference in crop establishment between the 2023 major and 2023 minor cropping seasons, as shown in Table 4.3, can be attributed to the differences in the climatic and edaphic factors that prevailed during the two cropping seasons (Table 4.1 and Appendix 3).

The results indicated that maize plants treated with a combination of NPK granules (70-50-50 kg/ha) and urea granules reached 50% tasseling and silking as well as physiological maturity and 100% maturity significantly earlier compared to plants grown on unamended plots in both 2023 major and 2023 minor cropping seasons. This could be due to the fact that combination of NPK and urea granules likely resulted in a more readily available and balanced supply of nutrients, particularly nitrogen, which is essential for the initiation and development of reproductive structures like tassels and silks (Degani *et al.*, 2022). This is in agreement with

Alameraw (2020) who reported that split application of N fertilizer reduce the days to 50% tasseling and silking as compared to the unamended plot. This improved nutrient availability can accelerate the transition from the vegetative to the reproductive phase, leading to earlier

tasseling and silking. Degani *et al.* (2022) further asserted that nitrogen is a crucial element for various plant processes, including vegetative growth, flowering, and grain development.

### **5.3 Effect of Different Rates of Granules NPK Fertilizer on Vegetative Growth of Maize**

The application of a fertilizer combination consisting of granule (90-60-60 kg/ha NPK) plus sulfur (S) and ammonium sulfate granules significantly enhanced plant growth (taller plants, a higher number of leaves per plant, and increased chlorophyll content of 5<sup>th</sup> and 6<sup>th</sup> leaves) compared to unamended plots across both cropping seasons. This might be that the balanced nutrient composition of the NPK fertilizer provided essential macronutrients—nitrogen (N), phosphorus (P), and potassium (K)—that are crucial for plant growth. Nitrogen, in particular, is vital for vegetative growth and leaf development, as it is a key component of chlorophyll, the pigment responsible for photosynthesis (Fageria, 2014). The addition of ammonium sulfate further enhances nitrogen availability, promoting robust leaf growth and increasing the overall leaf area, which can contribute to greater photosynthetic capacity. The increasing trend in chlorophyll content with higher nitrogen doses indicates improved nitrogen uptake by maize plants, resulting in greener leaves (Hassan *et al.*, 2010). The addition of sulfur (S) is significant for plant growth. Sulfur is a key component in the synthesis of chlorophyll and proteins. It also plays a role in nitrogen fixation and is essential for the formation of certain amino acids. The presence of sulfur might have enhanced overall plant metabolism and contributed to increased plant height and leaf count (Wan *et al.*, 2021). This indicates that maize plants responded positively to higher rates of NPK (90-60-60 kg/ha NPK) as evident from the significant increase in vegetative growth parameters as compared to the lower rates.

Maize plants that received Granule (90-60-60 kg/ha NPK) plus Urea Granules showed the widest stem diameter and largest leaf area compared to both the untreated and other fertilizer treated plots. This can be attributed to the balanced nutrient supply provided by the NPK

formulation, which includes essential macronutrients: nitrogen (N), phosphorus (P), and potassium (K). Cheema *et al.* (2010) reported that increased nitrogen levels enhance plant height, stem thickness, leaf area, leaf area index, dry matter accumulation, net assimilate ratio, and yield per hectare.

Nitrogen is crucial for vegetative growth and chlorophyll production, phosphorus supports energy transfer and root development, and potassium regulates physiological processes such as water uptake and enzyme activation. Enhanced photosynthesis is another key factor, as the increased nitrogen availability boosts chlorophyll content and photosynthetic rates, leading to improved plant growth. Improved root development, facilitated by phosphorus, enhances nutrient and water uptake, supporting above-ground biomass. Research by Qadeer *et al.* (2018) confirms that balanced fertilization and increased nitrogen availability significantly improve maize vegetative growth particularly stem diameter and plant height. Similarly, Ali & Anjum (2017) found that increased nitrogen application led to significant improvements in plant height, leaf area per plant, leaf count, stem diameter, green fodder yield, dry matter content, crude protein levels, crude fiber content, and total ash percentage.

The synergistic effects of the combined NPK and urea granules contribute to overall plant vigour particularly stem diameter and leaf area. Urea provides an additional nitrogen source, ensuring a continuous and balanced nutrient supply, which promotes hormonal balance, cellular expansion, and stress resistance. These nutrients work together to enhance water use efficiency and stress resilience, as potassium regulates stomatal function, maintaining turgor pressure and cellular functions under varying environmental conditions (Hasanuzzaman *et al.*, 2018).

Generally, maize plants that received Granule (70-50-50 kg/ha NPK) + Urea Granules, Granule (90-60-60 kg/ha NPK) + Urea Granules and Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules significantly enhanced internode length than the other amended plots and

unamended plot. This could be that the urea present provided an additional nitrogen source, ensuring a continuous and balanced nutrient supply, which promoted effective vegetative growth and development as compared to the treatment without urea.

The treatments applied in the study exhibited similar effects and therefore had no significant impact on shoot dry weight, across both cropping seasons. This lack of significant difference suggests that the variations in treatments did not provide a differential advantage in terms of biomass accumulation in the shoots or roots of the maize plants.

#### **5.4 Effect of Different Rates of Granules NPK Fertilizer on Physiological Growth of Maize**

Generally, treatments, seasons and treatment x seasons interactions had no significant effect on crop growth rate and relative growth rate from 0-7 WAP to 9-11 WAP. This might be that the treatments had similar efficacy in promoting crop growth, resulting in no significant differences. This aligns with the findings of Sitthaphanit et al. (2010), who observed that reduced and delayed basal fertilizer applications did not affect CGR or RGR during the first 30 days compared to the control. This contradicts the findings of Essilfie et al. (2023), who reported that amending soils with 10 t/ha CM, as well as 5 t/ha CM + 1.5 t/ha GB, resulted in higher CGR and RGR values compared to the control. Generally, there was a reduction in RGR values from 0-7 WAP to 9-11 WAP across both cropping seasons. This might be due to rise in metabolically active tissue that played a smaller role in overall plant growth, contributing to the observed downward trend (Tajul et al., 2013). This was in agreement with Bell (2010) who noted a sharp increase in RGR during the early phase, particularly during 30 days after planting (DAP) until reaching 90 days after planting, followed by a gradual decrease.

## 5.5 Effect of Different Rates of Granules NPK Fertilizer on Yield And Yield

### Components of Maize

The different granule NPK fertilizer combinations had significant effect on yield and yield components of maize across both cropping seasons. The application of a fertilizer combination consisting of granule (70-50-50 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> granules significantly enhanced maize growth, resulting in a higher number of plants harvested, more cobs per plot, seeds per cob, increased dehusked cob weight per plot, and wider cob diameter compared to maize grown on other amended and unamended plots across both cropping seasons. Similarly, Kumah-Amenudzi *et al.* (2024) found that the application of Granule NPKS 10- 20-20-3 (400 kg ha<sup>-1</sup>) + Granule Urea 87 kg ha<sup>-1</sup> to maize enhanced cob diameter. This might be that, the addition of ammonium sulphate provided a readily available source of nitrogen, which is crucial for plant growth and development. Studies have shown that nitrogen fertilization significantly improves maize yield components, including the number of cobs and cob size (Ann *et al.*, 2021). Again, the presence of sulfur in the fertilizer combination might have played a critical role in the synthesis of amino acids and proteins.

The inclusion of sulfur in the fertilizer mix can enhance nutrient uptake efficiency and improve overall plant health, leading to better yield outcomes in terms of number of plants harvested, cobs per plot and cob diameter (Scherer, 2013). The combination of NPK, sulfur, and ammonium sulphate may create synergistic effects that enhance nutrient uptake and utilization. Studies have demonstrated that the co-application of different nutrient sources can lead to improved nutrient interactions in the soil, maximizing their availability to plants and resulting in better yield components (Ghosh *et al.*, 2014).

In 2023 major cropping season, maize plants that received Granule (70-50-50 kg/ha NPK) + Urea Granules significantly produced higher stover weight per plot and higher harvest index than the other amended and unamended plots whereas in 2023 minor cropping seasons maize plants that received (90-60-60 kg/ha NPK) + Urea Granules recorded the highest stover weight

per plot and harvest index than the other amended and unamended plot. Urea is a highly concentrated nitrogen source that provides an immediate supply of nitrogen to plants. The increased nitrogen availability from urea likely contributed to the enhanced stover weight and cob weight observed in the fertilizer treated plots across both cropping seasons. The harvest index is a measure of the efficiency with which a plant converts biomass into harvestable yield. The application of NPK and urea likely improved the allocation of resources towards reproductive structures (cobs), resulting in a higher harvest index (Zhang *et al.*, 2020). This indicates that the fertilizer treated plants were more efficient in converting biomass into grain yield.

The significant improvements in 100-seed weight, cob length, and reduced lodging observed with the application of granule (90-60-60 kg/ha NPK) plus sulfur and ammonium sulphate granules can be attributed to enhanced nutrient availability, improved soil structure, synergistic nutrient effects, and increased photosynthetic capacity. Similarly, Kumah-Amenudzi *et al.* (2024) found that maize plants treated with Granule NPKS 10-20-20-3 (400 kg/ha) combined with Granule Urea (87 kg/ha) exhibited significantly longer cob lengths and higher 100-seed weight compared to those in other amended and unamended plots. These conditions collectively fostered an optimal environment for maize growth, enhancing yield components and reducing the risk of lodging. Adu-Gyamfi *et al.* (2019) also demonstrated that the availability of granular NPKS fertilizer significantly impacted maize yield and its components by facilitating nutrient uptake. Adu-Gyamfi *et al.* (2019) additionally asserted that a single application of multi-nutrient fertilizer briquettes led to an increase in maize seed weight.

The different rates of granular fertilizer applied significantly affected grain weight per plot and grain yield in both cropping seasons.

The significant improvements in grain weight per plot and overall grain yield observed with the application of granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules and Granule (90-60-60 kg/ha NPK) + Urea Granules can be attributed to enhanced nitrogen and sulfur

availability, balanced nutrient supply, improved soil conditions, and synergistic effects of nutrient combinations which created favorable environment for maize growth, leading to higher yields and better yield components (Qahar & Ahmad, 2016). However, these results showed that the maize grain yield recorded by all the treatments was below the national achievable yield of approximately 6.0 t ha<sup>-1</sup> in Ghana which might be due to the late climate change and application of the granular fertilizer for the uptake by the crops (Adzawa *et al.*, 2024). This was in agreement with Bawa (2021). The unamended plot recorded the lowest grain weight per plot and overall grain yield across both cropping seasons, likely due to insufficient initial soil nutrients to support and promote effective plant growth, development, and grain formation during the grain-filling stage.

## **5.6 Correlation Matrix Analysis**

The moderate and positive correlation between leaf chlorophyll content and grain yield ( $r = 0.57^{**}$ ) suggests that higher chlorophyll levels, which are indicative of better nitrogen uptake and photosynthetic capacity, contribute to greater grain production. Similarly, a moderate and positive correlation was found between cob diameter and grain yield ( $r = 0.57^{**}$ ), implying that thicker cobs are associated with higher grain yields, likely due to the larger number of kernels or greater kernel size. This was in agreement with Micskei *et al.* (2012) who observed that the grain yield was in close positive correlation with grain number per ear and to the thousand-kernel weight. The correlation between plant height and grain yield suggests that taller plants had a slight tendency to produce more grain, although the relationship was weaker compared to chlorophyll content and cob diameter.

During the 2023 major cropping season, there was a very strong and positive correlation between plant height and leaf chlorophyll content ( $r = 0.99^{***}$ ), indicating that taller plants tended to have higher chlorophyll content in their leaves. This relationship suggests that factors promoting increased plant height, such as optimal nutrient availability, also enhance chlorophyll synthesis, thereby improving photosynthetic efficiency. Leaf chlorophyll content

and grain yield were also strongly and positively correlated ( $r = 0.69^{***}$ ), reinforcing the idea that higher chlorophyll levels, indicative of better nitrogen uptake and photosynthetic capacity, are closely linked to increased grain yields. This finding aligns with Sid'Ko *et al.* (2017) who observed a strong correlation between chlorophyll content of leaf, grain yield, and chlorophyll content of various cultivars of wheat, barley, and oat.

### **5.7 Partial Budget Analysis**

The total grain yield was adjusted by 10% in calculating for the gross farm gate benefits. The scaling down was necessary to prevent overestimation of the returns that farmers are likely to get, since experimental yields are usually higher than farmers yield because of higher management levels, small plot size, better harvesting methods and precision in harvesting. Apart from the control treatment (no fertilizer), all the other four treatments (Granule (70-50-50 kg/ha NPK) + Urea Granules, Granule (70-50-50 kg/ha NPK) + S +  $(\text{NH}_4)_2\text{SO}_4$  Granules Granule (90-60-60 kg/ha NPK) + Urea Granules and Granule (90-60-60 kg/ha NPK) + S +  $(\text{NH}_4)_2\text{SO}_4$  Granules) produced a significant benefit to cost ratio of more than 1. The highest net benefit recorded on plants which received Granule (90-60-60 kg/ha NPK) + Urea Granules in both seasons might be due to rapid nutrient availability which improved yields, and potentially lower overall costs of production.

## CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

### 6.1 Conclusion

Based on the findings of the study it can be concluded that;

#### Objective one:

- Application of Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules , Granule (70-50-50 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules and Granule (70-50-50 kg/ha NPK) + Urea Granules to the soil enhanced the chemical properties of the soil as compared to the control plot.

#### Objective two:

- Granule (70-50-50 kg/ha NPK + Urea granules tasselled, silked, reached physiological maturity and maturity earlier than the other treatments and also had higher stover weight per plot, cob weight per plot and longer internodes in both cropping seasons.
- Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules and Granule (90-60-60 kg/ha NPK) + Urea granules emerged earlier and had taller plants, more number of leaves per plant, higher leaf chlorophyll content, wider stem and leaf area, higher harvest index, stover weight per plot, cob weight per plot, least number of lodged plants per plot and higher grain yield.
- Granule (70-50-50 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> granules had higher number of plants harvested, number of cobs per plot, cob length and cob diameter across both cropping seasons.

#### Objective three:

- All the other four treatments (Granule (70-50-50 kg/ha NPK) + Urea Granules, Granule (70-50-50 kg/ha NPK) + S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules Granule (90-60-60 kg/ha NPK) + Urea Granules and Granule (90-60-60 kg/ha NPK) + S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules) produced a significant benefit to cost ratio

## 6.2 Recommendations

It is recommended that;

- Farmers can use Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules , Granule (70-50-50 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules and Granule (70-50-50 kg/ha NPK) + Urea Granules to enhance the chemical properties of the soil.
- Maize farmers should apply Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules and/or Granule (90-60-60 kg/ha NPK) + Urea Granules for enhanced vegetative growth that can directly translate into higher grain yield.
- For higher number of cobs per plot, longer cob length, wider cob diameter and higher number of seeds per cob, farmers should apply Granule (70-50-50 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules to their maize plants
- Farmers should grow maize and apply Granule (90-60-60 kg/ha NPK) + 20S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules and Granule (90-60-60 kg/ha NPK) + Urea Granules for heavier grain weight per plot and higher grain yield.
- Granule (70-50-50 kg/ha NPK) + Urea Granules and Granule (90-60-60 kg/ha NPK) + S + (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> Granules are recommended for consideration for higher profitability.
- The study should be conducted in different agro-ecology of Ghana to confirm the results obtained.

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## LIST OF APPENDICES

### Appendix 1: Guide to interpretation of soil analytical data in Ghana

Nutrient	Rank/Grade			
<b>Phosphorus, P (ppm), (Bray 1)</b>				
< 10	Low			
10 – 20	Moderate			
> 20	High			
<b>Potassium, K (pmm)</b>				
< 50	Low			
50 – 100	Moderate			
> 100	High			
<b>Calcium, Ca (ppm)/Meg = 0.25 Ca</b>				
< 5.0	Low			
5.0 – 10.0	Moderate			
> 10.0	High			
<b>ECEC (cmol (+)/kg)</b>				
< 10	Low			
10 - 20	Moderate			
> 20	High			
<b>Soil pH (Distilled Water Method)</b>				
< 5.0	Very Acidic			
5.1 – 5.5	Acidic			
5.6 – 6.0	Moderately Acidic			
6.0 – 6.5	Slightly Acidic			
6.5 – 7.0	Neutral			
7.0 – 7.5	Slightly Alkaline			
7.6 – 8.5	Alkaline			
> 8.5	Very Alkaline			
<b>% Organic Carbon</b>	<b>% Organic Carbon</b>	<b>Interpretation</b>		
< 1.0	< 1.5	Low		
1.0– 2.0	1.6 – 3.0	Moderate		
2.0-4.0	3.0	Adequate		
> 4.0	>3.0	High		
<b>Nitrogen (%)</b>				
< 0.1	Low			
0.1 – 0.2	Moderate			
> 0.2	High			
<b>Exchangeable cations (cmol (+)/kg)</b>	<b>Units</b>	<b>low</b>	<b>moderate</b>	<b>High</b>
Sodium (Na)	(cmol (+)/kg)	-	0-2	> 2.0
Potassium (K)	(cmol (+)/kg)	<0.2	0.2 – 0.4	> 0.4
Calcium (Ca)	(cmol (+)/kg)	< 2.0	2.0-10	> 10
Magnesium (Mg)	(cmol (+)/kg)	< 1.0	1.0-3.0	> 3.0

Source: (SRI, 2007).

Appendix 2: Climatic data for 2023 major rainy season at the experimental site

Month	Total Rainfall (mm)	Relative Humidity (%)		Mean Temperature (°C)	
		6:00 hrs	15:00hrs	Min	Max
March	57.8	88	55	23.1	33.8
April	258.8	91	59	22.7	33.3
May	71.3	90	60	23.2	32.8
June	198	92	70	23	30.3
July	198.9	91	71	21.8	28.4
Total	784				

*(Ghana Meteorological Agency– Asante Mampong, 2023)*

Appendix 3: Climatic data for 2023 minor rainy season at the experimental site

Month	Total Rainfall (mm)	Relative Humidity (%)		Mean Temperature (°C)	
		6:00 hrs	15:00hrs	Min	Max
Augus	213.4	93	74	22.5	29.0
September	196	92	69	22.4	30.6
October	286.4	90	62	23.0	32.0
November	91.1	91	59	23.5	33.1
December	0	74	44	22.7	34.5
Total	786.9				

*(Ghana Meteorological Agency– Asante Mampong, 2023)*