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IMPACT OF FERTILIZER FORMULATION AND RATE OF APPLICATION ON FIELD PERFORMANCE AND NITROGEN USE EFFICIENCY OF MAIZE (*Zea mays L.*)

BY

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DECLARATION

Student

I hereby declare that this thesis is the result of my own research and that it has never been presented either in Cull or part in any other institution for a Master Degree.

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ABSTRACT

Maize takes up a lot of nutrients from the soil, and therefore requires sufficient nutrients supply throughout the growth and development stages. Nutrient deprivation at any stage of growth could have an adverse effect on the crop's yield. Fertilizer briquetting is a useful innovation that ensures steady supply of nutrients at every stage of growth and development of the maize plant. This study is aimed at determining the right fertilizer formulation and the right rate of application that can ensure good yield while enhancing the efficient use of nutrients. The study involved two trials, both conducted on-station at Nyankpala in the Guinea Savannah ecological zone of Ghana's Northern Region during the 2022 farming season. Experiment one consisted of seven treatments that compared different briquette fertilizer rates. Experiment two had eight treatments which compared similar rates of granular and briquette fertilizers. Both trials were laid in randomized complete block design with four replications per treatment. The differences between the different rates of briquette fertilizer in Experiment 1 were not statistically different as far as yield was concerned, meaning that applying lower rate of briquette fertilizer did not result in any detrimental effect on growth and yield of maize. The lower rates of briquette fertilizer also recorded far superior performances in Nitrogen Use Efficiency. In Experiment 2, the comparative analysis of similar rates of briquette and granular fertilizer did not show a pattern of superior performances by either of the formulations as far as the growth parameters were concerned. The briquette treatments however, in nominal terms, produced better performances in grain yield and nitrogen use efficiency. This suggests that fertilizer briquetting ensures efficient use of nutrients by crops even at lower rates of application. It is therefore recommended for the adoption of briquetting fertilizer in order to ensure efficient use of nutrients.

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DEDICATION

I dedicate this to all my family, friends and well-wishers who have supported me in diverse ways and stood by me throughout my time of study at the University for Development Studies.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE **TITLE** **PAGE**

LIST OF TABLES

TABLE **TITLE** **PAGE**

CHAPTER ONE

1.0 INTRODUCTION

Maize (*Zea mays L.*) is said to have been introduced to Ghana in the late 16th century, and has been in cultivation since then, becoming a staple crop in most parts of the country (Darfour and Rosentrater, 2016). According to Ragasa *et al.* (2014), the importance of maize is emphasized by the fact that, of the total cereal crop production in Ghana, the crop accounts for over fifty percent. Maize is very well suited to the Ghanaian climatic conditions across all the ecological zones (Adu *et al.,* 2014).

Maize yield is generally low notwithstanding the great effort and investment being made in the sector. MoFA (2023) reported that in 2022, a total of 19,280.15 metric tons certified seeds of cereals (maize, rice and sorghum) and legumes (soyabean, groundnut and cowpea) altogether were procured and distributed to farmers in Ghana for planting. Out of this total, maize alone accounted for 10,446 metric tons (MoFA, 2023), emphasizing the lengths government has gone to improve maize productivity. In fact Bua *et al.* (2020); Hengl *et al.* (2017) think that in Africa the most serious drawback to agriculture has to do with lesser productive capacity resulting from continuous nutrient utilization and limited input usage that consequently bring about soil fertility challenges. Applying nutrients directly as fertilizer is the most widely used method of replenishing soil nutrients. The rate of application of inorganic fertilizer on maize farms in Ghana is greater on the average than all other crop farms, however this is still not enough (Hill and Kirwan, 2015). Adopting efficient methods of application coupled with rising rates of application has the tendency to seriously grow the yields of crop farms (Hill and Kirwan, 2015). However, excessive and inefficient use of fertilizer causes an enormous amount of the nutrients to be lost to the environment through nitrification, denitrification, leaching and volatilization (Awada and Phillips, 2021).

High cost of fertilizer coupled with the relatively low nutrient use efficiency as a result of losses pose a great challenge to the already financially burdened farmer. Slow-release fertilizer strategies are being explored as a means of providing crops with adequate and consistent supply of the needed nutrients during their most critical need (Yusuf *et al.,* 2018). Just like other fertilizer formulations, briquette fertilizers can be made into compound fertilizers that supply crops with nutrients for a much longer period of time as compared with regular granular formulations (Yusuf *et al.,* 2018). The use of briquette fertilizer is one of the means that reduces nutrient losses thereby increasing nutrient use efficiency. Fertilizer briquetting ensures a smaller surface area per unit mass of fertilizer when compared to the widely used granular fertilizer (IFDC, 2007). Smaller surface area therefore implies that the briquette fertilizer has the tendency to reduce the rate of dissolution by releasing the nutrients at a much slower rate to meet the nutrient demand of crops. This reduces nutrient loss and increases the nutrients available to crops (Adu-Gyamfi *et al.,* 2019), and hence increasing yield. Among the briquette fertilizers is NPK briquette that provides an avenue for a more balanced and accurate application of fertilizer nutrients so as to reduce fertilizer nutrient losses, saving cost associated with labor due to its one-time application, as opposed to regular granular and prilled fertilizers that require two or more split applications (Wang *et al.,* 2020).

1.1 Problem statement

Maize is a heavy feeder, requiring a lot of nutrients throughout its growth and development stages. Soils that are deprived of nutrients therefore result in poor yield. There are diverse ways in which soil fertility is enhanced for crop production. Among them is the use of commercially available synthetic fertilizer. Application of chemical fertilizer has become the easiest and most widely used method of replenishing depleted soil nutrients. This is because they are fast-acting, easier to apply and less bulky as compared to organic manure. The problems associated with these fertilizers however are that, they are prone to losses to the environment through leaching, surface run-off, denitrification and volatilization. These losses do not only cause environmental pollution, but also result in wastage of fertilizer nutrients otherwise required by crops. Crops are therefore denied the needed nutrients during their most critical period. With the cost of fertilizer already high, any losses of the fertilizer pose a great challenge to farmers. Reducing losses through fertilizer briquetting has been gaining traction. However, at what rate of application is considered economical, producing good yield while enhancing nutrient use efficiency. Determining the appropriate formulation at the required application rate is imperative for achieving the proper usage of fertilizers.

1.2 Justification

Fertilizers are generally expensive, especially in our part of the world. Nutrient losses create inefficiency in the use of these fertilizers, and therefore pose a huge challenge to the already financially burdened farmers. Fertilizer briquetting has been identified as a means of reducing nutrient losses as well as enhancing crop growth by making nutrients available when needed by crops. Fertilizer briquettes are made in a way that they are able to release their nutrients at a slower rate, making nutrients available for longer in the soil. This important quality of briquette fertilizers ensures that lower rates of application do not result in detrimental effect on crops. The result of the trial has the tendency to direct attention towards the use of fertilizer briquettes as a means of reducing the quantity of fertilizer applied by farmers, thereby reducing the cost burden associated with fertilizer application. The study will not only add to the literature on fertilizer briquetting, but also shape government's policy on the type of fertilizer formulation that should be adopted and made available to farmers.

1.3 Objectives

1.3.1 General objectives

The general objective of the research is to establish the comparative advantage of briquette fertilizer over similar rate of granular fertilizer.

1.3.2 Specific objectives

The specific objectives of the study were to determine if:

- application of briquetted NPK and urea is advantageous over granular NPK and urea in growth and yield of maize.
- lower rates of N, P_2O_5 and KO_2 in briquetted and granular NPK will not be detrimental to the performance of maize.
- nitrogen use efficiency is influenced by how the fertilizer is formulated.

CHAPTER TWO

2.0. LITERATURE REVIEW

Cereals are believed to provide more nourishment to humankind than any other class of food, and provide almost half of the total caloric requirement (Ranum *et al.,* 2014). Rice, maize, oats, barley, wheat, millet are some of the cereals utilized by humans, of which maize, wheat and rice are the most important food source for humans. Cereal consumption varies greatly according to the location, with wheat being the most favoured cereal crop across Central Asia, the Middle East, North and South America, as well as Europe. In the rest of Asia however, rice is the most widely consumed, whereas maize is the most utilized in most of Africa and Central America (Ranum *et al.,* 2014).

2.1. History of maize

Smith (2001) is of the view that the origin of maize is not a straightforward one. However, there is a general acceptance that it has its origins pointing to the Caribbean regions from the native people within the Arawac tribes. As a consequence of its common name, Linnaeus included the name as a species epithet in the botanical classification Zea (*Zea mays* L). Maize is a part of the grass family called Poaceae (Adiaha, 2020). It is said to be part of the pioneer crops that was produced by farmers around 7000 to 10,000 years ago, with clear evidence of this being shown in archaeological analysis of small corn cobs that were found in Mexico and said to be 5000 years ago (Ranum *et al.,* 2014). Another school of thought attributes the origin of maize to the Himalayas region in Asia, and is said to be the result of crossing Coix spp. and some Andropogoneas (presumed to be a specie of sorghum) (Smith, 2001). The high Andes of Peru, Ecuador and Bolivia have also been thought of as the likely origin of maize, manifested by the South American region being dominated by popcorn (Smith, 2001).

Another perspective to the origin of maize is that maize is said to have originated from teosinte, a wild grass which varies slightly as compared with present day maize (Ranum *et al.,* 2014). There are other view-points that indicate that maize is actually a hybrid of Zea diplopernnis, a perennial sub-specie of teosinte and a specie of Tripsacum, which are two wild grasses (Ranum *et al.,* 2014). Over the next 1000 years, and through continuous selection and cultivation, they were able to produce maize that is characterized by bigger cobs with numerous kernel rows that is more preferable for human consumption (Ranum *et al.,* 2014). Indigenes from native tribes located in Mexico and Central America helped the spread of maize to several parts of Latin America, North America and the Caribbean (Brown and Darrah, 1985). European travelers saw to its spread in Europe, while traders from Asia and Africa ensured its proliferation in those parts of the world (Brown and Darrah, 1985).

Flour corn, popcorn, dent corn, flint corn, sweet corn, amylomaize and striped maize are some of the maize varieties that have been cultivated at various places across the world by farmers (Adiaha, 2020). Sweetcorn is so called due to its high sugar content, and is known by other names such as sugar corn and pole corn (Huma *et al.,* 2019). Its sweetness is as a result of what has been described as a metabolic reaction involving recessive mutation that ultimately hinders the conversion of sugar to starch (Huma *et al.,* 2019). Pod corn is a type of wild maize which has each kernel covered in husk, and mostly grown for the purpose of research so that the genetic origin of maize can be unearthed (Ziegler *et al.,* 2003). Dent corn has a small indentation at the kernel, hence the name (Huma *et al.,* 2019). Flour corn possess a fragile starchy endosperm with a thin pericarp, and is basically utilized in making corn flour (Huma *et al.,* 2019). Flint corn has a tiny center which is soft, and surrounded by a larger proportion of hard endosperm and mostly grown across Latin American as well as Europe for food. It is early maturing and possess greater resistance to pathogenic fungi and other insects resulting from its deficiency in moisture absorption (Huma *et al.,* 2019).

Maize has been considered to be the most cultivated crop plant in Sub Saharan Africa covering an estimated 25 million hectares, mostly on small holder farms (Bua *et al.,* 2020). Maize production has been going on in Ghana for ages, and has become a staple crop in the country following its introduction adoption somewhere in the 16th century (Darfour and Rosentrater, 2016). Maize production currently covers a total land area of 1.2 million hectares in Ghana (Bua *et al.,* 2020), and is well adjusted, growing across all the ecological zones in the country (Adu *et al.,* 2014). Bua *et al.* (2020) report that among cereals, maize is the principal crop produced on large acreages across the country.

2.2. Importance of maize

Humans have always utilized crops for their survival and development in areas including food and health sectors, as well as research and economic purposes (Adiaha, 2020). As far as food crops are concerned, maize, wheat and rice are the most explored by mankind due to their significance to the well-being of humans (Adiaha, 2020). Unlike some other cereals such as rice and wheat, maize production is done across the world, and is considered a staple for many people from diverse regions worldwide (Darfur and Rosentrater, 2016). In fact, Saeed and Saeed (2020) describe maize as the queen of cereals the world over. In the Ghanaian context, it is the most widely cultivated cereal crop by smallholder farmers (Hill and Kirwan, 2015).

Maize has several uses in both domestic and industrial sectors. It is consumed by humans in the form of maize flour and cornmeal, and is also widely used as a major component of feed for livestock (Ranum *et al.,* 2014). From the maize grain, various products such as cornmeal, grits, starch, flour, tortillas, snacks and breakfast cereals (Rouf-Shah *et al*, 2016). The oil obtained from maize has been preferred by pharmaceutical and food industries due to its protein-rich status and the minute proportions of saturated fatty acids present in it as opposed other sources of protein, particularly animals (Adiaha, 2020). Oladejo and Adetunji (2012) reported about the oil obtained from corn being used for anti-freezing purposes. Along with cooking, Huma *et al.* (2019) state that the oil is used in soap making, while pharmaceutical companies utilize maize starch as diluents, and in cosmetics.

As an important food source, maize has been considered a main delicacy on the continent of African, with the rate of consumption for a person ranging from 58 to 328 daily (Ranum *et al.,* 2014). Among the importance of maize production is its use in the production of ethanol fuel, also known as ethyl alcohol, which is a type of alcohol that is used to produce alcoholic beverages. This alcohol is also essential, as it is use as fuel to power vehicles (Ranum *et al.,* 2014). This is further buttressed by Adiaha (2020) who listed production of bio-fuel and ethanol as some of its industrial uses.

Sorghum and millet have been the most utilized cereal crops in Ghana, especially in the Northern sector, but in recent years maize has overtaken both crops as the most staple crop satisfying the caloric needs of a majority of the people (Adu *et al.,* 2014). Hill and Kirwan (2015) opined that 20% of the caloric intake in Ghana is made up by maize, a reason why it is considered the most essential for small scale production. It is a good source of phosphorus, and also supplies more carbohydrates than wheat and sorghum (Mboya *et al.,* 2011). Along with carbohydrates, maize contains crude fibre and protein. It is a major contributor of amino acid to the body, even though it lacks lysine and tryptophan, which are essential amino acids (Adiaha, 2020).

Corn syrup contains a high-fructose content, which is a sweetener that is added to food for the purpose of preserving its moisture content (Khawar *et al.,* 2007). Dilip and Aditya (2013) also state that selenium is a component of maize that plays a role in stimulating the thyroid gland and improving human immunity. This is similar to what has been reported by Huma *et al.* (2019) that it also plays a critical role in fortifying the immune system and the thyroid gland due to its rich supply of vitamins A and C, along with beta-carotene, selenium and to some extent vitamin K. Maize is also rich in B-complex vitamins which is important for the skin and hair, whilst also playing a significant role in the proper functioning of the digestive system and other body organs such as the heart and brain, as well as the prevention of symptoms of rheumatism due to its ability to improve joint motility (Huma *et al.,* 2019).

The silk of maize is also used in herbal medicine (Oladejo and Adetunji, 2012), for the treatment of prostrate disorders, problems associated with the urinary system and kidney-related issues (Dilip and Aditya, 2013). Adiaha (2020) also reported that corn silk is used, mostly in China, for the treatment of fluid retention disorder, jaundice, improvement of blood pressure and liver functioning support as well as bile production.

2.3. Problems associated with maize production

Human population growth has brought about the need to increase food production to take care of the ever-growing mouths that need to be fed. Increasing the volumes of food that must be produced to satisfy the population has always presented a challenge in areas that experience very limited rainfall due to the small amount of organic matter that characterizes these areas, ultimately leading to soil nutrient and soil acidity challenges (Ojeniyi, 2010). Yield of maize in Ghana is one of the lowest in the world (Ragasa *et al.,* 2014). Between 2017 and 2022, yields have been ranging from 1.9-2.5 mt/ha (USDA, 2024). Other countries such as Thailand and Mexico that have similar growing conditions (lowland, rain-fed and tropical environment) pose higher yield than what pertains in Ghana, averaging 3.5-4.02 mt/ha (Ragasa *et al.,* 2014). This low yield is attributable to factors including soil nutrient deficiency, soil physical constraints, low input of fertilizer, pests and diseases as well as inefficient management (Hengl *et al.,* 2017). Even though there has not been any available evidence that apportions the contribution of each factor to the underperformance of maize, results from many trials point to the incessant land cultivation that is not accompanied by application of fertilizer as well as crop remnants being moved to other locations, resulting in nutrient depletion and inevitable yield loss (Bua *et al.,* 2020). Agriculture production system that is dominated by usage of inadequate levels of synthetic fertilizer causes yield levels of crops to be low, resulting in diminished incomes for rural folks, and subsequently increases the rate of poverty (Bua *et al.,* 2020). The prospect of Ghana stepping up production and seriously bridge the deficit in yield for cereal crops is bright, even though present yield levels are low (Bationo *et al.,* 2018). Bationo *et al.* (2018) further stated that the yield recorded for maize for most farmers seldom go beyond 1 mt/ha. Despite N, P, and K compound fertilizer applied, they observed low yield in maize farms. The increase in fertilizer use, however, has not led to substantial increases in crop productivity. Regardless of the hike in usage of fertilizer, especially N, P and K compound fertilizer, the intended growth in crop output has however not materialized (Bationo *et al.,* 2018).

Low soil fertility, inadequate amount and poor distribution of rainfall, as well as low usage of inputs are the challenges that affect the crop sector in Ghana. The country therefore continuous to import rice, wheat and maize to make up for the short-fall in production (Bua *et al.,* 2020). Continuous cultivation of crops on the same piece of land, as well as traditional practice of bush burning leading to the depletion of useful plant biomass, have exacerbated the problems of soil fertility (Bationo *et al.,* 2018), accounting for the poor yield output of farmlands.

Environmental factors such as low amount of rainfall received, deficiency in soil nutrients, as well as management practices especially low input usage are some of the challenges that affect the crops (Bua *et al.,* 2020). In general, crop yield fall way below their potential in Ghana, with short-fall in production approaching 66% (Bua *et al.,* 2020). Variation in soil characteristics and land variability play some role producing low yield (Kravchenko and Robertson, 2007). Soil water movement within the soil is directly influenced by the topography of the land and is therefore a determinant of some soil physical and chemical properties (Kravchenko and Robertson, 2007). Topography also influences the depth of the root zone which impacts on crop growth and yield (Guilpart *et al.,* 2017). This is especially rife in Ghana where the depth of soil is very shallow in most of the areas where cereal crops are produced. (Sadras and Calvino, 2001) found in their study that maize yield was the most affected by shallow soil depth when compared with other crops such as soybean, sunflower and wheat (Sadras and Calvino, 2001). For maize in particular, the yields recorded are far less than what can realistically be achieved in Ghana, which calls for action to be taken as regard farming practices in order to bridge this gap (Hill and Kirwan, 2015).

(Adu *et al.,* 2014) reported that in Ghana, the most challenging factors that limit the production of maize in Ghana include soil nutrient deficiency, weeds (especially striga), pest and diseases as well as the setting in of drought during the initial growth stages. Other factors relate to improper management and operational practices which include the adoption of less plant population than recommended, wrong timing of planting, poor weed control, lack of credit facilities, inadequate fertilizer and improved seeds, wrong usage of fertilizer, post-harvest losses caused by inadequate drying and lack of storage facilities, in addition to poor market access (Adu *et al.,* 2014).

The maize plant is at its most vulnerable for weed competition at the early stage of growth, where there is competition for nutrients, light, water and space resulting in loss of yield, poor grain quality and increased production cost (Adu *et al.,* 2014). It is imperative that weeds are not allowed to out-grow the maize, especially during the critical period of 2-4 weeks after planting in order to achieve higher grain yield (Adu *et al.,* 2014).

The disparity in maize yield between the northern and southern sectors of Ghana has been a concern to policy makers. Even though farmers in the northern sector, on the average, cultivate more acreage than their southern counterparts, more yield is ironically produced in the south (Hill and Kirwan, 2015). On the average, much more money is spent per hectare of maize produced by farmers from the north, with the cost relating to labour and tillage operations (Hill and Kirwan, 2015). However, more spending has been targeted towards certified seeds and harvesting operations by those in the southern sector (Hill and Kirwan, 2015). Even though more fertilizer is being used in the northern sector as compared to the south, low rainfall distribution and the challenging weather conditions means that applying more fertilizer may just be to combat the impact of these adverse conditions faced by northern farmers (Hill and Kirwan, 2015). Hill and Kirwan (2015) also opined that regardless of the increased fertilizer utilization by northern farmers, less than 15% of them heed to the usage of recommended seeds, compared to about 74% of the fertilizer users in the South. This may account for the higher yield recorded in the South than in the North as fertilizer typically gives the best results when the seeds used are certified of the recommended quality (Hill and Kirwan, 2015).

2.4. Fertilizer usage in maize production

Soil fertility management through the use of fertilizer is one of the driving forces behind the increased global agriculture production that is needed to feed the rising human population

(Bindraban *et al.,* 2015). There has been a huge jump in crop production ever since synthetic fertilizers were adopted some decades ago (Maguire *et al.,* 2019). Volumes of fertilizer being used across the world has seen enormous increment due to more farmlands coming on stream and increased application rates (Yusuf *et al.,* 2018). The significance of fertilizers is further underlined by the fact that without them more lands would have to be cultivated just to produce about half of the food needed across the globe (Reetz, 2016). In general, plants require as much as 18 nutrients, with nitrogen, phosphorus and potassium being the most important (Iqbal *et al.,* 2020). Synchronizing crop nutrient requirements with the amount of fertilizer used is essential, due to variation in crop needs and soil characteristic (Maguire *et al.,* 2019).

In Ghana, the use of fertilizer and its application rate appears to be high in cash crop production, while application rate in maize is in the intermediate range (Bua *et al.,* 2020). Hill and Kirwan (2015) further contend that although the average use of fertilizers in maize fields is high, the application rate is low, with studies showing that increasing the rate of application and efficient use of fertilizer significantly increases yield. In Africa, there are several reasons why fertilizer use is low. In Ghana however, the most common reason has to do with the high cost of fertilizers (Hill and Kirwan, 2015). The role of chemical fertilizer usage in agriculture policy has been clearly documented, but implementation challenges are still rife (Bationo *et al.,* 2018). By the year 2019, the average usage of fertilizer in Ghana stood at 20.9 kg/ha^{-1}, which is significantly below what was agreed upon by the Abuja Declaration in 2006, at a rate of 50 kg/ha^{-1} by the year 2015 (Bua *et al.,* 2020). This figure is higher than the 10 kg/ha^{-1} average in Sub-Saharan Africa, but far adrift of the 118 kg/ha^{-1} global average fertilizer rate (Hill and Kirwan, 2015). Adopting the general application rate pose a challenge in ascertaining whether nutrient requirements of particular crops are being met under particular soils and in varying climatic conditions. It is therefore imperative to develop a science-based approach to fertilizer recommendations that is evidenced on yield responses, though this can be a tedious and a time-consuming process (Bua *et al.,* 2020).

2.5. Uses/importance of fertilizer

Fertilizer utilization in crop production has become a very important management tool to address soil fertility limitations and provide crops with the nutrients required to achieve good yield and a profitable farming venture (Yusuf *et al.,* 2018). Soil as natural body require continuous fertility management. Sand, silt, clay and organic matter are some of the soil constituents that play a significant role in providing tilth necessary for aeration and water intake, they are however limited in their ability to maintain adequate plant food for the growth of crops. Fertilizer application as method of soil fertility management is such a crucial operation in farm management (Liu *et al.,* 2021). Applying fertilizer results in improvement in soil nutrient content and consequently the yield produced (Choudhary *et al.,* 2021). Yusuf *et al.* (2018) add that fertilizer usage creates a situation where crops are able to satisfy their nutrient need even when the soil is deficient in plant food. These nutrients are absorbed in solution into the cells of plants to play their various roles in the growth process of the plant (Yusuf *et al.,* 2018). The impact of fertilization cannot be over emphasized in food production for both short and long term (Ghosh *et al.,* 2019). Regardless of the type of fertilizer, they all enhance soil fertility and productivity, which is critical in addressing global food sustainability challenges brought about by incessant populating growth (Yusuf *et al.,* 2018). Addressing the threat of hunger will hinge on how aggressive we are able to rump up food production, which will largely depend on how well fertilizers are utilized since farmlands continue to dwindle (Jaja and Barber, 2017). An important feature of chemical fertilizers is that nutrient content available in the fertilizer is specified, and can be calibrated to take care of the specific need of the crops in a timely fashion (Jaja and Barber, 2017). Chen *et al.* (2017) also report that chemical fertilizers are especially preferred due to their high nutrient content which is readily available upon application, as well as their ease of usage.

As far as growth, yield components and yield are concerned, nitrogen has been described as the most essential by (Awadalla and El-hafeez, 2018). It is very influential in those compounds that influence the growth of plants, chlorophyll as well as enzyme action. It constitute up to 4 percent of plant biomass, and plays a critical role in amino acid and protein synthesis (Yusuf *et al.,* 2018). Additionally, nitrogen is very influential in plants ability to absorb other nutrients (Yusuf *et al.,* 2018).

Apart from nitrogen, phosphorus is a major plant nutrient whose deficiency causes huge challenges for most crops. With the critical role it plays in protein synthesis, as well as phospholipids and phytin, they are highly embedded in the grain (Awadalla and El-hafeez, 2018). It carries out various functions in plant metabolism, and therefore required in adequate amount for the performance of numerous metabolic processes (Awadalla and El-hafeez, 2018). Yusuf *et al.* (2018) further state that plant internal processes such as cell differentiation, tissue formation and photosynthesis are highly influenced by phosphorus, and as a result make up a chunk of plant biomass. Apart from nitrogen, phosphorus limitation causes poor yield than the rest of the nutrient elements (Yusuf *et al.,* 2018).

Along with nitrogen and phosphorus, potassium also plays an essential role in crop production, with is role in the activation of numerous enzymes, maintenance of turgor pressure of cells as well as osmo-regulation of cells (Awadalla and El-hafeez, 2018). In addition, potassium influences the transport of assimilates and regulation of photosynthetic rate in plants. Like nitrogen, it constitute up to 4 percent of plant biomass, while also activating in excess of 60 enzymes (chemical substances which govern life) (Yusuf *et al.,* 2018). Potassium also plays the unique role of enhancing plants' ability withstand drought and disease conditions (Yusuf *et al.,* 2018).

2.6. Challenges associated with fertilizer usage

There is little doubt about the impact of fertilizers in attaining global food security. One of the most crucial agricultural practices is fertilization (Liu *et al.,* 2021), therefore its importance cannot be over emphasized. Continuous fertilizer usage has been proven by research to have a positive effect on soil fertility and crop performance (Choudhary *et al.,* 2021; Gosal *et al.,* 2018). However, other studies have pointed to negative effect on soil nutrient balance due to imprudent fertilization (Luo *et al.,* 2020). Yang *et al.* (2019) also observed detrimental effect on crop productivity and soil fertility due to immoderate fertilization, which causes disruption of soil N and P absorption and distribution in crops. The challenge however concerns how to effectively adapt the use of inorganic fertilizers that ensures environmental sustainability in producing food and cash crops (Reetz, 2016). However, for a good number of farmers the world over, especially those from poor African countries and some other regions, fertilizers seldom meet the objective of increased productivity and food sufficiency (Bindraban *et al.,* 2015). Yield responses of maize to fertilization are highly variable across different agro-ecological zones (Bindraban *et al.,* 2021). Up to 8 mt/ha of maize was produced as a consequence of the use of fertilizer in some areas, whereas other locations recorded as low as 0.5 mt/ha (Njoroge, 2019). There are therefore questions to answer regarding the significant variability observed in the yield of maize despite the major rise in rate of application of especially NPK fertilizer in the last few years (MoFA, 2020).

The problems associated with the use of fertilizer relates to its high cost, wrong application/usage and losses due to leaching. The ultimate aim of fertilizer application has to do with making sure the nutrients are consumed by the plant only. However, the situation as it pertains is that not all the nutrients contained in the fertilizer end up in the plant, with some of them lost to the environment or made unavailable by complex chemical processes (Bindraban *et al.,* 2015). Disproportionate use of fertilizer also causes numerous unintended consequences that are detrimental to the environment (Yusuf *et al.,* 2018). These problems relate to pollution of water bodies and the surrounding air, acidification of soil, which ultimately result in yield shortfalls (Yusuf *et al.,* 2018). Also, it is the suggestion of Hill and Kirwan (2015) that recording of poor yield despite the use of fertilizer could be attributed to the use of maize seeds that are unresponsive to fertilizer, which therefore calls for the use of certified seeds. When fertilizers are applied to crops, the expectation is to a positive response by the plants manifested in growth and yield produced, but due to some factors this is not always the case. Among these factors are soil characteristics, rainfall pattern and amount, and prevailing temperature (Kyei-Mensah *et al.,* 2019). The effect of rainfall variability is so telling as it extends beyond soil fertility issues to disease prevalence (Leng and Huang, 2017). Predictability is an important trait in crop production, hence any uncertainties cause serious disruption to the overall agriculture production system (Onduru and Du Preez, 2007). Yusuf *et al.* (2018) identify a number of factors that defeat the purpose of fertilizer usage. The specific crop requirement of a particular fertilizer nutrient and the actual amount of it needed is one of such factors (Yusuf *et al.,* 2018). Other reasons may be due soil characteristics and climatic conditions, which are a huge determinant to the kind of dertilizer formulation, the amount to be applied and the precise method and period to apply them (Yusuf *et al.,* 2018).

Fertilization application, apart from its environmental cost, has an even greater economic cost to farmers, showing a limited impact on crop yield and thereby failing to positively impact the lives of poor farmers, especially in Africa (Bindraban *et al.,* 2015).

Synthetic fertilizers are generally expensive, owing to the high demand and other factors such as changing input prices (Ruder and Bennion, 2013). Ghana imports almost all the fertilizer that is consumed in the country, recording the biggest fertilizer imports in 2020 in the West African sub-region (International Trade Administration (ITA), 2022). All the fertilizer types that were imported into Ghana averaged around $120 million between 2019 and 2021 (International Trade Administration (ITA), 2022). The apparent decline in the value of fertilizer imports in that period could be attribute to financial challenges faced by importers as a result of government's delay in the payment of fertilizer subsidies (GCB Strategy and Research Department, 2022). The Ghanaian fertilizer market is price sensitive, with prices affected by a variety of factors. The cost of fertilizer haulage had tripled in 2021 globally. Coupled with exchange rate depreciation, with the Ghana Cedi depreciating 15% against the US dollar in the first quarter of 2022, fertilizer prices have been negatively affected (International Trade Administration (ITA), 2022). In terms of the cost build up, the port in Tema receives all the traffic as far as fertilizer importation is concerned, and also hosts most of the blending and storage facilities. Even though taxes are exempted on fertilizer, domestic distribution costs add 40-45% to the cost imported and locally blended fertilizer (International Fertilizer Development Center (IFDC), 2019). On the average, 38% are financial cost, with just over 40% of the cost relating to operations, the two making up over two-thirds of the cost involved from the warehouses to the retailers (International Fertilizer Development Center (IFDC), 2019). Around fifty percent of the retail cost of fertilizer is actually as a result of internal transportation to selling points (International Fertilizer Development Center (IFDC), 2019).

Despite its numerous benefits, fertilizer utilization comes with an environmental cost. For instance, loss of nitrogen from agriculture has resulted in a major deleterious impact on the environment.

Among them is the increase in nitrous oxide (N2O), which is a greenhouse gas and an important catalyst to ozone depletion, soil acidification and fertility deficiency (Awada and Phillips, 2021).

There is also the danger of leached and washed away fertilizer polluting ground and surface water. Disproportionate fertilizer application causes nutrient loss in larger proportions to the environment through nitrification, denitrification, leaching and volatilization (Awada and Phillips, 2021). These fertilizers contain substances and ingredients that, if not used in the recommended way, can become detrimental to both plant and soil health, and by extension other living organisms (Yusuf *et al.,* 2018). Other constituents of soil such as soil micro-organisms are adversely affected, causing an imbalance in soil make up which eventually affect the soil's ability to provide the needed condition for plants' proper functioning, tolerance to drought and pest and disease resistance (Yusuf *et al.,* 2018).

Nitrogen availability is a significant determining factor for growth and yield of crops (Roy *et al.,* 2018). Due to the fact that nitrogen is the most needed nutrient for most crops, proper application of nitrogen-rich fertilizer has become problematic as a result of various losses and increased fertilizer cost, with only about 30-40% of the applied nitrogen being utilized by crops (Chen *et al.,* 2017). High cost of fertilizer coupled with the relatively low nutrient use efficiency poses a great challenge to the already financially burdened farmers.

2.7. Types of fertilizer formulations

Industrially manufactured chemical fertilizers are available in many forms in the market (Iqbal *et al.,* 2020). The current chemical fertilizers available in the market are in solid forms (either granular, crystalline, powder or pills), spikes and pellets that have controlled release qualities, liquid form and tablets (Iqbal *et al.,* 2020). Yusuf *et al.* (2018) added that the variations that come with mineral fertilizers could be in their appearance, size and shape (Yusuf *et al.,* 2018). Regardless of the formulation, the fertilizer may contain a definite ratio of the major nutrients (N, P and K). Beyond the three major nutrients, there those that incorporate other major nutrients and micronutrients (Iqbal *et al.,* 2020). Another form of granular fertilizer is what is known as prilled fertilizer, which is made in a fluid by the solidification droplets into spherical form (Mahler, 2002). Like prilled fertilizer, another kind of granular fertilizer is coated fertilizer, which has been made by covering it a layer of clay or plastic. This is done to ensure slow release (Mahler, 2002). The coating ensures that the rate of release is more targeted (England *et al.,* 2012). Adjusting the level of thickness ensures more exertion of control on the release rate (England *et al.,* 2012). Slow-release or controlled-release fertilizers release their nutrients slowly, providing them over a relatively long period (6 weeks to 12 months) (Mahler, 2002). Yusuf *et al.* (2018) also describe slow or controlled release fertilizer types as those that are made in such a way that they discharge their nutrients over an extended period ostensibly to ensure constant and consistent nutrient availability for use by plants. How they release their nutrients may however be influenced by certain conditions such as moisture, temperature, and with the coated one, how thick the coating is (England *et al.,* 2012). The ingenuity applied in their production make them a bit costly as compared to usual inorganic fertilizers (Mahler, 2002). Another form of the slow-release fertilizers is what is now known as briquettes. The briquette fertilizers are manufactured by the physical modification of the ordinary granular and prilled fertilizers into pillow-like structures which are engineered for controlled release (Roy *et al.,* 2018).

2.8. Briquette fertilizers and their impact on reducing nutrient losses

Among the major concerns confronting farmers and the entire agriculture value chain in general is minimizing the amount of fertilizer nutrients that find their way into water sources in addition to also maintaining or enhancing productivity. Synchronizing fertilizer application with crop requirement for fertilizer nutrient is essential to possibly remedying this challenge (Adu-Gyamfi *et al.,* 2019). The most widely held practice is to split the application of the fertilizer into two. The first application (basal application) is done a couple of weeks after planting, with the second application (top dressing) done several weeks after. The rationale for the split application is to make nutrients available to crops throughout the growth and development stage, and the fact that granular fertilizers dissolve at a faster rate and lend themselves to losses through leaching and surface run-off. Hence fertilizer formulation that makes it feasible to apply the fertilizer during sowing of seeds, minimizing losses of nutrient while enhancing crop growth and development is imperative for sustainable agriculture (Adu-Gyamfi *et al.,* 2019). It is therefore imperative that fertilizers produced with better plant uptake potential would minimize nutrient losses, and therefore reduce the amount of fertilization required (Bindraban *et al.,* 2015).

Fertilizer briquetting typically diminishes the total surface area on a mass of fertilizer when juxtaposed with the widely used prilled/granular fertilizer (IFDC, 2007). A relatively reduced surface area minimizes the surfaces in contact with soil, thereby slowing how fast they dissolve. This minimizes fertilizer wastage and enhance the nutrients available to crops (Adu-Gyamfi *et al.,* 2019). This position is corroborated by Wang *et al.* (2020), who also state that NPK briquette, due to its less surface area, dissolves slower and releases its stored nutrients over a much stretched period of time at a measured rate commensurate with plant needs, thereby ameliorating the risk of nutrient loss, especially nitrogen, and therefore protect the integrity of the surrounding air and water. NPK Briquette is an essential formulation that is intended to not only provide plant nutrients across a longer period of time compared with granular fertilizers, but also play a critical role in preventing environmental pollution occasioned by nutrient losses because of its slow release nature due to smaller surface area (Savant and Stangel, 1990). It is further reported by Roy *et al.* (2018) that application of urea briquette (otherwise known as Urea Super Granules) makes nitrogen available at a much slower rate, and therefore positively affecting the amount of nitrogen lost due leaching and volatilization. Kokare *et al.* (2015) reported in a study that adopting the fertilizer deep placement method significantly reduces losses due to fixation, leaching, and run-off, which then result in better retention and release of nutrients. Briquette fertilizer usage is therefore an effective means of maximizing fertilizer use efficiency, thereby saving cost involved in fertilization.

2.9. Impact of fertilizer briquetting on nutrient use efficiency and crop yield

One of the factors that contribute to sustainable agriculture is the scientific and efficient use of fertilizers (Kokare *et al.,* 2015). There has been lack of improvement in yield levels as a result of nutrient deficiency and imbalances, which calls for enhanced effort to increase nutrient use efficiency, thereby increasing yield (Bua *et al.,* 2020). The results that are obtained from the application of chemical fertilizer can differ from one geographical area to another or even within the same geographical area, and also varies with crop (Yusuf *et al.,* 2018). In general, the efficiency associated with fertilizer utilization, especially in our part of the world is extremely low, indicating that a lot of the nutrients contained in the fertilizer are not used by plants but rather find their way into the environment with their attendant problems (Yusuf *et al.,* 2018). If more of the nutrients are used by plants, it will materially curtail the amount of fertilizer nutrients that are wasted, thereby preventing the need to continually apply fertilizer, and hence bring down the cost of production of crops. This means that fertilizer nutrient use efficiency positively impacts the general economies of farmers and the environment as a whole (Yusuf *et al.,* 2018). Bindraban *et al.* (2015) contend that adopting agronomic practices in applying mineral fertilizers taking into cognizance the time of application, how close they should be placed to the plant, the quantity required and the make up of the fertilizer being used result in improvement in fertilizer use efficiency. Achieving this will require an understanding of the factors that influence efficiency of these fertilizers, and formulating fertilizers that largely respond to the needs of plants (Bindraban *et al.,* 2015). This fertilization strategy ensures that plants receive a balanced proportion of what is most needed at any point in time, reducing wastage and cost (Bua *et al.,* 2020). Any initiative that seeks to regulate nutrient release to coincide with plants need must take into consideration all the factors capable of limiting the efficiency of fertilizers (Bindraban *et al.,* 2015). This can have a major impact in causing a significant move away from the regular practice of using fertilizer based on the amounts applied per unit area to using fertilizer on need bases (Bindraban *et al.,* 2015).

Nitrogen fertilizer utilization efficiency is generally low. This relates to losses caused by chemical reactions such as denitrification and volatilization, as well as natural occurrences such as surface run-off and leaching. Employing proper management practices when using nitrogen fertilizers have been proposed to help deal with this challenge. Deep placement of briquette fertilizer at a depth of between 8 cm and10 cm depth has the tendency to reduce wastage of applied nitrogen by about 30% more than prilled urea, as well as increase nutrient absorption rate (Roy *et al.,* 2018). According to Adu-Gyamfi *et al.* (2019), adoption of fertilizer briquette for maize production in the savannah agro-ecological zone resulted in more than 77% recovery of the nutrients applied, and increased maize yield by more than 30% as against granular fertilizer applied in tranches. The high yield obtained as result of the briquette fertilizer application suggests that there is the availability of nutrients during the various stages of the plant's growth (Adu-Gyamfi *et al.,* 2019). It was also found by Agyin-Birikorang *et al.* (2018) that the use of NPK briquette as nitrogen source resulted in 16% more yield other sources of nitrogen such as ammonium sulfate (supplemented with P and K), when considered against urea however, the figure jumps to between 23%-34% under normal weather conditions. Similar results was obtained by Islam *et al.* (2011) in rice where significantly more yield was recorded by the application of NPK briquette. Using the Broadcasting of prilled urea increases nitrogen losses resulting in lower yield as opposed to deep placement of briquettes which controls release of nutrients, curtailing losses, enhancing nutrient uptake and therefore increasing yield. Applying of multi-nutrient briquette fertilizer recorded over 66% nutrient use efficiency more than the granular/prilled fertilizer which recorded 35% nutrient use efficiency (Agyin-Birikorang *et al.,* 2018). Akter *et al.* (2015) reported a profitable outcome in non-lowland vegetable crops including cabbage, tomato, potato and cauliflower when urea and NPK briquettes are applied. Applying NPK briquette by deep placement provides the nitrogen, phosphorus and potassium needed by crops compared with conventional practices. This also reduces environmental losses, as well as giving greater vegetable yield as compared to conventional fertilizer practices (Akter *et al.,* 2015).

CHAPTER THREE

3.0. MATERIALS AND METHODS

3.1. Experimental site

This research was carried out at the experimental field of the University for Development Studies at Nyankpala campus. The site is located on latitude N 09.41158^{0}c and longitude W 000.98263^{0}c with an altitude of 163 m above sea level. The area experiences a unimodal rainfall pattern ranging from 1000 mm to 1200 mm. Rainfall starts in late April and reaches a peak in July to September; there is a sharp decline and absolutely no rain in November (SARI, 2004). The trial spanned the period from June, 2022 to November, 2022.

3.2. Experimental design and treatment

The study consisted of two trials. In Experiment 1 the idea that briquetted fertilizer reduces nutrient requirement was explored and it consisted of seven treatments. It sought to understand how the reduction of the rates of N, P_2O_5, K_2O in briquetted NPK (10-20-20) will impact on crop performance. Experiment two compared briquetted NPK and urea with granular counterpart at different rates. In both trials the treatments were laid down on 5 m x 5 m plot using randomized complete block design with four replications. An alley of 1 m and 2 m was kept between plots and blocks respectively. NPK 10-20-20 fertilizer grade was used for both experiments. The treatment compositions of the two experiments are shown in tables 1 and 2. The rates for similar granular and briquette treatments vary marginally.

Table 1: Nutrient rates of fertilizer used to formulate briquettes used in experiment 1

Fertilizer form	N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	NPK 10-20-20 (g)/plot	Urea (g)/plot	# NPK briq/hill	# Urea briq/hill
Control							
Granule	120	40	40	500	543.5		
Briquette	121	59	59	733	500	4	3
Briquette	114	44	44	550	500	3	3
Briquette	91	59	59	733	333.3	4	2
Briquette	76	29	29	367	333.3	2	2
Briquette	31	29	29	367	166. 7	2	1

Table 2: Rates of N, P_2O_5, K_2O in granular and briquetted form used in experiment 2

Fertilizer form	N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	NPK 10-20-20 (g)/plot	Urea (g)/plot	# NPK briq/hill	# Urea briq/hill
Control							
Granule	120	40	40	500	543		
Granule	116	48	48	600	500		
Granule	86	48	48	600	337		
Granule	55	48	48	600	168		
Briquette	114	44	44	550	500	3	3
Briquette	83	44	44	550	333	3	2
Briquette	53	44	44	550	167	3	1

3.3. Land preparation and planting

Prior to planting, the field was ploughed and then harrowed afterwards. The maize variety that was used was Sanzal-sima, a local open-pollinated drought tolerant variety that takes 110 days to mature with yield potential of 5400 kg/ha. Planting was done on June 28, 2022 on both fields. Seeds were planted at an inter-row spacing of 75cm and an intra-row spacing of 40cm with three seeds per hill that were later thinned to two seeds per hill after emergence. Pre-emergence herbicide, Pendimenthaline mixed with glyphosate, was applied immediately after planting.

3.4. NPK briquetting and treatment application

Briquetting was done by an IFDC approved Fertilizer Company in Tamale, Garnoma. The NPK type used was 10-20-20. The basal NPK and urea needed were compressed into briquettes of about 1.5 cm in diameter. The average weight of a briquette was 2.2 g. The treatments were applied in split manner for both experiments. The basal application, consisting of briquette NPK and granular NPK were applied at two weeks after planting (WAP) for both experiments. Top dressings, consisting of either urea briquette or granular urea were applied at seven weeks after planting.

For the granular treatments, a pre-determined quantity was applied per hill. All fertilizers were buried by dibbling at 5-7 cm away from plants and 7-10 cm deep.

3.5. Cultural practices

3.5.1. Weed control

Weeds were controlled using both chemical and manual weeding. Post emergence herbicide Nicotine and Atrazine powder were mixed and applied to control weeds at five weeks after planting. Hoeing was done at eleven weeks after planting.

3.5.2. Pest control

There was fall armyworm outbreak at the vegetative phase four weeks after planting and were controlled by spraying the crops with Emastar at 17 ml/15 L Knapsack. The second control was done six weeks after planting, also with Emastar at the same rate.

3.6. Data collection

Within each plot, five plants were randomly selected and tagged within the inner rows for repetitive non-destructive measurements. Data were then taken on the following parameters.

Plant Height

Plant height was taken at 4, 6 and 8 weeks after planting (WAP). The height of each of the 5 tagged plants was measured using a measuring tape from the base to the flag leaf, and the average taken to represent the plot (treatment).

Greenery of leaves

A SPAD meter was used to measure the greenery of the leaf which correlates with chlorophyll concentration. Five (5) plants were tagged in each plot. Six (6) SPAD readings were taken on each of the 5 tagged plants (three on the 5th leaf and another three on the 6th leaf, counting from the bottom). Each plot will therefore have 10 leaves, totaling 30 measurements. The average value of the thirty readings were computed. These measurements were taken at three weekly intervals at 5, 8 and 11 WAP.

Leaf Area Index (LAI)

Three leaves were taken from bottom, middle and upper part of a plant and their lengths and widths measured. Leaf length was measured from the tip of the leaf to the point of attachment to the stalk. The width was taken from the middle where maximum width can be obtained. In all, a total of 15 leaves were used per plot and the average length (L) and width (W) were computed. The leaf area of individual leaf was calculated using the formula $Area = L\ x\ W\ x\ K$ where L is the mean leaf length, W is the mean leaf width and K is a constant, 0.75. In order to obtain the leaf area of a plant the individual leaf area computed was multiplied by the total number of leaves on the plant. The leaf area was used to calculate the Leaf Area Index (LAI) by dividing the leaf area by the ground cover of a plant. The ground cover was obtained using the planting distance of 75 cm x 40 cm (3000 cm^2). This was done at two weeks intervals starting from week 4 through to 8.

Days to 50% and 100% flowering

At 6 weeks after planting, field observation and monitoring started to determine the onset of tasseling. The number of plants that tasseled were countered on daily basis to determine how many days it took for half of the plants to tassel for each plot. Counting the number of plants that tasseled continued in order to determine the number of days it took for all the plants to tassel for each plot. They were recorded as days to 50% and 100% flowering respectively.

Days to 50% and 100% maturity

Field monitoring was carried out to determine the number of days it took for half of the plants to attain physiological maturity for each of the plots. This was recorded as days to 50% maturity. Again, the number of days it took for all the plants to reach physiological maturity was recorded as days to 100% maturity.

Stem Girth

Stem girth was taken at tasseling using a Vernier caliper. The girth of the stem of each of the tagged plants was measured at the third internode from the soil surface, and then averaged.

Cob Length

This was done at harvest. The cobs were de-husked, and the length measured using a rule from the base to the tip of the cob for five randomly selected cobs and the average computed.

Biomass and Grain yield

An inner area of 8 m^2 was marked from the 25 m^2 plot for harvesting. Plants from this area were harvested from the ground. Total biomass was measured from all plants harvested from the marked 8 m^2. Five plants were randomly selected from the lot and their biomass was also taken. They were then separated into stock, leaves and cobs and were bagged. The cobs of the five selected plants were de-husked and de-grained and placed in a labelled bag for weighing. The grains were dried for three days before weighing with electronic weighing scale. The figures were recorded in grams (g) and the grains were finally kept in sacks to be used for the protein content analysis. The cobs of the rest of the harvested plants from 8 m^2 were removed and were de-husked. The grains were removed from the cobs manually. Grains from a plot were sun-dried for three days. The weight of the grains from each plot was measured in kilograms and the weight of the grains from the five cobs were added. The grain weight was subsequently converted into kilograms per hectare (kg/ha).

100 Grain Weight

After de-graining the cobs, the grains were sun-dried for three days. 100 grains were randomly selected and weighed. The weight was recorded in grams (g).

Nitrogen Use Efficiency (NUE)

Nitrogen Use Efficiency was assessed as the Agronomic Efficiency of applied nitrogen (AEN).

For each treatment, Agronomic Efficiency was determined by subtracting the yield produced by the control treatment (no fertilizer) from the yield produced by the fertilizer treatment, and the difference divided by the total nitrogen used. Thus;

$$\text{Agronomic Efficiency} = \frac{(Fertilizer\ treatment\ yield - control\ yield)\ kg/ha}{Total\ N,\ \ kg/ha}$$

3.7. Data Analysis

Data collected were subjected to analysis of variance (ANOVA) using Genstat Statistical Package software, Teaching and Learning version, 18th edition. Treatment differences were determined using least significant difference at 5% probability level.

CHAPTER FOUR

4.0. RESULTS

4.1. Results of Experiment 1

4.1.1. Plant height

The highest rate of N -P_2O_5 - K_2O contained in Briq 121-59-59 resulted in higher plant height throughout the period height was recorded (Figure 1). However, the effect of treatments on plant height was not significant in the 4th and 8th week after planting ($P>0.05$). In the 6th week, plant height showed significant differences, with Briq 121-59-59 resulting in higher plant height than the other treatments. As to be expected, the absolute control (no fertilizer) plants recorded the least plant height throughout the growth period.

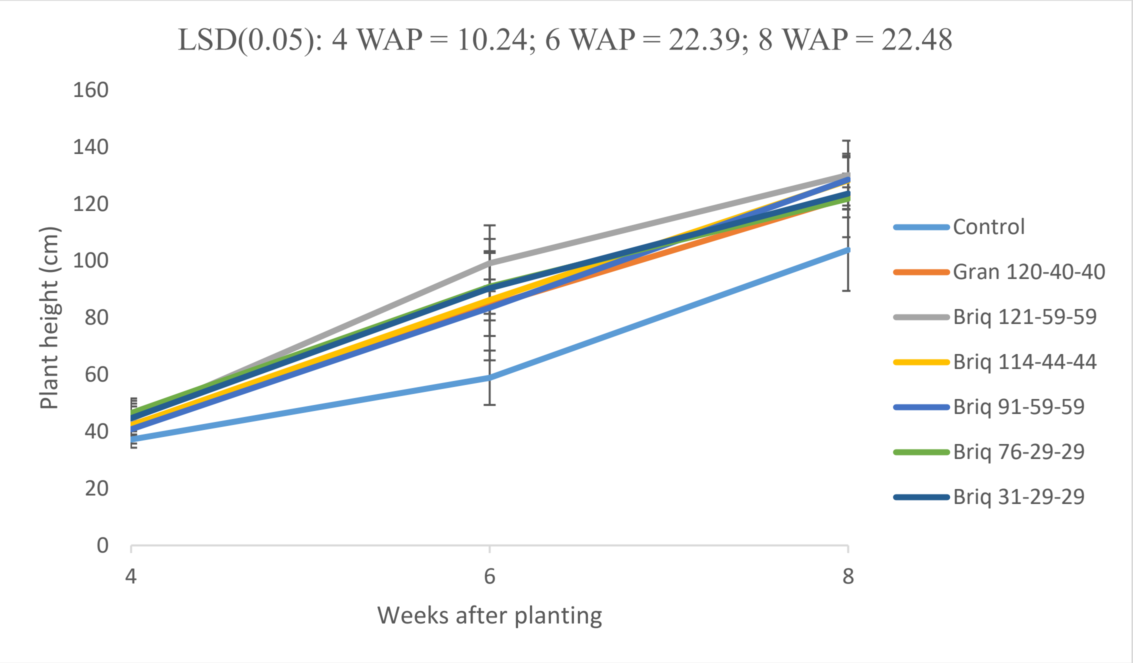

Figure 1: Effect of rate of application of briquette fertilizer on plant height from week 4 to 8 after planting. Error bars represent Standard Error of Means (SEMs)

4.1.2. Greenery of leaves

The influence of the fertilizer treatments on greenery of leaves was significant in all the weeks that SPAD readings were taken. The treatments with highest N rate, Briq 121-59-59 and Gran 120-40-40, resulted in greener leaves especially from the 8th to the 11th week after planting as compared to the other treatments with low N rates. For the entire period however, the absolute control treatment with no fertilizer had the least SPAD values (Figure 2). It was observed that between week 8 and week 11 after planting, the fertilizer treatments recorded increased SPAD values while that of the absolute control recorded reduced SPAD value (Figure 2).

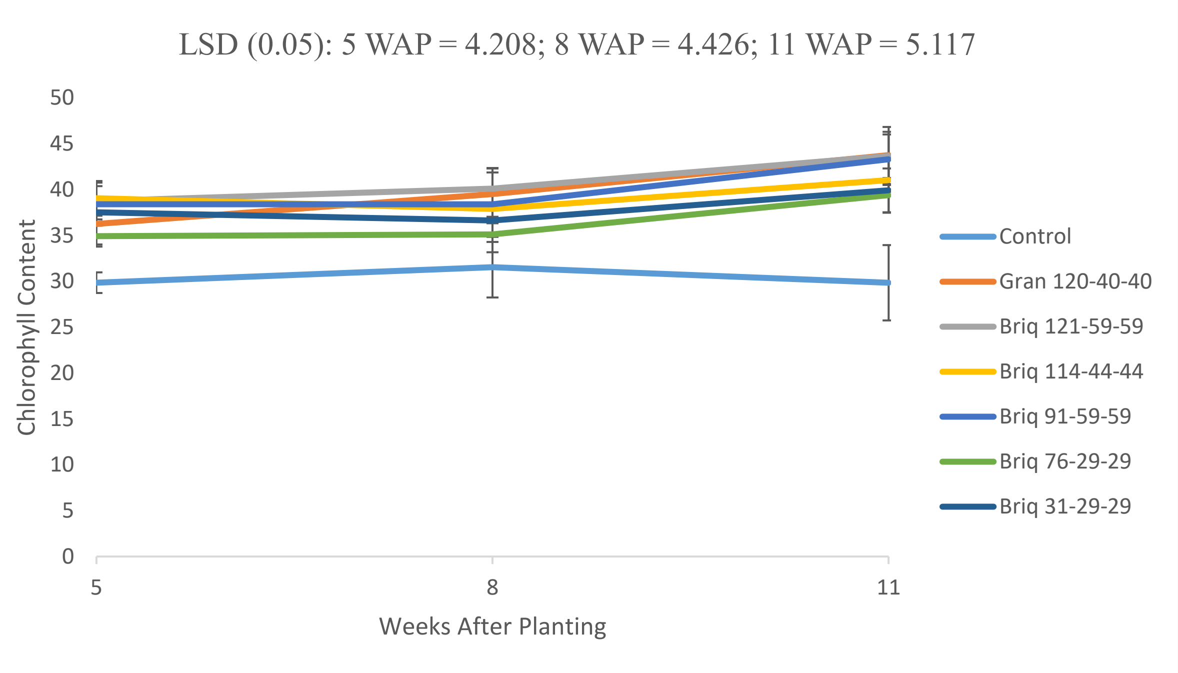

Figure 2: Effect of rate of application of briquette fertilizer on greenery of leaves from week 5 to 11 after planting. Error bars represent SEMs.

4.1.3. Leaf Area Index

The influence of the fertilizer treatments on leaf area index was not significant in both the 4th week and 6th week after planting (P>0.05). However, at 8 WAP, the differences among the treatments were significant. It was observed that the highest rate of N -P_2O_5 - K_2O contained in Briq 121-59-59 caused a higher leaf area index (Figure 3).

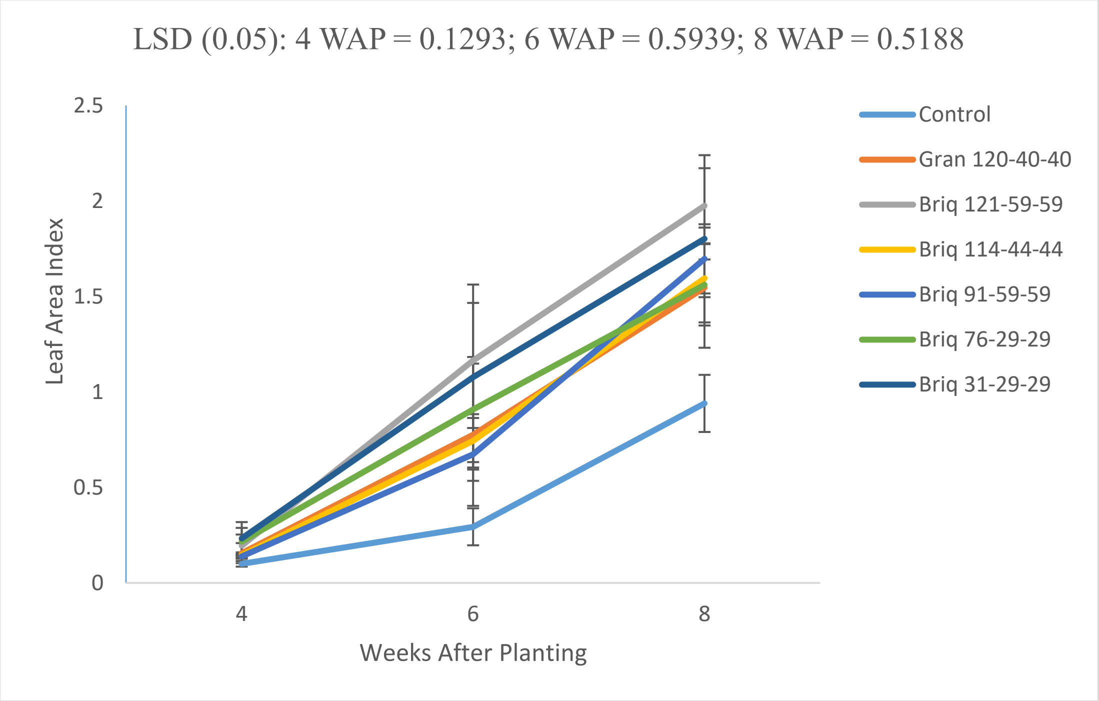

Figure 3: Effect of rate of application of briquette fertilizer on leaf area index from week 4 to 8 after planting. Error bars represent SEMs.

4.1.4. Flowering

The rate of application did not significantly affect days to 50% flowering (*P=0.864*). Although the plants subjected to the absolute control (no fertilizer) took the longest to reach 50% flowering, the difference was not statistically significant (Figure 4).

There was no significant effect of the fertilizer treatments on the number of days to 100% flowering (*P=0.194*). (Figure 5).

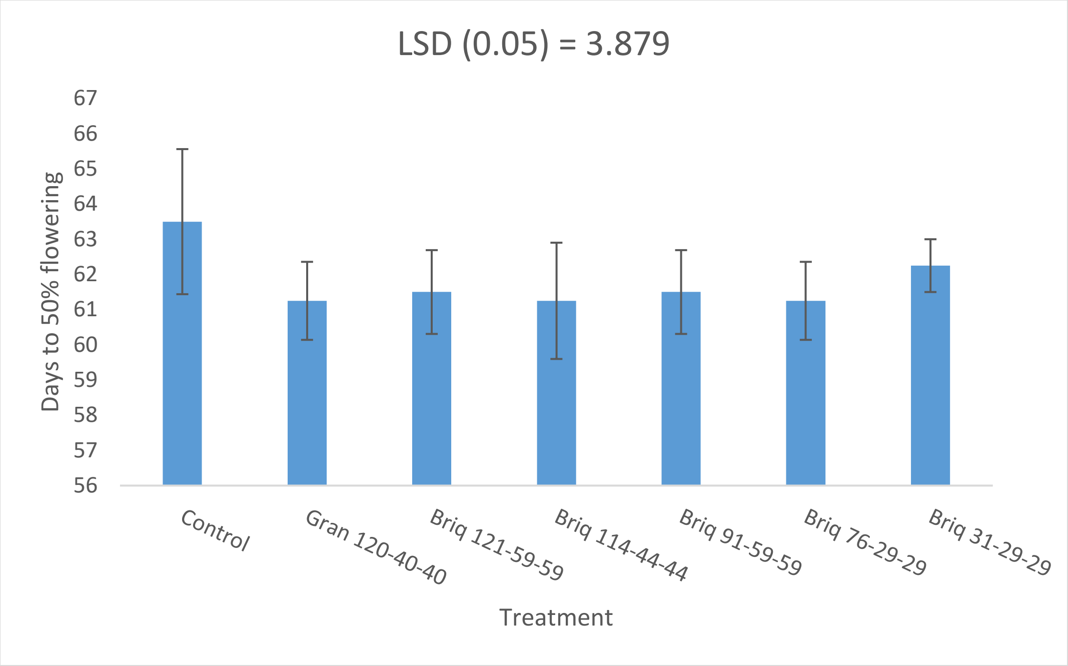

Figure 4: Effect of rate of application of briquette fertilizer on days to 50% flowering. Error bars represent SEMs.

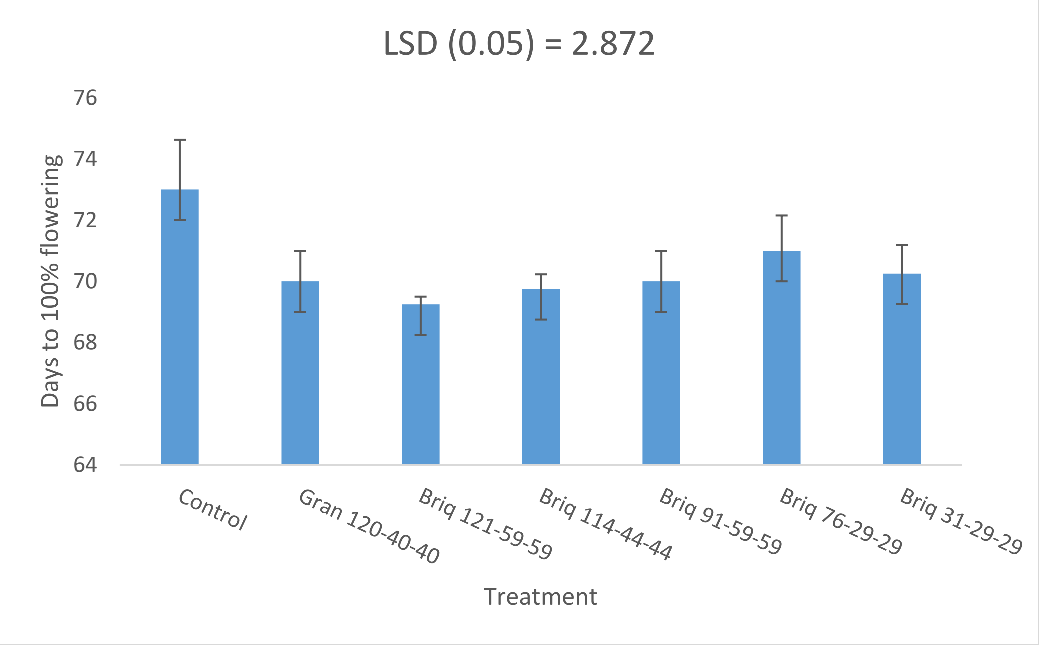

Figure 5: Effect of rate of application of briquette fertilizer on days to 100% flowering. Error bars represent SEMs.

4.1.5. Maturity

There was significant effect of the treatments (*P=0.009*) on days to 50% maturity. The plants treated with the highest rate of N -P_2O_5 - K_2O (i.e. Briq 121-44-44) used the least number of days to attain 50% physiological maturity. The other treatments were similar. However, the absolute control (no fertilizer) took the longest time to attain 50% maturity (Figure 6).

Again, the effect of rate of application on days to 100% maturity was highly significant (*P<0.001*). The plants subjected to the fertilizer treatments used significantly lesser days to reach 100% maturity when compared to the absolute control (no fertilizer) treatment (Figure 7). However, there was no significant difference between the effect of higher rate of N -P_2O_5 - K_2O and the lower rate of N -P_2O_5 - K_2O.

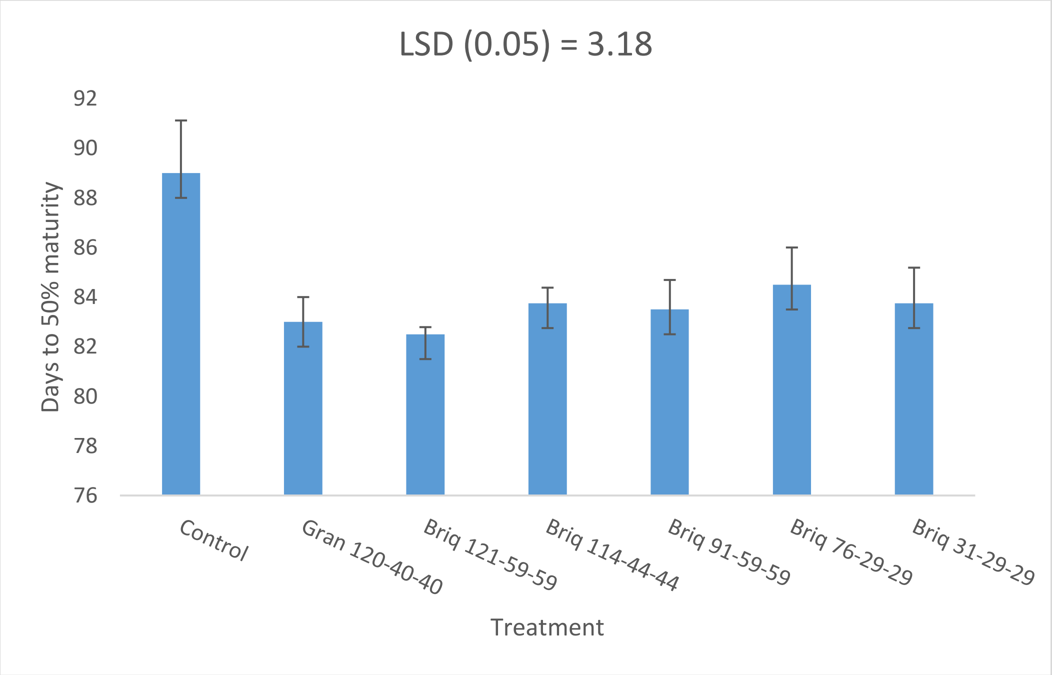

Figure 6: Effect of rate of application of briquette fertilizer on days to 50% maturity. Error bars represent SEMs.

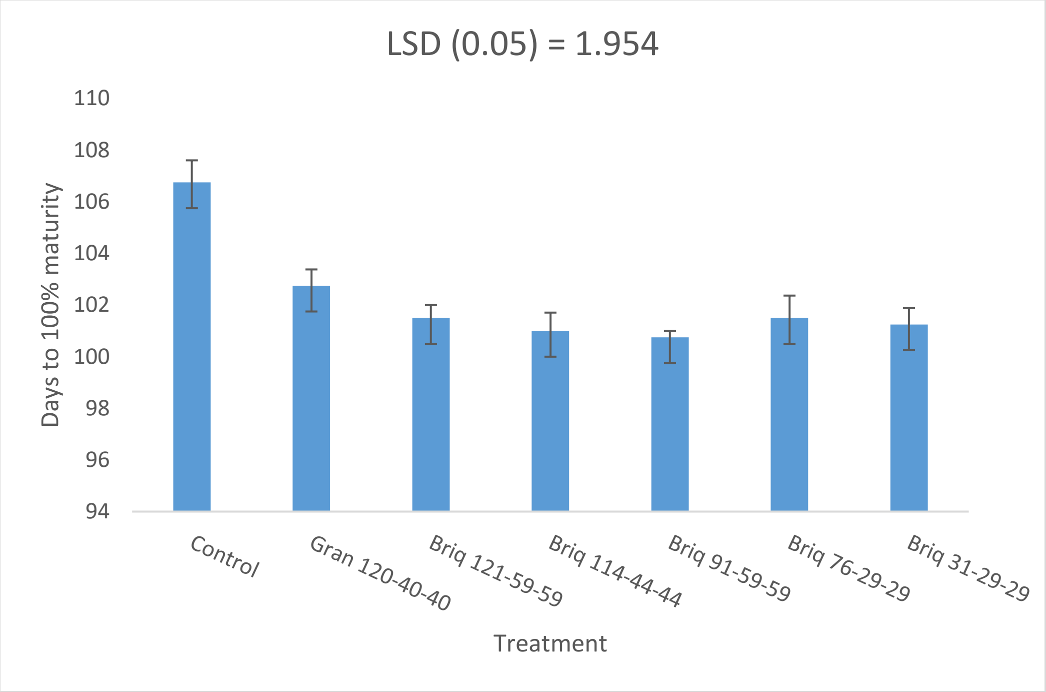

Figure 7: Effect of rate of application of briquette fertilizer on days to 100% maturity. Error bars represent SEMs.

4.1.6. Stem Girth

There was a significant effect of the briquette fertilizer rate on stem girth (*P=0.025*). The result again showed that the plants treated with Briq 121-59-59 produced greater stem girth, closely followed by the plants treated with the lowest rate (i.e. Briq 31-29-29) (Figure 8).

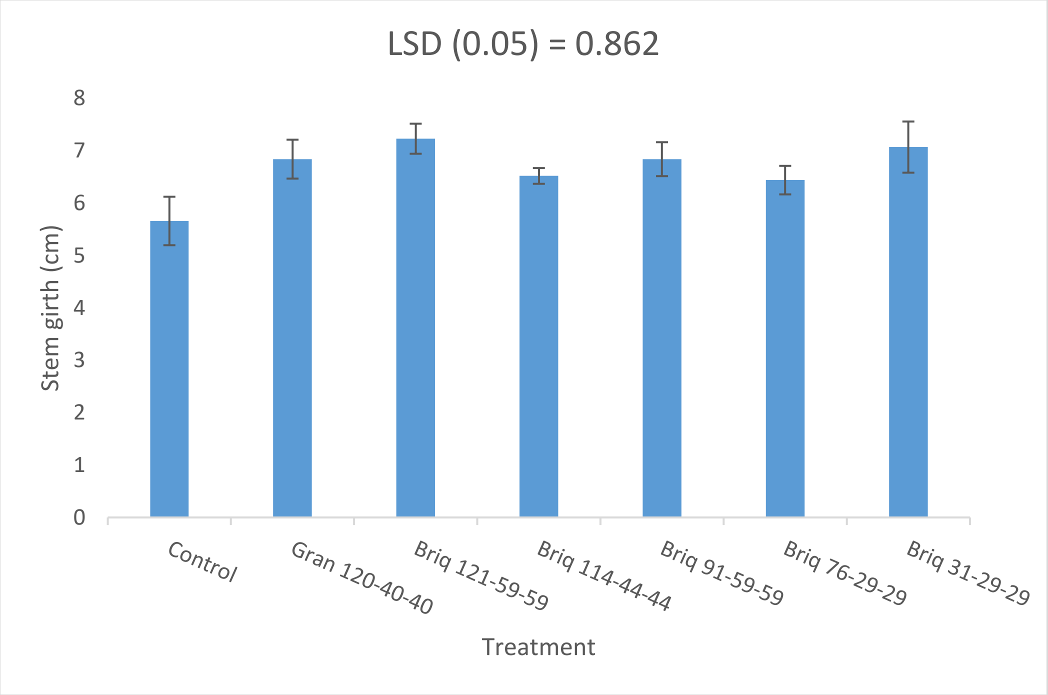

Figure 8: Effect of rate of application of briquette fertilizer on stem girth. Error bars represent SEMs.

4.1.7. Cob Length

The plants that received fertilizer treatments produced significantly longer cobs than the absolute control. However, there was no significant differences in the cob length of plants treated with the different application rates (Figure 9).

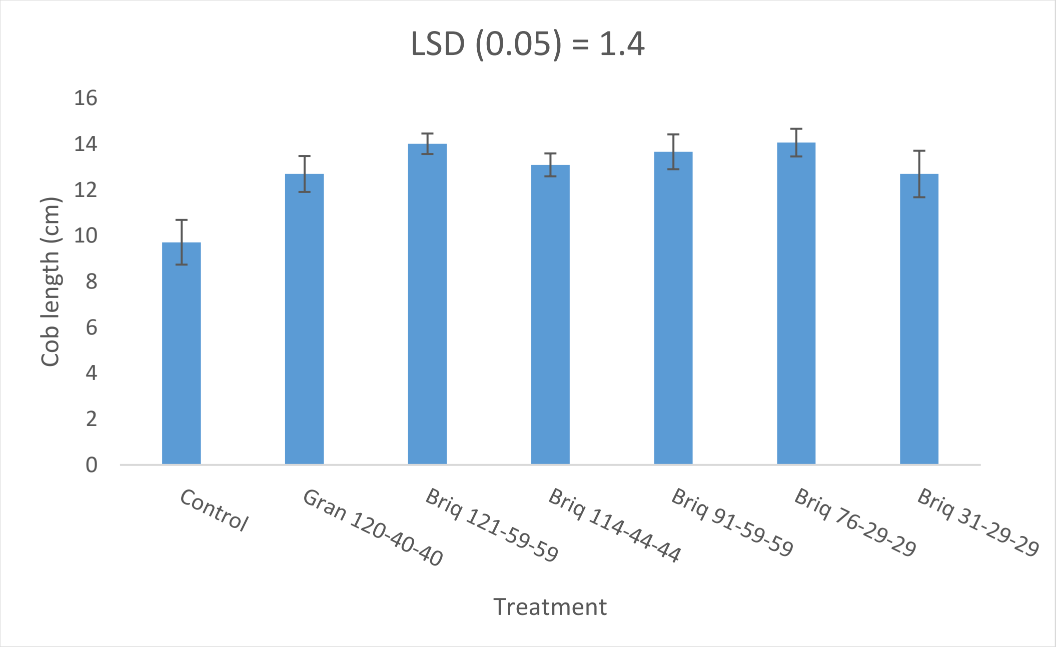

Figure 9: Effect of rate of application of briquette fertilizer on cob length. Error bars represent SEMs.

4.1.8. Biomass and Grain Yield

The influence of the briquette fertilizer treatments at different rates on biomass was highly significant (*P<0.001*). The plants that received Briq 121-59-59 produced significantly higher biomass than those that received the granular control (Gran 120-40-40) or the 31-29-29 briquette treatments (Figure 10). Plants treated with the different fertilizer rates recorded higher biomass than the absolute control (Figure 10).

There was a significant effect of the treatments (*P=0.004*) on grain yield. The plants treated with Briq 121-59-59 produced significantly higher grain yield than the those treated with the granular control (Gran120-40-40). Grain yield from the absolute control was the least, below a ton per hectare (Figure 11).

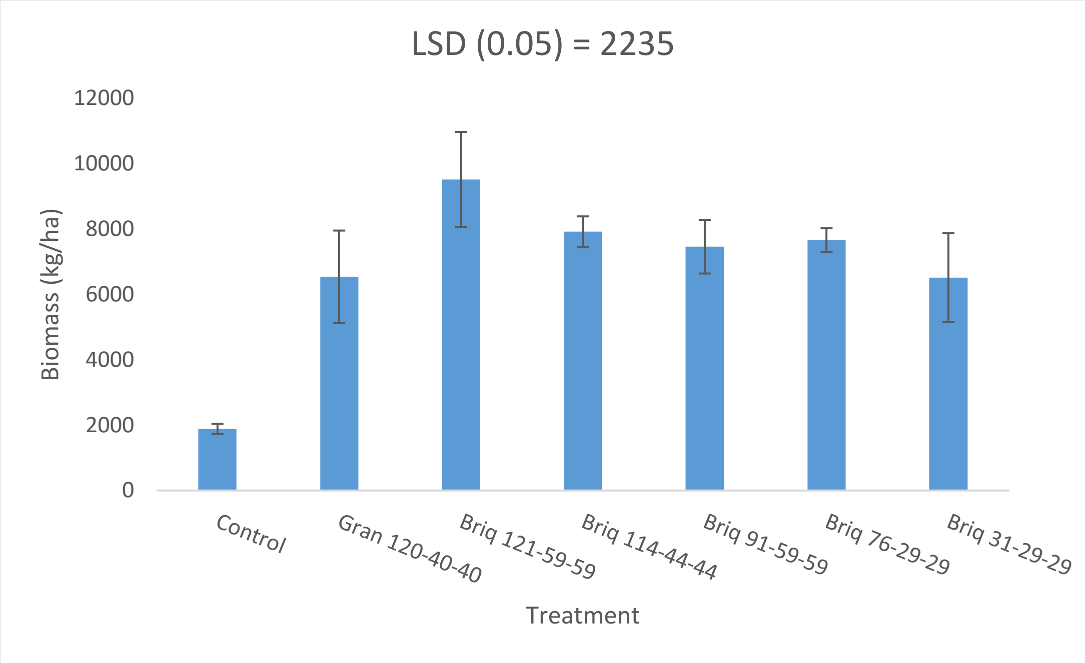

Figure 10: Effect of rate of application of briquette fertilizer on biomass. Error bars represent SEMs.

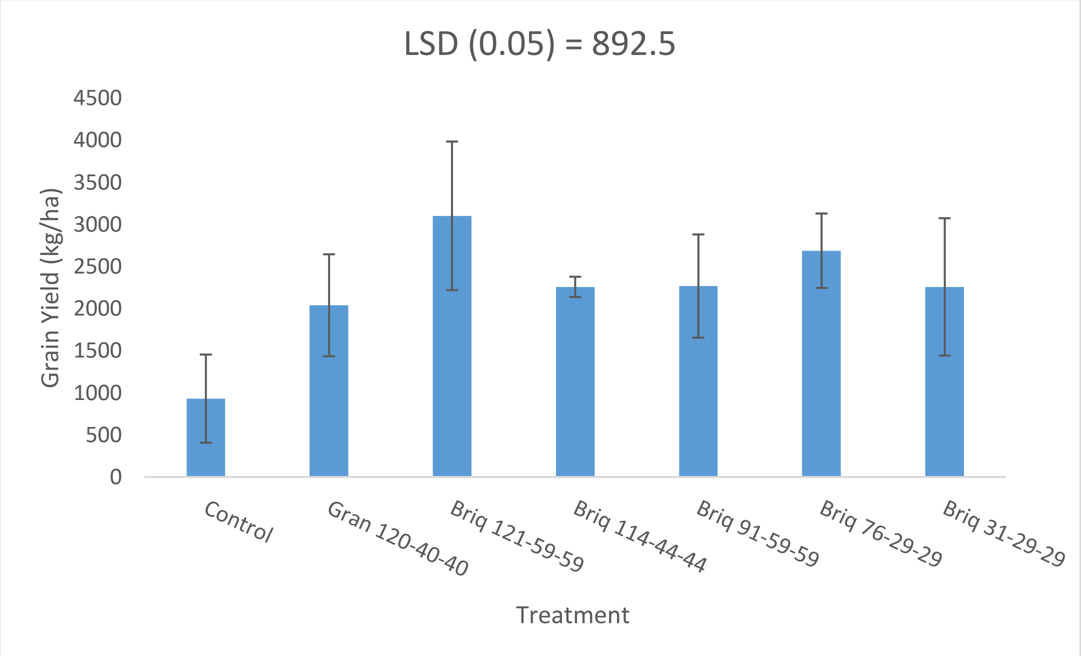

Figure 11: Effect of rate of application of briquette fertilizer on grain yield. Error bars represent SEMs.

4.1.9. 100 Grain Weight

The effect of the different briquette fertilizer rates on 100 grain weight was not significant (*P=0.324*). The plants that were treated with higher rate of N -P_2O_5 - K_2O did not show superiority in 100 grain weight, neither did the plants that received lower rate of N -P_2O_5 - K_2O show any detrimental effect (Figure 12).

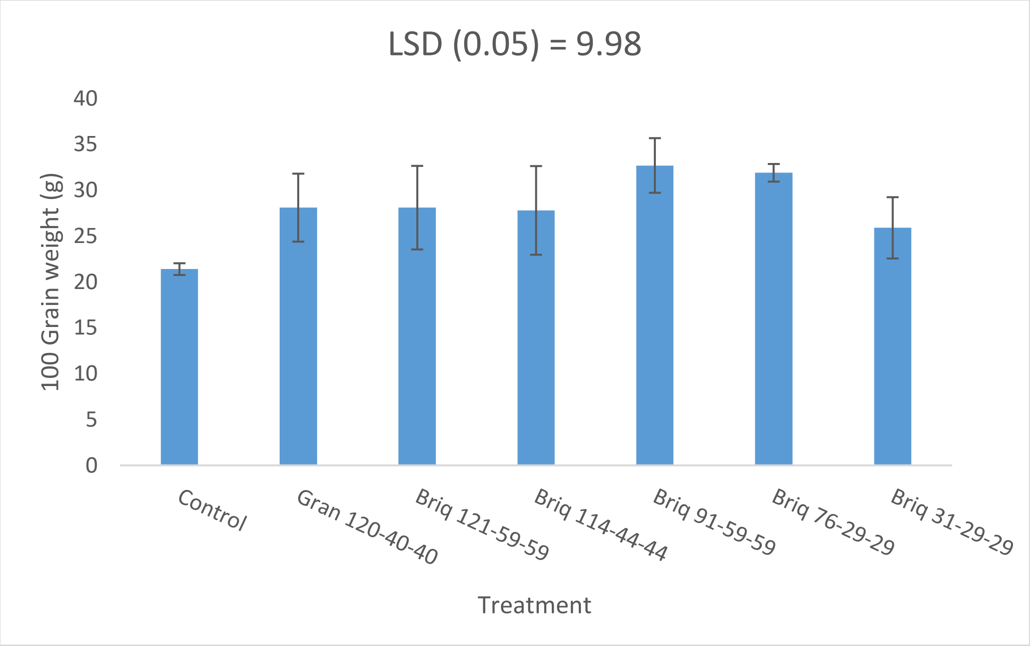

Figure 12: Effect of rate of application briquette fertilizer on 100 Grain Weight. Error bars represent SEMs.

4.1.10. Nitrogen Use Efficiency (NUE)

The Agronomic Efficiency of the applied nitrogen (AEN) was significantly different among the treatments (*P=0.005*). Interestingly, the plants treated with Briq 31-29-29, the treatment with the lowest N -P_2O_5 - K_2O rate, elicited the highest AEN, about 85% higher than values recorded by the plants that received the next best treatment, Briq 76-29-29. Plants that received briquette treatments recorded better AEN than those that received Gran 120-40-40, the granular control (Figure 13).

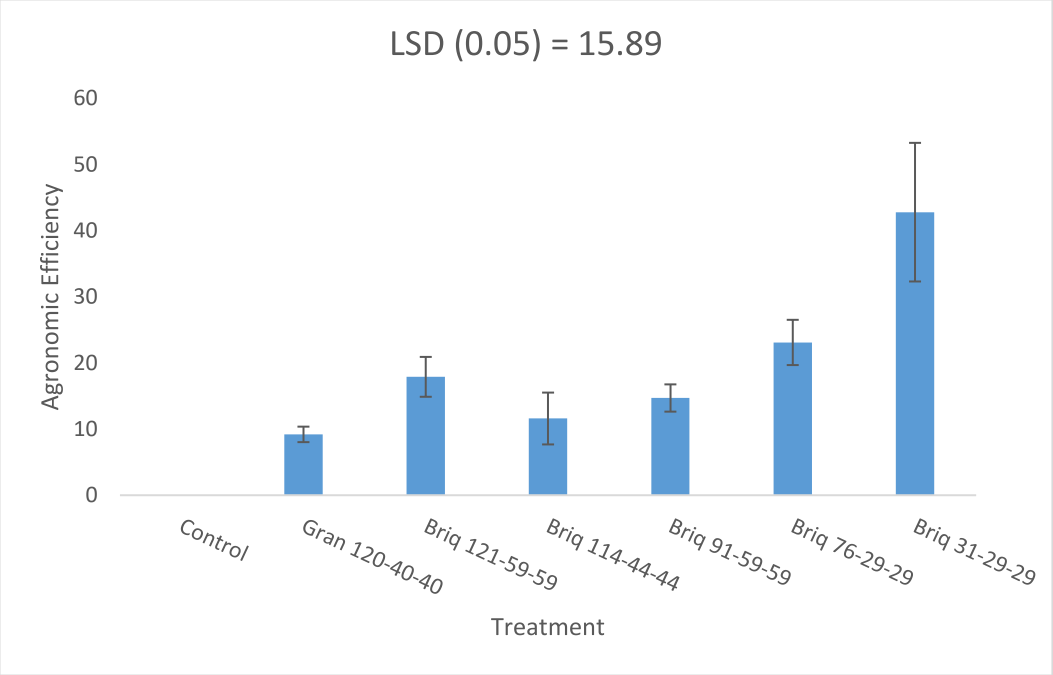

Figure 13: Effect of rate of application of briquette fertilizer on NUE. Error bars represent SEMs.

4.2. Results of Experiment 2

4.2.1. Plant height

There was no effect of briquette or granular fertilizer treatment on plant height at both 4 and 6 weeks after planting. In the 8th week after planting, the influence of the briquette and granular treatments on plant height was significant. However, no pattern emerged as to whether the briquette treatments resulted in plants performing better in plant height than similar rate of the granular treatment or the granular treatments producing higher plant height than similar rate of the briquette treatments. For example, Gran 55-48-48 treated plants performed better than Briq 53-44-44 treated plants, whilst Briq 83-44-44 treated plants outperformed Gran 86-48-48 treated plants (Figure 14). The control treatment recorded the least plant height for the entire period.

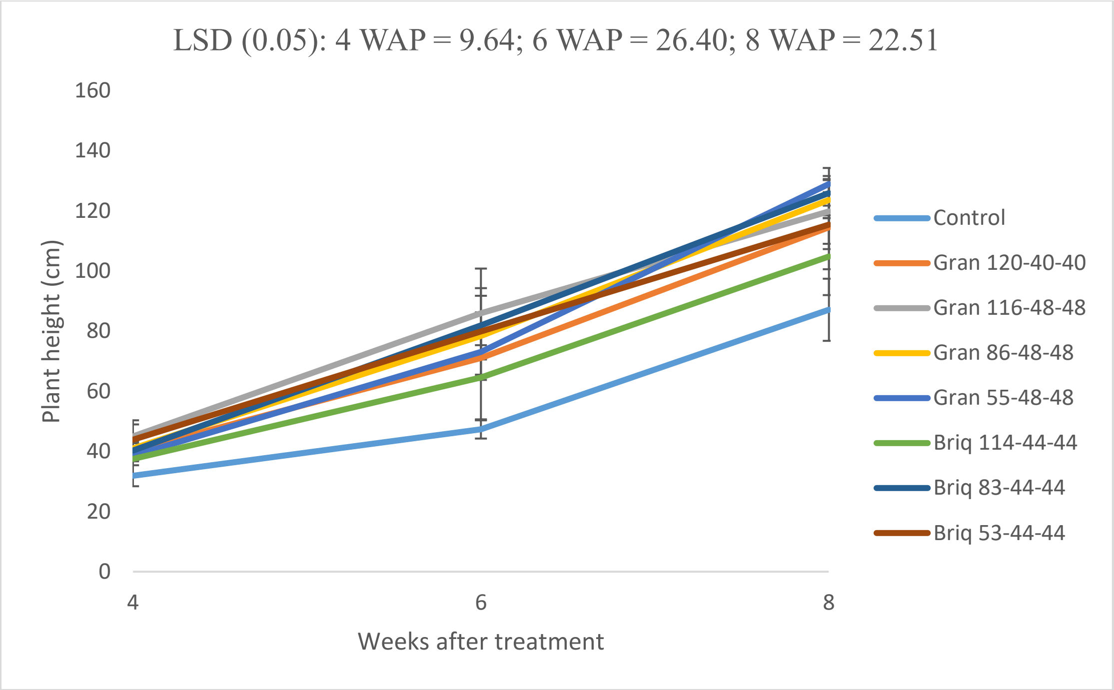

Figure 14: Effect of fertilizer formulation and their rates on plant height from week 4 to 8 after planting. Error bars represent SEMs.

4.2.2. Greenery of leaves

The briquette and granular treatments produced significant effect on the plants as far as greenery of leaves was concerned in both the 5th and 8th week after planting. Again, the effect was highly significant in the 11th week after planting (*P<0.001*). The briquette treatments however did not establish a pattern of superior performances than their granular counterparts (Figure 15). Even though Briq 83-44-44 caused plants produce greener leaves than the plants that received Gran 86-48-48, the other granular treatments resulted in plants performing better than their corresponding briquette treated plants. It was further observed that between week 8 and 11 after planting the fertilizer treated plants recorded increased SPAD values while that of the absolute control recorded reduced SPAD value (Figure 15).

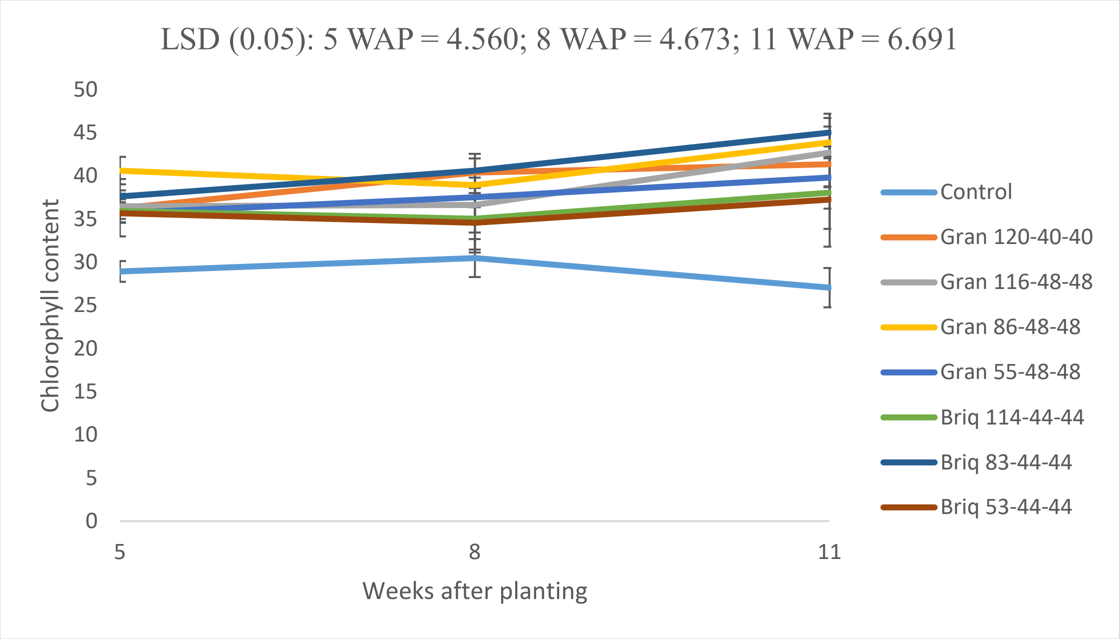

Figure 15: Effect of fertilizer formulation and their rates on greenery of leaves from week 5 to 11 after planting. Error bars represent SEMs.

4.2.3. Leaf Area Index

Apart from the 6th week after planting where the treatments resulted in plants producing similar leaf area index (*P=0.073*), there were significant differences among the treated plants in the 4th and 8th weeks after planting. Even though Gran 116-48-48 treated plants recorded superior performance in leaf area index across the entire period, there was again no clear pattern as to which formulation resulted in the plants performing better. Whereas Briq 83-44-44 and Briq 53-44-44 treated plants outperformed Gran 86-48-48 and Gran 55-48-48 treated plants respectively, Gran 116-48-48 caused plants to perform better than plants that received Briq 114-44-44 (Figure 16). The control treatment plants recorded the least leaf area index across in all the weeks.

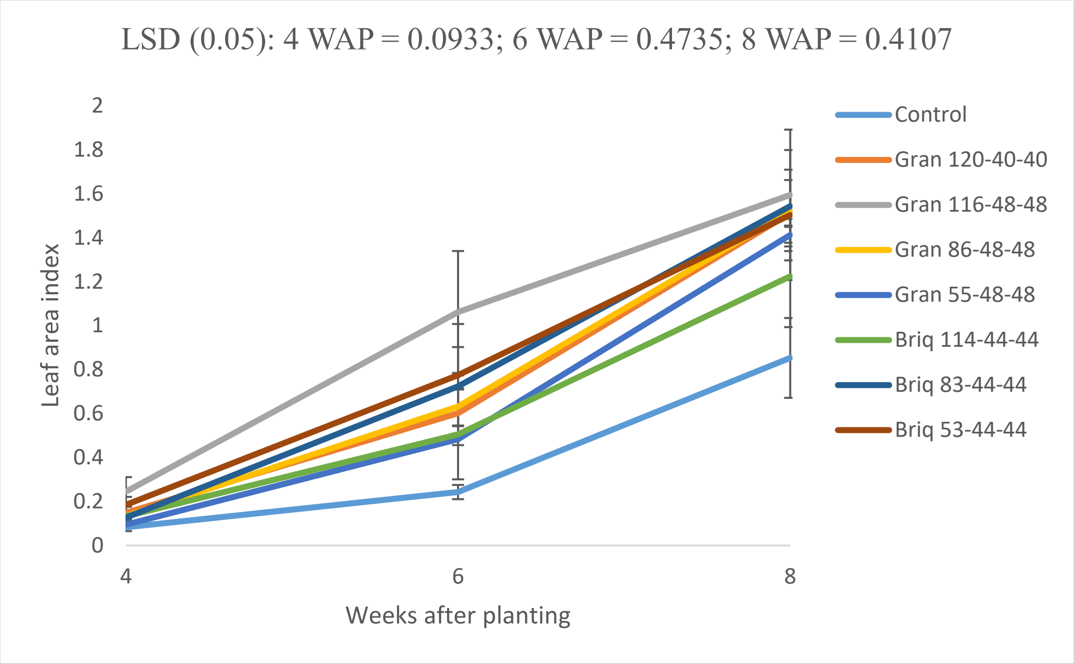

Figure 16: Effect of fertilizer formulation and their rates on leaf area index from week 4 to 8 after planting. Error bars represent SEMs.

4.2.4. Flowering

The influence of the briquette and granular fertilizer treatments on days to 50% flowering was not significant (*P>0.05*), as the plants used fairly similar days to reach 50% flowering.

The effect of the granular and briquette fertilizer treatment on the number of days it took for the plants to achieve 100% flowering was however significant (*P=0.004*). Plants the received Briq 83-44-44, Gran 86-48-48 and Gran 55-48-48 used the least number of days for all the plants to flower. The control treatment plants again used the longest days to reach 100% flowering (Figure 18).

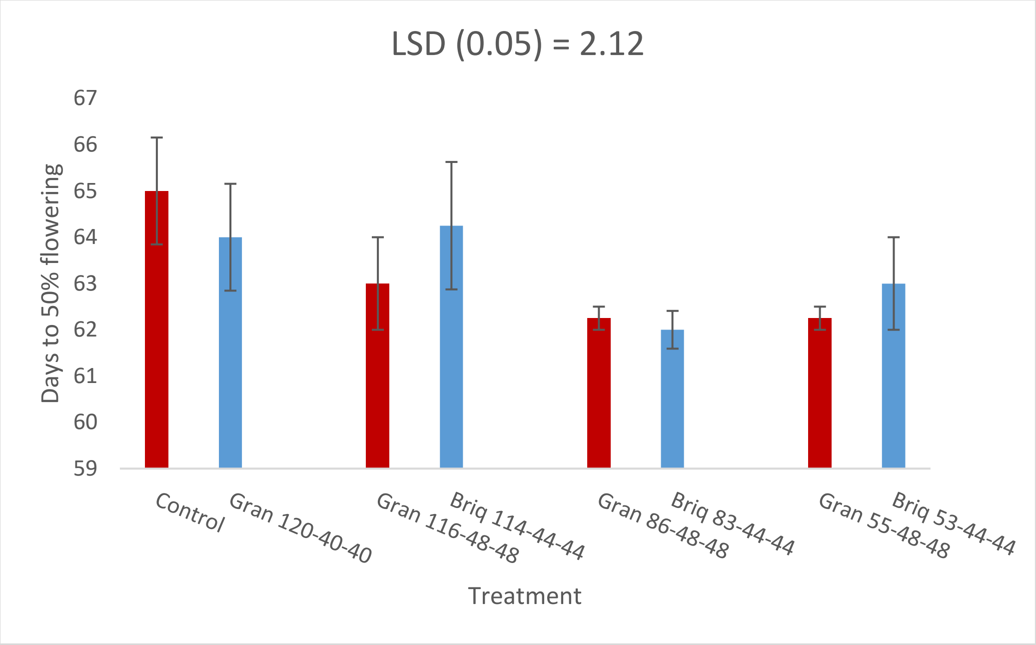

Figure 17: Effect of fertilizer formulation and their rates on days to 50% flowering. Error bars represent SEMs.

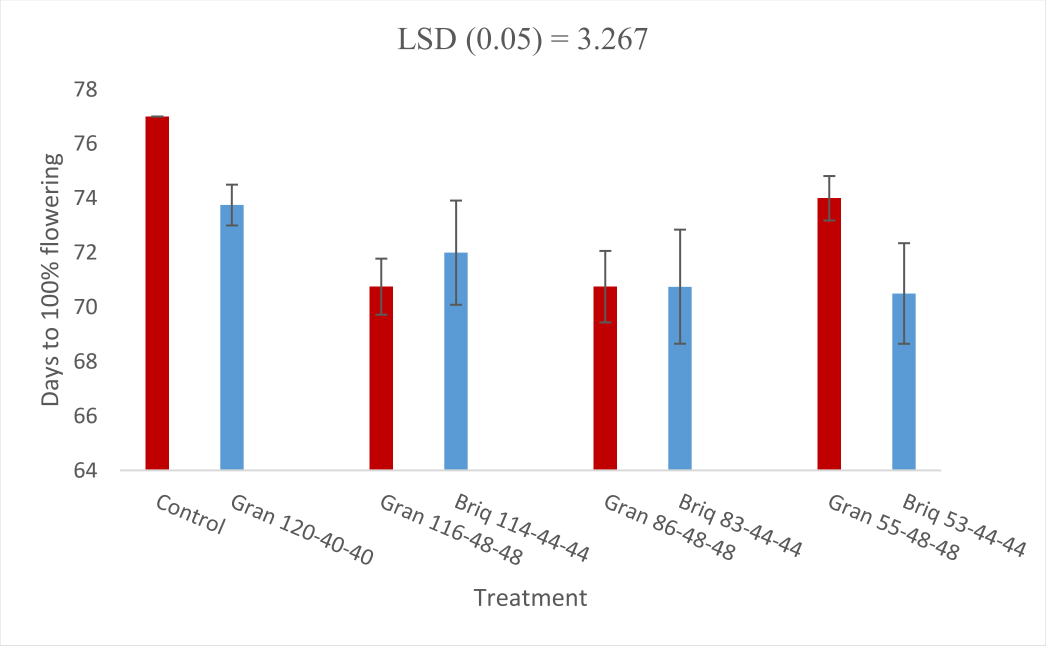

Figure 18: Effect of fertilizer formulation and their rates on days to 100% flowering. Error bars represent SEMs.

4.2.5. Maturity

The result showed highly significant differences among the treated plants concerning days to 50% maturity ($P<0.001$). The Briq 83-44-44 and Gran 116-48-48 resulted in plants using the least number of days to reach 50% maturity. All the briquette and granular treated plants used lesser number of days than the plants that received the granular control treatment (Gran 120-40-40) and the absolute control treatment (Figure 19).

Also, the influence of the briquette and granular fertilizer treatments on days to 100% maturity was highly significant ($P<0.001$). All the fertilizer treated plants used significantly less days to attain 100% maturity as compared to the absolute control (Figure 20), with Briq 53-44-44 and Briq 83-44-44 resulting in plants using the least number of days.

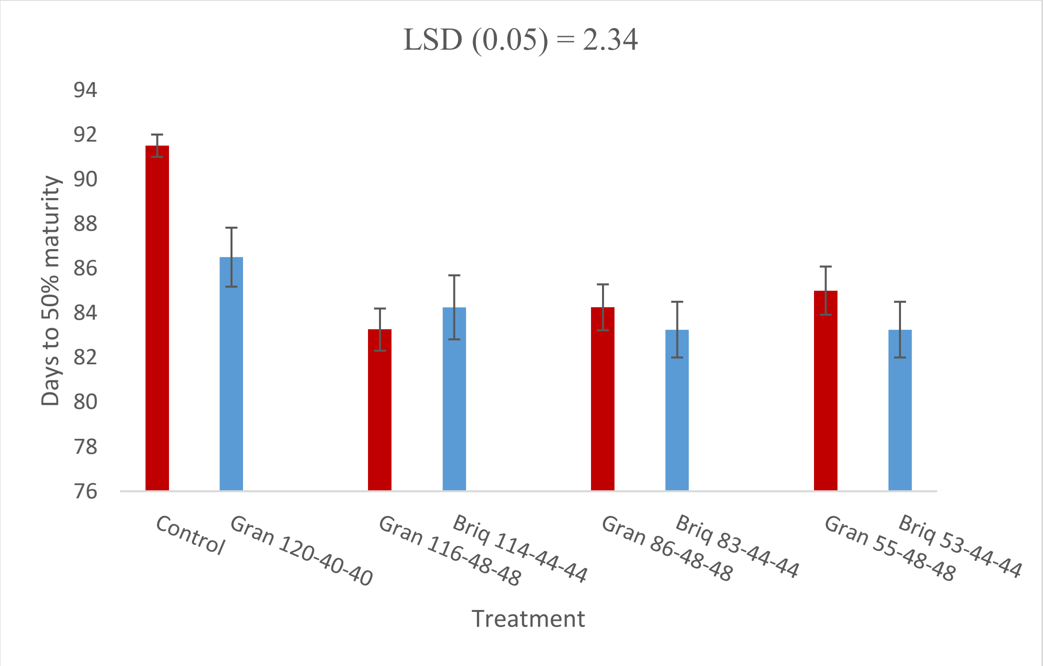

Figure 19: Effect of fertilizer formulation and their rates on days to 50% maturity. Error bars represent SEMs.

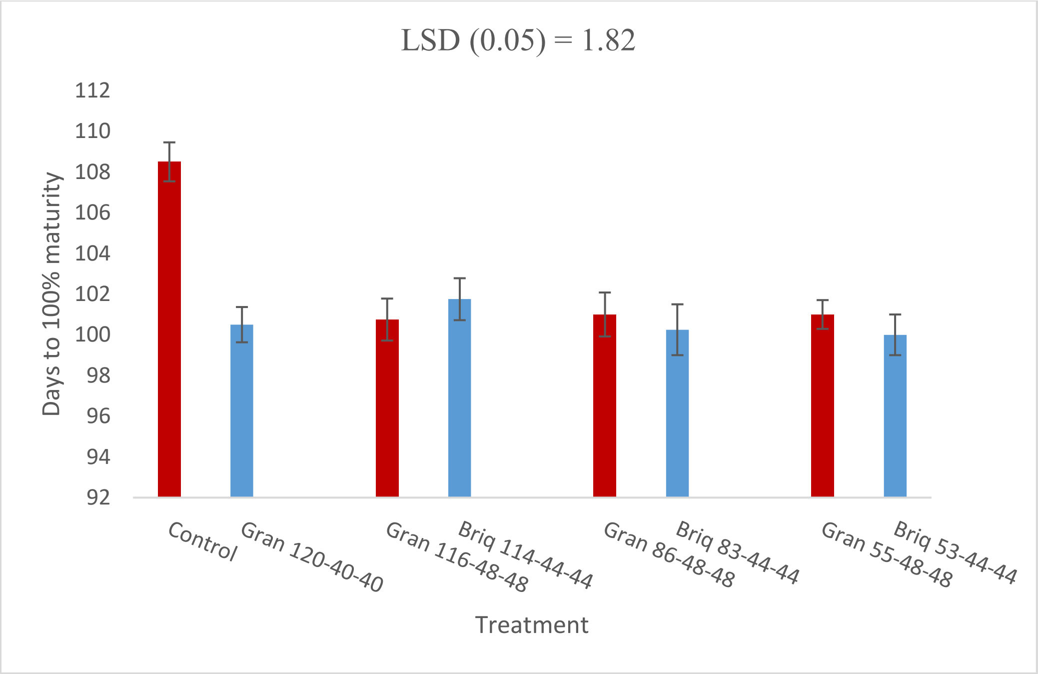

Figure 20: Effect of fertilizer formulation and their rates on days to 100% maturity. Error bars represent SEMs.

4.2.6. Stem Girth

Stem girth produced by the maize plants was significantly influenced (*P=0.006*) by the briquette and granular treatments. Even though plants that received the granular control (Gran 120-40-40) achieved the best performance in stem girth, all the fertilizer treated plants produced bigger girth than the absolute control (no fertilizer) (Figure 21).

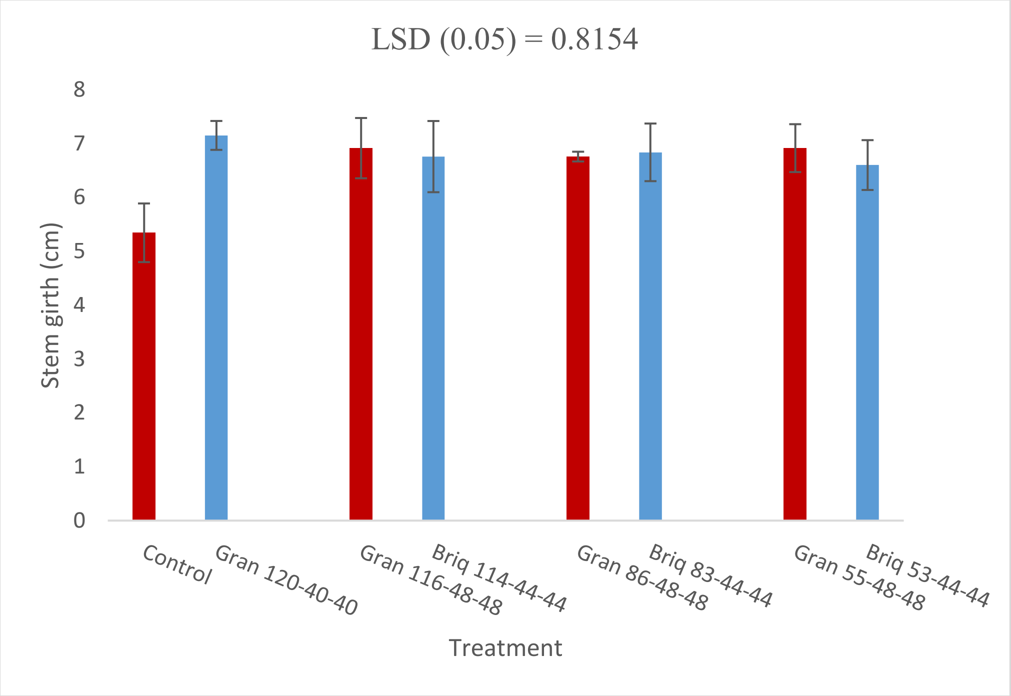

Figure 21: Effect of fertilizer formulation and their rates on stem girth. Error bars represent SEMs.

4.2.7. Cob Length

There were very significant differences among the treatments in their influence on cob length produced by plants. All the fertilizer treatments enhanced longer cob length significantly better than the absolute control (Figure 22). The granular treated plants on average gave longer cob length (13.84 cm) than the briquette treated plants (13.58 cm).

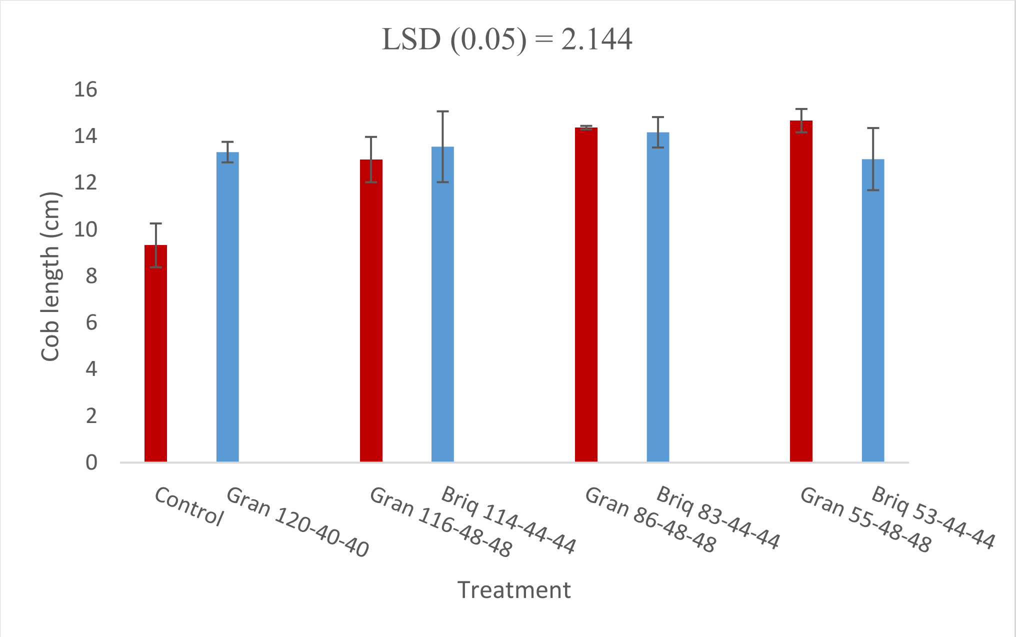

Figure 22: Effect of fertilizer formulation and their rates on cob length. Error bars represent SEMs.

4.2.8. Biomass and Grain Yield

The influence of the fertilizer treatment on plant biomass was not significantly different among the treatments (*P=0.120*), with none of the formulations showing a clear pattern of superior plant biomass production (Figure 23).

Again, the treatments did not significantly differ from each other (*P>0.05*) as far as their influence on grain yield produced by plants was concerned. However, the briquette treatments resulted in plants, on the average, producing 2071 kg/ha while the granular treated plants averagely yielded 1936.8 kg/ha. Plants that were treated with P and K at the rate of 48 kg/ha gave similar results no matter the amount of nitrogen in the granular treatments. Briq 83-44-44 again produced the best performance in grain yield, even though it was not significantly different from the other treatments (Figure 24). Grain yield of the absolute control plant was very low, about half a ton per hectare (Figure 24).

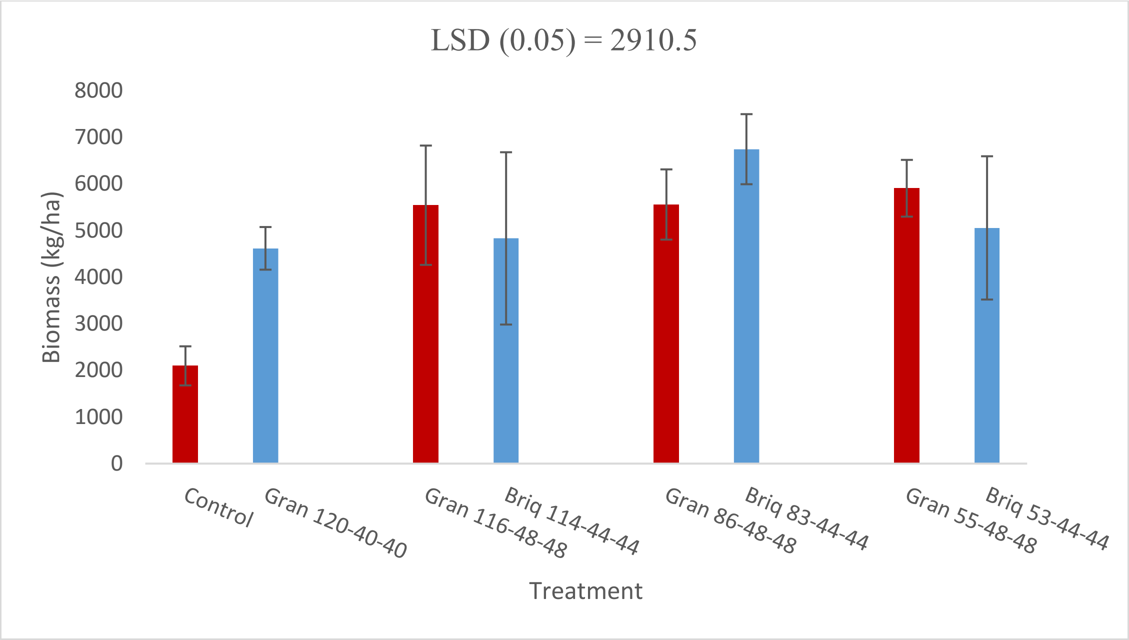

Figure 23: Effect of fertilizer formulation and their rates on biomass. Error bars represent SEMs.

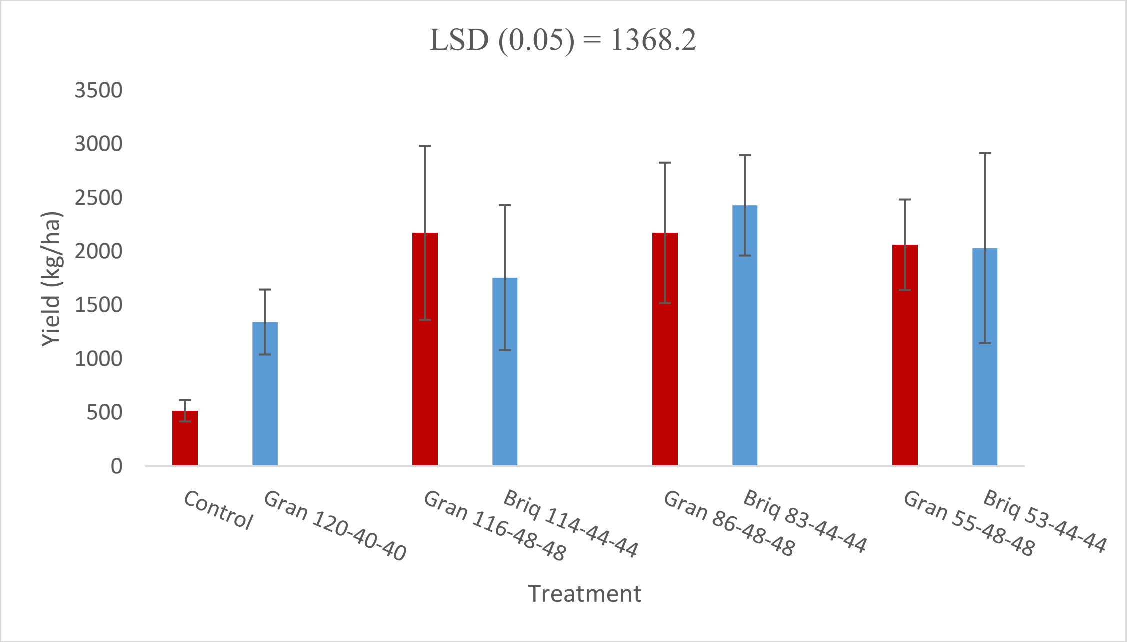

Figure 24: Effect of fertilizer formulation and their rates on grain yield. Error bars represent SEMs.

4.2.9. 100 Grain Weight

The results showed that the briquette and granular treatments were similar in their influence on 100 Grain Weight (*P>0.05*). All the fertilizer treated plants however performed better than the absolute control treated plants, though the differences were not significant (Figure 25).

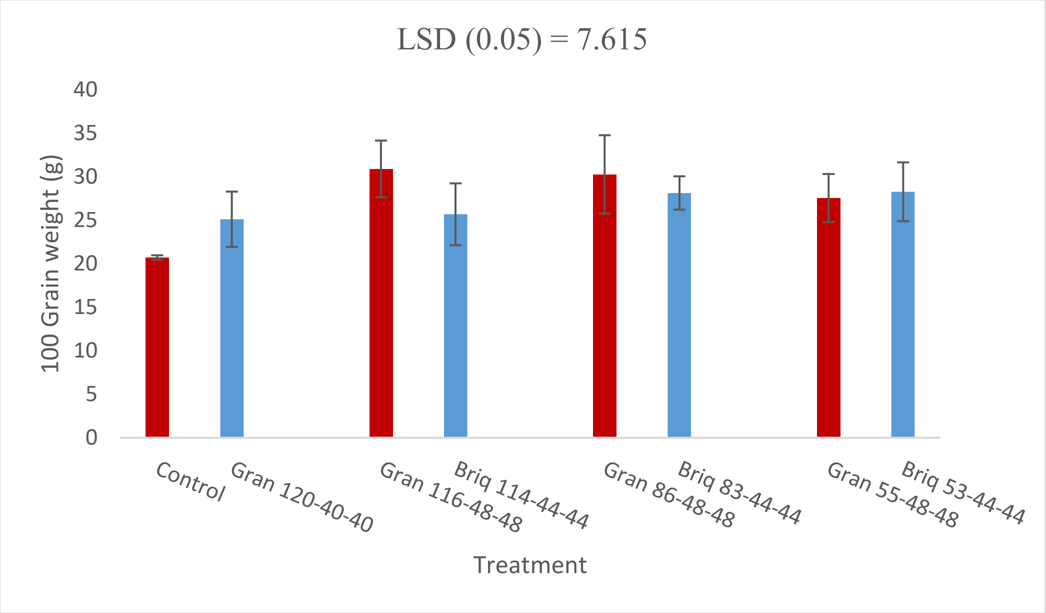

Figure 25: Effect of fertilizer formulation and their rates on 100 Grain Weight. Error bars represent SEMs.

4.2.10. Nitrogen Use Efficiency (NUE)

The effect of the briquette and granular treatments on the plants' agronomic efficiency (AEN) was significant, albeit slightly (*P=0.048*). The briquette and granular treatments that had similar rate of application resulted in plants producing similar AEN. However, for both the briquette and granular treatments, the plants treated with the lowest rate of N -P_2O_5 - K_2O (i.e. Gran 55-48-48 and Briq 53-44-44 respectively), recorded the highest AEN (Figure 26).

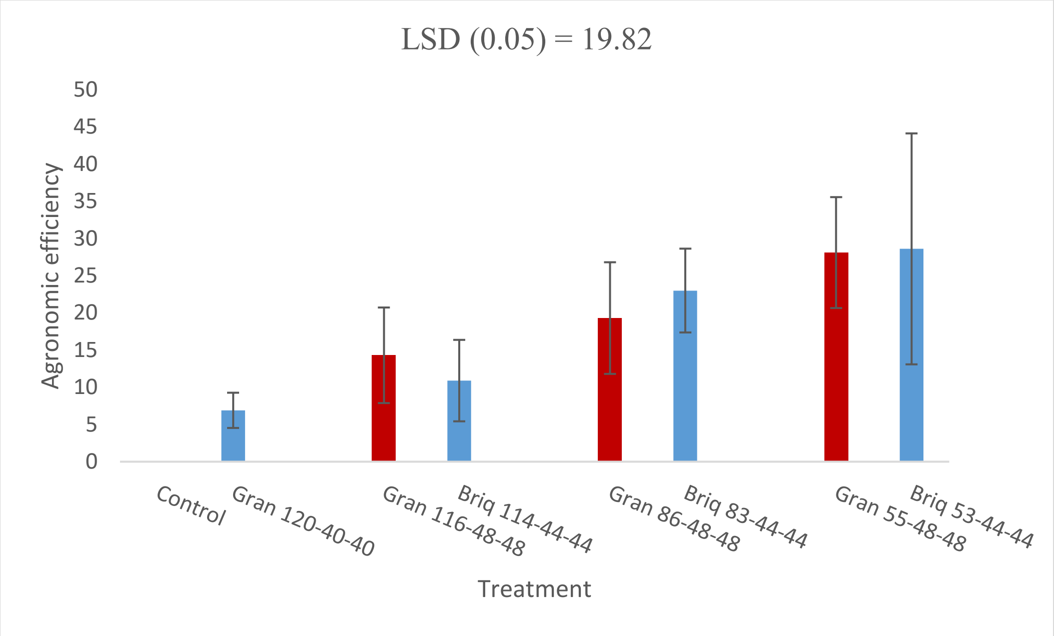

Figure 26: Effect of fertilizer formulation and their rates on NUE. Error bars represent SEMs.

CHAPTER FIVE

5.0. DISCUSSION

5.1. Discussion for Experiment One

5.1.1. Effect of different rates of application of briquette fertilizer on growth parameters of maize

The result showed a clear pattern of superior performances recorded by the treatment with the highest rate of N -P_2O_5 - K_2O, that is Briq-121-59-59, in plant height, leaf count, greenery, leaf area index and stem girth. This suggests that higher doses of N -P_2O_5 - K_2O influenced growth parameters of maize better than lower doses. This finding is corroborated by Law-ogbomo and Law-ogbomo (2009), who found that applying higher rates of NPK fertilizer produce higher plant height, stem girth, leaf count and leaf area index.

Higher application rates result in taller plants reflecting the influence of the nutrients nitrogen, phosphorus and potassium (Law-ogbomo and Law-ogbomo, 2009). Higher rate of application of briquetted NPK fertilizer produced the biggest stem girth in nominal terms, though not statistically significant. This is a clear manifestation of the retention of assimilates in large quantities in the stem which helps the production of leaves (Law-ogbomo and Law-ogbomo, 2009). Nitrogen, phosphorus and potassium are essential plant nutrients that play a critical role in accumulative growth, hence their influence on stem girth (Dada *et al.*, 2019).

In most of the weeks, plants treated with the different rates of briquettes fertilizer recorded similar LAI, except during the 8th week. Leaf area index increased with increasing fertilizer application rate, with the highest rate showing superior ground cover. The lower rates in the briquettes did not suppress growth and it will be desirable if they did not adversely affect the production of grains.

Law-ogbomo and Law-ogbomo (2009) also reported increases in leaf area index as a result of higher rate of applied fertilizer, suggesting that higher LAI associated with the fertilized plants was probably due to higher number of leaves. Berdjour *et al*. (2020) noted that higher plant nutrient supply is a pre-requisite for attaining maximum leaf area index. Kumar *et al*. (2007) also reported increases in LAI with increasing levels of NPK at all growth stages of sweet corn. Enhanced nitrogen supply plays a critical role in increased plant cell enlargement, leaf area development and photosynthetic activity (Pyne *et al*., 2022).

The treatments with higher rates of N -P_2O_5 - K_2O produced the highest green matter (chlorophyll) and this was seen in both the briquetted treatments and the granular control treatment. This is in line with what has been reported by Uysal (2018) that increased doses of nitrogen resulted in increased chlorophyll content. Nitrogen and Sulphur fertilizers are largely responsible for chlorophyll content. This is why nitrogen uptake from the soil can be estimated using the leaf chlorophyll content (Skudra and Ruza, 2017).

5.1.2. Effect of different rates of application of briquette fertilizer on earliness to flowering and maturity

The rate of application did not significantly influence both days to 50% flowering and days to 100% flowering. However, significant differences existed among the treatments regarding their influence on maturity. Briq 121-44-44 which had the highest rate of N -P_2O_5 - K_2O used the least number of days for half of the plants to reach maturity. High rate of nitrogen, phosphorus and potassium promote healthy plant growth, leading to increased photosynthesis, improved root development and enhanced nutrient uptake. This has the potential to accelerate plant growth and early maturity (Law-ogbomo and Law-ogbomo, 2009). Loha *et al.* (2023) also reported that early maturation resulted from higher doses of fertilization which stimulated growth and development.

5.1.3. Effect of different rates of application of briquette fertilizer on yield parameters of maize

The result showed significant differences among the treatments regarding their influence on cob length. A careful examination of the result however revealed that lower rate of application of briquette fertilizer does not result in a detrimental effect on cob length. This was evidenced by the fact that Briq 76-29-29, though not statistically different, produced longer cobs over Briq 121-59-59. As briquette fertilizers are designed to release their nutrients slowly over time, even lower rates can still provide an adequate amount of nutrients required for maize growth. As long as nutrient requirements of maize are met, cob length may not be significantly affected (Usman *et al.,* 2015).

Rate of application did not significantly influence 100 Grain Weight. However, the influence of rate of application on biomass and grain yield was significant. The highest biomass and grain yield were produced by the treatment with the highest rate of N -P_2O_5 - K_2O, Briq 121-59-59. This is similar to what was found by Kwadwo (2015) who reported that the highest yield of maize was obtained from the highest rate of NPK applied. This can be attributed to several factors. Higher nitrogen levels have a significant influence on chlorophyll production. Improved chlorophyll production enhances photosynthesis which leads to greater biomass accumulation, ultimately resulting in increased yield (Zhang *et al.,* 2019). Higher rates of phosphorus and potassium fertilization also has a greater impact on grain yield of maize by enhancing grain formation and kernel development (Liu *et al.,* 2021). The treatments with lower rate of application produced appreciable grain yield, hence did not show significantly detrimental effect on grain yield. Usman *et al.* (2015) pointed out that the controlled release nature of briquette fertilizer makes it capable of meeting the specific nutrient need of maize, and lower rates can therefore still result in a positive yield influence.

5.1.4. Effect of different rates of application of briquette fertilizer on Nitrogen Use Efficiency

Nitrogen Use Efficiency was assessed as the Agronomic Efficiency of Applied Nitrogen (AEN). The treatments were significantly different from one another regarding their influence on agronomic efficiency. Briq 31-29-29, which was the lowest rate, had the best agronomic efficiency, at least 85% better that the next best. Generally, the treatments with lower rate of application proved to be more superior in agronomic efficiency as compared with the treatments with higher rates of application. This was due to the fact that grain yield was not different among the briquette fertilizer rates which is utilized in AEN calculation. This is similar to what was found by Abera *et al*. (2019) that lower N application rates produced higher agronomic efficiency in maize when the differences in yield is not substantial. They also found that using half the recommended nitrogen rate significantly produced better fertilizer N use efficiency. This suggests that increasing N rate does not necessarily result in increased agronomic efficiency if increased rate will not lead to higher grain yield. In fact, increasing N rate may actually result in decreased NUE and agronomic efficiency. Nduwimana *et al*. (2020) reported that NUE decreased significantly with increasing amount of nitrogen fertilizer. The fact being that plants have a limited capacity to absorb and utilize nitrogen efficiently, therefore excessive application of nitrogen may exceed the plant's capacity to take it up leading to wastage (Cassman *et al*., 2002).

5.2. Discussion for Experiment Two

5.2.1. Effect of similar rates of briquette and granular fertilizers on growth parameters of maize

Comparing similar rates of briquette and granular fertilizers, the briquette treated plants did not show a clear pattern of superior performance than the granular treated plants in the growth parameters. Similarly, the granular treated plants did not also produce consistently better performances than the briquette treated plants. While some granular treated plants performed better in the growth parameter than similar rate of briquettes, other briquette treated plants outperformed their granular counterparts in the growth parameters. The seeming good performance of the granular fertilizers might be due to their fast release of nutrients, which may coincide with the time of need of the plants, hence having a greater impact on plant height, greenery, leaf area index and stem girth. Adu *et al.* (2014) explained that granular fertilizers often have a higher solubility rate, which means they release nutrients more rapidly when in contact with moisture. This can be beneficial when immediate nutrient availability is required, especially during critical growth stages (Adu *et al.,* 2014). The briquette treatments being the slow-release type which take a much longer time to release their nutrients, may not be readily available in the amounts that are required by plants at particular moments, especially when adverse conditions such as drought set in. Plants largely absorb nutrients in solution, drought conditions therefore reduce dissolution of fertilizer making nutrients not to be readily available for plant uptake (Yusuf *et al.,* 2018).

5.2.2. Effect of similar rates of briquette and granular fertilizers on earliness to flowering and maturity

The influence of the briquette and granular treatments on the number of days it took plants to reach 50% flowering did not significantly differ from each other. However, the differences among the treated plants were significant regarding the number of days to 100% flowering. On the average, it took the briquette treated plants less time for all the plants to flower when compared with the granular treated plants.

The briquette and granular treated plants again showed highly significant differences among each other as far as number of days to 50% maturity and days to 100% maturity was concerned. The briquette treatments resulted in plants using less days for half of the plants to reach maturity, and also for all the plants to reach maturity. The controlled-release mechanism of briquette fertilizer ensures a steady supply of nutrients to cater for the growth needs of plants. As a result, the crops receive a consistent and balanced nutrient availability, which can promote healthy growth and early maturity (Akter *et al*., 2015). Roy *et al.* (2018) further added that the tendency for briquette fertilizers to reduce nutrient loss means that they are able to provide a more consistent and sustained nutrient supply to crops, potentially leading to early maturity.

5.2.3. Effect of similar rates of briquette and granular fertilizers on yield parameters of maize

The result show that there were differences among the treatments regarding their influence on cob length produced by plants. The granular treated plants appeared to record superior performances in cob length as compared to their briquette counterparts. In nominal terms the two best performances in cob length were produced by plants treated with Gran 55-48-48 and Gran 86-48-48, though not statistically different from the briquette treatments. Singh and Singh (2015) think that granular fertilizer may have a comparative advantage over briquette fertilizer due to their ability to release their nutrients quicker, ensuring even distribution and adequate supply of nutrients which eventually lead to bigger and better cobs.

Generally, the biomass of this trial was very low. The effect of the briquette and granular treatment on biomass was not significant though Briq 83-44-44 resulted in plants producing nominally higher biomass. However, on the average the granular treated plants gave an overall better performance than the plants that received the briquette treatments. The granular fertilizers by their nature ensure an even spread of nutrients. This uniform distribution ensures nutrient availability, leading to overall plant growth and increased plant biomass (Singh and Singh, 2015).

The briquette and granular treatments were not significantly different from each other as far as their influence on both 100 grain weight and grain yield of plants was concerned. Again, Briq 83-

44-44 treated plants recorded the highest grain yield in nominal terms. However, the difference was not statistically significant when compared to the other treated plants. These results therefore do not suggest a clear superiority in yield performance by either of the formulations.

5.2.4. Effect of similar rates of briquette and granular fertilizers on Nitrogen Use Efficiency

The treatment effect on agronomic efficiency was different among the treated plants. For both formulations, the lower rates caused plants to produce superior performances in agronomic efficiency than those treated with higher rates. In general, however, the briquette treated plants recorded better agronomic efficiency as compared to their granular counterparts. That result is similar to the findings of Naznin *et al.*, (2013) who reported that deep placement of NPK briquette and Urea Super Granules (USG) gave plants higher NUE than application of granular urea. Roy *et al.*, (2018) also reported that the application of urea-organic briquette and USG saved fertilizer by reducing N losses, thereby enhancing efficient N uptake and utilization in rice field. The advantage of briquette fertilizer over granular fertilizer as regard agronomic efficiency is largely due to the slow-release mechanism of briquette fertilizer, which minimizes nutrient loss. This reduction in nutrient loss ensures a greater proportion of the applied N is effectively utilized by plants, leading to improved agronomic efficiency (Zhang *et al.*, 2019).

CHAPTER SIX

6.0. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

From the analysis and interpretation of the data from the two trials, a number of conclusions can be drawn.

- Applying lower rate of briquette fertilizer does not have any detrimental effect on the general performance of maize. Even though the highest rate resulted in plants having better performance in most growth parameters, the lower rates of application recorded better performances in other growth parameters such as stem girth, and yield parameters like cob length and 100 Grain weight, as well as NUE.
- The briquette treated plants did not show any superiority in the growth parameters such as plant height, greenery, leaf area index and stem girth when compared with similar rates of granular treatment. They did however perform better in critical parameters such as grain yield and agronomic efficiency.
- The briquette treated plants used the applied N more efficiently than similar rates of granular fertilizer. This shows that nitrogen use efficiency is influenced by how the fertilizer is formulated.
- Nitrogen use efficiency is also greatly influenced by rate of N application, with lower rates ensuring that crops utilize nitrogen more efficiently than higher rates.

6.2. Recommendations

- From the conclusions reached, it is recommended that fertilizer briquetting should be adopted as the preferred form of fertilizer formulation.

- It is also recommended that briquette fertilizer at lower N rate should be adopted in order to achieve good yield as well as efficient N utilization, thereby reducing cost.
- Benefit cost analysis should be done on briquette and granular fertilizer treatment to justify the two recommendations made.

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APPENDIX

Appendix 1: Analysis of variance for Plant Height at 4 WAP for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	946.53	315.51	6.64	
REP.*Units* stratum					
TRT	6	222.00	37.00	0.78	0.597
Residual	18	854.93	47.50		
Total	27	2023.47			

Appendix 2: Analysis of variance for Plant Height at 6 WAP for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	10320.0	3440.0	15.14	
REP.*Units* stratum					
TRT	6	3801.0	633.5	2.79	0.043
Residual	18	4088.6	227.1		
Total	27	18209.5			

Appendix 3: Analysis of variance for Plant Height at 8 WAP for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	6160.5	2053.5	8.97	
REP.*Units* stratum					
TRT	6	1911.4	318.6	1.39	0.271
Residual	18	4120.0	228.9		
Total	27	12191.9			

Appendix 4: Analysis of variance for Plant Height at 4 WAP for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	606.96	202.32	4.70	
REP.*Units* stratum					
TRT	7	463.39	66.20	1.54	0.208
Residual	21	903.11	43.01		
Total	31	1973.46			

Appendix 5: Analysis of variance for Plant Height at 6 WAP for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	3427.6	1142.5	3.54	
REP.*Units* stratum					
TRT	7	4223.9	603.4	1.87	0.126
Residual	21	6769.7	322.4		
Total	31	14421.2			

Appendix 6: Analysis of variance for Plant Height at 8 WAP for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	4223.9	1408.0	6.01	
REP.*Units* stratum					
TRT	7	5168.3	738.3	3.15	0.019
Residual	21	4919.0	234.2		
Total	31	14311.2			

Appendix 7: Analysis of variance for Greenery of leaves at 5 WAP for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	104.938	34.979	4.36	
REP.*Units* stratum					
TRT	6	251.104	41.851	5.22	0.003
Residual	18	144.446	8.025		
Total	27	500.488			

Appendix 8: Analysis of variance for Greenery of leaves at 8 WAP for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	407.958	135.986	15.32	
REP.*Units* stratum					
TRT	6	209.623	34.937	3.94	0.011
Residual	18	159.773	8.876		
Total	27	777.354			

Appendix 9: Analysis of variance for Greenery of leaves at 11 WAP for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	407.36	135.79	11.45	
REP.*Units* stratum					
TRT	6	572.10	95.35	8.04	<.001
Residual	18	213.52	11.86		
Total	27	1192.98			

Appendix 10: Analysis of variance for Greenery of leaves at 5 WAP for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	47.756	15.919	1.66	
REP.*Units* stratum					
TRT	7	297.588	42.513	4.42	0.004
Residual	21	201.931	9.616		
Total	31	547.275			

Appendix 11: Analysis of variance for Greenery of leaves at 8 WAP for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	376.05	125.35	12.41	
REP.*Units* stratum					
TRT	7	321.29	45.90	4.54	0.003
Residual	21	212.09	10.10		
Total	31	909.44			

Appendix 12: Analysis of variance for Greenery of leaves at 11 WAP for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	721.71	240.57	11.62	
REP.*Units* stratum					
TRT	7	902.22	128.89	6.23	<.001
Residual	21	434.76	20.70		
Total	31	2058.69			

Appendix 13: Analysis of variance for Leaf Area Index at 4 WAP for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.093744	0.031248	4.12	
REP.*Units* stratum					
TRT	6	0.053697	0.008949	1.18	0.360
Residual	18	0.136439	0.007580		
Total	27	0.283880			

Appendix 14: Analysis of variance for Leaf Area Index at 6 WAP for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	4.1782	1.3927	8.71	
REP.*Units* stratum					
TRT	6	1.9908	0.3318	2.08	0.107
Residual	18	2.8768	0.1598		
Total	27	9.0457			

Appendix 15: Analysis of variance for Leaf Area Index at 8 WAP for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	3.0814	1.0271	8.42	
REP.*Units* stratum					
TRT	6	2.5212	0.4202	3.44	0.019
Residual	18	2.1956	0.1220		
Total	27	7.7982			

Appendix 16: Analysis of variance for Leaf Area Index at 4 WAP for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.016818	0.005606	1.39	
REP.*Units* stratum					
TRT	7	0.074436	0.010634	2.64	0.040
Residual	21	0.084542	0.004026		
Total	31	0.175796			

Appendix 17: Analysis of variance for Leaf Area Index at 6 WAP for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.6892	0.2297	2.22	
REP.*Units* stratum					
TRT	7	1.6179	0.2311	2.23	0.073
Residual	21	2.1773	0.1037		
Total	31	4.4844			

Appendix 18: Analysis of variance for Leaf Area Index at 8 WAP for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	2.23798	0.74599	9.56	
REP.*Units* stratum					
TRT	7	1.70234	0.24319	3.12	0.020
Residual	21	1.63844	0.07802		
Total	31	5.57876			

Appendix 19: Analysis of variance for Days to 50% flowering for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	31.286	10.429	1.53	
REP.*Units* stratum					
TRT	6	16.714	2.786	0.41	0.864
Residual	18	122.714	6.817		
Total	27	170.714			

Appendix 20: Analysis of variance for Days to 100% flowering for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	18.964	6.321	1.69	
REP.*Units* stratum					
TRT	6	36.714	6.119	1.64	0.194
Residual	18	67.286	3.738		
Total	27	122.964			

Appendix 21: Analysis of variance for Days to 50% flowering for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	38.594	12.865	6.19	
REP.*Units* stratum					
TRT	7	33.219	4.746	2.28	0.068
Residual	21	43.656	2.079		
Total	31	115.469			

Appendix 22: Analysis of variance for Days to 100% flowering for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	82.375	27.458	5.56	
REP.*Units* stratum					
TRT	7	149.875	21.411	4.34	0.004
Residual	21	103.625	4.935		
Total	31	335.875			

Appendix 23: Analysis of variance for Days to 50% maturity for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	58.000	19.333	4.22	
REP.*Units* stratum					
TRT	6	113.214	18.869	4.12	0.009
Residual	18	82.500	4.583		
Total	27	253.714			

Appendix 24: Analysis of variance for Days to 100% maturity for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	5.857	1.952	1.13	
REP.*Units* stratum					
TRT	6	105.714	17.619	10.18	<.001
Residual	18	31.143	1.730		
Total	27	142.714			

Appendix 25: Analysis of variance for Days to 50% maturity for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	70.594	23.531	9.30	
REP.*Units* stratum					
TRT	7	218.469	31.210	12.33	<.001
Residual	21	53.156	2.531		
Total	31	342.219			

Appendix 26: Analysis of variance for Days to 100% maturity for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	64.094	21.365	13.95	
REP.*Units* stratum					
TRT	7	218.219	31.174	20.36	<.001
Residual	21	32.156	1.531		
Total	31	314.469			

Appendix 27: Analysis of variance for Stem Girth for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	4.4414	1.4805	4.40	
REP.*Units* stratum					
TRT	6	6.5051	1.0842	3.22	0.025
Residual	18	6.0535	0.3363		
Total	27	17.0000			

Appendix 28: Analysis of variance for Stem Girth for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	15.4213	5.1404	16.72	
REP.*Units* stratum					
TRT	7	8.6305	1.2329	4.01	0.006
Residual	21	6.4574	0.3075		
Total	31	30.5093			

Appendix 29: Analysis of variance for Cob Length for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	31.2714	10.4238	11.30	
REP.*Units* stratum					
TRT	6	53.7386	8.9564	9.71	<.001
Residual	18	16.5986	0.9221		
Total	27	101.6086			

Appendix 30: Analysis of variance for Cob Length for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	36.824	12.275	5.78	
REP.*Units* stratum					
TRT	7	78.914	11.273	5.30	0.001
Residual	21	44.631	2.125		
Total	31	160.369			

Appendix 31: Analysis of variance for Biomass for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	43421847.	14473949.	6.39	
REP.*Units* stratum					
TRT	6	136579877.	22763313.	10.06	<.001
Residual	18	40741887.	2263438.		
Total	27	220743611.			

Appendix 32: Analysis of variance for Biomass for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	29362639.	9787546.	2.50	
REP.*Units* stratum					
TRT	7	52231219.	7461603.	1.90	0.120
Residual	21	82268102.	3917529.		
Total	31	163861960.			

Appendix 33: Analysis of variance for Grain Yield for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	25560804.	8520268.	23.61	
REP.*Units* stratum					
TRT	6	10780319.	1796720.	4.98	0.004
Residual	18	6496544.	360919.		
Total	27	42837667.			

Appendix 34: Analysis of variance for Grain Yield for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	15669414.	5223138.	6.03	
REP.*Units* stratum					
TRT	7	10611238.	1515891.	1.75	0.151
Residual	21	18178785.	865656.		
Total	31	44459438.			

Appendix 35: Analysis of variance for 100 Grain Weight for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	139.89	46.63	1.03	
REP.*Units* stratum					
TRT	6	340.86	56.81	1.26	0.324
Residual	18	811.59	45.09		
Total	27	1292.33			

Appendix 36: Analysis of variance for 100 Grain Weight for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	353.71	117.90	4.40	
REP.*Units* stratum					
TRT	7	295.26	42.18	1.57	0.198
Residual	21	563.16	26.82		
Total	31	1212.13			

Appendix 37: Analysis of variance for Nitrogen Use Efficiency for Exp 1.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	150.7	50.2	0.45	
REP.*Units* stratum					
TRT	5	2986.2	597.2	5.37	0.005
Residual	15	1667.7	111.2		
Total	23	4804.6			

Appendix 38: Analysis of variance for Nitrogen Use Efficiency for Exp 2.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	2039.4	679.8	4.09	
REP.*Units* stratum					
TRT	7	2926.9	418.1	2.51	0.048
Residual	21	3494.1	166.4		
Total	31	8460.4			