AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING AND ENTREPRENEURIAL DEVELOPMENT

GROWTH AND YIELD RESPONSE OF MAIZE (*ZEA MAYS L.*) TO NPK BRIQUETTE AND GRANULE FERTILIZERS

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AKENTEN APPIAH-MENKA UNIVERISTY OF SKILLS TRAINING AND ENTREPRENEURIAL DEVELOPMENT

EFFECT OF DIFFERENT RATES OF NPK FERTILIZER (BRIQUETTE AND GRANULES) ON GROWTH AND YIELD OF MAIZE (*ZEA MAYS* L.)

BY

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MARCH, 2024

DECLARATION

Candidate's Declaration

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

Cynthia Olerckie Nongorh

Signature:……. Date:…..……

Supervisors' Declaration

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

Prof. (Mrs.) Margaret Esi Essilfie (Principal Supervisor)

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ABSTRACT

Two field experiments were conducted concurrently at Atebubu in the Atebubu Municipality in the Bono East Region and Dormaa Ahenkro in the Dormaa Municipality in the Bono Region of Ghana from April to August, 2022. The primary objective of the study was to determine the growth and yield of maize to different rates of NPK briquette and granule fertilizers. The experimental design used was a Randomized Complete Block Design (RCBD) with four replications. The treatments were; T1-No Fertilizer (Control), T2-Granule (120-40-40 kg/ha NPK), T3-Granule (116-48-46 kg/ha NPK), T4-Granule (86-48-46 kg/ha NPK), T5-Granule (55-48 46 kg/ha NPK), T6-Briquette (116-48-46 kg/ha NPK), T7-Briquette (86-48-46 kg/ha NPK) and T8-Briquette (55-48-46 kg/ha NPK). The result showed that amending soils with briquette and granule NPK fertilizers had a positive impact on the chemical properties (OM, CEC, Fe, K, Zn) of the soil at both experimental sites. The NPK fertilizer in the form of briquettes and granule did not influence percentage crop establishment, number of days to 50% tasseling and 50% silking. Maize plants that received briquette and Granule (55-48-46 kg/ha NPK) recorded significantly higher crop growth rates (CGR) than the control from 0-7 and 7-9WAP at both locations whereas maize plants that received granules and briquette (116-48-46 kg/ha NPK) and (55-48-46 kg/ha NPK) fertilizer recorded significantly higher RGR than the control at both locations. The application of granule and briquette (116-48-46 kg/ha NPK) fertilizer to maize enhanced vegetative growth parameters across both locations. Maize plant that received granule and briquette (116-48-46 kg/ha NPK) were superior in all the yield and yield component measured then the control across both locations. The grain yield ranged between 5.53 - 5.92t ha^{-1} and 5.53 to 5.52 t ha^{-1} at Atebubu and Dormaa Ahenkro respectively. It is recommended

that for optimized grain yield and heavy grains, maize farmers should apply Granule and briquette (116 - 48 - 46 kg/ha NPK). Additionally, the study should be repeated in other agro-ecological zones of Ghana to confirm the results obtained.

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DEDICATION

This work is dedicated to my beloved late mother Margaret Martey.

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LIST OF ABBREVIATIONS

kg	Kilogram
g	gram
m	meter
cm	centimetre
ha	Hectare
CM	Chicken manure
OM	Organic matter
CEC	Cation exchange capacity
t/ha	Tonne per hectare
Briq	Briquette
HSD	Honest Significant Difference
GPS	Global positioning system
CV	Coefficient of variation
NPK	Nitrogen, Phosphorus and Potassium
CEC	Cation exchange capacity
MSD	Meteorological Service Department
AOAC	Association of Official Agricultural Chemists
IITA	International institute for Tropical Agriculture
IFDC	International Fertilizer Development Centre
EDTA	Ethylenediaminetetraacetic Acid

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Maize *(Zea mays* L.) is a member of the Poaceae family and it is among the popular cereal crops with high yielding potential (Matsumoto & Yamano, 2011). Maize is primarily grown for the grain which is used for food but it is also cultivated for fodder, especially in developed countries (Murdia *et al*., 2016). Among the cereal crops, maize (*Zea mays L*.) is one of the most important cereal crops and ranked third after wheat and rice in the world (Farnia *et al*., 2015). It is a short duration crop and successively grown twice in a year as early and late crops because of its higher adaptability and hence popularly known as "Queen of Cereals". Maize grain is a major source of feed for poultry and livestock across the globe (Dei, 2017). Maize grain is nutritionally enriched, containing 72 % starch, 10 % protein, 4.8 % oil, 8.5 % fibre, 3.0 % sugar and l.7 % ash (Kaul *et al*., 2019), with the endosperm containing approximately 80 % carbohydrates, 20 % fat and 25 % minerals; whiles the embryo contains about 80 % fat, 75 % minerals and 20 % protein found in the kernel (Galani *et al*., 2022).

Maize is the largest staple crop in Ghana and contributes significantly to consumer diets (Adjei-Nsiah & Kermah, 2012). It is the number one crop in terms of area planted and accounts for 50-60% of total cereal production (Adjei-Nsiah & Kermah, 2012). Additionally, maize represents the second largest commodity crop in the country after cocoa and it is one of the most important crops for Ghana's agricultural sector and for food security. Utilization of maize varies among people in different parts of the world and it is

consumed indirectly as secondary produce, mainly in meat, eggs and dairy products in developed countries (Gellings & Parmenter, 2016). In developing countries, maize is consumed directly and serves as staple diet for over 200 million people (Haque *et al*., 2020). Maize in a processed form is found as fuel (ethanol) and starch. The bulk of maize produced goes into food consumption and it is certainly the most important crop for food security Hellin *et al*., (2011). The maize sub-sector in Ghana has witnessed the implementation of many projects and research activities aimed at improving maize production and productivity. Notable among them are the Ghana Grains Development Project (GGDP) and the Sasakawa Global 2000 maize improvement programme (Akumbole *et al*., 2019). Successful maize production depends on correct application of production inputs that will sustain the environment as well as agricultural production. Keen among these inputs is fertilization.

Maize is a heavy feeder, particularly of nitrogen, phosphorus, and potassium; and requires adequate and balanced supply of these nutrients to attain optimum yield (Mukherjee, 2013). The assimilation of nitrogen, phosphorus and potassium reaches its peak during flowering. At maturity, the total nutrient uptake of a single maize plant is approximately 8.7 g of nitrogen, 5.1 g of phosphorus and 4.0 g of potassium (Ciampitti & Vyn, 2012). Each tonne of grain produced removes 15.0 to 18.0 kg of nitrogen, 2.5 to 3.0 kg of phosphorus and 3.0 to 4.0 kg of potassium from the soil (Shehu *et al*., 2019). Around 40 % of Africa's maize-growing area faces occasional drought stress in which yield losses are 10–25 % (Fisher *et al*., 2015). Again, 25 % of the maize crop suffers frequent drought, with losses of up to half the harvest. To reduce vulnerability and improve food security, the Drought Resistant Maize

for Africa (DRMA) project has released of 160 drought resistant (DR) maize varieties, between 2007 and 2013 (Makate *et al*., 2017). The DR maize varieties have been bred using modern conventional methods, without genetic modification. In addition to drought tolerance, the varieties have other attractive traits, such as resistance to major diseases and high protein content (Makate *et al*., 2017). The DR maize varieties have similar labour requirements and seed costs as non-DR commercial varieties. Importantly, some of the DR maize varieties are also nitrogen use efficient. Although the switch from local to improved maize can be a catalyst for increasing farmers' use of other inputs, especially fertilizer (Achieng *et al*., 2010).

1.2 Problem Statement and Justification

Food security is an urgent global issue as the world population is expected to grow by over 2.3 billion between 2009 and 2050 (Hellin *et al*., 2012). Nearly all of this growth is forecast to take place in the developing countries, including sub-Saharan Africa (Fosu, 2015). The need to produce more food and fibre to feed a growing population is challenged with a lot of factors. Eighty percent (80%) of the growth in crop production in developing countries is expected to come from higher yields and increased cropping intensity, with the remainder coming from land expansion (Martins *et al*., 2013). The impact of continuous cultivation has contributed adversely to the rapid depletion and imbalances of soil plant nutrients (Aliyu *et al*., 2021).

Several decades of nutrient depletion has transformed the originally fertile arable lands that yielded 2 to 4 t/ha of cereal grain, into infertile ones where cereal crops yields of less than

1 t/ha are common (Zingore, 2016). Low soil fertility has been identified as one of the major biophysical constraints adversely affecting maize production in the tropics (Bationo *et al*., 2018). In order to meet the demands of food grain production for an ever-increasing population, improving and maintaining soil fertility have become important in developing countries. Good soil fertility management ensures adequate nutrient availability to crops and increased yields (Johnston & Poulton, 2018). However, it is impossible to guarantee sustainable crop yields without the application of fertilizers. Agriculture in Ghana is largely a rural based economic activity and mainly undertaken by smallholder farmers deploying rudimentary technologies and tools in managing and operating largely subsistence cropping to produce about 80% of the country's agriculture products (Boon & Anuga, 2020; Botchway *et al*., 2016). According to Abdul-Rahman *et al*. (2019) though there is increase in the production of fertilizer in Ghana, crop production and yield is still not high. The use of chemical fertilizer, plays an important role for the maintenance of physico-chemical properties and fertility of the soil (Abdul-Rahman *et al*., 2019).

According to Goswami *et al*. (2019), soil fertility decline has been recognized as one of the major biophysical constraints affecting arable crop production, particularly nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and sodium (Na) deficiencies. Majority of the farmers in Ghana who use fertilizer in cultivating maize often resort to using granule fertilizer which is mostly available. Though there are good reasons to use granular fertilizer, there are some disadvantages in using it because granular fertilizer requires water to get into the soil, there's a possibility the nutrients won't make it to the soil if there's not enough rainfall whereas in cases where there's excess rainfall nutrients are leached away and plants

not able to utilize them. This can lead to those valuable nutrients sitting near the soil's surface and not doing their job effectively. Applying a granular fertilizer evenly is difficult for a few reasons. First, you may need to calibrate and spread or broadcast all over the field or measure and place at a distance from the plant to avoid burning. It is sometimes difficult to see where you've already fertilized, especially in thick grass. Spreading granular fertilizer requires a lot of work, not only do you have to dump that heavy bag into the spreader, but you must also walk your entire field in a precise pattern, then water the fertilizer into the soil and or wait for rainfall. Previous studies have shown that subsurface incorporation and deep placement of multi-nutrient fertilizer briquettes (produced by physical compaction of granular fertilizer); and organically enhanced N fertilizer (OENF) (manufactured from organic additives extracted from sterilized bio-solids plus ammonium sulphate) significantly increased maize yields and nutrient use efficiency, compared with split application of granular fertilizer (Wang *et al*., 2020).

The study also shows that protein, oil, ash, and starch contents of maize grain were not compromised, but increases in grain fiber content was observed following the application of briquettes and OENF. This work adds to the proven benefits of briquetting granular fertilizers into super granules for deep placement into the root zone of the crop, and also incorporating organic sources into the commercially-available inorganic fertilizers. This and other research demonstrate the feasibility of NPK briquettes to reduce N pollution while enhancing crop yields. Additionally, OENF, an innovative N fertilizer source, presents another climate-friendly fertilizer management practice. OENF has environmental benefits, as a product of recycling municipal and domestic waste, that have the potential to reduce

nitrogen losses thereby lowering N consumption and mitigating negative impacts on water and air compared with commonly used N fertilizers. The projected trend in population growth will mean that, market demand for food would continue to grow. Demand for cereals as human food and animal feed, is projected to reach over 3 billion tonnes by 2050 (Islam & Karim, 2019). This implies significant increase in the production of several key commodities. Annual cereal production, for instance, would have to grow by almost one billion tonnes, 72 % of which is expected to come from developing countries, up from the 58% today (Islam & Karim, 2019). The low fertility status of most tropical soils hindered maize production because maize has a strong exhausting effect on the soil. According to Xiong & Zhao, (2024), maize fails to produce good grain in the absence of adequate nutrients. Inorganic fertilizers exert strong influence on plant growth, development and yield. The availability of sufficient growth nutrients from inorganic fertilizers lead to improved cell activities, enhanced cell multiplication and enhancement of growth (Emmanuel *et al*., 2016).

Growth enhancement resulting from fertilizer application leads to larger dry matter production owing to better utilization of solar radiation and more nutrient (Ullah *et al*., 2019). With the introduction of new and high yielding crop varieties, soil nutrient leaching will be on the increase when mineral fertilizer additions are absent or not in adequate amounts. Around 40 % of Africa's maize-growing area faces occasional drought stress in which yield losses are 10-25 % (Fisher *et al*., 2015). Nutrient losses through surface runoff and leaching from agricultural lands could have effects on the growth and yield of cultivated crops. Massive losses affect farmers profit since farmers spend high amount of money in

the purchasing of fertilizers. Nutrient management strategies that synchronize nutrient uptake with availability will increase nutrient recovery efficiency and minimize nutrient losses to the environment. For environmental sustainability, the one-time application of multi-nutrient fertilizer briquettes could be an ideal fertilizer management strategy for maize production in Ghana. In addition to the environmental benefit of decreased nutrient leaching, one-time application of multi-nutrient fertilizer briquettes could provide significant agronomic benefits of increased yields from increased nutrient retention in the soil and improved nutrient utilization by the maize plants. Again, the declining maize yields in Ghana, calls for effective nutrient management strategies that increase maize productivity and profitability among smallholder farmers.

A study by Adu-Gyamfi *et al*. (2019) revealed that, the one-time application of multi-nutrient fertilizer briquettes increased maize grain yields. Burke *et al*. (2017), noted that, for most crops, the best fertilizer type, rate and time of application are not known and that this constitutes a constraint to the use of mineral fertilizer. The authors also noted that mineral fertilizers are not used because of their high cost, suggesting that mineral fertilizers should be included in fertilizer trials as these may be more acceptable to producers. There is the need for the cultivation of maize with increased growth, yield, and grain quality and thus, this study seeks to compare the response of maize to different rates of inorganic fertilizers application in the form of both NPK fertilizer Briquette and organically enhanced N fertilizer in the form of granules.

1.3 Objectives of the Study

The main objective of the study was to determine the growth and yield performance of maize to different application rates of briquette and granule NPK fertilizers.

The specific objectives of this study were to;

1. Determine the effect of granular and briquette NPK fertilizers on physical and chemical properties of soil.
2. Evaluate the effect of different rates of NPK fertilizers (Briquette and Granular) on the growth and yield response of maize.

1.4 Research Hypothesis

H_a: N.P.K fertilizer in the form of granule and briquette application has a significant effect on the growth and yield of drought resistant maize.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and Distribution

There are numerous theories from the ancestors of modem maize. According to them, it is widely accepted that maize was domesticated from its ancestor teosinte *(Zea mexicana)*, though several authors have diverse opinions as to whether it is actually so (Gaudin *et al*., 2011). Evidence suggests that cultivated maize arose through natural crossings, perhaps first with Gama grass to yield teosinte and then possibly with backcrossing of teosinte to primitive maize to produce modem races (Gaudin *et al.*, 2011). Maize is perhaps the most completely domesticated of all field crops. Its perpetuation for centuries has depended wholly on the care of man. It could not have existed as a wild plant in its present form. Although maize is indigenous to the western hemisphere, its exact place of origin is far less certain (Nagoshi *et al*., 2018).

Archeological evidence of com's early presence in the western hemisphere was identified from com pollen grain considered to be 80,000 years old obtained from drill cores 61metres below Mexico City (Wu *et al*., 2014a). Another archeological study of the bat caves in New Mexico revealed com cobs that were 5,600 years old by radiocarbon determination. Most historians believe maize was domesticated in the Tehuacan Valley of Mexico. The original wild form has long been extinct (Wilkes, 2014; Buckler & Stevens, 2006). Maize plant is often 2.5 m in height, though some natural strains can grow 12 m. The stem is commonly composed of 20 internodes which are 18 cm in length (Jaramillo *et al*., 2013). A leaf grows

from each node, which is generally 9 cm in width and 120 cm in length (Raza *et al*., 2019). Maize can form 8-20 leaves which are usually arranged spirally on the stem in two opposite rows. Its leaf is typical of the grasses, consisting of a sheath, ligules, auricles and a blade. The leaf blade is distinctively conspicuous, long, narrow, undulating and tapers towards the tip and is glabrous to hairy (Raza *et al.*, 2019). The plant has a fine root system that grows profusely. Total root length, excluding the root hairs, can reach 1.5 m under optimal conditions. The female inflorescence (ear) is enclosed by bracts and the silk (Grieder *et al*., 2014). The silk of the flowers at the bottom appears first and before those on the upper part of the ear. The silk remains receptive to pollen for approximately three weeks; its receptivity however, decreases after the tenth day (Grieder *et al.*, 2014). Wang *et al*. (2020) proposed that maize was dispersed from its proposed center of origin via two routes; the northward route which traces from Mexico's highlands through northern Mexico into south western United States and the southward route from Mexico's highlands to western and southern lowlands of Mexico into Guatemala and the Caribbean islands (Wang *et al*., 2020).

Maize was brought to Europe in the 16th century by Columbus who took the seeds from Cuba to Spain and later spread to Italy and other parts of the world (Owoyele *et al*., 2010). The Portuguese introduced maize to Africa for planting in the Congo basin and the crop spread throughout the continent due to its high yield and numerous uses. Maize was sent to Asia through the Indian Ocean route and Mediterranean trade route (Heywood, 2012). Through years of intensive breeding and selection, the crop can now be grown in tropical, subtropical and temperate climates simply by selecting the right variety and scheduling the planting time to avoid harsh environmental conditions including low temperatures below

19 ^{O}C or mean summer temperatures of 23 ^{O}C and high temperatures above 32 ^{O}C. Maize does not tolerate frost and water logging (Khalkho *et al*., 2013). In Ghana, maize is grown in all the regions of the country and all the ecological zones from the Coastal savanna through the Forest and Forest savanna transitional zone to the Guinea savanna and Sudan savanna with the Forest savanna transitional zone being the highest producing area. The crop is also grown under a wide range of conditions ranging from soil type, soil fertility, moisture level, temperature and cultural practice (Garcia *et al*., 2015).

2.2 Botany

Maize (*Zea mays* L.) belongs to the tribe, Tripsaceae (Maydeae) of the family Gramineae. It is a tall, determinate annual plant producing large, narrow, opposing leaves (about a tenth as wide as they are long), borne alternately along the length of a solid stem. The stem of the maize is erect, cylindrical, from 50 cm to 3 meters high and two (2) to three (3) cm thick (Galani *et al*., 2022). It is filled with loose parenchyma, has distinct nodes and internodes. The leaves grow alternatively on the opposite sides of the stem. They bear small hairs on them and number of leaves varies from ten (10) to twenty (20) (Kaul *et al*., 2019). The upper leaves in are more responsible for light interception and are major contributors of photosynthate to grain. The root system is strong and fibrous, deeply penetrating into the soil. The maize caryopsis germinates through one embryonic root followed by seedling or seminal roots. Their principal function of seminal roots is to supply the maize plant with water and nutrients during the first two to three (2-3) weeks of vegetation until the nodal roots develops and begin to function (Badau *et al*., 2013). The seminal roots are later replaced by permanent adventitious (nodal) roots that originate from the crown present at

the end of mesocotyl third and fourth (3-4) leaf stage. The lateral roots branch profusely, spread widely and penetrate deeply. The bulk of the maize roots are concentrated in the 30 cm soil layer (Prasad *et al*., 2017a). Besides these roots, 'prop or brace roots' frequently develop on the lower aerial nodes of the stem. On reaching the soil, they branch out and take part in the nutrition of the maize plants, but their main function is preventing the plants from lodging (Buckler & Stevens, 2006).

The distinguishing feature of maize is the separation of the sexes among its flowering structures such as monoecious plants. Maize produces male inflorescences (tassels) which crown the plant at the stem apex, and female inflorescences (cobs or ears), which are borne at condensed, lateral branches protruding from leaf axils (Wu *et al*., 2014a). The male (staminate) inflorescence, a loose panicle, produces pairs of free spikelets each enclosing a fertile and a sterile floret. The female (pistillate) inflorescence, a spike, produces pairs of spikelets on the surface of a highly condensed rachis (central axis, or "cob") (Nagoshi *et al*., 2018).

Each of the female spikelets encloses two fertile florets, one of whose ovaries will mature into a maize kernel once sexually fertilized by wind-blown pollens. The maize grain is botanically a caryopsis, a dry fruit containing a single seed fused to the inner tissues of the fruit case (Lee & Stein, 2022). Seed contains a germ from which a new plant will develop, and an endosperm which will provide nutrients for that germinating seedling until the seedling establishes sufficient leaf area to become autotroph (Maresma *et al*., 2019). The germ consists of a miniature plant axis, including approximately five embryonic leaves, a

radicle, from which the root system will develop, and an attached seed leaf (scutellum). The germ is the source of maize "vegetable oil" (total oil content of maize grain is 4% by weight). The endosperm occupies about two thirds of a maize kernel's volume and accounts for approximately 86% of its dry weight (Prasad *et al*., 2017b).

2.3 Some Maize Varieties grown in Ghana

2.3.1 Obatanpa

Obatanpa maize is a medium maturity white dent and flint endosperm Quality Protein Maize (QPM) with elevated levels of lysine and tryptophan and was first released by CRI, Ghana in 1992 as Obatanpa to help improve the protein nutritional status and the health of a large population of low-income groups in sub-Saharan Africa who depend on maize as a major component of their dietary protein intake (Boateng, 2015). Maize has such a critical nutritional role to play because it is the most important staple food crop across sub-Saharan Africa (Ekpa *et al*., 2018). Traditionally, maize is consumed as a starchy base in a variety of forms such as gruels, porridge, pastes etc. It is also widely fed as porridge to weaning children 2 to 3years, until the children are completely weaned at the age of 15 to 24 months) and preschool children (3 to 5 yrs) without protein supplements (Klute, 2018). The normal maize has a major nutritional constraint as human food because even though it has about 10% protein, the protein is deficient in two essential amino acids, lysine and tryptophan (Dhakal *et al*., 2022). The result is that, infants fed on normal maize without any balanced protein supplements suffer from malnutrition and develop diseases such as *kwashiorkor*, a fatal syndrome characterized by initial growth failure, irritability, skin lesions, edema, and fatty liver (Aliyu *et al*., 2021)

2.3.2 Honampa Maize

Honampa maize is an orange-colored pro-vitamin A maize variety which was produced and released to famers in the year 2012 by CSIR-CRI (Ortiz-Martinez *et al*., 2017). It is an Open Pollinated Variety (OPV), flint seed, streak tolerant. Honampa maize variety is adapted to growing condition in Ghana with pro-vitamin A levels of between 7-15 microgram per gram and mature in 110 days with yield potentials of between 5-6 tons/ha (Afriyie-Debrah *et al*., 2018). It is suitable for human, poultry and livestock consumption. Regarding to the level of pro – vitamin A, it is capable of boosting the immune system of consumers and further enhance the decline in vitamin A deficiency in the country (Afriyie-Debrah *et al.*, 2018).

2.3.3 Abontem Maize

Abontem is a Quality Protein Productive yellow maize (vitamin A <3ug/g) produced by CSRI-CRI in 2010 (Emmanuel *et al*., 2016). Abontem is an OPV flint seed maize with drought and striga tolerant. It has 75-80 days maturity period of 4.7 tons/ha potential yield (Nartey & Odoi, 2018). Abontem maize is suitable for human, poultry and livestock consumption and it is suitable for all agro-ecological zone in Ghana (Nartey and Odoi, 2018).

2.4 Nutritional Value and Uses

Maize is an important source of carbohydrate, vitamin A and Vitamin B, protein, iron and minerals. The per capita consumption of maize is average to be 100 kg per year supplying about 40% of the calorie needs in Eastern and Southern Africa.

The primary component of endosperm is starch together with 10% bound protein (gluten) and this stored starch is the basis of the maize kernel's nutritional uses. Whole, ground maize meal has an energetic value of 3, 578 calories per kilogram.

2.5 Nutrient Composition of Maize Grain

2.5.1 Protein content of maize grain

The maize grain is deficient in protein, but its variability is low with standard error of the order 7 g/kg of crude protein (Adjei-Nsiah, 2010). The protein content of maize grain ranges from 11 g/100 g grain of dry matter. The various fractions of grain vary considerably in protein content. Even though the majority of protein in the grain occurs in the endosperm, the germ (184 g/kg DM) is considerably higher in protein content than the endosperm (80 g/kg DM) (Dei, 2017). Generally, the low protein content of the grain limits its nutritive value as the only source of food for both humans and livestock (Nawaz *et al*., 2020). The amino acid composition of whole maize grain is determined by both the relative proportions of the various protein fractions and the amino acid composition of each fraction (Gebru *et al*., 2019).

Maize grain endosperm proteins are usually referred to as albumins, globulins, prolamins and glutelin, depending on their solubility in different solvent systems. Prolamins and glutelin also referred to as storage proteins are confined to the endosperm, whereas albumins and globulins also referred to as water-soluble proteins are also found in the aleurone layer and the germ (Ortiz-Martinez *et al*., 2017). Vitamins in maize grain are concentrated mainly in the aleurone layer and the germ (Ndolo & Beta, 2013). Analysis of

the vitamin content of maize indicates that the grain furnishes significant quantities of riboflavin, pantothenic acid, choline and pyridoxine which are sufficient to satisfy the requirements of most livestock (Gebru *et al*., 2019). However, the most significant feature of the vitamin pattern in maize is the low niacin content. Besides, much of niacin that occurs in the grain is in a bound form (Niacytin), which is not available to monogastric animals (Rizwan *et al*., 2017).

Furthermore, the high level of the essential amino acid, leucine, in the maize grain increases niacin requirement in humans (Prasanna, 2012). Thus, people who live only on a diet of maize suffer from the disease pellagra, associated with niacin deficiency. Nevertheless, niacin shortage alone would not cause pellagra if normal maize were rich in tryptophan or heat-treated with alkali (Ndolo & Beta, 2013). Yellow maize shows vitamin A activity, whereas white maize does not. The vitamin A potency of yellow maize results primarily from the presence of carotenes in the grain. The carotene content of yellow maize is 0.46 mg/100 g of grain (Wu *et al*., 2014b). The vitamin content of maize grain is represented in the Table 2.1.

Table 2.1: Vitamin content of maize grain

Vitamin	Concentration (g/kg)
Carotene	4.6
Vitamin E	0.46
Thiamine (B_1)	4.83
Riboflavin (B_2)	1.61
Nicotinic acid	25.29
Pantothenic acid	6.44
Pyridoxine (B_6)	8.74
Choline	655.17

(Source: Zhang et al., 2012).

2.6 Nutrient Requirement of Maize

Major nutrients required by maize for optimum performance include: Nitrogen (N) required for obtaining maximum yield and quality, Phosphorus (P) required particularly by the growing tips of the plant for root growth, Potash (Potassium (K) is required in the greatest amount by maize (Zhang *et al*., 2020). The assimilation of nitrogen, phosphorus and potassium reaches its peak during tasseling (Kuan *et al*., 2016). Maize also requires Sulphur (S) which is a constituent of protein together with nitrogen and Magnesium (Mg) an essential element in chlorophyll used for photosynthesis (Waraich *et al*., 2011). It is not very sensitive to trace element deficiencies, but boron, copper, zinc, manganese and iron may occasionally be deficient on soils where there is shortage of manure (Michalak *et al*., 2020).

2.7 Climatic and Soil Requirements

Maize is a warm weather crop and is not grown in areas where the mean daily temperature is less than 19 ^{0}C or where the mean of the summer months is less than 23 ^{0}C. According to Wang *et al* (2014), maize does well within a temperature range of 21-30 ^{0}C. Minimum temperature for germination is 12 ^{0}C. Germination will, however, be faster and less variable at soil temperatures of 16 to 18 ^{0} C (Brown *et al*., 2014). At 20 ^{0}C, maize should emerge within five to six days. The critical temperature detrimentally affecting yield is approximately 32 ^{0}C (Itelima *et al*., 2018). While the growth point is below the soil surface, new leaves will form and frost damage will not be too serious. Approximately 10 to 16 kg of grain are produced for every millimeter of water used. A yield of 3152 kg/ha requires between 350 and 450 mm of rain per annum (Ureta *et al*., 2020). At maturity, each plant will have used 250 litres of water in the absence of moisture stress. Maize thrives in well drained sandy loam soil with a pH of 5.7-7.5 and 500-800 mm of rainfall evenly distributed throughout the growing season for good yield (Abdul-Ganiyu *et al*., 2015).

The most suitable soil for maize is one with a good effective depth, favourable morphological properties, good internal drainage, an optimal moisture regime, sufficient and balanced quantities of plant nutrients and chemical properties that are favourable specifically for maize production (Kamran *et al*., 2018). Although large-scale maize production takes place on soils with a clay content of less than 10% (sandy soils) or in excess of 30% (clay and clay-loam soils), the texture classes between 10 and 30% have air and moisture regimes that are optimal for healthy maize production (Rizwan *et al*., 2017). Maize can be grown on a wide variety of soils, but performs best on well-drained, well-

aerated, deep warm loams and silt loams containing adequate organic matter and well supplied with available nutrients (Rizwan *et al.*, 2017).

Although it grows on a wide range of soils, it does not yield well on poor sandy soils, except with heavy application of fertilizers. On heavy clay soils, deep cultivation and ridging is necessary to improve drainage. Maize is suited for off-season cropping in swamps provided drainage is adequate though planting in swamps is not always recommended for environmental reasons (Abdul-Ganiyu *et al*., 2015). It does not tolerate water logging; it can be killed if it stands in water for as long as two days. Maize can be grown successfully on soils with a pH of 5.0 - 7.0 but a moderately acid environment of pH 6.0 - 7.0 is optimum (Ureta *et al*., 2020). Outside the range results in nutrient deficiency and mineral toxicity. Liming is required for good yields on more acid soils. Maize has a high nitrogen requirement; and high yields of maize make a heavy drain on soil nutrients (Bukhsh *et al*., 2012). High yields are obtained from optimum plant population with appropriate soil fertility, and adequate soil moisture. Where possible, it is advisable to have soils routinely analysed in order to know the characteristics of the soils and to get advice on how to improve soil fertility and/or correct soil pH for optimum maize production (Gebru *et al*., 2019). Low organic carbon (<1.5%), total nitrogen (<0.2 %), exchangeable potassium (<100 mg/kg) and available phosphorus (<10 ppm) are characteristics of soils in the major maize production areas in Ghana (Tetteh *et al*., 2018). Large proportions of the soil are also shallow and contain iron and manganese at high concentrations. These shortcomings together with poor soil fertility management, is a major constraint to maize production in the country (Tetteh *et al.*, 2018).

2.8 Crop Propagation

2.8.1 Planting material Quality Declared Seed (QDS)

Seed is a precious element of agricultural productivity and farmers are entitled to access of quality seed for improved production. In sub-Saharan Africa (SSA), this is seldom achieved by farmers, especially the resource-poor farmers and those in country sides where formal seed system is lacking (Gildemacher *et al*., 2017). To address this issue, QDS has been introduced as a class of seed that farmers can access. Usually, Quality Declared Seed (QDS) is produced under local regulations that are less rigorous than the conventional seed certification rules, but ensure that, basic quality of seed is maintained hence increasing access to quality seed by smallholder farmers (Deconinck, 2019; Prasad *et al*., 2017b; Van Zeeland & Ringersma, 2017). Major maize germplasm falls within the tropical (low/highlands), sub-tropical and temperate categories. Maize grown in SSA are mainly of white grain types belonging to the tropical and sub-tropical, medium to late maturity groups (Maresma *et al*., 2019).

2.8.2 Planting Material (seed)

Seed is any part of a crop that germinates or reproduces to become the same crop and which satisfies expectations in terms of the desired characteristics. Therefore, to enhance productivity, seed must be availed to farmers. However, maize is an out-crossing crop whereby, any seed (OPV or hybrid) production activity must strictly adhere to the rules and requirements. Various management practices and techniques have been adopted to generate maize seed with acceptable quantity and quality (Nagmoti *et al*., 2012)

2.8.3. Planting Depth and Time

Planting is the exercise of putting seed into seed bed for an intended crop growth and development. Maize planting commences as soon as land preparation is complete and suitable soil moisture and temperature availed (Wu *et al*., 2014a). Maize planted on soil with unfavourable environmental conditions such as drought, excessive water, and extreme soil temperatures may fail to germinate hence dies. Normal planting depth for maize is 3- 5 cm. Planting at this depth provides the seed with adequate moisture and protection while allowing the shoots to reach the soil surface easily. Other practices include spacing and plant population size (Yenesew & Tilahun, 2009).

2.8.4 Planting Distance

For most maize varieties, the recommended planting distance is between 30 to 40 centimeters between individual plants in a row. The rows should be spaced about 75 to 90 centimeters apart (Buckler & Stevens, 2006). These distances can be adjusted slightly based on the maize variety and the fertility of the soil (Chen *et al*., 2018).

2.8.5 Plant Population/Plant per Hill

Plant population size is determined based on rain-fed or irrigated systems, prevailing environmental conditions and variety used (Murdia *et al*., 2016). Maize planted under irrigation usually has high plant density compared to rain-fed system. Maize planting density for maximum yield has been estimated by other workers to range between 40 and 60×10^3 plants/ha. In Ghana, optimum density has also been shown to vary between 40 and 60×10^3plants/ ha (GGDP) (Buckler & Stevens, 2006).

2.9 Land Preparation

Land preparation is the process by which a piece of land is made suitable for planting of seed. It involves bush clearance and tilling of soil. In land that is not covered with thick bushes or one that has been cultivated the previous season, bush clearance may not be necessary. Soil tillage is a farming system referring to physical soil cultivation practices resulting into change in soil structure, hydraulic properties and stability, so as to allow optimum plant growth (Du Plessis, 2003). Conventionally, and for better crop establishment, tillage is performed 1-3 times depending on the field conditions. The field should be tilled to a suitable depth of 10-20 cm in order to allow optimum water absorption, root development and crop establishment (Aceves *et al*., 2010; Belfield & Brown, 2008). Soil tillage enhances water infiltration and aeration which are vital for plant growth and development (Dilip Kumar & Jhariya, 2013). After tillage is complete, harrowing is performed so as to level the field such that seed can be planted on suitable bed. Care should be taken not to level the seed bed so smooth such that run-off can occur.

A variety of implements including hand hoe are commercially available to farmers for land preparation in SSA (Garcia *et al*., 2015). Common among them include moldboard ploughs, disc ploughs and discs, chisel ploughs and harrows, oxen-driven and hand hoe (Williams *et al*., 2014). In places where weed is not a major problem and soil erosion is not common, farmers may adopt minimum or no-tillage systems of maize cultivation. No-tillage involves a practice where seed is directly planted into the field without tilling and the soil is left

undisturbed until harvest (Aceves *et al*., 2010). Different minimum soil tillage practices are being adopted where soil is partly tilled and weed control is mostly by chemicals.

2.10 Agronomic Practices

Maize plant is adapted to wider environments including rain-fed and irrigated conditions. Under irrigation, water management is essential and if well managed, grain yield can be as high as 20 tons per hectare (t/ha) (du Plessis, 2003). Different irrigation equipment used in SSA includes sprinklers and drip irrigation. Irrigation regime should be set based on the growth stage, soil type and prevailing environmental conditions, and pumping capacity of the equipment (Yenesew & Tilahun, 2009), Like most cereal crops, maize requires appropriate cultural practices and management so as to realize maximum yield.

Weed is any plant/grass growing in the maize field and which is not intended to be there since it competes with maize plant for water and nutrients, leading to poor yield. Weed is one of the major constraints facing maize production worldwide (Suleiman *et al*., 2015). Proper management of weed is a prerequisite for maximum maize yield. Common weed management practices in SSA include mechanical removal of weeds by hand hoe or machine, use of herbicides to kill the weed and good agronomic practices such as use of clean seed (Ladha *et al*., 2016). Various chemicals under different commercial names such as Atrazine, Imazethpyr+imazapyr and Imazapyr+pyrithiobac are being effectively used for pre- and post-emergence weed control in maize (Yawson *et al*., 2010). Weeding can also be done by machine provided row spacing is large. Depending on field conditions, weeding of maize field can be conducted 2 to 3 times during the vegetative stages and before maturity (Mensah *et al*., 2021). First weeding is normally done 2 weeks after seeding emergence,

followed by second weeding before flowering and the last one during or immediately after flowering. It is a good practice to keep an eye on maize field so that any weed that might have escaped weeding is pulled out manually by hand (Karaya *et al*., 2009a).

Maize is an aggressive consumer of soil nutrients due to its nature of growth and development. Normally, maize field is supplemented with nutrients in the form of inorganic fertilizers (though organic fertilizers are also applicable) (Vanlauwe *et al*., 2015; Aceves *et al*., 2010). The organic fertilizers are found in the form of manures and have been commonly used for fertility supplementation in maize but their bulkiness which poses difficulties in management since maize is always planted in big area. It is important that before any fertilizer application, nutrient requirements of the soil be correctly determined through soil analysis and correct recommendation of fertilizer rates given in the form of kilogram per hectare (kg/ha) (Islam & Karim, 2019). Farmers should strictly adhere to the recommendations from the soil analysis so as to obtain good results in the field. Incorrect application of fertilizer negatively impacts on soil physical properties and chemical properties, leading to poor maize yield (Fryer *et al*., 2019)

Major inorganic fertilizers used to supplement maize nutrients include urea (N), phosphorus (P), potassium (K) and zinc (Zn) with each differing in requirement and time of application. Nitrogen fertilizer is critical for healthy growth and development of maize and can be applied 2-3 times during maize growth period (Saha *et al*., 2017). First application is during planting where the fertilizer is placed 50 mm in soil below and by the side of the seed then buried. Second application comes two weeks after seedling emergence followed by the third

application (Wu *et al*., 2014b). Third application is very crucial because at this stage maize plant requires a lot of energy to perform the multi tasks of growth and reproduction (Kato *et al*., 2019). Both second and third applications are conducted by topdressing (that is, putting the required quantity of N on top of the soil and 100 mm away from the plant (Ortiz-Martinez *et al*., 2017).

Direct contact between N and the plant leads to plant burn and sometimes death. Residual soil N and weather conditions affect requirement and application of N. When N is applied and the soil continues to remain dry, the fertilizer will be lost due to heat and evaporation and the plant will not benefit. Therefore, it is recommended that N should be applied while the soil is moist (Soares *et al*., 2019). For topdressing, N should be administered after rain or when rain is about to fall however, when the weather is humid, especially in late afternoon, the fertilizer can be applied. In addition, it is advisable to apply N after weeding to avoid competition between maize and the weeds. Quantity of N (kg) applied per ha varies depending on the soil requirements, residual N in the soil and plant population (Ureta *et al*., 2020).

Nitrogen fertilizer is sold in the markets informs of urea, NPK and CAN. Nitrogen deficiency in the soil can be recognized by pale to light green appearance of young maize plant in the field. Also, at later stage, older leaves show inverted V shape and yellowing (Vanlauwe *et al*., 2015). Phosphorus is an important element for maize growth and establishment. The fertilizer is applied at planting at 50 mm below the seed and at the seed side then buried. Unlike N, P is applied just once for the whole of maize growth in the field.

Phosphorus plays key role in providing nutrients to young maize seedling since at this early stage, the seedling has undeveloped root system hence unable to absorb its own nutrients from the soil (Aceves *et al*., 2010). Phosphorus fertilizer is commonly available in the markets informs of ammonium phosphate (DAP) and NPK. Maize plant lacking P can manifests dark green leaves with reddish purple tips and margins, especially when the plant is still young. However, maize seedling also shows purple symptoms when soil temperature drops below 12°C. This is because under cold conditions, soil cannot release P to plant (Ten Berge *et al*., 2019). Therefore, prior to adding up to the field, care should be taken to understand whether the purple symptom is due to lack of P in the soil or due to low soil temperature (Kuan *et al*., 2016).

Potassium (K) should be placed 50 mm below and beside the seed during planting. This application is done just once. A quantity of 30 to 50 kg of K is appropriate for 1 ha depending on the soil requirements. Potassium fertilizer is commercially available as Potash and NPK (Prasanna, 2012). Lack of K in the soil is reflected as yellowing or necrotic leaf margins starting from lower leaves and progresses upwards to younger leaves (Coker *et al*., 2015). The deficiency has also been implicated in stalk rot and lodging in maize. Zinc is another important micro element required for good maize growth and development. Application of Zn is similar to the procedures followed for P and K above. Deficiency in Zn is observed on maize plant as light streaks between leaf veins while mid rib and leaf tip remain green, leading to stunted growth (Rizwan *et al*., 2017).

Insects and pests of maize refer to those organisms that feed on maize and cause significant yield losses (t/ha) or reduction in quality of stored grain. A great number of insects and pests of maize has been reported (Matova *et al*, 2017; Aceves *et al*., 2010). Better control of insect/pest of maize is achieved through application of "integrated pest management" system. This is where pest population is suppressed using a combination of practices including chemical control, biological control, host resistance and cultivation control. Some animals and birds are also known to attack maize and cause great damages and yield losses (Murdia *et al*., 2016). Various chemicals have been effectively used for control of the organisms though costs of buying chemicals, for example, pesticides are usually high that most farmers cannot afford (Karavina, 2014).

However, chemical pest control is effective, especially when maize is grown under irrigated system. Commonly used chemicals for pests' control in maize fields include Abamectin + Chlorantraniliprole (e.g, Voliam Targo 063 SC), Lufenuron (e.g, Match 50EC), Chlorantraniliprole (e.g, Coragen 20SC), Emamectin benzoate (e.g, Prove 1.92EC), Pyriproxyfen (e.g, Profen 10.8EC) and Acephate (e.g, Orthene Pellet) (Prasanna *et al.*, 2018). In biological pest control, different organisms use maize plant as part of their ecosystem in order to survive and perpetuate. This relationship sometimes leads to competition among themselves as a result, the stronger organisms (natural enemies or beneficial insects) displace or kill the weaker ones (preys) (Obiri-Nyarko, 2012). The concept known as biological control, and can be successfully used for reducing insect/pest population in maize fields (Babendreier *et al*., 2019). For example, ladybird insect can feed on aphids leading to reduction in population of the latter in the field. Furthermore,

population of beneficial insects can be enhanced by spraying maize field with chemicals (insecticides) which are non-toxic to the natural enemies but kill the pests (Waraich *et al*., 2011).

Maize, due to its wide adaptation, has attracted various pathogens including bacteria, fungi, viruses and mycotoxins that cause significant yield losses all over the world. This presents a serious threat to food security and livelihood, especially in SSA where over 80% of the population depends on maize as source of food (Matova *et al*., 2021; Mahuku *et al*., 2015; Magenya *et al*., 2008). For example, mycotoxins which are special compounds that cannot be neutralized by processing, can affect both human and animals. Depending on concentration of the toxins in food or feed, it causes serious health implications and even death in certain cases (Mwalwayo & Thole, 2016; Mutiga *et al*., 2015; Okoth & Ohingo, 2004). Each region/country has its own level of acceptable percentage of mycotoxin contamination in food/feed (Wu *et al*., 2014b). Like for insect/pest management, similar practices can be applied for disease, management especially for insect/pest transmitted viral diseases. These include use of fungicides, crop rotation, host plant resistant, weeding, and removal and burning of infected plants (Tamirat *et al*., 2014). In case of severe or endemic disease outbreak, movement into and within the field is highly restricted so as to avoid infections and disease spread.

2.11 Effect of Inorganic Fertilizer Briquette on the Growth and Yield of Maize

N.P.K fertilizer briquette of large-sized super granules is an alternate N source, supplying N along with P and K with a goal of increasing the N, P, and K use efficiencies (Kato *et al*.,

2019). N.P.K fertilizer briquette is manufactured via the physical manipulation of the current commercially available prilled and granular N, P, and K fertilizers (Karaya *et al*., 2009b). It is entirely mineral and supplies N, P, and K nutrients in a ratio that fits the targeted crop and soil. This kind of N.P.K briquette fertilizer product, therefore, allows for nutrient-balanced site-specific fertilization in order to reduce nutrient, particularly N, losses and save labour because of its single application relative to the two to three split applications of commonly used prilled and granular fertilizers (Deconinck, 2019).

N.P.K briquettes fertilizer possess less surface area and thus dissolves slower, releasing nutrients at a more moderate pace for a longer time, which eventually reduces nutrient losses, particularly N, and consequently protects water and air quality compared with the prilled and granular fertilizers. A study reported that, N.P.K briquette fertilizer increased maize yield by 16 % compared with ammonium sulphate (+P and K) and by 23 % to 34 % relative to urea (+P and K) under normal weather conditions. N.P.K briquette fertilizer also resulted in higher N, P, and K use efficiencies (Umesha *et al*., 2014). Rice yields increased by 25 % to 50 % with the application of the fertilizer briquette compared with commercial granular fertilizer in Ghana (Jaramillo *et al*., 2013). The increased N-use efficiency with the fertilizer briquette implies lower N losses to water bodies and the atmosphere through leaching and volatilization (Huffman *et al*., 2019).

2.12 Effect of Inorganic Fertilizer on Soil Physical and Chemical Properties

Soil chemical properties include concentrations of specific chemicals such as phosphorus, nitrogen, carbon and major cations including (calcium, magnesium, sodium, potassium,

sulfur, trace metals and elements), pH, cation exchange capacity, anion exchange capacity, base saturation, salinity, sodium adsorption ratio, enzymes, and electrical conductivity (Ely *et al*., 2016). These properties affect processes such as nutrient cycling, biological activity, soil formation, pollutant fate, and erosion. The use of inorganic fertilizer has helped in improving soil nutrients and enhances soil quality. However, over fertilization of the soils may lead to the development of acidic soils as a consequence of excessive leaching of basic cations, mainly Ca, Mg and K in climatic conditions characterized by excessive rainfall (Asibi *et al*., 2019).

Chemical properties of soils are important in that, along with their physical and biological properties, they regulate the nutrient supplies to the plant. Without these nutrients supplied by the soil or inorganic fertilizers may be applied (Asghar *et al*., 2010). Soil pH is an important soil property that affects plant suitability, nutrient availability, soil microorganism activity, chemical cycling, and mobility of pollutants such as metals (Farnia *et al*., 2015). Soil pH can be managed by measures such as applying the proper amount of nitrogen fertilizer, liming, and cropping practices that improve soil organic matter and overall soil health. CEC affects the nutrient status of soil. Soils with greater organic matter and/or clay content have higher CEC and typically have greater amounts of available nutrients than sandy soils (Sindhu *et al*., 2016). Soils with high sodium concentrations (sodic soils) will have a high percent of sodium as the exchangeable cation. According to Zingore (2016), excess sodium is detrimental to soil structure. In acidic soils (pH < 5), aluminum becomes an exchangeable cation. Aluminum has no nutritional value for plants and can be toxic to plants. Soil physical properties define movement of air and

water/dissolved chemicals through soil, as well as conditions affecting germination, root growth, and erosion processes. Obiri-Nyarko (2012) reported that, soil physical properties form the foundation of several chemical and biological processes, which may be further governed by climate, landscape position, and land use. The structure of the soil dictates organic C accumulation, infiltration capacity, movement and storage of gases, water and nutrients, emergence of seedlings and root, and microbial community activity (Obiri-Nyarko, 2012).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental Site and Location

Two field experiments were conducted concurrently at Atebubu in the Bono East Region and Dormaa Ahenkro in the Bono regions of Ghana. Atebubu District is located between latitudes 7° 23” N and 8° 22” N and longitudes 0° 30’W and 1° 26’W. It shares boundaries with the Pru District to the North, the Sene District to the East and to the West Kintampo South and Nkoranza North all in the Brong East Region of Ghana. To the South, it is bounded by three districts in the Ashanti Region namely Ejura-Sekyedumase, Sekyere East and Sekyere West districts. Atebubu is the district capital which is about 158 km from the regional capital, Techiman. The Atebubu district has a land area of about 2,624 square kilometres.

As high as 70.2 % of households in the district are engage in agriculture. In the rural localities, eight out of ten households (89.4 %) are agricultural households. Most households in the district (95.5 %) are involved in crop farming. Poultry (chicken) is the dominant animal reared in the district. The Atebubu district has a plain landscape with rolling and undulating land surface with a general elevation of between 60-300 m above sea level. The district is not associated with any significant highlands or hills. The area is mainly drained by the Pru River which is a tributary to the Volta Lake. It flows across the Northern part of the district. Other important streams in the district include the Nyomo and Bresuo rivers. The sluggish flows of these rivers permit the deposition of alluvial soils on the river

beds and along their banks. The water table in the district is however very low, resulting in the drying of water bodies including wells and boreholes, especially during the dry season. Water from the Pru river is currently been treated to be supplied to the inhabitants of the Atebubu Township and a few surrounding communities (MoFA, 2012).

3.1.1 Soil and Climatic Conditions of Atebubu (Bono East)

Soils in the Atebubu Municipality in the Bono East region range from fine sandy loams to clayey loams and are mostly poorly drained. The district experiences the tropical continental or interior savannah type of climate; which is a modified form of the wet semi-equatorial type of climate. This is due to the location of the district in the transitional zone, (between the two major climatic regions in Ghana, for example, the Ashanti Region and the Savannah Region). The mean monthly temperature ranges from 30 ^{0}C in March to 24 ^{0}C in August. Mean annual temperature ranges between 26.5 ^{0}C and 27.2 ^{0}C. In extreme cases temperatures rise to about 40 ^{0}C. The district comes under the influence of the Northeast Trade Winds (Harmattan) between November and March/April. The total annual rainfall is between 1,400 mm to 1,800 mm and occurs in two seasons. The first rainy season begins in May whilst the second rainy season begins in September.

The difference between the minor and the major rainy seasons is hardly noticed because of the transitional nature of the area. The underlying rock soils are of the Upper Voltaian Series with its main components being the sandstone, shale and mud stone-beds, shale intrusions and sand, and pebbly bed series. These are sedimentary rocks which result in the formation of soils derived from the weathering of the Voltaian sandstone. Soils in the Municipality

are of the Savannah Ochrosol type which is mainly made up of sandy loam or clay. The major characteristics of this soil type is that they are well drained, deep, light in colour, well aerated and rich in organic matter and plant nutrients as well as high water-retaining capacities. The Atebubu Municipal falls within the interior wooded savannah or tree savannah. However, owing to its transitional nature, the area does not totally exhibit typical savannah conditions. The savannah is heavily wooded, though most of the trees are not as tall and gigantic as those in the moist deciduous forest. It is believed that the transitional zone was once forested and that the savannah conditions currently prevailing have been the result of human activities. The Map of the Study area is shown below in Figure 1.

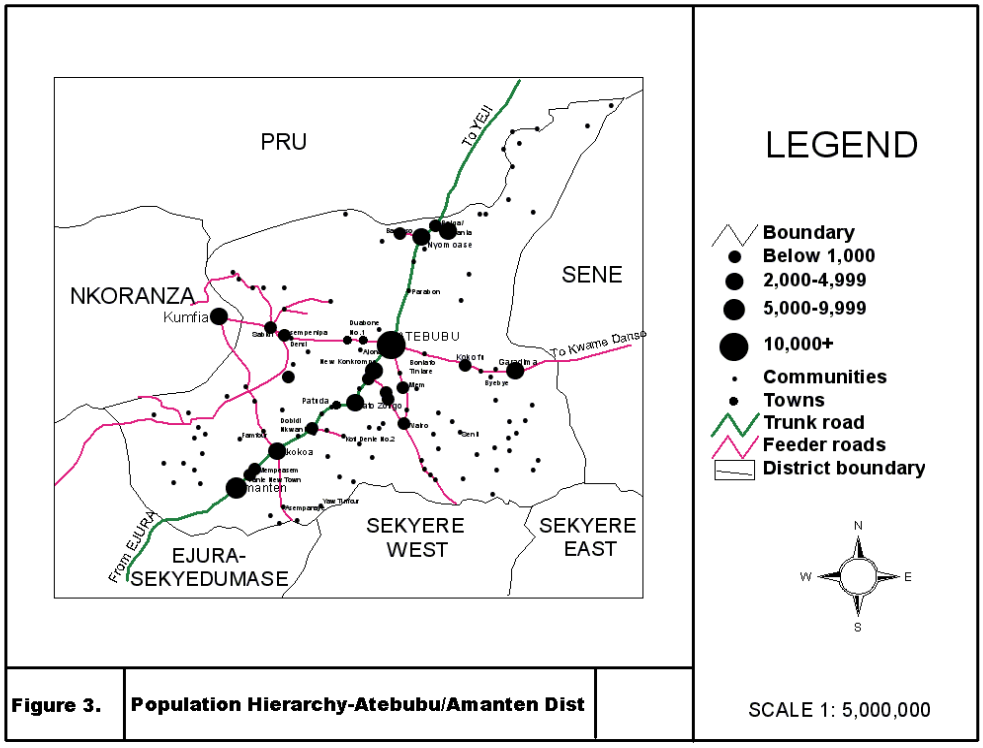

Figure 1: Map of Atebubu, the first Study Area (Bono East)

3.1.2 Soil and Climatic Conditions at Dormaa Ahenkro

The second trial was conducted at the Dormaa Ahenkro in the West of Bono Region located in the transitional agroecological zone of Ghana. Dormaa Ahenkro Municipal has an annual rainfall ranging between 1250 mm and 1750 mm and temperature ranging from 26.1 °C to 30 °C [Ghana Statistical Service (GSS), 2014]. The district has an estimated total area of 381 km^2, known to be prone to dry spells which have negatively affected cocoa production and yield in the area. Dormaa Ahenkro Municipal is one of the twelve districts in Bono Region of Ghana. GPS coordinates for Dormaa Ahenkro is Latitude 7.2671N and Longitude 2.8677 W. Dormaa Ahenkro has a tropical savanna climate and situated at the western part of the Bono Region. It is a municipal capital and located about 80 kilometers west of the regional capital, Sunyani and also about 46.3 kilometers from Berekum (GSS).

The topography of Dormaa Ahenkro experimental site is mainly characterized by a low elevation not exceeding 152 metres above sea level. It has moist semi-deciduous forest and the soil is very fertile. The region produces cash crops like cashew, timber, and food crops such as maize, cassava, plantain, cocoyam, tomatoes, and many others. The district yearly temperature is 27.72ºC and it is -1.14% lower than Ghana's averages. Dormaa Ahenkro typically receives about 63.52 millimeters of precipitation and has 136.18 rainy days (37.31% of the time) annually. Geologically, the Dormaa Ahenkro municipal is underlain by Precambrian formation which is believed to be rich in mineral deposits. Associated with the Birimaian formation are extensive masses of granite. About 85% of the soil in the municipality generally falls into the Ochrosols groups with good water retention capacity.

The ecological zone is Semi Deciduous Forest. Map of the second study area is shown below in Figure 2.

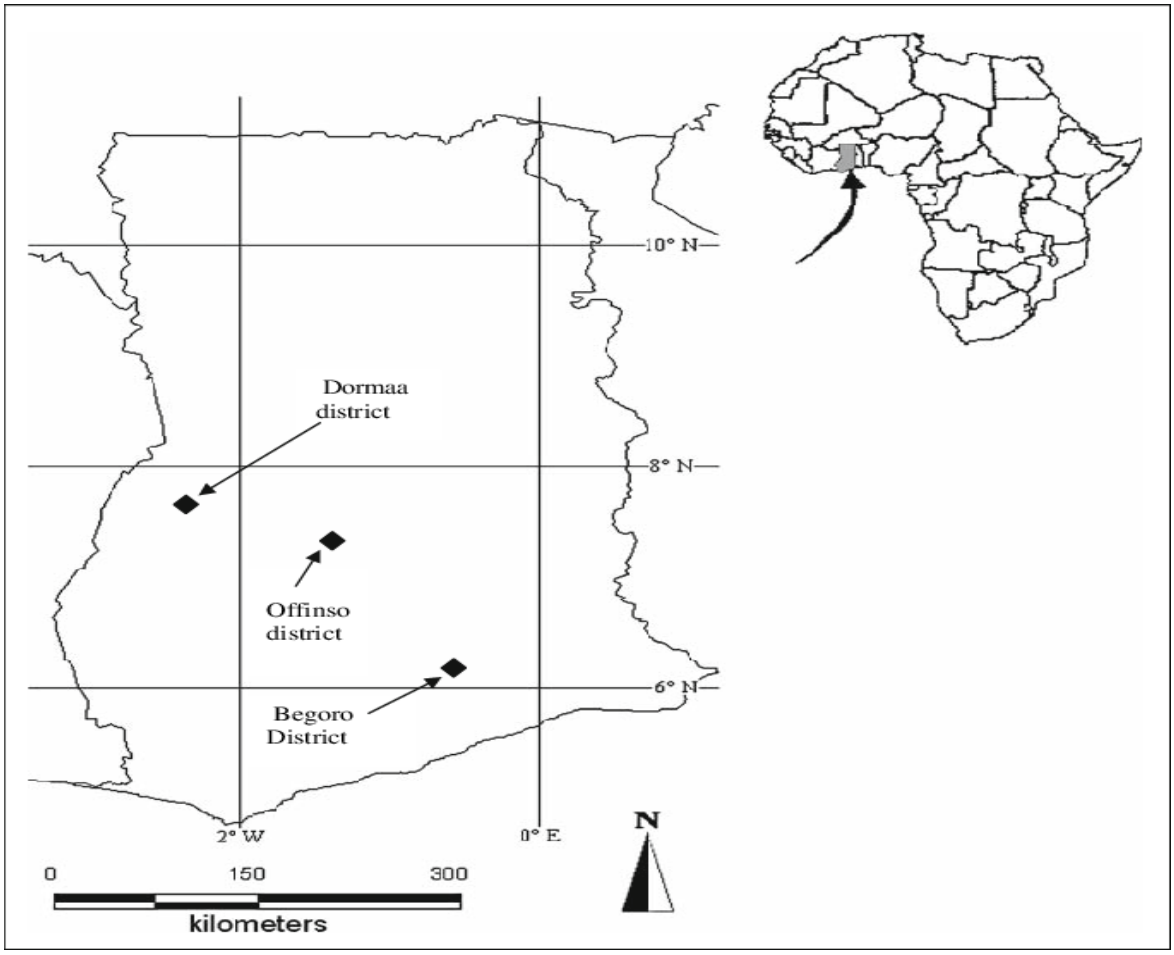

Figure 2: Map Showing the Second Study Area (Dormaa Ahenkro)

3.2 Experimental Design and Treatments

The experimental design used for both experiments (Atebubu and Dormaa Ahenkro) was a Randomized Complete Block Design (RCBD) with eight (8) treatments and each treatment replicated four (4) times.

The treatments used were;

T1-No Fertilizer (Control)

T2-Granule (120-40-40 kg/ha NPK)

T3 Granule (116-48-46 kg/ha NPK)

T4 Granule (86-48-46 kg/ha NPK)

T5 Granule (55-48 46 kg/ha NPK)

T6 Briquette (116-48-46 kg/ha NPK)

T7 Briquette (86-48-46 kg/ha NPK)

T8 Briquette (55-48-46 kg/ha NPK

Rates of fertilization

Table 2: Rate of application of treatments

	(kg/m^2)		
Treatment	N	P_20_5	K_20
T_1 Control	-	-	-
T_2 Granule	120	40	40
T_3 Granule	116	48	46
T_4 Granule	86	48	46
T_5 Granule	55	48	46
T_6 Briquette	116	48	46
T_7 Briquette	86	48	46
T_8 Briquette	55	48	46

3.3 Land Preparation and Field Layout

Land was prepared in Atebubu and subsequently at Dormaa Ahenkro by removal of stumps followed by ploughing, harrowing and leveling. After properly removing all undesirable

tree stumps, stones and other materials lining and pegging was carried out using ropes and pegs. The experimental site was divided into four (4) blocks with 2 m alley between them. Each block was then divided into eight (8) plots. Each plot measures 5 m× 5 m with a 1m distance between plots making a total of 32 plots. The total field size was 47 m x 26 m (1, 222 m^2).

3.4 Agronomic and Cultural Management Practices

3.4.1 Planting Material and Planting

The planting material used for the study was the *Sanza sima* maize which was obtained from the International Fertilizer Development Center (IFDC). IFDC is a science-based public international organization working to alleviate global hunger by introducing improved agricultural practices and fertilizer technologies to farmers and by linking farmers to markets. The *Sanza sima* maize variety seed is white. *Sanza sima* maize variety was chosen because it is resistant to drought and most maize diseases, adapted to local growing conditions, has medium maturity period which matures within 110 days after planting. Planting of seeds was carried out at Atebubu on the 13th of April 2022 and subsequently on 20th April at Dormaa Ahenkro using the same seed variety. Three (3) seeds were sown per hole and later thinned to two (2) seedlings per hole. The planting distance was 75 cm x 40 cm. The number of rows per plot was 6 and the number of hills per row was 12. Seedling emergence started 4 days after sowing and then after 7 days, vacant holes were refilled with new seeds.

3.4.2 Agronomic Practices

Weeds were controlled manually using a hoe for both experiments I and II (Atebubu and Dormaa Ahenkro) at 2-3 weeks after planting. After the 2-3 weeks period, second and third weed control were done at tasseling and before harvest using a hoe to weed between rows. The incidence of pests and diseases was periodically monitored during routine visits to the experimental sites to check for pests like the fall armyworm (Spodoptera exempta). Fall Armyworm was controlled by spraying with ‘’Gro-safe’’ organic pesticide containing Azacdiractin as the active ingredient, with the recommended rate of 200 ml of neem oil + 50 ml of emulsifier in 15-litre Knapsack sprayer tank for both locations (Atebubu and Dormaa Ahenkro). This was done four (4) weeks after planting for both locations. The different rates of briquette and granular NPK fertilizers were applied 3 weeks after planting by using side placement method and according to treatment.

3.5 Data Collected

3.5.1 Soil Sampling and Analysis

Soil sampling was carried out at both experimental locations before and after planting. This was done as it is the best practice to ensure quality cores with consistent depths. To ensure uniform soil sampling, the experimental plot was divided into four portions using ropes and pegs. The soil samples were selected from each of the four plots using a core sampler. The soil samples were then taken at a depth of 0-20 cm deep. The core sampler was pushed into the soil using a stick. After picking the soil samples, plant debris were removed from the soil and the samples were kept in separate polythene bags, labelled and transported to Kwame Nkrumah University of Science and Technology (KNUST) laboratory for physico-chemical properties analysis of the soil before planting and after harvest. A total of 32

undisturbed soil samples were taken with core sampler 5 cm internal diameter and a height of 5 cm from each plot. These samples were used for the determination of bulk density, total porosity, and particle density. Undecomposed plant materials were removed and the remaining soil was crushed to pass through a 2 mm mesh size sieve to obtain the fine fraction and used for the determination of particle size distribution and chemical analysis. Other undisturbed soil samples were also collected randomly from 0 - 20 cm soil depth on each plot for the determination of particle size and chemical properties.

3.5.1.1 Porosity

Total porosity is the volume percentage of the total bulk density of the soil not occupied by solid particles**.** The porosity was calculated using the formula (Terzaghi *et al*., 1996):

$$\text{Porosity} = \frac{\text{Fresh weight of soil} - \text{Oven dry weight of soil}}{\text{Volume of soil}} \times 100\ \%$$

3.5.1.2 Particle Size Analysis

The hydrometer method (Klute, 1986) was used in the determination of the particle size. This method was used because it allows for the non-destructive sampling of suspensions undergoing settling and also, provides for multiple measurements on the same suspension so that detailed particle-size distribution can be obtained with minimum effort. Fifty-one grams (51 g) of air-dried soil from each plot were weighed into milk-shake cup bottles. Ten millilitres (10 ml) of 5 % Calgon (Sodium hexametaphosphate) alongside 100 ml of distilled water were added to the soil. The Calgon served as a dispersing agent for the soil particles.

The mixture was shaken with a mechanical shaker for twenty (20) minutes and the content was poured into a 1000 ml measuring cylinder, the milk-shake bottle cap was rinsed with distilled water and added to the content to reach the 1000 ml mark. The cylinder with the content was shaken to distribute the particles equally throughout the suspension and the first hydrometer and temperature readings were taken after 40 seconds. The suspension was left to stand for three (3) hours to allow the soil particles to settle. Hydrometer and temperature readings were taken after three hours and the per cent fractions of each soil component were calculated as follows:

$$\% \text{ Sand} = 100 - [H_1 + 0.2(T_1 - 20) - 2] \times 2$$

$$\% \text{ Clay} = H_2 + [0.2\,(T_2 - 20) - 2] \times 2$$

$$\% \text{ Silt} = 100 - (\% \text{ Sand} + \% \text{ Clay})$$

Where H1 is the first hydrometer reading after 40 seconds; H2 is the second hydrometer reading after three hours, T1 is the first temperature reading after 40 seconds and T2 is the second temperature reading after three hours. The textural class was determined using the textural triangle.

3.5.1.3 Field Infiltration (I)

Infiltration is the amount of water that enters the soil from the surface per unit area. A study on infiltration was conducted in the field using the single-ring infiltrometer (Klute, 1986). Before the infiltration measurements were made, soil samples were taken to determine the moisture content of the soil at each spot. A cylindrical infiltrometer of 10 cm in diameter and height of 30 cm was driven into the soil to a depth of 15 cm with the aid of a wooden plank and a mallet. The soil surface was mulched with plant debris (dry

grass and leaves) to prevent the disturbance of the soil surface (dispersion and clogging of soil pores) and false measure of infiltration amount when the soil surface in the infiltrometer was instantaneously ponded with water. A constant water head of 5 cm from the soil surface was maintained in the cylinder with water from a 1000 ml (1 litre) measuring cylinder. The volume of water that was used to maintain a constant head of 5 cm in the infiltrometer at a chosen time was a representation of the amount that entered the soil at the stipulated time. The vertical infiltration was measured from the cylinder for a period of 60 minutes for each spot. The initial infiltration was measured at 30-second intervals for the first five minutes when infiltration was very fast after which the interval was increased to 60, 180 and 300 seconds respectively as infiltration slowed down over time towards the steady state.

3.5.1.4 Soil pH

Soil pH was determined using a pH glass electrometer. Ten grams (10 g) of the soil sample was weighed into a 50 ml beaker and 25 ml of distilled water (1:2.5 soil: water) was added. The solid-liquid mixture was then stirred several times for 30 min and allowed to stand for the suspended clay to settle out. Using a standard solution of pH 4.0 and 7.0, the pH meter was standardized. The standardized electrode was then inserted into the supernatant of the suspension to measure the pH of the soil sample.

3.5.1.5 Organic Carbon Determination

The wet combustion method of Walkley and Black (Walkley *and* Black, 1934) was used to determine the organic carbon content of the soil. Ten millimeters of 0.167 M potassium

dichromate (K2Cr2O7) solution and 20 ml concentrated sulphuric acid (H_2SO_4) were added to a 1g soil sample (which had been sieved through a 0.5 mm sieve) in an Erlenmeyer flask. The flask was then swirled to ensure full contact of the soil with the solution after which it was allowed to stand for 30 mins. The unreduced K2Cr2O7 remaining in the solution after the oxidation of the oxidizable organic material in the soil sample was titrated against 0.2 N ferrous ammonium sulfate solution after adding 5 ml of orthophosphoric acid and 2 ml of barium diphenylamine sulfate indicator.

$$\%\ \text{Organic Carbon} = \frac{(\text{Blank} - \text{ titre value}) \text{ x } 1.33 \text{ x } 0.003\text{x } 100}{\text{weight of soil(g)}}$$

Carbon = 58 % of organic matter. Therefore, organic matter is determined by;

$$Organic\ matter\ (OM) = \frac{\text{Carbon x } 100}{58}$$

3.5.1.6 Total P Determination in Soil

Total P was determined by digesting 2 g of sieved soil with 25 ml of a mixture of concentrated HNO3 and 60 % HClO4 prepared in a ratio of 2:3. The solution was heated on a digestion rack until the solution became colourless. The digest was cooled, diluted, and filtered through a Whatman filter paper No. 42 into a 250 ml volumetric flask and made to cool. Phosphorus in the filtrate was determined using the molybdate-ascorbic acid method of Watanabe and Olsen (Watanabe *and* Olsen, 1965). Suitable aliquots of the filtrate were taken (in duplicate) into 50 ml volumetric flasks containing distilled water. The pH was adjusted using a P-nitrophenol indicator and neutralized with a few drops of 4 M ammonium hydroxide (NH_4OH) until the solution turned yellow. The solution was diluted to about 40 ml with distilled water after which 8 ml of reagent B was added and

made to volume with more distilled water. The solution was mixed thoroughly by shaking and allowed to stand for 15 minutes for the colour to stabilize. A blank was prepared with distilled water and 8 ml of reagent B. The method was calibrated using a 25 mg /L standard P solution in the same manner as above. The intensity of the blue colour was measured using the Philips PU 8620 spectrophotometer at a wavelength of 712 nm. P was calculated using the formula:

$$P = \frac{(\text{Sp. Reading} - \text{Blank}) \times \text{Vol. of extractant}}{\text{Vol. of aliquot} \times \text{weight of soil}}$$

3.5.1.7 Total Nitrogen Determination

Half of a gram (0.5 g) of air-dried soil was weighed into a 250 ml Kjeldahl flask and a tablet of digestion accelerator, selenium catalyst, was added followed by 5 ml of concentrated H_2SO_4. The mixture was digested until the digest became clear. The flask was then cooled and its content was transferred into a 100 ml volumetric flask with distilled water and quantitatively made up to volume. A 5 ml aliquot of the digest was taken into a Markham distillation apparatus. Five ml of 40 % NaOH solution was added to the aliquot and the mixture was distilled. The distillate was collected in 5 ml of 2 % boric acid. Three drops of a mixed indicator containing methyl red and methylene blue were added to the distillate in a 50 ml Erlenmeyer flask and then titrated against 0.01M HCl acid solution (Bremner, 1965). The % nitrogen was calculated as:

$$\%N = \frac{\text{Molarity of HCl x Titre value} \times 0.014 \times \text{volume of extractant}}{\text{Weight of soil sample x volume of aliquot}} \times 100$$

where 0.014 = milliequivalent of nitrogen

3.5.1.8 Available P determination

Soil-available phosphorus was determined using the Bray P1 method (Olsen and Sommers, 1982). Two grams of air-dried soil was weighed into a 50 ml shaking bottle. Twenty millilitres (20) ml of Bray^{-1} solution was added as an extracting agent and the mixture was shaken for ten minutes and then filtered through Whatman No. 42 filter paper. Ten millilitres (10 ml) of the filtrate were pipetted into a 25 ml volumetric flask and 1 ml each of molybdate reagent and reducing agent was added for colour development. The absorbance was measured at 660nm wavelength on a spectronic 21D spectrophotometer. The concentration of P was obtained from a standard curve.

$$P\ (\frac{\text{mg}}{kg}) = \frac{(\text{a} - \text{b}) \times\ 20 \times 10 \times mcf}{w}$$

Where: a= mg/1 P in sample extract, b = mg/l P in blank, w = sample weight in gram, mcf = moisture correction factor, 20 = volume of extracting solution, 10 = final volume of sample solution.

3.5.1.9 Determination of Available Potassium (K)

The flame photometric method by the Soil Science Society of Ghana (2009) was used. Appropriate aliquots of standard samples digest and blank were taken. K-emission in an air-propane flame at 768 nm wavelength was measured. The concentration of K was calculated as:

$$\%K = \frac{(\text{a} - \text{b}) \times m}{factor}$$

Where a = measured mgK/ ml in samples, b = measured mgK/ml in blank, m = moisture correction factor, $factor = \frac{200}{\text{Dilute factor}}$

3.5.1.10 Cation Exchange Capacity

Weigh 2.5 g of soil into an extraction bottle. 40 ml of 1.0 M ammonium acetate solution at pH 7.0 was added to the soil in the extraction bottle. The contents were shaken in a tabletop shaker at 180 RPM for 5 minutes to ensure thorough mixing and exchange of cations between the soil and the ammonium ions in the solution. Then, the mixture was poured into leachate tubes. The leachate tubes were arranged in a centrifuge machine and centrifuged for 5 minutes at 4000 RPM. This step is to separate the soil particles from the solution. The supernatant (liquid) was carefully removed from the tubes, leaving the soil particles at the bottom. Any non-adsorbed NH4+ ions were washed off by adding and washing with methanol. This step ensures that only cations held by the soil's cation exchange sites are considered for CEC determination. After washing, the NH4+-saturated soil was leached four times with acidified 1.0 M KCl. This step replaces the adsorbed ammonium ions with potassium ions from the KCl solution. Collect the KCl filtrate after each leaching step. The Ammonium ion concentration (mol/L) in the KCl filtrate was measured using an ELIT 9808 ion analyzer. The CEC of the soil was calculated in cmol/kg based on the ammonium ion concentration in the KCl filtrate and the amount of soil used in the extraction bottle. The formula for calculating CEC can be expressed as:

$$CEC = \frac{(\mathrm{C1} - \mathrm{C2}) \times \mathrm{V} \times 1000}{w}$$

Where:

CEC is the cation exchange capacity in cmol/kg. 54C1 is the initial concentration of ammonium ions in the ammonium acetate solution before it comes into contact with the soil (mol/L).

C2 is the final concentration of ammonium ions in the KCl filtrate after leaching with 1.0 M KCl (mol/L).

V is the volume of KCl filtrate used (L).

W is the weight of the soil sample used (kg).

3.5.1.11 Exchangeable Bases

Ten grams of the soil sample were weighed into a 200 ml centrifuge tube and 100 ml of 1 N neutral ammonium acetate (NH4OAc at pH 7.0) solution was added. The suspension was shaken for 1 hour, and filtered through a Whatman No. 42 filter paper. Suitable aliquots of the extract were used for the determination of exchangeable cations.

3.5.1.12 Exchangeable Calcium and Magnesium

An aliquot of 10 ml of the extract was taken into a conical flask and 10 ml of 10 % KOH and 1 ml of methylamine were added. Three drops of KCN solution and a few crystals of Cal-red indicator were added. The mixture was then titrated with 0.2 N EDTA using Eriochrome Black T (EBT) as an indicator.

Ten ml of the extract was transferred into a conical flask and titrated with EDTA using Cal-red as an indicator. Exchangeable Mg was estimated by difference. Exchangeable potassium and sodium were determined by flame photometry.

3.5.1.13 Exchangeable Acidity

Twenty-five ml of 1 M KCl was added to 10 g of soil sample in a 250 ml conical flask. The content was mixed by swirling and then allowed to stand for 30 min. The suspension was filtered through a Whatman No. 42 filter paper into a volumetric flask. The soil was consecutively leached with five (batches of 25 ml 1 M KCl to a total volume of about 150 ml. Four drops of phenolphthalein were added to the leachate and titrated against 0.1M NaOH to the first permanent pink endpoint. Potassium chloride extractable exchangeable acidity was calculated C mol kg^{-1} KCl acidity = (ml NaOH sample - ml NaOH blank) x M x 100 / Sample weight) where M is the Molarity of NaOH. For the estimation of Al^{3+} and H^{+}, the titre for NaOH was recorded; 10 ml NaF was added to the NaOH and titrated with 0.1M HCl until the pink colour disappeared. The solution was then allowed to stand for about 30 min and additional HCl was added to the clear endpoint (Thomas, 1982)

3.6 Maize Phenological Data

3.6.1 Percentage crop establishment

Percent crop establishment was measured by counting the number of plants that had established in each 3m x 3m plot and the percentage of crops established were subsequently measured. Percentage crop establishment was determined as the ratio of established plants to the total number of plants expected to be established from the four middle rows of each treatment plot.

3.6.2 Days to 50% tasseling and silking

The number of days to 50% tasseling and silking was determined on the plants within the (3mx3m) of each plot in (Atebubu and Dormaa Ahenkro). It was determined by counting the number of days from sowing to when 50% of plants within the 3mx3m per plot had tasseled or silked.

3.7 Maize Vegetative Growth Data

The vegetative growth data taken were plant height, number of leaves per plant, shoot dry weight, root dry weight, stem diameter, leaf chlorophyll content.

3.7.1 Plant height

Five plants per plot were randomly selected and tagged from the (3 m x 3 m) area per plot for data collection at both experimental locations (Atebubu, Dormaa Ahenkro). Plant height was measured using a meter rule as a vertical distance from the plant collar to the tip of the apical leaf at five (5) and seven (7) weeks after planting and at two-weeks interval

and the mean plant height was estimated for each treatment.

3.7.2 Number of leaves Per Plant

The total number of leaves per plant was counted on the five tagged plants from the 3 m x 3 m area per plot at five and seven weeks after planting and at two-weeks interval and the mean leaf number was computed.

3.7.3 Shoot and root dry weight

The dry weight of the shoots and roots per plant were determined after a sample of 200g has been oven-dried for 72 hours at a temperature range of 70^0-75^0C. Dried samples were then weighed using an electronic weighing scale and the mean dry weight computed.

3.7.4 Stem Diameter

Stem diameter of the five randomly selected tagged plants from the 3 m x 3 m area per plot was measured at about 5cm above ground level from the base of the plant at 5 and 7 WAP and at two-weeks interval using a vernier caliper and mean estimated.

3.7.5 Leaf chlorophyll content

The leaf chlorophyll content was measured from the 5th and 6th leaves of each of the 5 randomly selected tagged plants within 3 m x 3 m area per plot at 5 and 7 WAP. The leaf chlorophyll content was determined using the SPAD meter.

3.7.6 Crop growth rate

This was measured in g/m^2/day using the formular as described by Memon *et al.* (2007).

CGR =$(\frac{1}{GA})$ $\boldsymbol{X}$ $(\frac{W2-W1}{T2-T1})$, Where CGR= crop growth rate; W_1=total dry matter at first harvest; W_2= total dry matter at second harvest; T_1= days of observation at first harvest; T_2= days of observation at second harvest.

3.7.7 Relative Growth Rate

This was measured in g/m^2/day using the formular described by Memon *et al.* (2007).

RGR =$(\frac{InW2-InW1}{T2-T1})$, Where RGR=relative growth rate; W_1=total dry matter at first harvest; W_2= total dry matter at second harvest; T_1= days of observation at first harvest; T_2= days of observation at second harvest; In=Natural log.

3.8 Yield and Yield Components

Yield and yield components data were taken from the (3mx3m) area per plot for determination of, number of plants harvested, Yield (t/ha), 100-seed weight, number of cobs per plant and per plot, cob weight per plot, biomass yield weight and harvest index.

3.8.1 Hundred seed weight

Hundred seeds were randomly sampled from (3mx3m) area of each plot after shelling, weighed using an electronic weighing scale and the mean was estimated.

3.8.2 Number of cobs per plot

The number of cobs from tagged and untagged plants from 3 m x 3 m area were counted

and the mean was estimated as the total number of cobs per plot.

3.8.3 Cob weight per plot

All cobs within the (3m x 3m) area of each plot was weighed at harvest using a salter suspended weigher with model number 235. The mean was estimated.

3.8.4 Biomass yield weight per plot at harvest

Biomass weight per plot was determined at harvest using a salter suspended weigher with model number 235 to weigh the biomass for each plot. The means were estimated accordingly.

3.8.5 Cob length

Five cobs were randomly selected from the (3mx3m) area per plot and the length was determined from the base of the cob to the tip with a meter rule. The means were estimated.

3.8.6 Harvest index

Harvest index was determined by the formula below as described by Amanullah *et al*. (2019).

Harvest index $=\frac{\text{Grain yield (kg)}}{Biological\ yield}$

3.8.7 Yield (kg/ha)

The yield within the harvestable area of each plot was calculated and computed in t/ha by

using the formula described by Amanullah *et al*. (2019).

$$\text{Yield (kg/ha)} = \frac{Yield\ (kg)}{Harvestable\ area\ (m^2)} \text{ x } \frac{10{,}000\ m^2}{1000}$$

3.9 Statistical Analysis

Data collected were subjected to the Analysis of Variance (ANOVA) model using GenStat Release Version 18.1 and treatment means compared using Tukey's Highest Significance Difference (HSD) at 5% probability level. The relationship between vegetative and yield and yield component parameters were determined by using Pearson correlation.

CHAPTER FOUR

RESULTS

4.1 Soil Chemical and Physical Properties

4.1.1 Initial Chemical Properties and Textural Class of Soil at Atebubu and Dormaa Ahenkro

Table 4.1 shows the nutrient contents of the soils at a depth of 0-20 cm before planting at Atebubu and Dormaa Ahenkro. The soil was slightly acidic and sandy loam in texture at Atebubu according to the guide to interpretation of soil analytical data in Ghana (Appendix 1). The nitrogen content, potassium, organic matter level, and phosphorus levels were low in the soils at Atebubu. Calcium, manganese and magnesium contents were high (Appendix 1). Similarly, at Dormaa Ahenkro, the soil had a pH of 5.5 which was acidic and the texture was sandy loam (Appendix 1). The nitrogen content, organic matter level, phosphorus, potassium and magnesium levels were low. Calcium, manganese and magnesium contents were high (Appendix 1).

Table 4.1: Initial Chemical Properties of Soil at Atebubu and Dormaa Ahenkro

Parameter	Atebubu	Dormaa Ahenkro
pH (1:2.5 H_2O)	6.49	5.5
Organic C (%)	0.87	0.87
Total N (%)	0.06	0.06
OM (%)	1.5	1.5
Ca^{2+} (ppm)	349	349
Mg^{2+} (ppm)	68	68
Exchangeable K^{+} ppm	<40	<40
Boron (ppm)	<0.5	<0.5
Available P (ppm)	0-10	0-10
Manganese (ppm)	118	118
Zinc (ppm)	1.1	1.1
CEC me/100g	3.9	3.9
Iron (ppm)	106	106
Soil texture	Sandy loam	Sandy loam

4.1.2 Initial Soil Physical Properties at Atebubu and Dormaa Ahenkro

Table 4.2 shows the initial physical properties of soils at Atebubu and Dormaa Ahenkro. Atebubu had a slightly higher bulk density of 1.34 g/cm^3 compared to Dormaa Ahenkro which had 1.32 g/cm^3 whereas the porosity values indicated that Dormaa Ahenkro had a higher porosity of 46.5% compared to Atebubu with 45.3%. The particle density values were quite similar, with Atebubu recording 2.62 g/cm^3 and Dormaa Ahenkro (2.64 g/cm^3). The infiltration rate at Dormaa Ahenkro was higher 40.7 mm/h compared to Atebubu (15.5 mm/h). The textural classification of the soil at both locations was sandy loam.

Table 3.2: Initial Soil Physical Properties at both Atebubu and Dormaa Ahenkro

	Atebubu	Dormaa Ahenkro
Bulk density (g/cm^3)	1.34	1.32
Porosity (%)	45.3	46.5
Particle density (g/cm^3)	2.62	2.64
Infiltration mm/h	15.5	40.7
Sand (%)	52.3	48.6
Silt (%)	35.4	43.8
Clay (%)	12.3	7.6
Texture classification	Sandy loam	Sandy loam

4.1.3 Final Soil Chemical and Physical Properties across both locations

Table 4.3 shows the final soil chemical and physical properties after harvesting of maize at Atebubu. The soil pH (1:2.5 H_2O) remained slightly acidic for all the treatments (Appendix 1). Nitrogen and phosphorus levels remained low across all the treatments. Organic matter and potassium contents were moderate. Calcium, manganese and magnesium contents remained high in all the treatments (Appendix 1). Boron and Zinc contents remained same. There was a slight increase in CEC and Iron contents across the treatments (Appendix 1). Soil texture remained sandy loam.

From Table 4.4, the soil pH (1:2.5 H_2O) remained acidic after harvesting of maize at Dormaa Ahenkro. Nitrogen, organic matter, potassium and phosphorus levels were low across all the treatments. Calcium, manganese and magnesium contents remained high in all the treatments (Appendix 1). Boron content remained same. There was a slight increase in CEC, Zinc and Iron contents across the treatments (Appendix 1). Soil texture remained sandy loam.

Table 4.3: Final Soil Chemical and Physical Properties at Atebubu during the 2022 Growing Season

Parameters	Treatments							
	Control	*Granule (120-40-40 kg/ha NPK)*	*Granule (116-48-46 kg/ha NPK)*	*Granule (86-48-46 kg/ha NPK)*	*Granule (55-48-46 kg/ha NPK)*	*Briquette (116-48-46 kg/ha NPK)*	*Briquette (86-48-46 kg/ha NPK)*	*Briquette (55-48-46 kg/ha NPK)*
pH (1:2.5 H_2O)	6.3	6.1	6.3	6.3	6.1	6.3	6.3	6.3
Organic C (%)	0.87	0.82	0.88	0.81	0.88	0.87	0.86	083
Total N (%)	0.07	0.08	0.07	0.07	0.06	0.07	0.07	0.07
OM (%)	1.8	1.8	1.7	1.8	1.8	1.6	1.7	1.7
Ca^{2+} (ppm)	800	800	788	798	799	801	800	800
Mg^{2+} (ppm)	130	130	130	139	130	128	129	130
Exchangeable K^{+} ppm	50	51.5	50	50	50.2	50	51	50
Boron (ppm)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Available P (ppm)	0-10	0-11	0-10	0-11	0-10	0-10	0-10	0-10
Manganese (ppm)	110	120	120	125	110	120	130	120
Zinc (ppm)	<1	<1	<2	<2	<1	<1	<1	<1
CEC me/100g	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Iron (ppm)	140	140	140	140	140	140	140	140
Soil texture	Sandy loam							

Table 4.4: Final Soil Chemical and Physical Properties at Dormaa Ahenkro during the 2022 Growing Season

Parameters	Treatments							
	Control	*Granule (120-40-40 kg/ha NPK)*	*Granule (116-48-46 kg/ha NPK)*	*Granule (86-48-46 kg/ha NPK)*	*Granule (55-48-46 kg/ha NPK)*	*Briquette (116-48-46 kg/ha NPK)*	*Briquette (86-48-46 kg/ha NPK)*	*Briquette (55-48-46 kg/ha NPK)*
pH (1:2.5 H_2O)	5.5	5.2	5.3	5.3	5.1	5.3	5.2	5.1
Organic C (%)	0.87	0.82	0.88	0.81	0.88	0.87	0.86	083
Total N (%)	0.06	0.08	0.07	0.05	0.06	0.07	0.07	0.07
OM (%)	1.5	1.4	1.5	1.3	1.4	1.6	1.5	1.3
Ca^{2+} (ppm)	349	400	288	328	339	321	330	334
Mg^{2+} (ppm)	68	69	71	65	66	65	69	64
Exchangeable K^{+} ppm	<40	<41.5	<40	<39.5	<40.2	<48	<41	<38
Boron (ppm)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Available P (ppm	0-10	0-11	0-10	0-11	0-9	0-10	0-9	0-10
Manganese (ppm)	118	118	117	116	117	116	118	118
Zinc (ppm)	1.1	1	2.1	2	1	1	1	1
CEC me/100g	3.9	3.3	4.3	3.4	4.2	3.2	3.3	3.4
Iron (ppm)	106	110	109	106	108	104	105	107
Soil texture	Sandy loam							

4.2 Climatic Conditions at the Experimental Sites

Table 4.5 shows the climatic data at Atebubu during the experimental period. The total rainfall during the experimental period from April to August was 909.00 mm with the peak in May and June, 2022. The monthly temperature during the experimental period varied between 24.9 °C and 32.3 °C. However, the highest monthly temperature of 34.2 °C and the lowest of 21.3 °C was recorded in April and June, 2022 respectively. The average relative humidity at 18.00hr and 15.00hr from April to August 2022 was 73.2% and 61.6 % respectively. The average windspeed during the experimental period was 4.3 m/s.

Table 4.6 shows the climatic condition recorded at Dormaa Ahenkro during the experimental period. From April to August. The total rainfall measured was 980 mm, with the peak occurring in May and April 2022. Throughout the study period, monthly temperatures ranged from 22.6 °C to 32.0 °C. Notably, April and June 2022 recorded the highest and lowest monthly temperatures of 34.5 °C and 21.6 °C, respectively. The average relative humidity at 18:00 hr and 15:00 hr from April to August 2022 was 71.00% and 55.00%, respectively. The average windspeed over the course of the experiment was recorded at 4.3 m/s (Table 8).

Table 4.5: Climatic Data for 2022 Major Rainy Season for Atebubu during the 2022 Growing Season

Months	Rainfall (mm)	Temp (Max)°C	Temp (Min)°C	Relative Humidity (%) 18.00hr	Relative Humidity (%) 15.00hr	Wind speed (m/s)
April, 2022	170	34.2	22.7	72.8	53.2	4.6
May	273	32.0	21.9	71.8	59.3	4.5
June	210	30.1	21.3	73.7	65.4	4.1
July	114	31.5	28.9	73.1	66.7	4.7
August	142	33.5	29.5	74.5	63.5	3.6
Total	**909**					

Table 4.6: Climatic Data for 2022 Major Rainy Season for Dormaa Ahenkro during the 2022 Growing Season

Months	Rainfall (mm)	Temp (Max)°C	Temp (Min)°C	Relative Humidity (%) 18.00hr	Relative Humidity (%) 15.00hr	Wind speed (m/s)
April, 2022	230	34.5	22.3	65.5	45.4	4.3
May	277	32.3	21.7	72.3	54.6	4.2
June	218	31.9	21.6	75.0	62.3	4.4
July	116	30.5	22.4	72.5	59.2	4.1
August	139	30.8	24.8	68.9	54.6	4.5
Total	**980**					

4.3 Phenology of Maize

4.3.1 Percentage Crop Establishment

Table 4.7 shows no significant ($P \geq 0.05$) difference among treatments with regard to percentage crop establishment although at Atebubu, the highest percentage crop establishment was recorded by Briquette (116-48-46 kg/ha NPK) and at Dormaa Ahenkro Granule (116-48-46 kg/ha NPK) recorded the highest. Atebubu had higher percentage number of established plants than Dormaa Ahenkro. There was no significant ($P \geq 0.05$) effects of location x treatment interactions on percentage crop establishment.

Table 4: Effect of different rates of NPK fertilizer (Granules and Briquettes) on Percentage Crop Establishment at Atebubu and Dormaa Ahenkro during the 2022 Growing Season

Treatment	Percentage crop establishment	
	Atebubu	Dormaa Ahenkro
No Fertilizer (control)	86.25	81.25
Granule (120-40-40 kg/ha NPK)	90.00	88.50
Granule (116-48-46 kg/ha NPK)	96.25	96.00
Granule (86-48-46 kg/ha NPK)	94.25	92.13
Granule (55-48-46 kg/ha NPK)	91.00	90.63
Briquette (116-48-46 kg/ha NPK)	97.13	94.63
Briquette (86-48-46 kg/ha NPK)	92.75	90.75
Briquette (55-48-46 kg/ha NPK)	93.63	91.18
Mean	**92.66**	**90.63**
HSD (P ≤ 0.05)	**6.78**	**9.12**
CV (%)	**3.08**	**4.24**
Treatment	= NS	
Location	= 1.68**	
Location x Treatment	= NS	

4.3.2 Days to 50% Tasseling

There was no significant (P≥0.05) differences among treatments with regard to days to 50% tasseling (Table 4.8). Though there was no significant (P≥0.05) differences, Granule (55-48-46 kg/ha NPK) recorded the lowest days to 50% tasseling across both locations. Least mean number of days to 50% tasseling was recorded in Dormaa Ahenkro than in Atebubu. There was no significant (P≥0.05) difference between location x treatment interactions in days to 50% tasseling.

4.3.3 Days to 50% Silking

There were no significant (P≥0.05) differences among treatments in days to 50% silking although maize plants without fertilizer recorded lower number of days to 50% silking than

plants that received the different Briquette and Granule (120-40-40 kg/ha NPK) at Atebubu (Table 4.8). Least mean number of days to 50% silking was recorded in Atebubu than in Dormaa Ahenkro. There was no significant (P≥0.05) difference between location x treatment interactions in days to 50% silking.

Table 4.8 : Effect of different rates of NPK fertilizer (Granules and Briquettes) on days to 50% tasseling and silking at Atebubu and Dormaa Ahenkro

Treatment	Days to 50% tasseling		Days to 50% silking	
	Atebubu	Dormaa Ahenkro	Atebubu	Dormaa Ahenkro
No Fertilizer (control)	51.25	52.20	55.00	56.75
Granule (120-40-40 kg/ha NPK)	52.50	50.50	55.25	55.25
Granule (116-48-46 kg/ha NPK)	52.00	51.00	54.50	56.55
Granule (86-48-46 kg/ha NPK)	51.50	51.50	54.50	57.45
Granule (55-48-46 kg/ha NPK)	51.00	49.50	54.50	53.55
Briquette (116-48-46 kg/ha NPK)	51.75	52.50	55.35	57.25
Briquette (86-48-46 kg/ha NPK)	53.50	50.75	57.75	54.75
Briquette (55-48-46 kg/ha NPK)	52.41	51.67	56.67	56.74
Mean	**51.99**	**51.20**	**55.44**	**56.04**
HSD (P ≤ 0.05)	**NS**	**NS**	**NS**	**NS**
CV (%)	**3.44**	**1.45**	**3.80**	**1.34**
Treatment	= NS		NS	
Location	= 0.72**		0.58**	
Location x Treatment	= NS		NS	

4.4 Vegetative Growth

4.4.1 Plant Height

Table 4.9 shows the results for plant height at 5 weeks after planting (5WAP) and 7 weeks after planting (7WAP). There were significant (P≤0.05) differences among treatments at Atebubu and Dormaa Ahenkro at 5 WAP. Maize that received Granule (55-48-46 kg/ha NPK) recorded the tallest plant at Atebubu at 5 WAP and was significantly different from

the control in plant height. Maize plants that received Granule (116-48-46 kg/ha NPK) recorded the tallest plants which differed significantly from the control, Granule (55-48-46 kg/ha NPK) and Briquette (55-48-46 kg/ha NPK) at 5 WAP at Dormaa Ahenkro.

At 7 WAP, maize plants that received Granule (116-48-46 kg/ha NPK) recorded significantly taller plants than the control and Briquette (55-48-46 kg/ha NPK) at both locations. Taller plants were measured in Dormaa Ahenkro than in Atebubu at both 5 and 7 WAP. There were significant (P≤0.05) differences between location x treatment interactions at both 5 WAP and 7 WAP.

Table 4.9: Effect of different rates of NPK fertilizer (Granules and Briquettes) on Plant height at Atebubu and Dormaa Ahenkro

Treatment	Plant height (cm)			
	5 WAP		**7 WAP**	
	Atebubu	Dormaa Ahenkro	Atebubu	Dormaa Ahenkro
No Fertilizer (control)	67.77c	83.55d	123.48d	125.58d
Granule (120-40-40 kg/ha NPK)	83.38b	115.95abc	155.45cd	184.85abc
Granule (116-48-46 kg/ha NPK)	95.09ab	134.38a	206.50a	206.50a
Granule (86-48-46 kg/ha NPK)	83.68b	109.96abcd	173.80abc	202.88ab
Granule (55-48-46 kg/ha NPK)	106.85a	96.20cd	196.23ab	162.42c
Briquette (116-48-46 kg/ha NPK)	94.57b	123.28abc	183.13abc	206.55a
Briquette (86-48-46 kg/ha NPK)	88.70b	129.50ab	161.45c	202.88ab
Briquette (55-48-46 kg/ha NPK)	86.40b	102.27bcd	172.40bc	175.60bc
Mean	**88.31**	**111.89**	**171.23**	**191.67**
HSD (P ≤ 0.05)	**12.10**	**27.75**	**34.08**	**30.72**
CV (%)	**5.78**	**10.46**	**8.37**	**7.02**
Treatment	**= 14.96****		**23.26****	
Location	**= 4.74****		**7.37****	
Location x Treatment	**= 24.13****		**37.51****	

4.4.2 Number of leaves per plant

The number of leaves per plant at 5 weeks after planting (5WAP) and 7 weeks after planting (7WAP) showed significant differences among the treatments (Fig 4.1). At 5 WAP the maize plants that received Granule (116-48-46 kg/ha NPK) recorded the highest number of leaves per plant that differed significantly from the control and Briquette (55-48-46 kg/ha NPK) at both Atebubu and Dormaa Ahenkro (Figure 4.1). At 7 WAP, maize plants that received Granule (116-48-46 kg/ha NPK) recorded significantly higher number of leaves per plant than the control, Granule (120-40-40 kg/ha NPK), Briquette (55-48-46 kg/ha NPK) and Granule (55-48-46 kg/ha NPK) at Atebubu. Similar trend was observed at Dormaa Ahenkro, where the maize plants that received Granule (116-48-46 kg/ha NPK) recorded significantly higher number of leaves per plant than the control, Granule (55-48-46 kg/ha NPK) and Briquette (55-48-46 kg/ha NPK) (Figure 4.1).

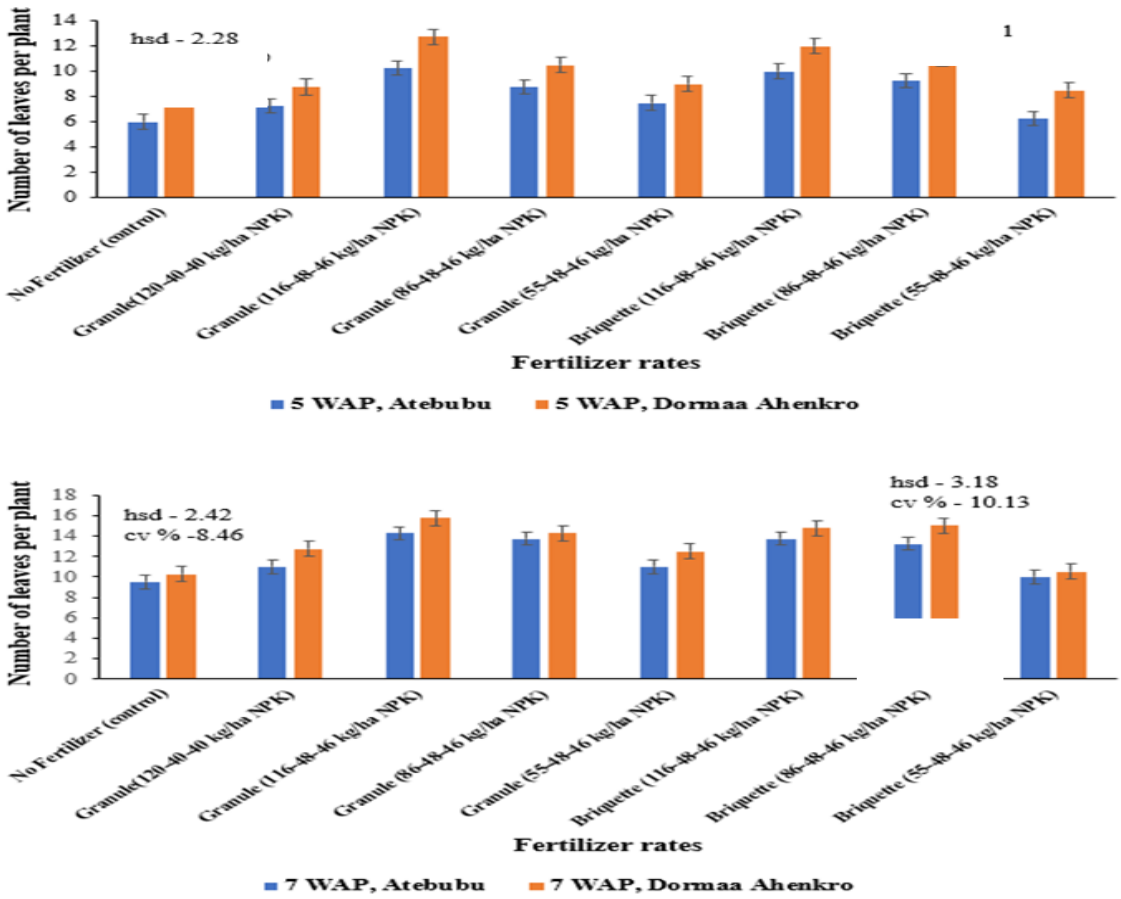

Figure 4.1: Effect of different rates of NPK fertilizer (Granules and Briquettes) on Number of leaves per plant at 7WAP and 9WAP at Atebubu and Dormaa Ahenkro during the 2022 Growing Season

4.4.3 Leaf Chlorophyll Content

The results on leaf chlorophyll content of the maize plants at 5 weeks after planting (5WAP) and 7 weeks after planting (7WAP) is presented in Table 12. There were significant ($P \leq 0.05$) differences among treatments at 5 WAP across both locations. Maize plants that received Granule (55-48-46 kg/ha NPK) recorded the greatest leaf chlorophyll content in Atebubu at 5 WAP and was significantly different from plants that received Granule (120-40-40 kg/ha

NPK) and the control. At Dormaa Ahenkro, maize plants that received Briquette (86-48-46 kg/ha NPK) had the greatest (47.95 spad) leaf chlorophyll content and was significantly different from plants that received Briquette (116-48-46 kg/ha NPK) and the control at 5 WAP.

Maize plants that received Granule (55-48-46 kg/ha NPK) had significantly higher leaf chlorophyll content than plants that received Granule (120-40-40 kg/ha NPK) and the control at 7 WAP in Atebubu. Maize plants that received briquette (86-48-46 kg/ha NPK) recorded the highest leaf chlorophyll content which differed significantly from plants that received Granule (120-40-40 kg/ha NPK) and the control plot at 7 WAP in Dormaa Ahenkro (Table 12). Higher leaf chlorophyll content was recorded in Dormaa Ahenkro than in Atebubu at 5 WAP and 7 WAP. There was a significant ($P \leq 0.05$) difference between the interaction of location and treatment in leaf chlorophyll content across both locations (Table 4.10).

Table 4.10: Effect of different rates of NPK fertilizer (Granules and Briquettes) on Leaf chlorophyll content at Atebubu and Dormaa Ahenkro

Treatment	Leaf chlorophyll content (spad)			
	5 WAP		7 WAP	
	Atebubu	Dormaa Ahenkro	Atebubu	Dormaa Ahenkro
No Fertilizer (control)	36.45bc	37.25bc	37.98c	42.53c
Granule (120-40-40 kg/ha NPK)	33.78c	46.63ab	39.23bc	49.53bc
Granule (116-48-46 kg/ha NPK)	42.59a	45.98ab	42.43abc	61.98ab
Granule (86-48-46 kg/ha NPK)	40.26ab	46.85a	41.08abc	58.30ab
Granule (55-48-46 kg/ha NPK)	44.27a	44.83ab	45.33a	50.70abc
Briquette (116-48-46 kg/ha NPK)	42.89a	31.10c	43.05abc	58.35ab
Briquette (86-48-46 kg/ha NPK)	40.01ab	47.95a	41.10abc	62.90a
Briquette (55-48-46 kg/ha NPK)	43.93a	42.08ab	43.68ab	53.78abc
Mean	**40.52**	**42.82**	**41.74**	**54.76**
HSD ($P \leq 0.05$)	**5.76**	**9.42**	**5.29**	**12.89**
CV (%)	**6.00**	**9.27**	**5.34**	**9.93**
Treatment	= 7.13**		7.41**	
Location	= 2.26**		2.35**	
Location x Treatment	= 11.50**		11.96**	

4.4.4 Stem Diameter

Results on stem diameter of maize plants are shown in Table 4.11. Significant differences were observed at 5 weeks after planting (5 WAP and 7 WAP) at Atebubu and Dormaa Ahenkro in stem diameter. Maize plants that received Granule (116-48-46 kg/ha NPK) recorded significantly wider stems than plants that received Granule (120-40-40 kg/ha NPK), Granule (55-48-46 kg/ha NPK), Briquette (55-48-46 kg/ha NPK), and the control in Atebubu at 5 WAP. Again, at Dormaa Ahenkro, maize plants that received Granule (116-48-46 kg/ha NPK) produced plants with significantly wider stem diameter than plants that received Briquette (55-48-46 kg/ha NPK) and the control at 5 WAP.

At 7 WAP at Atebubu, maize plants that received Granule (116-48-46 kg/ha NPK) produced significantly wider stem diameter than plants that received Briquette (55-48-46 kg/ha NPK) and the control. Similarly, at Dormaa Ahenkro, amending soils with Granule (116-48-46 kg/ha NPK) produced significantly wider stems than plants that received Granule (120-40-40 kg/ha NPK), Granule (55-48-46 kg/ha NPK), Briquette (55-48-46 kg/ha NPK), and the control at 7 WAP. Wider stem diameter was recorded at Dormaa Ahenkro than at Atebubu at 5 WAS and 7 WAP. Location x treatment interaction had no significant effect on stem diameter at 5 WAP. There was a significant ($P \leq 0.05$) difference between the interaction of location and treatment in stem diameter at 7 WAP (Table 4.11).

Table 4.11: Effect of different rates of NPK fertilizer (Granules and Briquettes) on Stem diameter at Atebubu and Dormaa Ahenkro

Treatment	Stem diameter (cm)			
	5 WAP		7 WAP	
	Atebubu	Dormaa Ahenkro	Atebubu	Dormaa Ahenkro
No Fertilizer (control)	1.33c	1.50c	1.50c	1.68d
Granule (120-40-40 kg/ha NPK)	1.40c	1.68bc	1.67bc	1.95cd
Granule (116-48-46 kg/ha NPK)	1.88a	2.10a	2.08a	2.35a
Granule (86-48-46 kg/ha NPK)	1.75ab	2.00ab	1.90ab	2.30ab
Granule (55-48-46 kg/ha NPK)	1.58bc	1.60c	1.70bc	1.83d
Briquette (116-48-46 kg/ha NPK)	1.80ab	1.85abc	2.00a	2.00bcd
Briquette (86-48-46 kg/ha NPK)	1.80ab	1.98ab	2.00a	2.23abc
Briquette (55-48-46 kg/ha NPK)	1.48c	1.53c	1.75b	1.73d
Mean	**1.63**	**1.78**	**1.83**	**2.01**
HSD ($P \leq 0.05$)	**0.27**	**0.36**	**0.23**	**0.33**
CV (%)	**6.95**	**8.63**	**5.31**	**6.93**
Treatment	= 0.22**		0.20**	
Location	= 0.07**		0.06**	
Location x Treatment	= NS		0.32**	

4.4.5 Shoot Dry Weight

Table 4.12 shows the results for shoot dry weight per plant at 7 and 9 WAP across both locations. At 7 WAP in Atebubu, maize plant that received Granule (116-48-46 kg/ha NPK) recorded the heaviest shoot dry weight per plant and was significantly ($P \leq 0.05$) different from plants that received different rates of Briquette NPK fertilizer and the control. Maize plants that received Granule (55-48-46 kg/ha NPK) recorded the heaviest shoot dry weight per plant and was significantly ($P \leq 0.05$) different from plants that received Granule (86-48-46 kg/ha NPK) and the control at 7 WAP at Dormaa Ahenkro.

At 9 WAP, maize plants grown without amendment recorded significantly ($P \leq 0.05$) heavier shoot dry weight per plant than plants that received Briquette (55-48-46 kg/ha NPK) at 9 WAP in Atebubu. At 9 WAP in Dormaa Ahenkro, amending soils with Granule (55-48-46 kg/ha NPK) recorded significantly ($P \leq 0.05$) heavier shoot dry weight per plant than plants that received Granule (86-48-46 kg/ha NPK) and the control. Heavier shoot dry weight per plant was recorded in Atebubu than in Dormaa Ahenkro at 7 WAP and vice versa in 9 WAP. The interaction between location and treatment had no significant effect on shoot dry weight per plant at 7 WAP. There was a significant ($P \leq 0.05$) difference between location x treatment interactions in shoot dry weight per plant at 9 WAP (Table 4.12). While the Control had higher dry matter per plant at Atebubu, Granule (55-48-46kg/ha NPK) and Briquette(116-48-46kg/ha) produced the highest dry matter per plant at Dormaa Ahenkro.

Table 5.12: Effect of different rates of NPK fertilizer (Granules and Briquettes) on Shoot dry weight per plant at Atebubu and Dormaa Ahenkro during the 2022 Growing Season

Treatment	Shoot dry weight per plant (g)			
	7 WAP		9 WAP	
	Atebubu	Dormaa Ahenkro	Atebubu	Dormaa Ahenkro
No Fertilizer (control)	110.25d	89.25bc	122.00a	102.00b
Granule (120-40-40 kg/ha NPK)	133.25ab	91.00abc	113.50ab	102.50b
Granule (116-48-46 kg/ha NPK)	139.75a	101.75abc	100.75bc	115.50ab
Granule (86-48-46 kg/ha NPK)	120.75abcd	87.25c	104.25abc	102.50b
Granule (55-48-46 kg/ha NPK)	128.75abc	114.00a	89.25c	129.75a
Briquette (116-48-46 kg/ha NPK)	116.75bcd	111.75ab	110.50ab	127.00a
Briquette (86-48-46 kg/ha NPK)	108.00d	99.75abc	102.75abc	110.75ab
Briquette (55-48-46 kg/ha NPK)	117.25bcd	106.50abc	84.75c	122.50ab
Mean	**121.84**	**100.16**	**103.47**	**114.06**
HSD (P ≤ 0.05)	**19.12**	**24.11**	**21.07**	**24.46**
CV (%)	**10.67**	**16.37**	**13.85**	**14.58**
Treatment	= 14.53**		NS	
Location	= 7.27**		7.80**	
Location x Treatment	= NS		22.08**	

4.4.6 Root Dry Weight per Plant

Table 4.13 shows the results for root dry weight per plant at 7 and 9 WAP across both locations. At 7 WAP, there were no significant (P≥0.05) difference among treatments at Atebubu. However, in Dormaa Ahenkro maize plants that received Granule (120-40-40 kg/ha NPK) and Granule (116-48-46 kg/ha NPK) recorded significantly (P≤0.05) heavier root dry weight per plant than the control at 7 WAP.

At 9 WAP, maize plants that received Briquette (86-48-46 kg/ha NPK) recorded significantly (P≤0.05) heavier root dry weight per plant than plants that received Granule (116-48-46 kg/ha NPK), Granule (120-40-40 kg/ha NPK), Granule (55-48-46 kg/ha NPK)

and the control plots at Atebubu. At 9 WAP in Dormaa Ahenkro, maize plants that received Briquette (86-48-46 kg/ha NPK) recorded significantly (P≤0.05) heavier root dry weight per plant than the control plot. Heavier root dry weight per plant was recorded in Atebubu than those planted in Dormaa Ahenkro at 7 WAP and 9 WAP. The interaction between location and treatment had no significant (P≥0.05) effect on root dry weight per plant at 7 WAP. There was significant (P≤0.05) difference between location x treatment interactions in root dry weight per plant at 9 WAP (Table 4.13).

Table 4.13: Effect of different rates of NPK fertilizer (Granules and Briquettes) on Root dry weight per plant at Atebubu and Dormaa Ahenkro

Treatment	Root dry weight per plant (g)			
	7 WAP		9 WAP	
	Atebubu	Dormaa Ahenkro	Atebubu	Dormaa Ahenkro
No Fertilizer (control)	77.75	25.00b	106.50a	40.25b
Granule (120-40-40 kg/ha NPK)	64.75	51.25a	78.50b	73.25a
Granule (116-48-46 kg/ha NPK)	71.50	51.25a	67.25b	83.00a
Granule (86-48-46 kg/ha NPK)	61.75	43.25ab	86.25ab	62.00ab
Granule (55-48-46 kg/ha NPK)	63.85	36.00ab	72.00b	66.00ab
Briquette (116-48-46 kg/ha NPK)	73.50	31.75ab	86.75ab	57.50ab
Briquette (86-48-46 kg/ha NPK)	85.25	51.00a	110.25a	76.25a
Briquette (55-48-46 kg/ha NPK)	77.75	44.50ab	76.50b	64.50ab
Mean	**72.01**	**41.75**	**88.11**	**65.34**
HSD (P ≤ 0.05)	**NS**	**20.89**	**27.23**	**27.37**
CV (%)	**28.31**	**23.03**	**21.66**	**28.48**
Treatment	= NS		NS	
Location	= 8.66**		9.42**	
Location x Treatment	= NS		26.64**	

4.5 Plant Growth Analysis

4.5.1 Crop growth rate

The results on crop growth rate (CGR) from 0-7 WAP and 7-9 WAP across both locations is presented in Table 4.14. At the initial stage of crop growth (0-7 WAP), the application of granule and briquette NPK fertilizers generally led to higher crop growth rates compared to the control across both locations. Maize plants that received Granule (120-40-40 kg/ha NPK) and Granule (55-48-46 kg/ha NPK) recorded significantly higher crop growth rate than the control from 0 – 7 WAP at Atebubu and Dormaa Ahenkro respectively. Generally, CGR values were high from 0 - 7 WAP which later decreased from 7 - 9 WAP across both locations. Maize plants that received Granule (86-48-46 kg/ha NPK) and Granule (55-48-46 kg/ha NPK) recorded significantly higher crop growth rate than the control from 7 – 9 WAP at Atebubu and Dormaa Ahenkro respectively. Locations had no significant ($P \geq 0.05$) effect on CGR from 0-7 and 7-9 WAP. There was significant ($P \leq 0.05$) difference between location x treatment interaction in CGR from 0-7 WAP with Granule (120-40-40 kg/ha NPK) and Briquette (55-48-46 kg/ha NPK) producing the highest CGR at Atebubu and Granule (55-48-46 kg/ha NPK) and Briquette (116-48-46 kg/ha NPK) producing the highest CGR at Dormaa Ahenkro. The interaction between location and treatment had no significant ($P \geq 0.05$) effect on CGR from 7-9 WAP.

Table 4.14: Effect of different rates of NPK fertilizer (Granules and Briquettes) on Crop growth rate at Atebubu and Dormaa Ahenkro during the 2022 Growing Season

Treatment	Crop growth rate (g m^{-2}/day^{-1})			
	0 - 7 WAP		7 - 9 WAP	
	Atebubu	Dormaa Ahenkro	Atebubu	Dormaa Ahenkro
No Fertilizer (Control)	32.82c	42.46bc	21.82b	21.33c
Granule (120-40-40 kg/ha NPK)	50.44a	43.29abc	29.69ab	19.15c
Granule (116-48-46 kg/ha NPK)	48.38ab	48.40abc	34.11a	25.71abc
Granule (86-48-46 kg/ha NPK)	48.02ab	41.51c	35.08a	25.39abc
Granule (55-48-46 kg/ha NPK)	45.25ab	54.23a	31.84ab	34.46a
Briquette (116-48-46 kg/ha NPK)	45.61ab	53.16ab	27.47ab	32.21ab
Briquette (86-48-46 kg/ha NPK)	42.84b	47.45abc	29.24ab	25.23abc
Briquette (55-48-46 kg/ha NPK)	50.30a	50.67abc	36.09a	34.10a
Mean	**45.46**	**47.65**	**30.67**	**27.20**
HSD(P<0.05)	**5.99**	**11.47**	**11.20**	**11.68**
CV (%)	**8.98**	**16.37**	**24.84**	**29.22**
Treatment	= 6.09**		7.87**	
Location	= NS		NS	
Location x Treatment	= 8.62**		NS	

4.5.2 Relative Growth Rate

The result on relative growth rate (RGR) from 0-7 WAP and 7-9 WAP across both locations is presented in Table 4.15. At the initial stage of crop growth (0-7 WAP), the application of granule and briquette NPK fertilizers generally led to significantly higher RGR compared to the control across both locations. Maize plants that received granule and briquette (55-48-46 kg/ha NPK recorded significantly ($P \leq 0.05$) higher crop growth rate than the control from 0 – 7 WAP at Atebubu and Dormaa Ahenkro respectively but differed insignificantly ($P \geq 0.05$) from all the amended plots in RGR across both locations. Generally, RGR values were high from 0 - 7 WAP which later decreased from 7 - 9 WAP across both locations. Higher RGR values were recorded in Atebubu than in Dormaa Ahenkro from 0 - 7 WAP.

Locations had no significant (P≥0.05) effect on RGR from 7- 9 WAP. There were no significant (P≤0.05) differences between location x treatment interactions on RGR from 0 - 7 and 7 - 9 WAP.

Table 4.15: Effect of different rates of NPK fertilizer (Granules and Briquettes) on Relative growth rate at Atebubu and Dormaa Ahenkro

Treatment	Relative growth rate (g m^{-2}/day^{-1})			
	0 - 7 WAP		7 - 9 WAP	
	Atebubu	Dormaa Ahenkro	Atebubu	Dormaa Ahenkro
No Fertilizer (Control)	0.51b	0.42b	0.29b	0.27b
Granule (120-40-40 kg/ha NPK)	0.71a	0.64a	0.38ab	0.43a
Granule (116-48-46 kg/ha NPK)	0.74a	0.66a	0.47a	0.42a
Granule (86-48-46 kg/ha NPK)	0.69a	0.64a	0.40ab	0.35ab
Granule (55-48-46 kg/ha NPK)	0.67a	0.68a	0.47a	0.41ab
Briquette (116-48-46 kg/ha NPK)	0.66a	0.66a	0.39ab	0.43a
Briquette (86-48-46 kg/ha NPK)	0.65a	0.66a	0.40ab	0.36ab
Briquette (55-48-46 kg/ha NPK)	0.75a	0.68a	0.44ab	0.33ab
Mean	**0.67**	**0.63**	**0.41**	**0.38**
HSD(P<0.05)	**0.13**	**0.04**	**0.15**	**0.14**
CV (%)	**13.41**	**4.47**	**25.88**	**26.32**
Treatment	= 0.07**		NS	
Location	= 0.03**		NS	
Location x Treatment	= NS		NS	

4.6 Yield and Yield Components

4.6.1 Number of Plants Harvested

The results revealed significant differences among treatments in number of plants harvested across both locations (Table 4.16). Maize plants that received Granule (116-48-46 kg/ha NPK) recorded significantly higher number of plants harvested than plants that received Briquette (55-48-46 kg/ha NPK) and the control across both locations (Table 4.16). Higher (54) number of plants were harvested in Dormaa Ahenkro than in Atebubu (45.94). There

were however no significant (P≥0.05) differences between location and treatment x location interaction in number of plants harvested.

4.6.2 Number of Cobs per Plot

At Atebubu, maize plants that received Briquette (116-48-46 kg/ha NPK) recorded significantly higher number of cobs per plot than plants that received Granule (55-48-46 kg/ha NPK) and Briquette (55-48-46 kg/ha NPK) (Table 4.16). At Dormaa Ahenkro, amending soils with Granule (116-48-46 kg/ha NPK) produced the highest (59.75) number of cobs per plot and was significantly (P≤0.05) different from plants that received Briquette (55-48-46 kg/ha NPK) and the control. Higher (54) number of cobs per plot were harvested in Dormaa Ahenkro than in Atebubu (46). There was no significant (P≥0.05) difference between treatment x location interaction in number of cobs per plot.

Table 4.16: Effect of different rates of NPK fertilizer (Granules and Briquettes) on Number of plants harvested per plot and Number of cobs per plot at Atebubu and Dormaa Ahenkro

Treatment	Number of plants harvested		Number of cobs per plot	
	Atebubu	Dormaa Ahenkro	Atebubu	Dormaa Ahenkro
No Fertilizer (control)	33.50b	48.50c	33.50a	48.50c
Granule (120-40-40 kg/ha NPK)	46.25ab	52.25bc	46.25ab	52.25bc
Granule (116-48-46 kg/ha NPK)	57.50a	59.75a	56.75a	59.75a
Granule (86-48-46 kg/ha NPK)	46.25ab	55.00ab	46.25ab	55.00ab
Granule (55-48-46 kg/ha NPK)	42.00b	50.00bc	42.00b	50.00bc
Briquette (116-48-46 kg/ha NPK)	57.25a	58.75a	57.00a	58.75a
Briquette (86-48-46 kg/ha NPK)	46.75ab	54.25abc	46.75ab	54.25abc
Briquette (55-48-46 kg/ha NPK)	38.00b	51.00bc	38.00b	51.00bc
Mean	**45.94**	**53.69**	**45.81**	**53.69**
HSD (P ≤ 0.05)	**13.32**	**6.48**	**13.76**	**6.48**
CV (%)	**12.22**	**5.09**	**12.66**	**5.09**
Treatment	= 7.96**		8.05**	
Location	= 2.52**		2.55**	
Location x Treatment	= NS		NS	

4.6.3 Biomass Weight per Plot at Harvest

Significant differences were observed in the biomass weight per plot at harvest among treatments at Atebubu and Dormaa Ahenkro (Table 4.17). Maize plants that received Granule (116-48-46 kg/ha NPK) recorded the highest biomass weight per plot (8.53 kg) and differed significantly (P≤0.05) from plants that received Briquette (55-48-46 kg/ha NPK at Atebubu. The highest biomass weight per plot at harvest 9.08 kg was recorded by plants that received Granule (86-48-46 kg/ha NPK) at Dormaa Ahenkro and differed significantly (P≤0.05) from plants that received Briquette (55-48-46 kg/ha NPK) (Table 4.17). Significantly heavier biomass weight per plot at harvest was recorded at Dormaa Ahenkro

than in Atebubu. There was no significant (P≥0.05) difference between treatment x location interaction in biomass weight per plot at harvest.

4.6.4 Cob Weight per Plot

There were significant differences among treatments in cob weight per plot at Atebubu and Dormaa Ahenkro (Table 4.17). Maize plants that received Briquette (116-48-46 kg/ha NPK) recorded significantly (8.5 kg) higher cob weight per plot than other treatments at Atebubu except Granule (86-48-46 kg/ha NPK). Granule (116-48-46 kg/ha NPK) recorded the highest (10.25 kg) cob weight per plot which differed insignificantly (P≥0.05) from the other treatments except t at Granule (120-40-40 kg/ha NPK) and the control at Dormaa Ahenkro. Heavier cob weight per plot was recorded in Dormaa Ahenkro than in Atebubu. There was significant (P≤0.05) difference between treatment x location interaction in cob weight per plot (Table 4.17).

Table 4.17: Effect of different rates of NPK fertilizer (Granules and Briquettes) on Biomass weight at harvest and Cob Weight per plot at Atebubu and Dormaa Ahenkro.

Treatment	Biomass weight per plot at harvest (kg)		Cobs weight per plot (kg)	
	Atebubu	Dormaa Ahenkro	Atebubu	Dormaa Ahenkro
No Fertilizer (control)	3.55c	4.98c	3.75c	4.50b
Granule (120-40-40 kg/ha NPK)	5.10c	6.30bc	4.25c	5.00b
Granule (116-48-46 kg/ha NPK)	8.53a	8.35ab	8.25a	10.25a
Granule (86-48-46 kg/ha NPK)	7.98ab	9.08a	7.25ab	6.25ab
Granule (55-48-46 kg/ha NPK)	5.50bc	6.46abc	4.75c	8.75ab
Briquette (116-48-46 kg/ha NPK)	7.85ab	8.60ab	8.50a	9.50a
Briquette (86-48-46 kg/ha NPK)	6.03abc	7.07abc	5.50bc	8.75ab
Briquette (55-48-46 kg/ha NPK)	4.20c	5.16c	5.25bc	7.50ab
Mean	**6.10**	**7.00**	**5.94**	**7.56**
HSD (P ≤ 0.05)	**2.64**	**2.71**	**2.09**	**4.32**
CV (%)	**18.29**	**16.32**	**14.87**	**24.08**
Treatment	= 1.75**		2.20**	
Location	= 0.55**		0.69**	
Location x Treatment	= NS		3.55**	

4.6.5 Grain Weight per Plot

There were significant differences among treatments in grain weight per plot at both Atebubu and Dormaa Ahenkro (Table 4.18). Maize plants that received Granule (116-48-46 kg/ha NPK) and Briquette (116-48-46 kg/ha NPK) recorded the highest mean values of (5.0 kg) and (5.33 kg) at Atebubu and Dormaa Ahenkro respectively and were significantly different from the control across both locations (Table 4.18). However, there were no significant (P≥0.05) differences between location and interaction of location and treatment in grain weight per plot.

4.6.6 Harvest Index

No significant (P≥0.05) differences were revealed in the harvest index among treatments and interaction of location and treatment across both locations (Table 4.18). There was however significant differences between location in harvest index (Table 4.18). Higher harvest index was recorded in Atebubu than in Dormaa Ahenkro.

Table 4.18: Effect of different rates of NPK fertilizer (Granules and Briquettes) on Grain weight per plot and Harvest Index at Atebubu and Dormaa Ahenkro.

Treatment	Grain weight per plot (kg)		Harvest index	
	Atebubu	Dormaa Ahenkro	Atebubu	Dormaa Ahenkro
No Fertilizer (control)	1.93c	1.87b	0.59	0.40
Granule (120-40-40 kg/ha NPK)	3.10c	2.42b	0.69	0.42
Granule (116-48-46 kg/ha NPK)	5.00a	4.97a	0.61	0.60
Granule (86-48-46 kg/ha NPK)	4.65ab	4.83a	0.61	0.55
Granule (55-48-46 kg/ha NPK)	2.90c	3.40ab	0.56	0.54
Briquette (116-48-46 kg/ha NPK)	4.98a	5.33a	0.67	0.64
Briquette (86-48-46 kg/ha NPK)	3.35bc	3.58ab	0.57	0.52
Briquette (55-48-46 kg/ha NPK)	2.68c	2.26b	0.70	0.48
Mean	**3.57**	**0.58**	**0.63**	**0.52**
HSD (P ≤ 0.05)	**1.48**	**2.05**	**NS**	**NS**
CV (%)	**17.51**	**24.10**	**25.07**	**25.19**
Treatment	= 0.70**		NS	
Location	= NS		0.07**	
Location x Treatment	= NS		NS	

4.6.7 100-Seed Weight

The weight of 100-seeds showed significant (P≤0.05) differences among treatments at Atebubu though treatment with fertilizer application weighed far more than the control (Table 21). Maize plants that received Granule (116-48-46 kg/ha NPK) recorded the highest hundred seed weight (35.5g) and (39.0g) across both locations followed by plants that

received Granule (86-48-46 kg/ha NPK) and differed significantly from the control (Table 4.19). The hundred seeds weight at Dormaa Ahenkro was significantly higher than seed weight produced at Atebubu. The interaction of location and treatment was highly significant in hundred seed weight (Table 4.19).

4.6.8 Cob Length

Significant differences were observed in cob length among treatments and between locations (Table 4.19). Maize plants that received Granule (86-48-46 kg/ha NPK) recorded the longest cob length at Atebubu (15.99 cm) whilst Granule (116-48-46 kg/ha NPK) recorded the longest at Dormaa Ahenkro (16.50 cm. Plants that received either granule or briquette NPK fertilizers at different rates had longer cob length than the control at Atebubu. The interaction between location and treatment was significantly different in cob length. Cob length of maize from Dormaa Ahenkro was longer than those from Atebubu.

4.6.9 Grain Yield (t/ha)

The grain yield ranged between 2.14 – 5.56 t/ha and 2.08 – 5.92 t/ha for Atebubu and Dormaa Ahenkro, respectively (Table 4.19). The application of different granule and briquette NPK fertilizers to maize showed significant ($P \leq 0.05$) differences between treatments in grain yield (t/ha) at Atebubu. Maize plants that received Granule (116-48-46 kg/ha NPK) recorded significantly higher (5.56 t/ha) grain yield than the other treatments at Atebubu whereas maize that received Briquette (116-48-46 kg/ha NPK) recorded significantly higher (5.92 t/ha) grain yield than other treatments at Dormaa Ahenkro. There

were however no significant differences between location and location x treatment interaction in grain yield (Table 4.19).

Table 4.19: Effect of different rates of NPK fertilizer (Granules and Briquettes) on 100-seed weight, Cob length and Grain yield at Atebubu and Dormaa Ahenkro.

Treatment	100-seed weight (g)		Cob length (cm)		Grain yield (t/ha)	
	Atebubu	Dormaa Ahenkro	Atebubu	Dormaa Ahenkro	Atebubu	Dormaa Ahenkro
No Fertilizer (control)	28.00b	28.00c	12.15c	11.00c	2.14c	2.08b
Granule (120-40-40 kg/ha NPK)	29.00b	29.00c	13.93bc	12.80bc	3.44c	2.69b
Granule (116-48-46 kg/ha NPK)	35.50a	39.00a	15.56ab	16.50a	5.56a	5.53a
Granule (86-48-46 kg/ha NPK)	35.25a	37.00a	15.99a	14.28ab	5.17ab	5.37a
Granule (55-48-46 kg/ha NPK)	30.25b	29.25bc	13.65bc	12.40bc	3.22c	3.78ab
Briquette (116-48-46 kg/ha NPK)	34.25a	37.00a	15.94a	13.93abc	5.53a	5.92a
Briquette (86-48-46 kg/ha NPK)	30.75b	34.75ab	14.13abc	13.25bc	3.72bc	3.99ab
Briquette (55-48-46 kg/ha NPK)	20.75b	29.00c	14.15ab	12.08bc	2.97c	2.52b
Mean	**30.47**	**32.88**	**14.47**	**13.28**	**3.97**	**3.99**
HSD ($P \leq 0.05$)	**2.94**	**5.58**	**1.98**	**3.11**	**1.65**	**2.28**
CV (%)	**3.90**	**7.16**	**5.80**	**9.87**	**17.51**	**24.10**
Treatment	**= 2.92****		**1.38****		**1.30****	
Location	**= 0.93****		**0.44****		**NS**	
Location x Treatment	**= 4.71****		**NS**		**NS**	

CHAPTER FIVE

DISCUSSIONS

5.1 Effect of Amendment on Soil Chemical Properties

Amending soils with both briquette and granule had a notable positive impact on the chemical properties (OM, CEC, Fe, K and Zn) of the soil in both experimental sites. This improvement can be attributed to the fact that these amendments likely provided supplementary nutrients in the form of exchangeable cations, including potassium (K), calcium (Ca), magnesium (Mg), and ammonium (NH_4^+), particularly in the upper soil layers. These elevated levels of exchangeable cations have the potential to significantly enhance plant growth by promoting better nutrient availability and overall soil fertility. The heightened presence of exchangeable cations, such as K, Ca, and Mg, is particularly advantageous for plant development. These cations serve as essential elements for various biochemical processes within plants, enabling improved nutrient uptake and utilization (Singhal *et al*., 2023). The fact that these levels are considered average suggests that the soil provides a reasonably sufficient amount of the essential nitrogen forms to support plant growth. The positive effects of soil amendments with briquettes and granules on nutrient availability and soil fertility align with existing research in soil science (Wang *et al*., 2020). Amending soils with both Briquette and Granule NPK fertilizer had no effect on soil pH, N, P, Ca, Mg, Mn and B content across all the treatments at both locations.

5.2 Effect of Briquette and Granules NPK Fertilizer on Phenology of Maize

The absence of significant differences between the different amendments and the control in

percentage crop establishment, number of days to 50% tasseling and days to 50% silking may likely be attributed to the fact that the application of inorganic fertilizers in the form of both briquettes and granules had no noticeable impact on these particular parameters. This suggests that, in this context, the utilization of these specific inorganic fertilizers did not exert any significant influence on the timing of the rate of crop establishment, or the developmental signs of tasseling and silking in the maize crop. The probable reason could be that application of both granule and briquette NPK fertilizers at different rates for the treatments and the control had similar effects and insignificant. These observations are consistent with previous research which has shown that the effects of inorganic fertilizers on plant growth and development can be highly insignificant in certain period of plant growth and development (Lehman *et al*., 2015)

Brown *et al*. (2014) have highlighted that, phenological development of maize could be attributed to genetical and environmental conditions rather than a specific fertilizer applied and plant responses to synthetic fertilizer applications. Again, environments play a crucial role in shaping the germination and establishment processes of crops. Edaphic factors including factors like texture, organic matter content, and nutrient composition, can significantly impact seed emergence and crop establishment. Soils with different amendments can have varying water-holding capacities and nutrient availability, which can influence the speed and success of germination and crop establishment ((Sarma & Gogoi, 2015). Variations in soil pH can affect nutrient availability to plants. Soils that are too acidic or alkaline may hinder nutrient uptake, potentially affecting the establishment of crops (Msimbira & Smith, 2020). Differences in temperature regimes can have a direct impact on

crop growth and development. Temperature affects seed germination rates, with some crops having specific temperature requirements for optimal germination (Zhang *et al.*, 2014). Dormaa Ahenkro and Atebubu experienced distinct temperature patterns that influenced crop establishment. Variations in precipitation patterns across both locations, including timing and quantity of rainfall, affected soil moisture levels and, consequently, seed germination and crop establishment. Adequate moisture is crucial for successful seedling establishment (Dantas *et al*., 2020).

5.3 Effects of Briquette and Granule NPK Fertilizer on Physiological Growth Parameters of Maize

Maize plants that received granule (120-40-40 kg/ha NPK) and both briquette and granule (55-48-46 kg/ha NPK) recorded significantly higher crop growth rate than the control from 0- 7 and 7 – 9 WAP at both locations whereas maize plants that received briquette and granule (55-48-46 kg/ha NPK) recorded significantly higher RGR than the control from 0-7 WAP. The increase in CGR and RGR may be due to supplementary application of briquette and granule (55-48-46 kg/ha NPK) fertilizers which intended enhanced soil nutrient status and subsequent increase in crop growth during the growing period. This result is in line with Essilfie *et al*. (2023) who reported that amending soils with 10 t/ha CM as well as 5 t/ha CM + 1.5 t/ha GB had higher CGR and RGR values than the control. Similarly, it could be that briquette and granule fertilizers applied likely provided a more sustained release of essential nutrients, including nitrogen (N), phosphorus (P), and potassium (K), during the critical early growth stages for plant uptake and utilization (Agyin-Birikorang *et al*., 2018). Generally, CGR and RGR increased from 0 - 7 WAP which

later decreased from 7 - 9 WAP. These results agree with Pragya Pandey & Bhambri, (2017) who reported decrease in crop growth rate with plant aging which could be associated with the cessation of vegetative growth, shedding of older leaves, transition from vegetative to reproductive development of the maize plants and changes in terms of reduction in dry matter accumulation or weight of the stems after tasseling and silking.

5.4 Effects of Briquette and Granule NPK Fertilizer on Vegetative Growth of Maize

The analysis of vegetative growth parameters including plant height, number of leaves per plant, leaf chlorophyll content, stem diameter and shoot and root dry weight showed variations between treatments and locations, suggesting the influence of Briquette and Granule NPK Fertilizer on maize growth. The observed differences indicate variations in plant vigour, growth rate, photosynthetic activity, and canopy development, which could be attributed to the specific fertilizer rates and rates and their effects on nutrient availability and uptake.

The different NPK fertilizer briquette and granule combinations revealed significant differences with regards to plant height, number of leaves per plant and stem diameter from 5 to 7 WAP in both locations. Generally, maize plants that received Granule (116-48-46 kg/ha NPK) had significantly taller plants, higher number of leaves per plant and wider stem diameter than the control from 5 to 7 WAP at both locations. This might be due to the fact that nutrients were readily available to the plants to absorb at the early stages of growth. This result conformed with the finding by Agegnehu *et al*. (2014), who indicated a higher

plant height within two weeks with mineral fertilizer as a result of increasing level of fertilizer application. The Granule (116-48-46 kg/ha NPK) formulation likely provided a more comprehensive nutrient profile, with balanced ratios of nitrogen (N), phosphorus (P), and potassium (K). This balanced nutrient supply is crucial for overall plant development, including increased plant height, leaf number, and stem diameter. Nitrogen is a key component of chlorophyll, essential for photosynthesis, and influences cell elongation, which collectively led to taller plants (Ghadirnezhad Shiade *et al*., 2024).

Significant ($P<0.05$) differences were recorded with respect to the number of leaves per plant at both locations (Fig 4.1). Granule (116-48-46 kg/ha NPK) performed significantly different from some of the briquette fertilizers and the control because it was readily available to the plants to absorb at the early stages of growth. These findings agree with the results by Kareem *et al*. (2020), who reported that increasing level of NPK fertilizer showed significant differences in leaf production. Nitrogen is a major constituent of amino acids and proteins, essential for leaf formation and expansion which enhanced leaf formation.

The significantly wider stem diameter recorded by Granule (116-48-46 kg/ha NPK) formulation, could be attributed to the balanced nutrient composition, which likely provided adequate phosphorus and potassium, contributing to a wider stem diameter (Tesfaye, 2019). Phosphorus plays a role in energy transfer, while potassium is involved in water regulation and overall plant structure. Granule fertilizers might have provided a more consistent and optimal nutrient supply compared to the control and Briquette treatments. This result

aligned with Dantas *et al.* (2020) who reported a significant increase in stem diameter when NPK rates were applied to two maize varieties (Dantas *et al*., 2020).

Amending soils with both briquette and granule NPK fertilizer (55-48-46 kg/ha NPK and 56-48-46 kg/ha NPK) significantly affected leaf chlorophyll content as compared to the control across both locations. This could be attributed to the supplemental NPK fertilizer supplied by the different rate of briquette and granule fertilizers. The result agreed with the findings by Wamalwa *et al.* (2019) who reported an increase in leaf chlorophyll content due to increase in NPK application rate of 100 kg/acre. Differences in leaf chlorophyll content across locations can be attributed to variations in environmental factors, including rainfall, relative humidity, and temperature (Wamalwa *et al*., 2019). Regular rainfall supplies water necessary for photosynthesis and plant metabolism, promoting healthy growth and higher chlorophyll concentrations in leaves. Conversely, insufficient rainfall leads to reduced chlorophyll content due to water deficiency and stress (Wang *et al*., 2020). High relative humidity maintains favourable atmospheric conditions for plant growth, leading to better photosynthetic efficiency and potentially higher chlorophyll content. Enzymes involved in chlorophyll synthesis have temperature-dependent activity and deviations from the optimal temperature range can hinder these enzymatic processes, leading to variations in chlorophyll content (Salgotra & Chauhan, 2023).

5.5 Impact of Briquette and Granule NPK fertilizer on Yield and Yield Components of Maize

Maize plants that received Granule (116-48-46 kg/ha NPK) recorded significantly higher

number of plants harvested than plants that received Briquette (55-48-46 kg/ha NPK) and the control across both locations. The differences in NPK ratios between the granular and briquetted fertilizers could have contributed to the variation in harvested plant numbers. The granule (116-48-46 kg/ha NPK) fertilizer contains slightly higher amounts of nitrogen (N), which could positively affect plant growth and development. Adu-Gyamfi *et al*. (2019) asserted that slow-release of fertilizers in granules form provided a steady supply of nutrients, minimizing nutrient losses due to leaching and improving nutrient utilization efficiency.

The higher number of cobs per plot recorded by maize plants that received Granule (116-48-46 kg/ha NPK) and Briquette (116-48-46 kg/ha NPK) than maize plants that received Granule (55-48-46 kg/ha NPK), Briquette (55-48-46 kg/ha NPK) and the control across both locations could be attributed to the higher amount of nitrogen present in the NPK fertilizers. Maize plants have a high demand for nitrogen, especially during the critical growth stages. Higher nitrogen levels supplied by the Granule (116-48-46 kg/ha NPK) and Briquette (116-48-46 kg/ha NPK) fertilizers might have facilitated better nitrogen uptake and utilization by the plants, resulting in increased cob formation (Urban *et al*., 2021).

The higher biomass weight at harvest recorded in maize plants that received Granule (116-48-46 kg/ha NPK) and Granule (86-48-46 kg/ha NPK) across both locations respectively, compared to those receiving Briquette (55-48-46 kg/ha NPK) and the control can be attributed to varying rates of nitrogen content which might have played a significant role. Nitrogen is a vital nutrient for plant growth and plays a crucial role in biomass

accumulation. The higher nitrogen content in the Granule (116-48-46 kg/ha NPK and 86-48-46 kg/ha NPK) fertilizers likely provided more available nitrogen for plant uptake, promoting vigorous vegetative growth and biomass production (Asibi *et al*., 2019). Efficient utilization of nitrogen by maize plants is essential for maximizing biomass production. Fertilizers with balanced nitrogen ratios, such as the Granule rates, can enhance nitrogen use efficiency, leading to increased biomass accumulation (Urban *et al.,* 2021).

Significant differences were observed among treatments in cob weight per plot. In both locations maize plants that received briquette and granule (116-48-46 kg/ha NPK) fertilizer performed better in cob weight per plot than the control. The high nitrogen content in the Granule and Briquette fertilizer rates likely provided the necessary nitrogen levels for optimal cob development, resulting in higher cob weights per plot (Adams *et al*., 2018). Maintaining a balanced nutrient profile is crucial for optimal plant growth and yield. The presence of adequate nitrogen levels, along with other essential nutrients provided by the fertilizers, likely contributed to the superior performance of maize plants in terms of cob weight per plot. The inability of the soil to supply essential plant nutrients needed for plant growth and development led to the lower cob weight per plot for maize plants grown on the unamended plots at both locations (Owusu *et al*., 2013).

Application of different granule and briquette NPK fertilizers had significant effect on grain weight per plot across both locations. Maize plants that received Granule (116-48-46 kg/ha NPK) produced significantly higher grain weight per plot than maize plants that received Briquette (55-48-46 kg/ha NPK) and the control at Atebubu. Whereas in Dormaa Ahenkro,

Briquette (116-48-46 kg/ha NPK) outperformed the control in grain weight per plot. Granular fertilizers like the Granule (116-48-46 kg/ha NPK) formulation may provide a more sustained release of nutrients, including nitrogen, supporting prolonged plant growth and higher grain weight per plot. Briquette fertilizers, on the other hand, might have released nutrients quickly upon contact with moisture, leading to rapid plant growth and higher grain weight per plot as experienced in Dormaa Ahenkro. The higher nitrogen content in the Granule (116-48-46 kg/ha NPK) and Briquette (116-48-46 kg/ha NPK) rates might have provided the necessary nitrogen levels for optimal grain development, resulting in higher grain weight per plot. However, the lower nitrogen content in the Briquette (55-48-46 kg/ha NPK) formulation might have limited grain development, leading to lower grain weight per plot.

The absence of significant differences in the harvest index among treatments and their interaction across both locations may suggest that the specific treatments applied did not have a statistically significant effect on the yield efficiency of maize. This lack of significance could indicate that the treatments tested did not lead to substantial variations in the harvest index values across different experimental conditions (Kamran *et al*., 2018). The significant differences observed between locations in the harvest index, with higher values in Atebubu than Dormaa Ahenkro, point towards the influence of environmental factors, soil quality, climate conditions, or other location-specific variables on maize yield. Atebubu likely offers more favorable conditions for maize growth compared to Dormaa Ahenkro, resulting in a higher harvest index due to better adaptation to local environmental factors.

Generally, amending soils with Granule (116-48-46 kg/ha NPK) and Briquette (116-48-46 kg/ha NPK) recorded significantly heavier 100-seed weight, longer cobs and higher grain yield than maize plants that received Briquette (55-48-46 kg/ha NPK) fertilizer and the control. This could be due to adequate N.P.K nutrient combinations applied for plants absorption and utilization. This result agrees with the findings by Faroque *et al*, (2015) who found significant differences in cob length by the application of 400 kg/ha NPK fertilizer. The findings on 100-seed weight are in tandem with Dhakal *et al.* (2022) who recorded higher 100-seed weight in maize when deep placement of briquette urea increased agronomic and economic efficiency of maize. The significantly enhanced vegetative growth recorded by the Briquette and Granule NPK fertilizer compared to the control directly translated into higher yield and yield components due to the substantial impact of N, P and K on plant growth, development and yield. Agyin-Birikorang *et al*. (2018) found that NPK Briq boosted maize yield by 16% over ammonium sulfate (+P and K) and by 23% to 34% compared to urea (+P and K) in normal weather conditions, with higher N, P, and K use efficiencies in Ghana. Wang *et al.* (2020) further indicated that the nutrient-balanced NPK Briq could be the same as or more effective and efficient for maize grain yield and quality relative to the commonly used nutrient management practices, urea (+P and K) and ammonium sulfate (+P and K), under normal weather conditions. Adu-Gyamfi *et al.* (2019) also asserted that utilizing multi-nutrient fertilizer briquettes as a one-time application served as a productive fertilizer management approach to enhance maize yields and profitability for smallholder farmers in the Guinea Savanna zone.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

- Amendment of soils with NPK fertilizer briquettes and granules improved soil fertility and nutrient availability (Zn, Fe, CEC and Organic matter), and subsequently, the potential for enhanced plant growth and development.
- Different rates of NPK fertilizer briquettes and granules had no significant effect on phenology of maize plants namely; percentage crop establishment, days to 50% tasseling and silking.
- Significant differences were observed in vegetative growth parameters as well as yield and yield components parameters measured, where Granule (116-48-46 kg/ha NPK) and Briquette (116-48-46 kg/ha NPK) largely performed better than the other briquette granule NPK fertilizer in most cases.
- The study demonstrated that maize plants that received briquette and granule (55-48-46 kg/ha NPK) showed significantly higher crop growth rate (CGR) and relative growth rate (RGR) compared to the control.

6.2 Recommendations

- Granule (116-48-46 kg/ha NPK) and Briquette (116-48-46 kg/ha NPK) fertilizer should be used by farmers for higher biomass weight that can serve as a source of mulching material and animal feed.

- Farmers should apply Granule (116-48-46 kg/ha NPK) or Briquette (116-48-46 kg/ha NPK) for optimized maize yield and enhance cob quality.
- The work should be repeated in other agro-ecological zones of Ghana to confirm the results obtained.

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APPENDICES

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

Nutrient	Rank/Grade
Phosphorus, P (ppm), (Bray 1)	
< 10	Low
10 – 20	Moderate
> 20	High
Potassium, K (pmm)	
< 50	Low
50 – 100	Moderate
> 100	High
Calcium, Ca (ppm)/Meg = 0.25 Ca	
< 5.0	Low
5.0 – 10.0	Moderate
> 10.0	High
ECEC (cmol (+)/kg)	
< 10	Low
10 - 20	Moderate
> 20	High
Soil pH (Distilled Water Method)	
< 5.0	Very Acidic
5.1 – 5.5	Acidic
5.6 – 6.0	Moderately Acidic

6.0 – 6.5	Slightly Acidic
6.5 – 7.0	Neutral
7.0 – 7.5	Slightly Alkaline
7.6 – 8.5	Alkaline
> 8.5	Very Alkaline
Organic Matter (%)	
< 1.5	Low
1.6 – 3.0	Moderate
3.0	High
Nitrogen (%)	
< 0.1	Low
0.1 – 0.2	Moderate
> 0.2	High
Exchangeable Potassium (cmol (+)/kg)	
< 0.2	Low
0.2 – 0.4	Moderate
> 0.4	High

Source: (SRI, 2007)