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Growth and Yield Response of Maize (*Zea mays* L.) to Different Rates of Briquette and Granule NPK Fertilizer

Cynthia Olerckie Nongorh [a], Margaret Esi Essilfie [a], Emmanuel Kofi Amponsah [a], Williams Kwame Atakora [b], Emmanuel Kwasi Asiedu [a] and Emmanuel Appiah [a*]

[a] *Department of Crop and Soil Sciences Education, Faculty of Agriculture Education, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED). P.O. Box 40, Mampong-Ashanti, Ghana.*
[b] *International Fertilizer Development Centre, PMB CT 284 Cantonments-No 133A, Mbabane Avenue, East Legon Residential Area Accra, Ghana.*

Authors' contributions

This work was carried out in collaboration among all authors. Author CON wrote the original draft, conducted literature searches, collected and interpreted the data. Author MEE developed the methodology, managed resources, supervised the research, reviewed, edited and assisted in literature searches. Author EKA reviewed, edited, assisted in literature searches and supervised the research. Author WKA reviewed, edited, supervised the research, managed resources, and developed the methodology. Author EKA reviewed, edited, supervised the research, and assisted in literature searches. Author EA assisted in manuscript preparation, literature searches, data analysis, and interpretation of results. All authors read and approved the final manuscript.

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**Corresponding author: E-mail: appiahemmanuel01@gmail.com;*

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ABSTRACT

Aims: Maize productivity in Ghana remains below its potential largely due to inefficient fertilizer use and inappropriate application methods. This study assessed the effect of application of NPK briquettes and granule fertilizers on maize growth and yield at two different locations.

Study design: The experimental design used was a Randomized Complete Block Design (RCBD with eight treatments, and each replicated four times.

Place and Duration of Study: Two field experiments were conducted concurrently at Atebubu Municipality in the Bono East Region and Dormaa Ahenkro Municipality in the Bono Region of Ghana, between April 2022 and August 2022.

Materials and Methods: The treatments included: (i) No Fertilizer (Control); (ii) Granule (120-40-40 kg ha^{-1} NPK); (iii) Granule (116-48-46 kg ha^{-1} NPK); (iv) Granule (86-48-46 kg ha^{-1} NPK); (v) Granule (55-48-46 kg ha^{-1} NPK); (vi) Briquette (116-48-46 kg ha^{-1} NPK); (vii) Briquette (86-48-46 kg ha^{-1} NPK); and (viii) Briquette (55-48-46 kg ha^{-1}) fertilizer.

Results: Application of NPK either in granular or briquettes had no significant impact on number of days to 50% tasseling and number of days to 50% silking. However, significant differences were observed in plant height and the number of leaves per plant at 5 and 7 weeks after planting (WAP), where the application of Granular NPK fertilizer to plots that received 116 - 48 - 46 kg ha^{-1} had superior performance in plant height and number leaves per plant at 7 WAP across both locations. Furthermore, plots in both locations that received granular and briquette NPK at 116-48-46 kg ha^{-1} were superior in producing higher yields. These results showed that the form of NPK fertilizer either briquette or granular had no effect on the yield of maize, however, the rate of application does.

Conclusion: The application of Granular NPK fertilizer to plots that received Granular and briquette at 116 - 48 - 46 kg ha^{-1} NPK fertilizer had a significant effect on maize growth and yield. It is recommended that for optimized maize grain yield, farmers should apply either granular and /or briquette at 116 - 48 - 46 kg ha^{-1} NPK fertilizer.

Keywords: Inorganic fertilizer; NPK briquette; granule fertilizers; maize; yield.

1. INTRODUCTION

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 the crop is also cultivated for fodder, especially in developed countries (Murdia *et al.*, 2016). Among the cereal crops, maize 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 72.0 % starch, 10.0 % 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). 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 (Mavengahama *et al.*, 2013). 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. 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 requires a balanced supply of nitrogen, phosphorus, and potassium for optimal yield (Mukherjee, 2013). The assimilation peak during flowering, with a single maize plant consuming approximately 8.7 g of nitrogen, 5.1 g of phosphorus, and 4.0 g of potassium (Ciampitti & Vyn, 2012). Around 40% of Africa's maize-growing area faces occasional drought stress, resulting in yield losses of 10-25%. The Drought Resistant Maize for Africa project has released 160 drought-resistant maize varieties between 2007 and 2013, offering resistance to diseases and high protein content. These varieties also have similar labour requirements and seed costs (Makate *et al*., 2017).

In Ghana, most farmers use granule fertilizer for maize cultivation, but it has disadvantages such as water availability, unpredicted rainfall pattern, timing of fertilizer application, improper application method, uneven application, and difficulty in measuring and spreading. Studies have shown that subsurface incorporation and deep placement of multi-nutrient fertilizer briquettes and organically enhanced N fertilizer (OENF) significantly increase maize yields and nutrient use efficiency compared to split application of granular fertilizer (Adjei-Nsiah, 2010). Previous study also shows that protein, oil, ash, and starch contents of maize grain were not compromised, but increases in grain fiber content were observed following the application of briquettes and OENF (Obiri-Nyarko, 2012). This adds to the proven benefits of briquetting granular fertilizers into super granules for deep placement into the root zone of the crop, and incorporating organic sources into commercially-available inorganic fertilizers. Recent statistics indicate growing interest in both granular and briquette fertilizers in maize production across sub-Saharan Africa, particularly Ghana, as farmers seek to increase productivity on nutrient-depleted soils. According to Adzawla *et al.* (2024) national fertilizer usage in Ghana has more than doubled in the last decade, yet average application rates remain below recommended levels at approximately 20–25 kg ha^{-1}, far less than the 70–90 kg ha^{-1} applied in more intensive maize systems. A study by Kouame *et al.* (2021) to compare forms and rates of NPK application showed that deep-placed briquette fertilizers significantly improve nutrient-use efficiency often exceeding 60% compared with surface-applied granular fertilizers, which commonly achieve only 30–40%. According to Adu-Gyamfi *et al.* (2019), one-time placement of multi-nutrient briquettes at recommended NPK rates produced highest yields. The projected trend in population growth will mean that market demand for food will continue to grow, with cereal production expected to reach over 3 billion tonnes by 2050 (GSS, 2021). Inorganic fertilizers exert strong influence on plant growth, development, and yield, and one-time application of multi-nutrient fertilizer briquettes could be an ideal fertilizer management strategy for maize production in Ghana.

Effective nutrient management strategies that increase maize productivity and profitability among smallholder farmers are needed to address soil fertility decline and improve maize productivity. The study therefore was to determine the growth and yield performance of maize to different application rates of briquette and granule NPK fertilizers.

2. MATERIALS AND METHODS

2.1 Experimental Location

Two field experiments were conducted concurrently at Atebubu in the Bono East Region and Dormaa Ahenkro in the Bono region of Ghana with a week interval in planting between the two locations. Atebubu District, located in the Brong East Region, shares boundaries with the Pru District to the North, the Sene District to the East, and the West Kintampo South and Nkoranza North. Atebubu District is located between latitudes 7°23' N and 8°22' N and longitudes 0°30' W and 1°26' W. Soils in Atebubu – Amantin Municipal range from fine sandy loams to clayey loams and are mostly poorly drained. The Municipality experiences a tropical interior savannah type of climate due to its location in the transitional zone. The mean monthly temperature ranges from 30°C in March to 24°C in August, with mean annual temperatures ranging between 26.5°C and 27.2°C. The Municipality comes under the influence of the Northeast Trade Winds (Harmattan) between November and March/April. Dormaa Ahenkro Municipal, located in the Bono Region, has an annual rainfall level ranging between 1250 mm and 1750 mm and a temperature ranging from 26.1°C to 30.0°C. Dormaa Ahenkro is situated at Latitude 7.2671 N and Longitude 2.8677 W. The topography of

Dormaa Ahenkro is mainly characterized by a low elevation not exceeding 152 meters above sea level, a moist semi-deciduous forest, and fertile soil. Geologically, 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.

2.2 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 measured 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).

2.3 Soil Sampling and Analysis

Initial soil samples were collected randomly from the field at a depth of about 0-30 cm using soil auger. The collected soil samples were dried and bulked into composite samples prior to fertilizer application. The soil sample was air-dried and sieved through a 2.00 mm mesh to for both physical and chemical analysis. Final soil samples were also collected from the respective treatment plots at a depth of about 0-30 cm using soil auger. Some of the parameters analyzed included: [pH (1:1 H2O), organic matter (%), organic carbon (%), total N (%), available P and K (ppm), exchangeable cations: Ca, Mg, K, Na (me/100g), and exchangeable acidity: Al and H (me/100g), and particle size analysis. The analyses were conducted at the Soil Science Laboratory of Council for Scientific and Industrial Research, Soil Research Institute-Kwadaso in Kumasi, Ghana. Soil texture was assessed using the hydrometer method, while soil pH in water was measured with a Veb Pracitron glass electrode pH meter from Dresden, Germany. Organic matter content was determined through the wet combustion method (Walkey & Black, 1934).

Total nitrogen was measured using the micro-Kjeldahl technique (AOAC, 1975). Available phosphorus was extracted using the Bray P-1 method and analyzed colorimetrically following the Bray & Kutz (1945) procedure.

Potassium concentration was determined by flame emission photometry (IITA, 1979). Exchangeable cations (Ca, Mg, K, and Na) were extracted with 0.1N ammonium acetate at pH 7.0 and measured via EDTA titration, as recommended by IITA (1979). Exchangeable aluminium was extracted using 1 M KCl solution (soil-to-solution ratio 1:5), filtered, and titrated with 0.01 M NaOH using phenolphthalein as an indicator. The volume of NaOH used determined the Al^{3+} concentration, following standard procedures (IITA, 1979).

2.4 Experimental Design and Treatment

The experimental design used for both the Atebubu and Dormaa Ahenkro experiments was a Randomized Complete Block Design (RCBD) with eight treatments, each replicated four times. The treatments included: T1 - No Fertilizer (Control); T2 - Granule (120-40-40 kg ha^{-1} NPK); T3 - Granule (116-48-46 kg ha^{-1} NPK); T4 – Granule (86-48-46 kg ha^{-1} NPK); T5 - Granule (55-48-46 kg ha^{-1} NPK); T6 - Briquette (116-48-46 kg ha^{-1} NPK); T7 - Briquette (86-48-46 kg ha^{-1} NPK); and T8 - Briquette (55-48-46 kg ha^{-1} NPK) fertilizer.

2.5 Planting Materials 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, a few vacant holes were refilled with new seeds.

2.6 Agronomic Practices

Weeds were controlled at 2-3 weeks after planting manually using hoe and hand pulling. 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 frugiperda)*. Fall Armyworm was controlled by spraying with ''Gro-Safe'' organic pesticide containing Azadirachtin as an active ingredient, a natural oil extract from neem seeds at a rate of 8 liters insecticide in 8, 000 liters of water per hectare 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. A total of 432 g - 576 g of briquette fertilizer was applied per plot depending on the treatment combination whereas the granule NPK fertilizer was applied at 600 – 750 g per plot depending on the treatment combinations.

2.7 Harvesting

Harvesting was done at when there were notable signs of maturity including plant lodging, leaf and stalk senescence, the drooping of leaves and ears, and the browning of the husk, tassel, and silk. The grain moisture content was also below 20 to 25 percent. The process was carried out using a cutlass to cut the stalk just above the soil surface. The maize ears were then twisted off the stalk.

2.8 Agronomic Data Collected

Percentage crop establishment was determined by counting the number of plants that had established in each 3 m x 3 m 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. The number of days to 50% tasseling and silking was determined on the plants within the (3 m x 3 m) 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 3 m x 3 m per plot had tasseled or silked. 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. 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. 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. Five cobs were randomly selected from the (3 m x 3 m) of each plot and the length was determined from the base of the cob to the tip with a meter rule. The means were estimated. Hundred seeds were randomly sampled from (3 m x 3 m) area of each plot after shelling, weighed using an electronic weighing scale and used to compute the mean. Harvest index was determined by the formula below as described by Amanullah *et al.* (2019).

$$\text{Harvest index} = \frac{\text{Grain yield (kg)}}{\textit{Biological yield}}. \quad (1)$$

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).

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

2.9 Statistical Analysis

The data was analyzed using the analysis of variance (ANOVA) with GenStat Release 18.1 Statistical Package. Treatment means were compared using Tukey's Honestly Significant Difference (HSD) at 5% level of probability.

3. RESULTS

3.1 Climatic Conditions at the Experimental Sites

Table 1 shows the climatic data at Atebubu and Dormaa Ahenkro during the experimental period. At Atebubu, 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.

At Dormaa Ahenkro, 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 1).

3.2 Initial Chemical and Physical Properties of Soil at Atebubu and Dormaa Ahenkro

Table 2 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 (SRI, 2007). The nitrogen content, potassium, organic matter level, and phosphorus levels were low in the soils at Atebubu. Calcium, manganese and magnesium contents were high. Similarly, at Dormaa Ahenkro, the soil had a pH of 5.5 which was acidic and the texture was sandy loam. The nitrogen content, organic matter level, phosphorus, potassium and magnesium levels were low. Calcium, manganese and magnesium contents were high.

Table 1. Climatic data at Atebubu and Dormaa Ahenkro during the experimental period

Months	Rainfall (mm)	Temp (Max)°C	Temp (Min)°C	Relative Humidity (%) 18.00hr (%)	15.00hr	Wind speed (m/s)
			Atebubu			
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**					
			Dormaa Ahenkro			
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**					

Table 2. 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

Table 3. Final soil chemical and physical properties at Atebubu during the 2022 Growing Season

Parameters	Treatments							
	Control	Granule (120-40-40 kg ha^{-1} NPK)	Granule (116-48-46 kg ha^{-1} NPK)	Granule (86-48-46 kg ha^{-1} NPK)	Granule (55-48-46 kg ha^{-1} NPK)	Briquette (116-48-46 kg ha^{-1} NPK)	Briquette (86-48-46 kg ha^{-1} NPK)	Briquette (55-48-46 kg ha^{-1} 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. Final soil chemical and physical properties at Dormaa Ahenkro during the 2022 growing season

Parameters	Treatments							
	Control	**Granule (120-40-40 kg ha^{-1} NPK)**	**Granule (116-48-46 kg ha^{-1} NPK)**	**Granule (86-48-46 kg ha^{-1} NPK)**	**Granule (55-48-46 kg ha^{-1} NPK)**	**Briquette (116-48-46 kg ha^{-1} NPK)**	**Briquette (86-48-46 kg ha^{-1} NPK)**	**Briquette (55-48-46 kg ha^{-1} 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							

3.3 Final Chemical and Physical Properties of Soil at Atebubu and Dormaa Ahenkro

Table 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. 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. Boron and Zinc contents remained same. There was a slight increase in CEC and Iron contents across the treatments. Soil texture remained sandy loam.

From Table 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. Boron content remained same. There was a slight increase in CEC, Zinc and Iron contents across the treatments. Soil texture remained sandy loam.

3.4 Phenology of Maize

3.4.1 Percentage crop establishment

Table 5 revealed 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^{-1} NPK) fertilizer and at Dormaa Ahenkro Granule (116-48-46 kg ha^{-1} NPK) fertilizer recorded the highest. Atebubu produced higher percentage number of established plants than Dormaa Ahenkro. There was no significant ($P \geq 0.05$) difference between location x treatment interactions in percentage crop establishment.

3.4.2 Days to 50% tasseling

Table 6 showed no significant differences in days to 50% tasseling between treatments, with Granule (55-48-46 kg ha^{-1} NPK) recording the lowest days across both locations. Dormaa Ahenkro had the least mean number of days to 50% tasseling than Atebubu. No significant differences were found between location and treatment interactions (Table 6).

3.4.3 Days to 50% silking

There were no significant ($P \geq 0.05$) 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^{-1} NPK) at Atebubu (Table 6). Least mean number of days to 50% silking was recorded in Atebubu than in Dormaa Ahenkro. There was no significant ($P \geq 0.05$) difference between location x treatment interactions in days to 50% silking.

Table 5. Effect of different rates of NPK fertilizer (Granules and Briquettes) on percentage crop establishment at Atebubu and Dormaa Ahenkro

Treatment	Percentage crop establishment (%)	
	Atebubu	Dormaa Ahenkro
No Fertilizer (control)	86.25	81.25
Granule (120-40-40 kg ha^{-1} NPK)	90.00	88.50
Granule (116-48-46 kg ha^{-1} NPK)	96.25	96.00
Granule (86-48-46 kg ha^{-1} NPK)	94.25	92.13
Granule (55-48-46 kg ha^{-1} NPK)	91.00	90.63
Briquette (116-48-46 kg ha^{-1} NPK)	97.13	94.63
Briquette (86-48-46 kg ha^{-1} NPK)	92.75	90.75
Briquette (55-48-46 kg ha^{-1} NPK)	93.63	91.18
Mean	**92.66**	**90.63**
HSD (P ≤ 0.05)	**NS**	**NS**
CV (%)	**3.08**	**4.24**
Treatment	= NS	
Location	= 1.68*	
Location x Treatment	= NS	

Table 6. 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^{-1} NPK)	52.50	50.50	55.25	55.25
Granule (116-48-46 kg ha^{-1} NPK)	52.00	51.00	54.50	56.55
Granule (86-48-46 kg ha^{-1} NPK)	51.50	51.50	54.50	57.45
Granule (55-48-46 kg ha^{-1} NPK)	51.00	49.50	54.50	53.55
Briquette (116-48-46 kg ha^{-1} NPK)	51.75	52.50	55.35	57.25
Briquette (86-48-46 kg ha^{-1} NPK)	53.50	50.75	57.75	54.75
Briquette (55-48-46 kg ha^{-1} 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	

3.5 Vegetative Growth

3.5.1 Plant height

Table 7 reveals significant differences in plant height at 5 and 7 weeks after planting. At Atebubu, maize plants receiving Granule (55-48-46 kg ha^{-1} NPK) and Granule (116-48-46 kg ha^{-1} NPK) had the tallest plants at 5 WAP and 7 WAP, respectively, significantly different from the control. At Dormaa Ahenkro, maize plants receiving Granule (116-48-46 kg ha^{-1} NPK) had the tallest plants at 5 and 7 WAP, and significantly taller than the control and Briquette (55-48-46 kg ha^{-1} NPK). Dormaa Ahenkro had taller plants than Atebubu at both 5 and 7 weeks. Significant differences were found between location and treatment interactions.

3.5.2 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 (Figs. 1 and 2). At 5 WAP the maize plants that received Granule (116-48-46 kg ha^{-1} NPK) recorded the highest number of leaves per plant that differed significantly from the control and Briquette (55-48-46 kg ha^{-1} NPK) at both Atebubu and Dormaa Ahenkro (Fig. 1). At

Table 7. 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^{-1} NPK)	83.38b	115.95abc	155.45cd	184.85abc
Granule (116-48-46 kg ha^{-1} NPK)	95.09ab	134.38a	206.50a	206.55a
Granule (86-48-46 kg ha^{-1} NPK)	83.68b	109.96abcd	173.80abc	202.88ab
Granule (55-48-46 kg ha^{-1} NPK)	106.85a	96.20cd	196.23ab	162.42c
Briquette (116-48-46 kg ha^{-1} NPK)	94.57b	123.28abc	183.13abc	206.50a
Briquette (86-48-46 kg ha^{-1} NPK)	88.70b	129.50ab	161.45c	202.88ab
Briquette (55-48-46 kg ha^{-1} 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*	

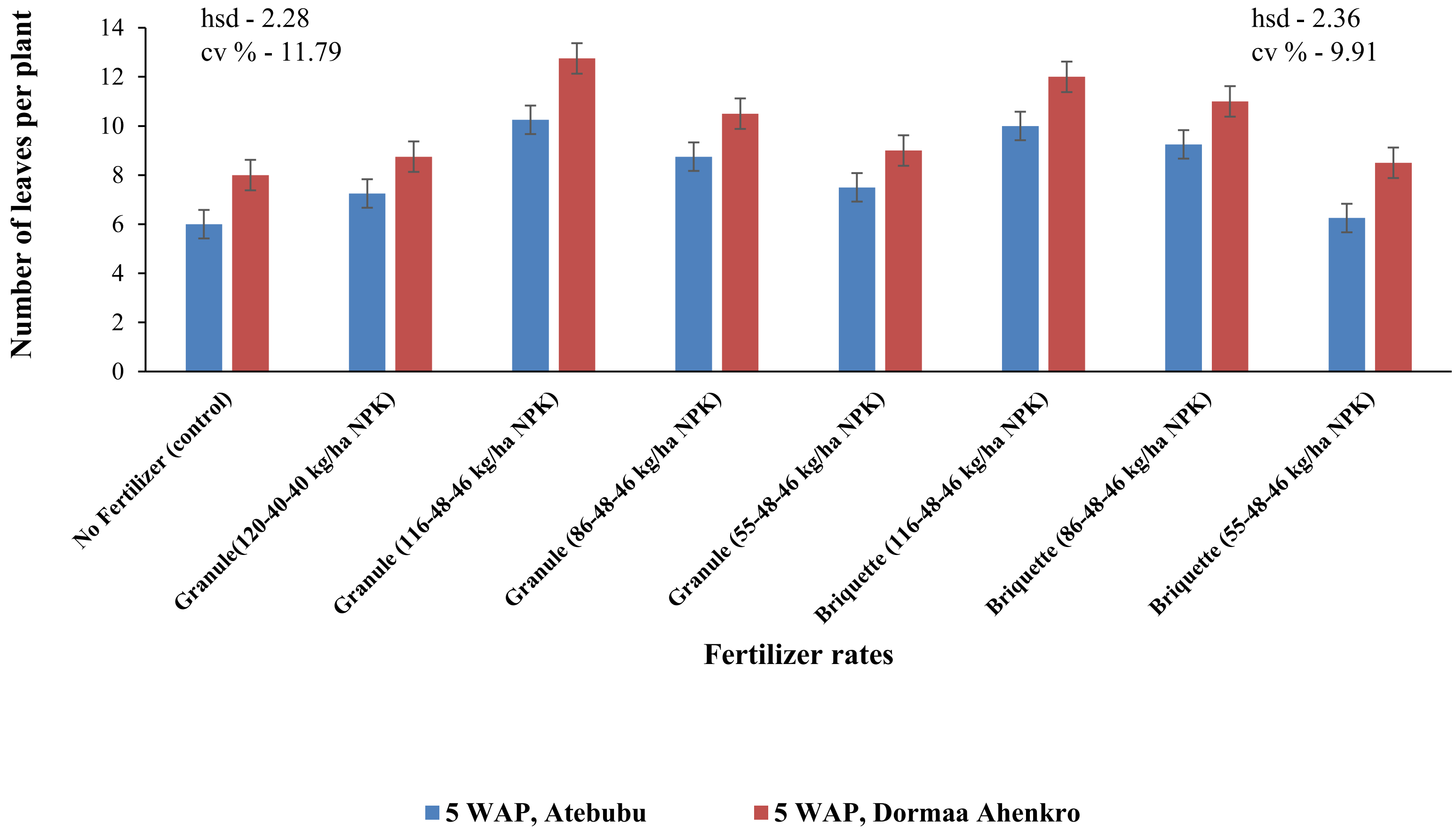

Fig. 1. Effect of different rates of NPK fertilizer (Granules and Briquettes) on Number of leaves per plant (5 WAP) at Atebubu and Dormaa Ahenkro

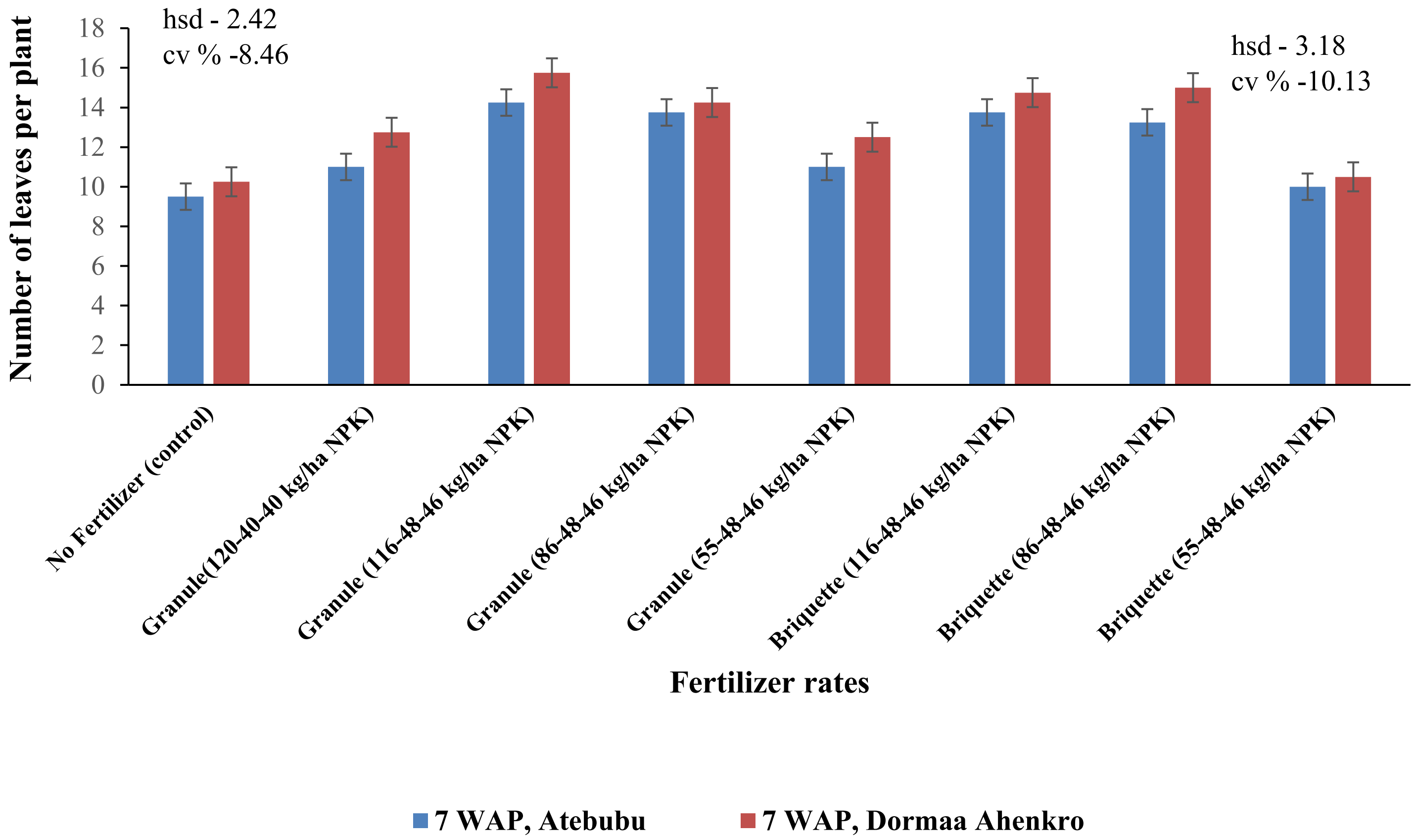

Fig. 2. Effect of different rates of NPK fertilizer (Granules and Briquettes) on Number of leaves per plant (7 WAP) at Atebubu and Dormaa Ahenkro

7 WAP, maize plants that received Granule (116-48-46 kg ha^{-1} NPK) recorded significantly higher number of leaves per plant than the control, Granule (120-40-40 kg ha^{-1} NPK), Briquette (55-48-46 kg ha^{-1} NPK) and Granule (55-48-46 kg ha^{-1} NPK) at Atebubu (Fig. 2). Similar trend was observed at Dormaa Ahenkro, where the maize plants that received Granule (116-48-46 kg ha^{-1} NPK) recorded significantly higher number of leaves per plant than the control, Granule (55-48-46 kg ha^{-1} NPK) and Briquette (55-48-46 kg ha^{-1} NPK) (Fig. 2).

3.6 Yield and Yield Components

3.6.1 Number of cobs per plot

At Atebubu, maize plants that received Briquette (116-48-46 kg ha^{-1} NPK) recorded significantly higher number of cobs per plot than plants that received Granule (55-48-46 kg ha^{-1} NPK) and Briquette (55-48-46 kg ha^{-1} NPK) (Table 8). At Dormaa Ahenkro, amending soils with Granule (116-48-46 kg ha^{-1} NPK) produced the highest (59.75) number of cobs per plot and was significantly ($P \leq 0.05$) different from plants that received Briquette (55-48-46 kg ha^{-1} NPK) and the control. Higher (54) number of cobs per plot were harvested in Dormaa Ahenkro than in Atebubu (46). There was no significant ($P \geq 0.05$) difference between treatment x location interaction in number of cobs per plot (Table 8).

3.6.2 100- seed weight

The weight of 100-seeds showed significant ($P \leq 0.05$) differences among treatments at Atebubu though treatment with fertilizer application weighed far more than the control (Table 9). Maize plants that received Granule (116-48-46 kg ha^{-1} 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^{-1} NPK) and differed significantly from the control (Table 9). 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 9).

3.6.3 Cob length

Significant differences were observed in cob length among treatments and between locations (Table 9). Maize plants that received Granule (86-48-46 kg ha^{-1} NPK) recorded the longest cob length at Atebubu (15.99 cm) whilst Granule (116-48-46 kg ha^{-1} 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.

Table 8. Effect of different rates of NPK fertilizer (Granules and Briquettes) on number of cobs per plot at Atebubu and Dormaa Ahenkro

Treatment	Number of cobs per plot	
	Atebubu	Dormaa Ahenkro
No Fertilizer (control)	33.50a	48.50c
Granule (120-40-40 kg ha^{-1} NPK)	46.25ab	52.25bc
Granule (116-48-46 kg ha^{-1} NPK)	56.75a	59.75a
Granule (86-48-46 kg ha^{-1} NPK)	46.25ab	55.00ab
Granule (55-48-46 kg ha^{-1} NPK)	42.00b	50.00bc
Briquette (116-48-46 kg ha^{-1} NPK)	57.00a	58.75a
Briquette (86-48-46 kg ha^{-1} NPK)	46.75ab	54.25abc
Briquette (55-48-46 kg ha^{-1} NPK)	38.00b	51.00bc
Mean	**45.81**	**53.69**
HSD (P ≤ 0.05)	**13.76**	**6.48**
CV (%)	**12.66**	**5.09**
Treatment	= 8.05*	
Location	= 2.55*	
Location x Treatment	= NS	

Table 9. Effect of different rates of NPK fertilizer (Granules and Briquettes) on 100-seed weight and cob length at Atebubu and Dormaa Ahenkro

Treatment	100-seed weight (g)		Cob length (cm)	
	Atebubu	Dormaa Ahenkro	Atebubu	Dormaa Ahenkro
No Fertilizer (control)	28.00b	28.00c	12.15c	11.00c
Granule (120-40-40 kg ha^{-1} NPK)	29.00b	29.00c	13.93bc	12.80bc
Granule (116-48-46 kg ha^{-1} NPK)	35.50a	39.00a	15.56ab	16.50a
Granule (86-48-46 kg ha^{-1} NPK)	35.25a	37.00a	15.99a	14.28ab
Granule (55-48-46 kg ha^{-1} NPK)	30.25b	29.25bc	13.65bc	12.40bc
Briquette (116-48-46 kg ha^{-1} NPK)	34.25a	37.00a	15.94a	13.93abc
Briquette (86-48-46 kg ha^{-1} NPK)	30.75b	34.75ab	14.13abc	13.25bc
Briquette (55-48-46 kg ha^{-1} NPK)	20.75b	29.00c	14.15ab	12.08bc
Mean	**30.47**	**32.88**	**14.47**	**13.28**
HSD (P ≤ 0.05)	**2.94**	**5.58**	**1.98**	**3.11**
CV (%)	**3.90**	**7.16**	**5.80**	**9.87**
Treatment	= 2.92*		1.38*	
Location	= 0.93*		0.44*	
Location x Treatment	= 4.71*		NS*	

3.6.4 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 10). There were however significant differences between location in harvest index (Table 10). Higher harvest index was recorded in Atebubu than in Dormaa Ahenkro**.**

3.6.5 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 10). The application of different granule and briquette NPK fertilizers to maize showed significant (P≤0.05) differences between treatments in grain yield (t/ha) at Atebubu. Maize grain that received Granule (116-48-46 kg ha^{-1} 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^{-1} 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 (t/ha) (Table 10).

Table 10. Effect of different rates of NPK fertilizer (Granules and Briquettes) on harvest index and grain yield at Atebubu and Dormaa Ahenkro

Treatment	Harvest index		Grain yield (t/ha)	
	Atebubu	Dormaa Ahenkro	Atebubu	Dormaa Ahenkro
No Fertilizer (control)	0.59	0.40	2.14c	2.08b
Granule (120-40-40 kg ha^{-1} NPK)	0.69	0.42	3.44c	2.69b
Granule (116-48-46 kg ha^{-1} NPK)	0.61	0.60	5.56a	5.53a
Granule (86-48-46 kg ha^{-1} NPK)	0.61	0.55	5.17ab	5.37a
Granule (55-48-46 kg ha^{-1} NPK)	0.56	0.54	3.22c	3.78ab
Briquette (116-48-46 kg ha^{-1} NPK)	0.67	0.64	5.53a	5.92a
Briquette (86-48-46 kg ha^{-1} NPK)	0.57	0.52	3.72bc	3.99ab
Briquette (55-48-46 kg ha^{-1} NPK)	0.70	0.48	2.97c	2.52b
Mean	**0.63**	**0.52**	**3.97**	**3.99**
HSD (P ≤ 0.05)	**NS**	**NS**	**1.65**	**2.28**
CV (%)	**25.07**	**25.19**	**17.51**	**24.10**
Treatment	= NS		1.30*	
Location	= 0.07*		NS	
Location x Treatment	= NS		NS*	

4. DISCUSSION

4.1 Effect of Briquette and Granules NPK Fertilizer 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 within 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.

4.2 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.,* 2021). 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).

4.3 Effect of Briquette and Granules NPK Fertilizer on Vegetative growth of Maize

The analysis of vegetative growth parameters including plant height, number of leaves per plant, 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 their effects on nutrient availability and uptake.

The different NPK fertilizer briquette and granule combinations revealed significant differences with regard to plant height and number of leaves per plant from 5 to 7 WAP in both locations. Generally, maize plants that received Granule (116-48-46 kg ha^{-1} NPK) had significantly taller plants, higher number and leaves per plant 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^{-1} 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 and leaf number. Nitrogen is a key component of chlorophyll, essential for photosynthesis, and influences cell elongation, which collectively led to taller plants (Ghadirnezhad *et al*., 2024).

Significant ($P<0.05$) differences were recorded with respect to the number of leaves per plant at both locations (Fig. 1). Granule (116-48-46 kg ha^{-1} NPK) fertilizer 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.

4.4 Effect of Briquette and Granules NPK Fertilizer on Yield and Yield Components of Maize

The higher number of cobs per plot recorded by maize plants that received Granule (116-48-46 kg ha^{-1} NPK) and Briquette (116-48-46 kg ha^{-1} NPK) fertilizers than maize plants that received Granule (55-48-46 kg ha^{-1} NPK), Briquette (55-48-46 kg ha^{-1} 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^{-1} NPK) and Briquette (116-48-46 kg ha^{-1} NPK) fertilizers might have facilitated better nitrogen uptake and utilization by the plants, resulting in increased cob formation (Urban *et al*., 2021).

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^{-1} NPK) and Briquette (116-48-46 kg ha^{-1} NPK) recorded significantly heavier 100-seed weight, longer cobs and higher grain yield than maize plants that received Briquette (55-48-46 kg ha^{-1} NPK) fertilizer and the control. This could be due to adequate N.P.K nutrient combinations applied for plants absorption and utilization. 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 Briquette 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 Briquette 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.

5. CONCLUSION

The study showed that amending soils with both briquette and granule NPK fertilizer had a positive impact on the chemical properties (OM, CEC, Fe, K and Zn) of the soil in both experimental sites with Granule (116-48-46 kg ha^{-1} NPK) or Briquette (116-48-46 kg ha^{-1} NPK) performing better in most cases. 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^{-1} NPK) and Briquette (116-48-46 kg ha^{-1} NPK) largely performed better in terms of number of cobs per plot, 100-seed weight and cob length than the other briquette and granule NPK fertilizer. The granule (116-48-46 kg ha^{-1} NPK) and briquette (116-48-46 kg ha^{-1} NPK) fertilizers produced the highest yields, indicating their effectiveness in enhancing maize productivity. However, no significant differences were found in the harvest index across treatments. It is recommended that, farmers should apply Granule (116-48-46 kg ha^{-1} NPK) or Briquette (116-48-46 kg ha^{-1} NPK) for enhanced soil chemical properties, optimized maize yield and enhanced cob quality.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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