Open Access Library Journal
2025, Volume 12, e14168
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Influence of NPK (Granule and Briquette) + Urea Fertilizers on Selected Soil Properties, Growth and Yield of Maize (*Zea mays* L.)

Carlos Mikeson Kofoya, Margaret Esi Esilfie, Emmanuel Kwesi Asiedu, Bennett Osei, Kofi Amponsah, William Atakora, Derrick Kumah-Amenudzi, Cynthia Olerckie Nongorh, Grace Nartey

Department of Crop and Soil Sciences Education, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Kumasi, Ghana
Email: aamusted.edu.gh

How to cite this paper: Kofoya, C.M., Esilfie, M.E., Asiedu, E.K., Osei, B., Amponsah, K., Atakora, W., Kumah-Amenudzi, D., Nongorh, C.O. and Nartey, G. (2025) Influence of NPK (Granule and Briquette) + Urea Fertilizers on Selected Soil Properties, Growth and Yield of Maize (*Zea mays* L.). *Open Access Library Journal*, **12**: e14168.
https://doi.org/10.4236/oalib.1114168

Received: August 26, 2025
Accepted: October 24, 2025
Published: October 27, 2025

Abstract

Two field studies were conducted simultaneously at two locations in Atebubu (Bono East region) and Adomase (Bono region) of Ghana during the 2022 major crop growing seasons to determine the effect of NPK (Granule and Briquette) + Urea fertilizers on selected soil properties, growth and yield of maize. The experimental design used was Randomized Complete Block Design (RCBD) with four replications. The treatment evaluated were; I Control with no amendment, II Granule NPK + Urea at 200 kg/ha, III Granule NPK + Zn + Urea at 133.2 kg/ha, IV Granule NPK + Zn + Urea at 120.2 kg/ha, V Granule NPK + Urea at 152 kg/ha, VI Briquette NPK + Urea at 115.2 kg/ha, VII Briquette NPK + Urea at 57.6 kg/ha, and VIII Briquette NPK + Urea at 100 kg/ha. The basal amendments (NPK granule and briquette) were applied three weeks after sowing (3 WAS) and the top dressing (Urea granule and briquette) at seven weeks after sowing (7 WAS). The results of the study demonstrated no significant differences among treatments for the soil chemical properties such as pH, total nutrients (N, P, K, B, Zn, Fe, Cu, CEC, C/N ratio), and extractable nutrients (P, K, Ca, B, Mn) and soil organic carbon content. There were significant differences ($p \leq 0.05$) among treatments with leaf chlorophyll content, in which (Granule NPK + Urea at 200 kg/ha) recorded the highest values of 51.4 SPAD. Again, Granule NPK + Urea at 200 kg/ha recorded the highest significant value in maize leaf area. The influence of the treatments significantly increased 100 seed weight, in treatments with fertilizer amendment. The Grain yield recorded no significant differences ($p \geq 0.05$) among treatments. Briquette NPK + Urea at 115.2 kg/ha, as well as Briquette NPK + Urea at 100 kg/ha have performed in equal measures with Granule NPK + Urea fertilizers in the following parameters: biomass at harvest, 100 seed weight, leaf area, and cob weight. In conclusion, the Briquette NPK + Urea fertilizers exerted as many similar effects on soil properties and on growth and yield of maize as the commonly used granule fertilizers, even though the briquette fertilizers were applied at lower rates than the granule fertilizers. Briquette fertilizers are promising and could be an alternate N source to granule fertilizers.

Subject Areas

Soil Science

Keywords

Inorganic Fertilizer, NPK Briquette, Granule Fertilizers, Maize, Yield

1. Introduction

Continuous cultivation of available arable lands has become vital due to an increase in human population [1]. This has resulted in a decline of soil fertility which is recognized as a severe problem affecting agricultural output and environmental well-being in Sub-Saharan Africa. Meanwhile, food production is expected to triple by 2050 to meet the demands of the world's rising population [1] [2].

Inorganic fertilizers have been used to boost food production [1]. Mineralization of the granule fertilizer is known to be very fast due to increase in surface area [3] [4]. However, their efficiency is known to be low, with approximately 40% - 70% N, 80% - 90% P and 50% - 70% K applied being lost through leaching, volatilization, and erosion contributing to the degradation of soil properties, environmental damage, biodiversity loss, groundwater contamination, and thus posing a health risk to humanity [5]. Also, the successive reduction of nitrate to nitrite and then to nitrogen gas contributes to global warming [6].

Over-application and under application of inorganic fertilizers in Sub-Saharan Africa according to Bijay-Sing and Craswell [7], is one of the major problems associated with granular fertilizer application, in which farmers use their own discretion and apply any fertilizer quantity. Inadequate fertilizer application has the tendency to cause a decline in the yield of the crop and consequently results in food shortage and hunger, whilst application of fertilizer more than crop requirement will increase the cost of production but would not necessarily increase yield [8]. Selecting fertilizer formulas that allow for minimal nutrient losses is crucial for soil fertility, agronomic and environmental sustainability [9]. Briquette NPK fertilizer is designed to minimize nutrient losses and it is efficient because it releases nutrients slowly [10]. Maize plants cultivated in Ghana's savanna agro-ecological zones retrieved about 77 percent of the briquette fertilizer applied, improving maize output by 30 percent when compared to split application of granular fertilizer sources, according to Adu-Gyamfi *et al.* [11]. Agyin-Birikorang *et al.* [12] reported that NPK briquettes increased maize yield by 16% compared with ammonium sulphate and by 23% to 34% relative to urea under normal weather conditions. NPK briquette also resulted in higher N, P, and K use efficiencies; Rice yields were increased by 25% to 50% with the application of the fertilizer briquette compared with commercial granular fertilizer in Vietnam and Cambodia [10] [13] [14]. Research in Bangladesh revealed that rice yield was enhanced by 25% - 35%, while expenditure on commercial fertilizer was decreased by 24% - 32% when the fertilizer briquette was used [15]. The increased N-use efficiency with the fertilizer briquette implies lower N losses to water bodies and the atmosphere through leaching and volatilization [3] [15].

2. Materials and Methods

2.1. Experimental Site and Location

The experiment was conducted at two locations concurrently with two-week intervals at Atebubu in Atebubu-Amantin District of the Bono East Region and Adomase in the Dormaa Central District of the Bono Region of Ghana in the major season from April to August, 2022. The district is located in the transitional zone (between the two major climatic regions in Ghana). The mean monthly temperature ranges from 30˚C in March to 24˚C in August [16]. The total annual rainfall is between 1,400 mm and 1,800 mm and occurs in two seasons. The first rainy season begins in May or June whilst the second rainy season begins in September or October [16]. The soil textural class was clay loam classified as Eutric Nitosol. Adomase is located in the Dormaa Central District of Bono Region of Ghana. The soil textural class was sandy loam classified as Rhodic Ferralsol.

2.2. Experimental Design and Treatment

The experimental design used for both Experiments (Atebubu and Adomase) was a Randomized Complete Block Design (RCBD) with eight (8) treatments and each treatment was replicated four (4) times. The treatments used for the study were:

T1 Control (No fertilizer)
T2 Granule NPK + Urea at 200 kg/ha
T3 Granule NPK + Zn and Urea at 133.2 kg/ha
T4 Granule NPK + Zn and Urea at 120.2 kg/ha
T5 Granule NPK + Urea at 152 kg/ha
T6 Briquette NPK + Urea at 115.2 kg/ha
T7 Briquette NPK + Urea at 57.6 kg/ha
T8 Briquette NPK + Urea at 100 kg/ha

2.3. Land Preparation and Field Layout

Land was prepared at both locations by removal of stumps followed by ploughing and harrowing. Lining and pegging were 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 × 26 m (1, 222 m^2).

2.4. Planting Material and Planting

The planting material used for the study was the Sanzal sima maize which was obtained from the International Fertilizer Development Center (IFDC). Seed planting was carried out at Atebubu on the 13th of April 2022 and subsequently on 27th April at Adomase. Three (3) seeds were sown per hole and later thinned to two (2) seedlings per hole. The planting distance was 75 cm × 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.

2.5. Cultural/Management Practices

Weeds were controlled for both experiments I and II (Atebubu and Adomase) at 2 - 3 weeks after planting manually using a hoe. 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 a 15-litre Knapsack sprayer tank for both locations (Atebubu and Adomase). This was done at six (4) weeks after planting for both locations. The different rates of briquette and granular NPK fertilizers were applied 3 weeks after planting by side deep placement method at 3 weeks after planting.

2.6. Data Collection and Statistical Analysis

Determination of Soil Physical Properties before Planting

Soil infiltration

Soil infiltration was measured using a single-ring infiltrometer as described by Blake and Hartge [17]. The unit was in mm/hour.

Bulk density

The bulk density was measured as described by Klute.

$$\text{Bulk density} = \frac{\text{Oven dried weight}(\text{kg})}{\text{Volume}(\text{cm}^3)} \tag{1}$$

Gravimetric water content

Gravimetric water content was measured as follows;

$$\text{Gravimetric water content} = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Dry weight}} \times 100\% \tag{2}$$

Porosity

The porosity was measured as described by Blake and Hartge:

$$\text{Porosity} = \frac{\text{Fresh weight of soil} - \text{Oven dry weight}}{\text{Volume of soil}} \times 100\% \tag{3}$$

Particle Density

The particle density was measured using Klute.

$$\text{The total Porosity (Pt)}, \quad \text{Pt} = \frac{1-(\text{Bulk density})}{(\text{Particle densty})} \times 100\%$$

$$\text{Particle density} = \frac{-(\text{Bulk density})}{(\text{PT})-1} \times 100\% \quad (4)$$

Soil Particle Size Determination

Particle size distribution was determined by the Bouyoucos Hydrometer method [18].

2.7. Phenological Data

The vegetative growth parameters were taken for both experiments at Atebubu and Adomase on five plants from each treatment plot which were randomly sampled from the four middle rows (3 m × 3 m plot). Data on vegetative growth parameters were taken at 2-week intervals beginning from 5 weeks after planting (5 WAP) to 7 WAP.

Days to 50% Tasseling and Silking

The number of days to 50% tasseling and silking was determined by counting the number of days from sowing to when 50% of plants within the 3 m × 3 m per plot had tasseled or silked.

2.8. Vegetative Growth Data

The vegetative growth data taken were plant height, number of leaves per plant and leaf chlorophyll content.

2.8.1. Plant Height

Plant heights were measured at 5 and 7 weeks after planting at both locations.

2.8.2. Leaf Chlorophyll Content

The leaf chlorophyll content was determined using the SPAD meter.

2.9. Yield and Yield Components

Yield and yield components data were taken from the (3 m × 3 m) area per plot for determination of number of plants harvested, Grain Yield (t/ha), 100-seed weight, number of grains per cob and Biomass weight (t/ha).

2.10. Grain Yield (t/ha)

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

$$\text{Yield} = \frac{\text{Yield}(\text{kg})}{\text{Harvestable area}(\text{m}^2)} \times \frac{10,000\text{m}^2}{1000} \quad (5)$$

100-seed weight was also recorded for each plot and means were estimated for each treatment.

2.11. 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.

3. Results

3.1. Initial Soil Physical Properties

The soil's initial physical properties are presented in Table 1.

Table 1. Initial soil physical properties at Atebubu and Adomase during the 2022 growing season.

Parameters	Units	Location	
		Atebubu	Adomase
Bulk density	g/cm^3	1.26	1.42
Porosity	%	44.1	46.3
Particle density	g/cm^3	2.62	2.66
Infiltration	mm/h	15.5	40.7
Gravimetric water content	%	24	11
Sand	%	27.3	48.8
Silt	%	34.4	43.6
Clay	%	38.3	7.6
Textural Class		Clay loam	Sandy Loam

3.2. Initial Soil Chemical Properties

Table 2 presents the initial soil chemical properties (0 - 20 cm depth) recorded at the experimental sites.

Table 2. Initial soil chemical properties within 20 cm depth at both experimental sites.

Parameters	Units	Location	
		Atebubu	Adomase
pH	1:2.5 H_2O	6.5	5.5
Organic C	%	0.87	0.87
Total N	%	0.07	0.06
OM	%	1.8	1.6
Ca^{2+}	Cmol(+)/kg	16	6.9
Mg^{2+}	Cmol(+)/kg	2.3	1.4
Ex. K^+	Cmol(+)/kg	0.3	0.1
Boron	Cmol(+)/kg	0.008	0.008
Available P	Cmol(+)/kg	0.03	0.03
Manganese	Cmol(+)/kg	2.6	2.36
Zinc	Cmol(+)/kg	0.015	0.017
CEC	Meq/100g	6.3	3.9
Iron	Cmol(+)/kg	2.52	1.92
Copper	%	2	1.8
C/N ratio	N/A	15	15

3.3. Soil Chemical Properties after Harvest of Maize

Table 3 and Table 4 show the soil chemical properties after the harvest of maize. The results revealed no significant difference among treatments in both locations (Table 3 and Table 4).

3.3.1. Exchangeable Bases (Ca^{2+}, K^+ and Mg^{2+})

The Ca^{2+} content differed significantly between the locations. Higher values were recorded in Atebubu than in Adomase. Whilst the values ranged from 15.6 to 16.0 cmol(+)/kg in Atebubu, they ranged from 5.7 to 6.9 cmol(+)/kg in Adomase (Table 3 and Table 4). No significant differences were recorded among treatments at both locations.

Similarly, the result revealed a significant difference between the locations in Mg^{2+}. The value recorded for the Mg^{2+} was higher at Atebubu than at Adomase. At Atebubu, the value was 2.6 cmol(+)/kg but at Adomase it was 1.4 cmol(+)/kg (Table 3). However, no significant differences were observed among treatments.

In a similar trend, 1.3 cmol(+)/kg was recorded for K^+ at Atebubu but the value for K^+ at Adomase was 1 cmol(+)/kg indicating a significant difference between the two locations (Table 3 and Table 4). The treatments however did not differ significantly at each location.

3.3.2. Available Phosphorus

A similar trend was recorded with respect to soil available phosphorus showing no significant difference among treatments as well as between the two locations (Table 3 and Table 4). The values recorded at both locations were 0.3 cmol(+)/kg (Table 3 and Table 4).

3.3.3. Zinc

Results in Table 3 show the values recorded for Zn which were similar ($p > 0.05$) among treatments and between locations. At Atebubu, for instance, the Granule NPK + Zn and Urea 133.2 kg/ha as well as Granule NPK + Zn and Urea 120.2 kg/ha recorded 0.03 cmol(+)/kg each while the rest recorded 0.02 cmol(+)/kg each (Table 3 and Table 4).

3.3.4. Cation Exchange Capacity (CEC)

All the treatments recorded a CEC of 6.3 meq/100g at Atebubu (Table 4). Meanwhile, at Adomase, the result ranged from 3.2 meq/100g to 4.1 meq/100g. The highest value of 4.1 meq/100g was recorded by Granule NPK + Urea 152 kg/ha while Briquette NPK + Urea 115.2 kg/ha recorded the least value of 3.2 meq/100g (Table 3). There was no significant difference ($p > 0.05$) among the treatments in both locations. However, there was a significant difference in CEC between the locations.

3.3.5. C/N Ratio

No significant difference was observed in C/N ratio both among treatments and between locations (Table 4). Generally, a C/N ratio of 15 was observed among all treatment at Atebubu whereas at Adomase, the C/N ratio ranged from 15 to 16 (Table 3 and Table 4)

Table 3. Final soil chemical properties after harvest of maize at Adomase.

Fertilizer Treatments (kg/ha)	pH 1:2.5 H_2O	Organic C (%)	Total N (%)	OM (%)	Exchangeable Bases (Cmol(+)/kg)			B (Cmol (+)/kg)	Avail.P (Cmol (+)/kg)	Mn (Cmol (+)/kg)	Zn (Cmol (+)/kg)	CEC (Meq /100g)	Fe (Cmol (+)/kg)	Cu (Cmol (+)/kg)	C/N ratio
					Ca	Mg	K								
Adomase															
Control	5.5	0.87	0.06	1.5	6.9	1.4	0.1	0.005	0.03	2.3	0.003	3.9	1.9	0.02	15
Granule NPK + Urea at 200	5.2	0.82	0.08	1.4	6.9	1.4	0.1	0.005	0.03	2.3	0.003	3.3	1.9	0.02	15
Granule NPK + Znand Urea at 133.2	5.3	0.88	0.07	1.5	5.76	1.5	0.1	0.005	0.03	2.3	0.003	4.1	1.9	0.02	15
Granule NPK + Zn and Urea 120.2	5.3	0.81	0.05	1.3	6.41	1.3	0.1	0.005	0.03	2.3	0.003	3.4	1.9	0.02	16
Granule NPK + Urea at 152	5.1	0.88	0.06	1.4	6.79	1.3	0.1	0.005	0.03	2.3	0.003	4.2	1.9	0.02	16
Briquette NPK + Urea at 115.2	5.3	0.87	0.07	1.6	6.41	1.3	0.1	0.005	0.03	2.3	0.003	3.2	1.9	0.02	15
Briquette NPK + Urea at 57.6	5.2	0.86	0.07	1.5	5.76	1.5	0.1	0.005	0.03	2.3	0.003	3.3	1.9	0.02	16
Briquette NPK + Urea at 100	5.1	0.83	0.07	1.3	6.41	1.3	0.1	0.005	0.03	2.3	0.003	3.4	1.9	0.02	16
Fpr	3.12	0.75	1.63	0.87	3.22	4.11	3.24	2.73	0.09	0.63	0.06	0.79	0.41	0.53	0.43
HSD (5%)	0.48	0.12	0.07	0.42	64.1	6.34	15.0	0.73	2.24	2.1	0.06	2.46	6.12	1.01	1.07
Fpr (Location × Treatment)	1.00	0.82	0.06	0.31	2.19	0.56	0.03	0.04	0.01	0.76	0.01	0.01**	0.03**	0.22	0.03**
HSD (5%)	0.00	0.23	0.19	0.00	0.00	0.00	0.01	0.52	0.17	0.41	0.26	0.02	0.00	0.06	0.06
CV (%)	0.42	2.05	7.72	7.14	1.88	3.99	4.70	6.23	3.23	4.13	2.78	6.27	1.16	1.11	5.16

Table 4. Final soil chemical properties after harvest of maize at Atebubu.

Fertilizer Treatments (kg/ha)	pH 1:2.5 H_2O	Organic C (%)	Total N (%)	OM (%)	Exchangeable Bases (Cmol(+)/kg)			B (Cmol (+)/kg)	Avail. P (Cmol (+)/kg)	Mn (Cmol (+)/kg)	Zn (Cmol (+)/kg)	CEC (Meq /100g)	Fe (Cmol (+)/kg)	Cu (Cmol (+)/kg)	C/N ratio
					Ca	Mg	K								
Adomase															
Control	6.3	0.87	0.07	1.8	16.0	2.6	0.3	0.005	0.03	2.6	0.002	6.3	2.5	0.03	15
Granule NPK + Urea at 200	6.1	0.82	0.08	1.8	16.0	2.6	0.3	0.005	0.03	2.6	0.002	6.3	2.5	0.03	15
Granule NPK + Znand Urea at 133.2	6.3	0.88	0.07	1.7	16.0	2.6	0.3	0.005	0.03	2.6	0.002	6.3	2.5	0.03	15
Granule NPK + Zn and Urea 120.2	6.3	0.81	0.07	1.8	15.9	2.6	0.3	0.005	0.03	2.6	0.002	6.3	2.5	0.03	15
Granule NPK + Urea at 152	6.1	0.88	0.06	1.8	15.6	2.6	0.3	0.005	0.03	2.6	0.002	6.3	2.5	0.03	15

Continued

Briquette NPK + Urea at 115.2	6.3	0.87	0.07	1.6	16.0	2.6	0.3	0.005	0.03	2.6	0.002	6.3	2.5	0.03	15
Briquette NPK + Urea at 57.6	6.3	0.87	0.07	1.7	16.0	2.6	0.3	0.005	0.03	2.6	0.002	6.3	2.5	0.03	15
Briquette NPK + Urea at 100	6.3	0.87	0.07	1.7	16.0	2.6	0.3	0.005	0.03	2.6	0.002	6.3	2.5	0.03	15
Fpr	4.3	0.15	1.45	3.92	2.33	1.82	0.86	1.77	0.02	0.01	0.34	0.11	0.02	0.01	0.55
HSD (5%)	0.50	0.33	0.26	0.70	14.1	0.08	0.76	0.08	1.32	17.01	1.46	0.47	0.18	1.53	0.22
Fpr (Location × Treatment)	1.00	0.82	0.06	0.31	2.19	0.56	0.03	0.04	0.01	0.76	0.01	0.01**	0.03**	0.22	**0.03****
HSD (5%)	0.00	0.23	0.19	0.00	0.00	0.00	0.01	0.52	0.17	0.41	0.26	0.02	0.00	0.06	**0.06**
CV (%)	0.42	2.05	7.72	7.14	1.88	3.99	4.70	6.23	3.23	4.13	2.78	6.27	1.16	1.11	**5.16**

3.4. Phenology of Maize

3.4.1. Days to 50% Tasseling

The results on days to 50% tasselling as influenced by the different rates of fertilizer were not significantly different among the treatments at Atebubu and Adomase. Again, there were no significant differences observed between locations (Table 5). The results revealed that plant treated with Granule NPK + Urea at 152 kg/ha had the earliest tasselling at 49.5 DAS (days after sowing) and 51 DAS at Adomase and Atebubu, respectively.

3.4.2. Days to 50% Silking

Table 5 revealed no significant difference in days to 50% silking among treatments at both locations (Table 5). Similarly, no significant difference was realised in days to 50% silking between the two locations. Days to 50% silking ranged from 54.5 to 57.75 at Atebubu and from 53.55 at Adomase.

Table 5. Effect of NPK + Urea fertilizer granules and briquettes on tasseling and silking at Atebubu and Adomase.

Treatment (kg/ha)	Days to 50% Tasselling		Days to 50% silking	
	Atebubu	Adomase	Atebubu	Adomase
T1 Control (No fertilizer)	51.25a	52.20a	55.00a	56.75a
T2 Granule **NPK + Urea** at 200	52.50a	50.50a	55.25a	55.25a
T3 Granule **NPK + Zn** and **Urea** at 133.2	52.00a	51.00a	54.50a	56.55a
T4 Granule **NPK + Zn** and **Urea** at 120.2	51.50a	51.50a	54.50a	57.54a
T5 Granule **NPK + Urea** at 152	51.00a	49.50a	54.50a	53.55a
T6 Briquette **NPK + Urea** at 115.2	51.75a	52.50a	55.35a	57.25a
T7 Briquette **NPK + Urea** at 57.6	53.50a	50.75a	57.75a	54.75a
T8 Briquette **NPK + Urea** at 100	52.41a	51.67a	56.67a	56.74a
HSD (P ≤ 0.05)	**4.16**	**4.31**	**5.66**	**4.4**
P-Value	**(0.07)**	**(0.86)**	**(0.48)**	**(0.75)**
CV (%)	**3.44**	**1.45**	**3.80**	**1.34**
Location =	**0.72** (p = 0.003)**		**0.68** (p = 0.004)**	
Location x Treatment =	**4.47 (p = 0.646)**		**3.66 (p = 0.875)**	

3.5. Vegetative Growth

3.5.1. Plant Height

Table 6 shows the results for plant height of maize at 5 and 7 weeks after sowing (5 WAS). There was no significant difference among treatments at Atebubu and Adomase at 5 WAS. Also, no significant differences were observed between the two locations. Similarly, the results recorded in the 7 WAS were not significantly different among treatments at Atebubu and Adomase as well as between the locations.

Table 6. Initial soil physical properties at Atebubu and Adomase during the 2022 growing season.

Treatment (kg/ha)	Days to 50% Tasselling		Days to 50% silking	
	5 WAS		7 WAS	
	Atebubu	**Adomase**	**Atebubu**	**Adomase**
T1 Control (No fertilizer)	45.75 a	56.00 a	145.58 a	173.50 a
T2 Granule **NPK + Urea** at 200	64.85 a	58.50 a	175.10 a	200.30 a
T3 Granule **NPK + Zn** and **Urea** at 133.2	55.87 a	59.00 a	152.50 a	174.45 a
T4 Granule **NPK + Zn** and **Urea** at 120.2	53.77 a	58.50 a	146.70 a	165.55 a
T5 Granule **NPK + Urea** at 152	60.65 a	59.50 a	145.80 a	174.45 a
T6 Briquette **NPK + Urea** at 115.2	64.45 a	58.50 a	158.15 a	186.50 a
T7 Briquette **NPK + Urea** at 57.6	53.12 a	58.75 a	157.97 a	178.45 a
T8 Briquette **NPK + Urea** at 100	55.57 a	57.67 a	152.63 a	178.65 a
HSD (P ≤ 0.05)	**24.49**	**5.46**	**45.68**	**47.12**
P-Value	**(0.246)**	**(0.166)**	**(0.435)**	**(0.257)**
CV (%)	**18.19**	**14.74**	**12.48**	**10.93**
Location =	**8.62** (p = 0.001)**		**11.12** (p = 0.014)**	
Location x Treatment =	**20.21 (p = 0.885)**		**56.60 (p = 0.754)**	

3.5.2. Leaf Chlorophyll Content

The chlorophyll content of the leaves of the maize plants was observed 5 weeks after sowing (5 WAS) and 7 weeks after sowing (7 WAS). The Granule NPK + Urea (200 kg/ha) recorded the highest chlorophyll content at Atebubu, at 5 and 7 WAS. There were significant pairwise differences (p > 0.05) among treatment means at Atebubu in the 5 weeks after sowing and the 7 weeks after sowing. The Granule NPK + Urea 200 kg/ha recorded the highest chlorophyll content in the 5 and 7 WAS at both locations (Table 7). Meanwhile, no significant differences were observed among fertilizer treatments at Adomase. The control recorded the least leaf chlorophyll content at both locations. Significant differences were observed between locations.

Table 7. Effect of NPK + Urea fertilizer granules and briquettes on Chlorophyll content at Atebubu and Adomase.

Treatment (kg/ha)	Chlorophyll content 5 WAS		Chlorophyll content 7 WAS	
	Atebubu	Adomase	Atebubu	Adomase
T1 Control (No fertilizer)	37.6 f	31.00 a	41.5 bc	39.8 a
T2 Granule **NPK + Urea** at 200	48.9 a	38.50 a	51.4 a	47.7 a
T3 Granule **NPK + Zn** and **Urea** at 133.2	40.1 def	29.90 a	40.3 c	45.8 a
T4 Granule **NPK + Zn** and **Urea** at 120.2	38.4 ef	38.50 a	41.0 c	43.2 a
T5 Granule **NPK + Urea** at 152	47.0 ab	30.60 a	48.2 ab	44.5 a
T6 Briquette **NPK + Urea** at 115.2	44.6 bc	28.50 a	45.3 abc	43.9 a
T7 Briquette **NPK + Urea** at 57.6	41.8 cde	33.75 a	44.2 bc	42.4 a
T8 Briquette **NPK + Urea** at 100	42.4 cd	32.70 a	44.1 bc	44.2 a
HSD (P ≤ 0.05)	3.86	10.67	6.93	8.17
P-Value	(0.001)	(0.245)	(0.003)	(0.475)
CV (%)	3.84	8.39	6.57	7.93
Location =	2.8** (p=0.006)		1.61** (p=0.006)	
Location x Treatment =	10.21 (p = 0.003)		8.19 (p = 0.183)	

3.5.3. Leaf Area

Table 8 revealed that at 5 weeks after sowing (5 WAS), Granule NPK + Urea 200 kg/ha produced the largest leaf area (395.38 cm^2) followed by Briquette NPK + Urea at 115.2 kg/ha (382.90 cm^2) at Atebubu. There was no significant difference among treatments in the 5 WAS at Atebubu. The least value (322.0 cm^2) was recorded under the control (Table 8). Results in the 7 weeks after sowing revealed that Granule NPK + Urea 200 kg/ha again recorded the highest (493.5 cm^2) and the least was recorded under the control showing significant differences among treatments.

Table 8. Initial soil physical properties at Atebubu and Adomase during the 2022 growing season.

Treatment (kg/ha)	Chlorophyll content 5 WAS		Chlorophyll content 7 WAS	
	Atebubu	Adomase	Atebubu	Adomase
T1 Control (No fertilizer)	322.0 a	331.0 a	396.4 b	399.8 a
T2 Granule **NPK + Urea** at 200	395.4 a	338.5 a	493.5 a	442.7 a
T3 Granule **NPK + Zn** and **Urea** at 133.2	335.2 a	329.9 a	402.1 b	444.8 a
T4 Granule **NPK + Zn** and **Urea** at 120.2	320.7 a	338.5 a	411.1 ab	443.2 a
T5 Granule **NPK + Urea** at 152	378.2 a	330.6 a	473.0 ab	433.5 a
T6 Briquette **NPK + Urea** at 115.2	382.9 a	328.5 a	477.2 ab	413.9 a
T7 Briquette **NPK + Urea** at 57.6	361.5 a	333.7 a	405.1 ab	445.4 a
T8 Briquette **NPK + Urea** at 100	332.9 a	342.70 a	432.3 ab	414.2 a

Continued

HSD ($P \leq 0.05$)	116.78	111.34	108.13	121.41
P-Value	(0.059)	(0.096)	(0.027)	(0.164)
CV (%)	14.12	8.39	8.82	7.93
Location =	40.70** (p = 0.001)		35.16** (p = 0.022)	
Location x Treatment =	79.45 (p = 0.835)		179.01 (p = 0.255)	

A similar trend was observed at Adomase in 5 weeks after sowing where Briquette NPK + Urea 100 kg/ha recorded the highest value (342.7 cm^2) and the least value (331 cm^2) was recorded under the control (Table 8). In the 7 weeks after sowing, Briquette NPK + Urea 57.5 kg/ha recorded the highest (445.4 cm^2) and the least (399 cm^2) was recorded under the control (Table 8). No significant differences were observed among treatments in the 5 WAS and 7 WAS at Adomase. There was, however, a significant difference between locations in the 7 weeks after sowing.

3.6. Yield and Yield Components

3.6.1. Grain Yield

Table 9 shows that the application of different granule and briquette fertilizers had no significant ($p > 0.05$) effect on the grain yield (t/ha) between treatments at Atebubu and at Adomase. However, the highest Grain yield value of 4.31 t/ha was recorded by both Granule NPK + Urea 200 kg/ha and Granule NPK + Zn + Urea 120.2 kg/ha. The second highest value 3.94 t/ha was recorded by Granule NPK + Urea 152 kg/ha. The least 2.87 t/ha was recorded by the control. There was a significant interaction effect between locations.

3.6.2. 100 Seed Weight

The weight of 100 seeds showed a significant ($p < 0.5$) difference among treatments at Atebubu where treatment with fertilizer application weighed far more than the control (Table 9). No significant difference was recorded at Adomase. However, there was significant interaction effect between locations.

Table 9. Effect of NPK + Urea fertilizer granules and briquettes on grain yield (t/ha) and weight of 100 seed at Atebubu and Adomase.

Treatment (kg/ha)	**Grain Yield (t/ha)**		**Weight of 100 Seed(g)**	
	5 WAS		**7 WAS**	
	Atebubu	**Adomase**	**Atebubu**	**Adomase**
T1 Control (No fertilizer)	2.87 a	3.22 a	31.7 b	34.0 a
T2 Granule **NPK + Urea** at 200	4.31 a	3.09 a	34.5 a	37.5 a
T3 Granule **NPK + Zn** and **Urea** at 133.2	2.98 a	2.92 a	35.0 a	33.5 a
T4 Granule **NPK + Zn** and **Urea** at 120.2	4.31 a	3.21 a	34.2 a	32.5 a
T5 Granule **NPK + Urea** at 152	3.94 a	3.24 a	34.7 a	35.0 a
T6 Briquette **NPK + Urea** at 115.2	3.48 a	3.24 a	35.7 a	35.5 a
T7 Briquette **NPK + Urea** at 57.6	3.53a	3.21a	34.5 a	30.0 a

Continued

T8 Briquette **NPK + Urea** at 100	2.92 a	3.07 a	35.0 a	37.5 a
HSD (P ≤ 0.05)	1.58	111.34	108.13	121.41
P-Value	(0.473)	(0.578)	(0.002)	(0.425)
CV (%)	29.90	7.69	1.56	19.04
Location =	0.24**(p = 0.001)		2.42** (p = 0.836)	
Location x Treatment =	1.24* (p = 0.835)		12.34 (p = 0.170)	

3.6.3. Number of Grains Per Cob

The result from this study showed that the various treatments had similar effects (p > 0.05) on the number of grains per cob at both locations and among the treatments (Table 10).

3.6.4. Biomass at Harvest

Again, no significant differences were observed in the biomass at harvest among treatments at Atebubu and Adomase. However, the highest biomass weight of 8.02 and 7.61 (t/ha) was recorded under Granule NPK + Urea 200 kg/ha and Granule NPK + Zn and Urea at 120.2 kg/ha at Atebubu and Adomase respectively (Table 10). There was a significant difference between locations.

Table 10. Effect of NPK + Urea fertilizer granules and briquettes on number of grains per cobs and biomass at harvest in Atebubu and Adomase.

Treatment (kg/ha)	Number of grains Per cob		Biomass at harvest (t/ha)	
	Atebubu	**Adomase**	**Atebubu**	**Adomase**
T1 Control (No fertilizer)	353.25 a	333.54 a	5.67 a	7.11 a
T2 Granule **NPK + Urea** at 200	342.25 a	317.54 a	8.02 a	7.56 a
T3 Granule **NPK + Zn** and **Urea** at 133.2	342.00 a	342.35 a	6.86 a	7.28 a
T4 Granule **NPK + Zn** and **Urea** at 120.2	352.50 a	328.14 a	7.24 a	7.61 a
T5 Granule **NPK + Urea** at 152	340.50 a	315.95 a	7.16 a	7.02 a
T6 Briquette **NPK + Urea** at 115.2	363.75 a	364.22 a	7.11 a	6.52 a
T7 Briquette **NPK + Urea** at 57.6	375.75 a	376.49 a	6.61 a	6.8 a
T8 Briquette **NPK + Urea** at 100	364.25 a	359.90 a	7.4 a	7.47 a
HSD (P ≤ 0.05)	77.58	91.07	2.54	2.03
P-Value	(0.459)	(0.153)	(0.275)	(0.752)
CV (%)	14.35	11.22	16.89	13.24
Location =	18.3** (p = 0.021)		0.54** (p = 0.041)	
Location x Treatment =	93.19 (p = 0.651)		2.74 (p = 0.431)	

4. Discussion

4.1. Soil pH

After the harvest, a look at the initial soil chemical properties (Table 2) compared with the final results (Table 3 and Table 4) revealed that the pH values did not significantly change at both locations. This trend may be due to the short-term nature of the study. This finding aligns with previous studies by Ayoola and Olutayo [19], who indicated that mineral fertilizer treatment did not have a significant difference in soil pH after planting for two years in a cassava-based cropping system.

4.2. Soil Organic Carbon

Soil organic carbon (0.88%) was observed in Granule NPK + Zn and Urea at 133.2 kg/ha; and Granule NPK + Urea 152 kg/ha in both locations. The least value of 0.81% was recorded by Granule NPK + Zn and Urea at 120.2 kg/ha in the two locations. The values recorded are not significantly ($p < 0.05$) different among treatments. This result agreed with the findings by Taiwo [20], who recorded no significant difference with NPK fertilizer on soil organic carbon after a long-term study of NPK fertilizers and organic manures on soil organic carbon management.

4.3. Total Nitrogen

The total N of the soils used for the experiment at both locations was lower than 0.15% showing that the soils were deficient in N [12] and thereby needed N fertilization. In **Table 3** and **Table 4**, the total N showed no significant ($p < 0.05$) differences among treatments and locations. This may be due to the plant N uptake or N loss through leaching or runoff [21], since volatilization was not anticipated because the fertilizers were applied in deep placement.

4.4. Exchangeable Bases

The Ca^{2+} content (**Table 3** and **Table 4**) has witnessed a significant ($p < 0.05$) difference between the locations. These differences could be attributed to the difference in the textural class of the soil found at Adomase and Atebubu [22]. The results recorded ranging from 3.26 to 5.76 cmol(+)/kg at both locations, however, were very low as they fell below the average value between 10 - 20 cmol(+)/kg [23].

The Mg^{2+} value recorded at Atebubu across all treatments was 2.6 cmol(+)/kg which was significantly different (**Table 3** and **Table 4**) from the values recorded at Adomase where the Mg^{2+} values range from 1.3 to 1.5 cmol(+)/kg as recorded by Briquette NPK + Urea 100 kg/ha, and Granule NPK + Urea 133.2 kg/ha respectively.

The exchangeable potassium (K^{+}) levels in the final soil results remained low and were consistent with the values as compared with the initial results (**Table 3** and **Table 4**), indicating that the applied K+ was either utilized by the crops or lost through leaching and or runoff as affirmed by Zhou [19]. There was a significant ($p < 0.05$) difference in the results between Adomase and Atebubu which were consistent with the initial and may be attributed to the soil textural class differences in each location [24].

4.5. Available P

No significant differences were observed in soil available P among treatments and locations (Table 3 and Table 4). This result conformed with that of Sanyal *et al.* [25] and Warren, G. P. [26] who attributed the P values in the NPK fertilizer to have either been utilized by the maize plant or were lost through leaching, erosion and or volatilization resulting in no significant difference in the soil test results after harvest.

4.6. Micro Nutrients

The micro elements namely Boron (B), Iron (Fe), Manganese (Mn), Copper (Cu), and Zinc (Zn) exhibited no significant difference among treatments and between locations (Table 3 and Table 4).

The value of Boron recorded in both locations and among all treatments did not show any significant differences (Table 3 and Table 4). There was no significant difference between the treatments that received the zinc and those that do not (Table 3 and Table 4). This suggested that the Zn supplement added could be utilized by the plants or lost. This agreed with the result of Sutar *et al.* [27] who indicated that Zinc supplement applied in maize nutrition could, either be utilized by the maize plant or it could be lost through leaching, runoff, or through volatilization.

A similar trend was observed for Cu in which a constant figure of 0.03 cmol(+)/kg for all treatments was recorded at Atebubu but a value of 0.02 cmol(+)/kg was recorded for all treatments at Adomase (Table 3).

4.7. Carbon-Nitrogen (C/N) Ratio

Carbon-to-nitrogen (C/N) ratio in both locations remained stable after the research (Table 3 and Table 4). A value of 15 was recorded for all treatments and locations. C/N ratio was relatively balanced, providing favourable conditions for nutrient mineralization and for plant uptake. According to Sutar *et al.* (27) C/N ratio of <25 ensures mineralization, between 25 - 35, there is no gain, whilst >35 will result in immobilization.

4.8. Cation Exchange Capacity (CEC)

The CEC values recorded after harvest were consistent with the initial values, suggesting no effects on the CEC by the various treatments. This is similar to the finding by Cui *et al.* [28], who stated that NPK application for two seasons in maize crop production did not have a significant difference in soil CEC. However, there was a significant ($p < 0.05$) difference between the locations. This could be due to the textural class differences between the soil in the two locations, that is sandy loam and clayey loam at Adomase and Atebubu respectively [29].

4.9. Effect of Briquette and Granules NPK Fertilizer on Phenology of Maize

The fertilizer treatments did not show any significant ($p < 0.05$) difference in the Days to 50% Tasseling and 50% silking of the maize plant (Table 5). This result is in line with the findings by Xiaohui *et al.* [30] and Rahman *et al.* [14], who stated that phenological development such as emergence, tasseling, silking, and maturity of maize plants is primarily influenced by genetics and environmental conditions rather than the specific fertilizers used.

4.10. Effects of Briquette and Granule NPK Fertilizer on Vegetative Growth of Maize

The analysis of vegetative growth parameters including plant height, leaf chlorophyll content and leaf area, showed variations between treatments and locations, suggesting the influence of NPK (Granule and Briquette) + Urea 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.

4.10.1. Plant Height

The various fertilizer combinations did not show significant differences with regard to plant height (**Table 6**). The significant differences observed between locations in the plant height, with higher values in Adomase than Atebubu, point towards the influence of environmental factors, soil quality, climate conditions, or other location-specific variables on maize yield. Adomase likely offers more favorable conditions for maize growth compared to Atebubu, resulting in a higher plant height due to better adaptation to local environmental factors. This result did not conform with the finding by Shoji *et al.* [31] who reported a taller plant height within two weeks with granule mineral fertilizer as a result of increasing level of fertilizer application rate. This trend might again be due to the fact that treatments with fertilizer amendments could not have utilized all nutrients and nutrients may have been lost through leaching, runoff, or volatilization.

4.10.2. Chlorophyll Content

Chlorophyll content in leaves under Granule NPK + Urea at 200 kg/ha, between treatments at Atebubu was significantly different ($p < 0.05$) from the rest of the treatments (**Table 7**). In this study, it was revealed that treatments containing Granule NPK + Urea 200 kg/ha as well as Granule NPK + Urea 152 kg/ha performed better with leaf chlorophyll content. This could be as a result of the nature of granule fertilizers with respect to surface area of the granule which ensures rapid nutrient release and plant uptake for photosynthetic activity [32]. Again, the result agreed with the findings by Wamalwa *et al.* [33] who reported an increase in leaf chlorophyll content due to an increase in NPK application rate of 100 kg/acre. Insufficient rainfall leads to reduced chlorophyll content due to water deficiency and stress [30]. 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 [34].

4.10.3. Leaf Area

The results, as presented in **Table 8**, revealed that at 5 weeks after sowing (5 WAS), Granule NPK + Urea at 200 kg/ha produced larger layer leaves (395.38 cm^2) followed by Briquette NPK + Urea 115.2 kg/ha (382.9 cm^2) at Atebubu. The least value (322.0 cm^2) was recorded under the control (**Table 8**). Results in the 7 weeks after sowing revealed that Granule NPK + Urea at 200 kg/ha again recorded the highest (493.5 cm^2) and the least was recorded under the control which showed significant differences among treatments. Nitrogen which is an important component in vegetative growth could have been responsible for the larger leaf layer under the granule NPK + Urea at 200 kg/ha. Nitrogen is a key component of chlorophyll, essential for photosynthesis, and influences cell elongation, which collectively led to broader leaf [35]. These results agree with [19] who recorded higher leaf area values with 120:60:60 NPK kg/ha fertilizer.

Adomase was recorded to have no significant effect on leaf area. Differences in leaf area across locations can be attributed to variations in environmental factors.

4.11. Impact of Briquette and Granule NPK Fertilizer on Yield and Yield Components of Maize

4.11.1. Grain Yield

A look at the data in **Table 9** revealed that the application of different granule and briquette fertilizers has a significant difference ($p > 0.05$) in the grain yield at Atebubu but not Adomase. The highest Grain yield value of 4.31 t/ha was recorded by both Granule NPK + Urea at 200 kg/ha and Granule NPK + Zn + Urea 120.2 kg/ha. The second highest value 3.94 t/ha was recorded by Granule NPK + Urea 152 kg/ha. The least 2.87 t/ha was recorded by the control. These findings did not agree with the result by Adu-Gyamfi, *et al.* [11] who reported that one-time application of multi-nutrient fertilizer briquettes increased maize grain yields. This could be due to the rate of fertilizer application in which this study saw a low rate of briquette fertilizer amendment as compared with the rate of granule fertilizers. Again, the nature of the briquette fertilizer may have delayed the release of the nutrients.

Similar trend was observed with 100-seed weight which revealed a significant difference ($p < 0.5$) among treatments at Atebubu where treatment with fertilizer application weighed far more than the control (**Table 9**). The highest 100 seed weight as recorded by the treatments with fertilizer application than the control suggests that nutrients were available which the plants used to form seeds with heavier seed than the control. These results agree with the findings by Dhakal, *et al.* [36] who recorded a higher 100-seed weight in maize when deep placement of briquette urea increased agronomic and economic efficiency of maize. Again, this result aligned with the finding by Wang *et al.* [30] who stated that under typical meteorological circumstances, nutrient-balanced NPK fertilizers have the same or larger effects on maize grain quality than the regularly used nutrient management techniques of urea and ammonium sulphate. No significant difference was recorded in Adomase.

4.11.2. Number of Grains Per Cob

No significant difference was observed in the number of grains per cob among treatments and locations (Table 10). This finding conforms with the result by Shamin *et al.* [37] who also recorded similar results with grain yield when the effects of nitrogen fertilization were used on maize production. The significant differences observed between locations in the number of grains per cob, point towards the influence of environmental factors, soil quality, climate conditions, or other location-specific variables on maize yield [38].

4.11.3. Biomass at Harvest

Significant differences were observed with respect to biomass yield at harvest at Atebubu. The higher biomass weight at harvest recorded in maize plants that received the Granule NPK + Urea 200 kg/ha recorded the highest biomass (7.22 kg). This observation could be due to the rate and the nature of the fertilizer amendment that was applied (Table 10). The higher nitrogen content in the fertilizers likely provided more available nitrogen for plant uptake, promoting vigorous vegetative growth and biomass production [39]. This observation affirms Anjum, *et al.* [4], assertion that, split nitrogen application had an influence on yield and yield components of maize varieties. This finding agrees with Syafruddin *et al.* [40], who found that application of NPK fertilizer increased maize yields.

Acknowledgements

We would like to acknowledge and give our sincere thanks to our supervisors Professor Kofi Agyarko and Mr. Emmanuel Kwasi Asiedu who made this work possible. Their guidance and advice carried me through all the stages of field project and thesis writing. Our special thanks go to our research work sponsors, Fertilizer Research and Responsible Implementation (FERARI) in collaboration with International Fertilizer Development Centre (IFDC), who gave us this opportunity under the FERARI Project.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] FAO (2021) Crop Prospects and Food Situation—Quarterly Global Report. https://doi.org/10.4060/cb5603en

[2] FAO and WFP (2021) Hunger Hotspots: Early Warnings on Acute Food Insecurity, June to October 2025 Outlook. World Food Programme. https://www.wfp.org/publications/hunger-hotspots-fao-wfp-early-warnings-acute-food-insecurity

[3] IFDC FERARI (2020) Yield Responses of Maize to Fertilizers in Ghana. IFDC FERARI Research Report No. 2.

[4] Anjum, M.M., Shafi, M., Ahmad, H., Ali, N., Iqbal, M.O., Ullah, S., *et al.* (2018) Influence of Split Nitrogen Application on Yield and Yield Components of Various Maize Varieties. *Pure and Applied Biology*, **7**, 721-726.

https://doi.org/10.19045/bspab.2018.70090

[5] Bijay-Sing and Craswell (2021) Leaching of Plant Nutrients from Agricultural Lands.

[6] WHO (2020) World Health Statistics: Monitoring Health for the SDGs. https://digitallibrary.un.org/record/3897953

[7] Bijay-Singh and Craswell, E. (2021) Fertilizers and Nitrate Pollution of Surface and Ground Water: An Increasingly Pervasive Global Problem. *SN Applied Sciences*, **3**, Article No. 518. https://doi.org/10.1007/s42452-021-04521-8

[8] IFAD (2021) Annual Report. https://www.ifad.org/en/annual-report-2021/

[9] IFDC (2018) Assessment of Fertilizer Distribution Systems and Opportunities for Developing Fertilizer Blends Ghana. AGRA IFDC.

[10] IFDC (2017) IFDC Annual Report. https://hub.ifdc.org/handle/20.500.14297/1714

[11] Adu-Gyamfi, R., Agyin-Birikorang, S., Tindjina, I., Ahmed, S.M., Twumasi, A.D., Avornyo, V.K., *et al.* (2019) One-Time Fertilizer Briquettes Application for Maize Production in Savanna Agroecologies of Ghana. *Agronomy Journal*, **111**, 3339-3350. https://doi.org/10.2134/agronj2019.04.0292

[12] Agyin-Birikorang, S., Winings, J.H., Yin, X., Singh, U. and Sanabria, J. (2018) Field Evaluation of Agronomic Effectiveness of Multi-Nutrient Fertilizer Briquettes for Upland Crop Production. *Nutrient Cycling in Agroecosystems*, **110**, 395-406. https://doi.org/10.1007/s10705-018-9905-y

[13] IFDC (2015) IFDC Magazine, Volume 40, No. 1. https://hub.ifdc.org/handle/20.500.14297/1847

[14] Rahman, M.M., Samanta, S.C., Rashid, M.H., Abuyusuf, M., Hassan, M.Z. and Sukhi, K.F.N. (2015) Urea Super Granule and NPK Briquette on Growth and Yield of Different Varieties of Aus Rice in Tidal Ecosystem. *Asian Journal of Crop Science*, **8**, 1-12. https://doi.org/10.3923/ajcs.2016.1.12

[15] Gaihre, Y.K., Singh, U., Jahan, I. and Hunter, G. (2017) Improved Nitrogen Use Efficiency in Lowland Rice Fields for Food Security. *Fertil Focus*, **4**, 48-51.

[16] Ghana Meteorological Agency (GMet) (2022) Map Showing the Synoptic Stations.

[17] Blake, G.R. and Hartge, K.H. (2018) Bulk Density. In: Klute, A., Ed., *SSSA Book Series*, Soil Science Society of America, American Society of Agronomy, 363-375. https://doi.org/10.2136/sssabookser5.1.2ed.c13

[18] Ayoola (2006) Soil Texture Analyses Using a Hydrometer: Modification of the Bouyoucos Method.

[19] Taiwo (2021) Influence of Poultry Manure and NPK Fertilizer on Yield and Yield Components of Crops under Different Cropping Systems in Southwest Nigeria. *African Journal of Biotechnology*, **5**, 1386-1392. https://www.researchgate.net/publication/285941710

[20] Kareem, I., Taiwo, O.S., Kareem, S.A., Oladosu, Y., Eifediyi, E.K., Abdulmaliq, S.Y., *et al.* (2020) Growth and Yield of Two Maize Varieties under the Influence of Plant Density and NPK Fertilization. *Journal of Applied Sciences and Environmental Management*, **24**, 531-536. https://doi.org/10.4314/jasem.v24i3.22

[21] Stoorvogel, J.J. and Smaling, E. (1990) Assessment of Soil Nutrient Depletion in Sub-Saharan Africa: 1983-2000, Vol. 1. Winand Staring Centre.

[22] Tetteh, F., Larbi, A., Nketia, K.A., Senayah, J.K., Hoeschle-Zeledon, I. and Adulrahman, N. (2016) Suitability of Soils for Cereal Cropping in Northern Ghana.

[23] Rabot, E., Wiesmeier, M., Schlüter, S. and Vogel, H. (2018) Soil Structure as an Indicator of Soil Functions: A Review. *Geoderma*, **314**, 122-137.

https://doi.org/10.1016/j.geoderma.2017.11.009

[24] Bekunda, M., Ebanyat, P., Nkonya, E., Mugendi, D. and Msaky, J. (2005) Soil Fertility Status, Management, and Research in East Africa. *Eastern Africa Journal of Rural Development*, **20**, 94-112. https://doi.org/10.4314/eajrd.v20i1.28362

[25] Sanyal, S.K., Majumdar, K. and Singh, V.K. (2014) Nutrient Management in Indian Agriculture with Special Reference to Nutrient Mining—A Relook. *Journal of the Indian Society of Soil Science*, **62**, 307-325.

[26] Warren, G.P. (1992) Fertilizer Phosphorus Sorption and Residual Value in Tropical African Soils. NRI Bull. 37, Natural Resources Institute Chatham.

[27] Sutar, R.K., Pujar, A.M., Kumar, B. and Hebsur, N.S. (2017) Sulphur Nutrition in Maize—A Critical Review. *International Journal of Pure & Applied Bioscience*, **5**, 1582-1596. https://doi.org/10.18782/2320-7051.6092

[28] Cui, Z., Zhang, F., Chen, X., Miao, Y., Li, J., Shi, L., *et al.* (2008) On-Farm Evaluation of an In-Season Nitrogen Management Strategy Based on Soil Nmin Test. *Field Crops Research*, **105**, 48-55. https://doi.org/10.1016/j.fcr.2007.07.008

[29] Ketterings, Q., Reid, S. and Rao, R. (2007) Cation Exchange Capacity (CEC), Agronomy Fact Sheet Series (22). Cornel University Cooperative Extension.

[30] Wang, X., Liu, S., Yin, X., Bellaloui, N., Winings, J.H., Agyin-Birikorang, S., *et al.* (2020) Maize Grain Composition with Additions of NPK Briquette and Organically Enhanced N Fertilizer. *Agronomy*, **10**, Article No. 852. https://doi.org/10.3390/agronomy10060852

[31] Shoji, S., Delgado, J., Mosier, A. and Miura, Y. (2001) Use of Controlled Release Fertilizers and Nitrification Inhibitors to Increase Nitrogen Use Efficiency and to Conserve Air and Water Quality. *Communications in Soil Science and Plant Analysis*, **32**, 1051-1070. https://doi.org/10.1081/css-100104103

[32] Agyin-Birikorang, S., Tindjina, I., Fugice, J., Dauda, H.W., Issahaku, A.R., Iddrissu, M., *et al.* (2022) Optimizing Sulfur Fertilizer Application Rate for Profitable Maize Production in the Savanna Agroecological Zones of Northern Ghana. *Journal of Plant Nutrition*, **45**, 2315-2331. https://doi.org/10.1080/01904167.2022.2063740

[33] Wamalwa, D.S., Sikuku, P.A., Netondo, G.W. and Khasabulli, B.D. (2019) Influence of NPK Blended Fertilizer Application on Chlorophyll Content and Tissue Mineral Contents of Two Finger Millet Varieties Grown in Acid Soils of Kakamega, Western Kenya. *International Journal of Plant & Soil Science*, **27**, 1-9. https://doi.org/10.9734/ijpss/2019/v27i430082

[34] Ghadirnezhad Shiade, S.R., Fathi, A., Kardoni, F., Pandey, R. and Pessarakli, M. (2023) Nitrogen Contribution in Plants: Recent Agronomic Approaches to Improve Nitrogen Use Efficiency. *Journal of Plant Nutrition*, **47**, 314-331. https://doi.org/10.1080/01904167.2023.2278656

[35] Dhakal, K., Baral, B.R., Pokhrel, K.R., Pandit, N.R., Thapa, S.B., Gaihre, Y.K., *et al.* (2020) Deep Placement of Briquette Urea Increases Agronomic and Economic Efficiency of Maize in Sandy Loam Soil. *AGRIVITA Journal of Agricultural Science*, **42**, 499-508. https://doi.org/10.17503/agrivita.v42i3.2766

[36] Gul, S., Khan, M.H., Khanday, B.A. and Nabi, S. (2015) Effect of Sowing Methods and NPK Levels on Growth and Yield of Rainfed Maize (*Zea mays* L.). *Scientifica*, **2015**, Article ID: 198575. https://doi.org/10.1155/2015/198575

[37] Kamran, M., Wennan, S., Ahmad, I., Xiangping, M., Wenwen, C., Xudong, Z., *et al.* (2018) Application of Paclobutrazol Affect Maize Grain Yield by Regulating Root Morphological and Physiological Characteristics under a Semi-Arid Region. *Scientific Reports*, **8**, Article No. 4818. https://doi.org/10.1038/s41598-018-23166-z

[38] Upasana, S., Ganesh, C.M., Mahua, B., Sagar, M. and Masina, S. (2025) Growth and Productivity of Maize (*Zea mays* L.) as Influenced by Nitrogen Management Options. *International Journal of Agriculture Environment and Biotechnology*, **14**, 207-214. https://www.researchgate.net/publication/353308909_Growth_and_Productivity_of_Maize_Zea_mays_L_as_Influenced_by_Nitrogen_Management_Options

[39] Morris, M., Kelly, V.A., Kopicki, R.J. and Byerlee, D. (2007) Fertilizer Use in African Agriculture. The World Bank.

[40] Morris, M., Kelly, V.A., Kopicki, R.J. and Byerlee, D. (2007) Fertilizer Use in African Agriculture. Lessons Learned and Good Practice Guidelines.