Growth and Yield Response of Maize (*Zea mays* L.) to Integrated Nutrient Management of Biochar, Organic and Inorganic fertilizers

ABSTRACT

Aims: Maize yield is largely influenced by integrated nutrient management of biochar, organic and inorganic fertilizers application. In view of this, field study to evaluate varying rates of chicken manure (CM), *Gliricidia sepium* biochar (GB) and NPK fertilizer on growth and yield of maize was carried out.
Aims: The aim of the study is to evaluate varying rates of chicken manure (CM), *Gliricidia sepium* biochar (GB) and NPK fertilizer on growth and yield of maize.

Study design: The study design was a2 x 6 factorialarranged in Randomized Complete Block Design with three replications.

Place and Duration of Study: The field study was carried out atMampong- Ashanti in the Forest-Savannah transition zone of Ghanaover 2 years in2021 minor and 2022 major cropping seasons.
Methodology: The studytreatmentswere different rates of amendments using biochar and chicken manure; [10 t ha^{-1} CM, 300 kg ha^{-1} NPK, 2.5 t ha^{-1} GB, 150 kg ha^{-1} NPK + 1.25 t ha^{-1} GB, 1.25 t ha^{-1} GB + 5 t ha^{-1} CM and No fertiliser (Control)] which were applied to two maize varieties (*Omankwa* and *Obatanpa*). Physiological growth parameters (crop growth rate and relative growth rate) were determined. Vegetative growth parameter (leaf count) as well as yield and yield traits (number of lodged plants per plot, husked cob weight per plot, number of filled and unfilled cobs per plot and grain yield) were estimated.
Results: The results revealed that the application of10 t/ha chicken manure and 1.25 t/ha GB + 5 t/ha CM to *Omankwa* and *Obatanpa* maize outperformed in crop growth rate (RGR), relative growth rate (RGR) and leaf count compared to the unamended plots in both seasons.*Omankwa* had significantly higher filled cobs per plot than *Obatanpa* across seasons. The interaction of *Omankwa* and 10 t ha^{-1} CM and 1.25 t/ha GB + 5 t/ha CM gave higher number of filled cobs per plot than *Obatanpa*on same although not significantly different in both cropping seasons. The grain yield of maize was enhanced by soil amendments in the major and minor cropping seasons, especially withinteraction of *Obatanpa* and 10 t/ha CM (7474.0 kg/ha), (3473.4 kg/ha) respectively.*Obatanpa* x 1.25 t/ha GB + 5 t/ha CM (6802.1 kg/ha) interaction followed closely in grain yield in the major season.
Conclusion: Both biochar, organic and inorganic fertilizers have varying effects on growth and yield of different maize varieties.For optimize maize grain yield, 10 t/ha CM or 1.25 t/ha GB + 5 t/ha CM application is recommended.

Keywords: Relative growth rate, Crop growth rate, chicken manure, Gliricidia sepium biochar.

1. INTRODUCTION

Maize (*Zea mays* L.) stands as the world's third most vital grain, following wheat and rice, boasting an annual global production surpassing 1 billion metric tonnes (Alam *et al.,* 2018).In sub-Saharan Africa (SSA), maize holds a central position as a staple, contributing significantly to poverty reduction and enhancing the food security of impoverished households (Tanumihardjo *et al*., 2020).According to FAOSTAT Food Supply records spanning four years (2010–2013) (FAO, 2020), Southern Africa records the highest average maize consumption for adults at 267 grams per person per day, followed by Eastern Africa at 157 grams, both exceeding the African average of 120 grams and significantly surpassing the global average of 48 grams.

The cultivation of maize covers diverse agro-climatic regions globally, leading to varying yields. Its unmatched adaptability allows it to thrive across extensive geographic ranges, spanning from 580 N to 400 S latitude, from below sea level to altitudes exceeding 3000 m, and in diverse rainfall conditions ranging from 250 mm to 5000 mm/year (Asfaw, 2022). The crop has a short growth duration of 3 to 4 months and is considered the most economical cereal grain available worldwide (Rafii *et al.,* 2018). In Ghana, maize cultivation spans approximately 1.2 million hectares, with an annual per capita consumption averaging at 62 kg (MoFA, 2019).

Maize serves as a nutrient source and contains vital phytochemical compounds like carotenoids, phenolic compounds, and phytosterols, essential in preventing chronic diseases (Demeke, 2018). In spite of these, in Ghana the utilization of low-yielding cultivars, pest and disease impact, as well as the high cost and limited availability of chemical fertilizers, have adversely affected maize production and in having negative impact on the livelihoods of local farmers (Wongnaa *et al.,* 2021).Additionally, the continuous application of inorganic fertilizers on the same agricultural landhas resulted in increased soil acidity. Moreover, in cases where organic fertilizers are applied to crops, the inappropriate application rates and the high transportation expenses have aggravated the problem and this has led to a considerable decline in maize yields.

According to Oluwagbemi *et al.*(2021), the use of organic fertilizers although has great impact on crop productivity and soil health, presents challenges such as bulkiness, high labour costs, and a slow rate of mineralization. However, increasing soil fertility can be a catalyst for improving crop yields, achieved through external applications such as appropriate usage of organic manures and agricultural residue (Biratu *et al.,* 2018). Among waste products from the poultry industry, chicken litter and chicken manure stand out as the most prevalent, serving as a widely used organic manure to enhance soil quality and boost crop yield (Tańczuk *et al.,* 2019). Fresh poultry manure, according to Aziz *et al.* (2020), contains vital nutrients such as 0.9-1.5% nitrogen, 0.4-0.5% phosphorus, and 0.8% potassium, all crucial for improving crop productivity.

In agricultural practices, a considerable amount of agricultural waste remains unused after crop harvesting, which can be converted into biochar, particularly in the transitional zone of Ghana, known for cereal and legume cultivation. Biochar, derived from biomass pyrolysis, is a carbon-rich material displaying potential in enhancing soil structure, augmenting nutrient retention, and stimulating microbial activity (Jahromi *et al.*, 2018). Mensah & Frimpong (2018) discovered that incorporating biochar into soils could serve as a potential carbon sink and enhance soil nutrient availability for agricultural purposes in Ghana, due to increased nutrient absorption and sorption potential. In a field experiment conducted by Arif *et al.* (2017), biochar treatment led to an 18% increase in wheat grain yield and a 24% increase in maize grain yield compared to a control plot without biochar addition. Similarly, Syuhada *et al.* (2016) observed that, applying higher biochar rates, specifically 15 and 20 t/ha, resulted in a substantial enhancement in maize grain yield by 150% and 88%, respectively, compared to untreated plots. The challenge lies in determining the most effective integration approach that maximizes growth and yield of maize while considering the interactions between biochar, organic and inorganic fertilizers, as well as their impact on soil health. The objective of the study therefore was to determine the effect of integrated nutrient management of biochar, organic and inorganic fertilizers on maize growth and yield.

2. MATERIAL AND METHODS

2.1Description of Study Area

Two field experiments were carried out across locations at the research field of Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED), Mampong campus, situated in the Ashanti Region of Ghana. The two field experiments were conducted under two different climatic conditions during the minor cropping season from August to December 2021(Experiment 1) and the major cropping season from March to July 2022 (Experiment 2).

Mampong-Ashanti, which is 457.5 meters above sea level, is situated in the forest savannah transitional agroecological zone of Ghana (Geodatos, 2020). The area experiences bimodal rainfall pattern with an average annual rainfall of roughly 1270 mm. The major rains start from April to July, while the minor rains begin in September and last through November (MSD, 2017). While there is a brief dry spell in August, the main dry season starts in December and ends in March. With a temperature range of 22 ^{o}C to 30 ^{o}C, the average annualtemperature in the area is 27 ^{o}C (Pabi *et al.,* 2019). The experimental site has GPS coordinates of latitude 7^{0}4'38.75196" North and longitude 1^{0}23'43.45908" West. The GPS reading at the experimental site is AM-0078-0227. The soil in the area is of the Savannah Ochrosol class and belongs to the Bediese Series. The soil is described as Chromic Luvisol derived from the Voltaian Sandstone according to the FAO/UNESCO (2008) system of classification (Asiamah, 1988). It is a sandyloam with a good water holding capacity, texture, and structure in addition to being well-drained and friable (Asiamah, 1988). Its pH ranges from 6.5-7.0.

Table 1. Climatic conditions at both experimental site during the cropping seasons

Minor cropping season, 2021					**Major cropping season, 2022**				
Month	**TMR (mm)**	**RH (%)**	**MMT (^{O}C)**		**Month**	**TMR (mm)**	**RH (%)**	**MMT (^{O}C)**	
			Max.	**Min**				**Max.**	**Min.**
August, 2021	169.5	77	29.7	22.7	March, 2022	109.2	67	34	23.9
September	225.1	77	30.3	23.2	April	79.6	66	33.1	23.5
October	208.7	72	32.1	22.3	May	147.8	71	32.7	23.8
November	73.4	68	33.1	23.4	June	149.0	74	31	23.3
December	0.0	58	34.3	23.7	July	203.6	74	30	22.7
Total	**676.7**				**Total**	**694.6**			

(Ghana Meteorological Agency – Mampong Ashanti, 2021, 2022)

TMR – Total monthly rainfall, RH – Relative humidity, MMT – Mean monthly temperature

2.2 Chicken Manure and Biochar Preparation

The chicken manure used for both experiments was sourced from the poultry farm at AAMUSTED-Mampong campus. The chicken manure was gathered and heaped under shade for a period of two weeks, covered with plantain leaves and later supported with sticks. This approach was used to facilitate further decomposition of chicken manure, as well as to minimize the volatilization of nitrogen through the release of Ammonia gas. From AAMUSTED, Mampong campus, hardwood branches of *Gliricidia sepium* were gathered and heaped, and subjected to a slow pyrolysis process at approximately 500°C in an anoxic pit reactor, as described by Asante *et al.* (2020) to produce a biochar. The biochar was subsequently crushed and milled into a powdered form using a milling machine, and packaged in plastic bags until it was ready to be used for the experiment.

2.3 Land preparation, Field layout and Fertilization

The experimental field was demarcated, followed by ploughing, harrowing, leveling, lining, and pegging. The field layout was in three blocks with plot size of 3.2 m in length and 4.8 m long (15.36 m^2). An alley of 0.5 m was left between plots and 2 m between blocks. One week prior to sowing of maize seeds, the application of *Gliricidia sepium*biochar and chicken manure to plots according to treatments was done by incorporating into the soil at a depth of approximately 10 centimeters using a hoe. At two weeks after sowing, the NPK (15:15:15) fertiliser was applied by placing it 5-7 cm away from maize plants at a rate according to treatment and by using side placement method.

2.4 Soil, chicken manure and *Gliricidia sepium* biochar sampling and analysis

Prior to planting and after harvest of maize, background soil and soil from plots without amendment (control) were sampled. The soil was randomly taken from Ap horizon at the uniform depth of 0-20 cm from the experimental site at AAMUSTED, Mampong campus and analyse for physical and chemical properties. Sub samples of chicken manure and *Gliricidia sepium* biochar were taken and analyse for chemical properties. The soil, chicken manure and biochar samples were bulked, air-dried, and sub-samples were taken for routine analysis at the Soil Science laboratory of the Department of Crop and Soil Sciences, Kwame Nkrumah University of Science and Technology (KNUST)-Kumasi, Ghana. The physical and chemical properties analyzed for include; soil texture, Soil pH, Organic matter, Total Nitrogen, Exchangeable cations (Calcium, Magnesium, Potassium, Sodium) Exchangeable acidity (Al and H) and organic carbon. The characteristics analyzed for included soil pH on 1:1 (soil: distilled water) and measured on a pH meter (Pracitronic pH meter) manufactured by Veb Pracitron in Dresden, Germany. Organic matter was determined by the Walkey and Black method (Walkey & Black, 1934), and total nitrogen was determined by the micro Kjeldahl method (AOAC, 1975).The available phosphorus was extracted by the Bray method and determined colorimetrically (Bray & Kutz, 1945). Exchangeable cations were determined by flame emission photometry (Bray & Kutz, 1945). Extraction was carried out by shaking the soil-extract mixture, followed by filtration or centrifugation. Ca and Mg were determined using an atomic absorption or spectrometry (AAS) after the removal of ammonium acetate and organic matter at pH 7.0.

2.5 Experimental Design and Treatment

A 2 x 6 factorial experiment arranged in a Randomized Complete Block Design (RCBD) was used as the experimental design with three replications and twelve treatments. The treatments consist of two factors and were as follows: (i) two maize varieties (*Obatanpa and Omankwa)*, and (ii) Fertiliser rates: [(T1 =10 t ha^{-1} Chicken Manure (CM), T2 = 300 kg ha^{-1} NPK 15:15:15, T3 = 2.5 t ha^{-1} *Gliricidia sepium* (GB), T4 = 150 kg ha^{-1} NPK 15:15:15 + 1.25 t ha^{-1} GB, T5 = 1.25 t ha^{-1} GB + 5 t ha^{-1} CM) and T6 = No fertiliser (Control)]. Each block had twelve plots on which *Omankwa* and *Obatanpa* maize varieties were allocated to.

2.6 Planting Materials and Planting

The two maize varieties (*Omankwa* and *Obatanpa*) used for both experiments were obtained from CSIR-Crops Research Institute in Kumasi, Ghana. *Omankwa* is a 90 to 95–day early maturing improved maize variety which tolerates drought and striga. The variety is most suitable for Guinea and Sudan savannah agroecological zones in Ghana. The grain of *Omankwa* is white flint/dent and it has a yield capacity of 4.5 t ha^{-1}. *Obatanpa* is a 105 to 110–day medium maturing maize variety. The variety is suitable for all agroecologies in Ghana. The grain of *Obatanpa* is white/dent with a yield capacity of 4.6 t ha^{-1}. Both *Omankwa* and *Obatanpa* are high quality protein maize (QPM) varieties, excellent for improved nourishment and healthiness of humans, poultry and livestock (CSIR, 2019). The maize seeds were planted by using 80 cm inter row spacing and 40 cm intra row spacing at 3 seeds per hill. Maize seedlings were later thinned to 2 plants per hill, a week after planting. Each plot had 4 rows with 96 plants. There were twenty-four (24) plants in each row and forty (40) plants within the two central rows.

2.7 Agronomic Practices

Ungerminated seeds on individual plots were replaced one week after planting. Control of weeds was carried out by using hand cultivation with hoe and hand-pulling methods two weeks after planting. Further weed control was done every two weeks using the same weed control method. Occurrence of pests and diseases were regularly monitored by visit to experimental site to assess their severity. The incidence of Fall Armyworm (FAW) outbreak was controlled by spraying with Warrior super insecticide which contains Emamectin benzoate as the active component, at a rate of 15 ml per 15 liters knapsack sprayer. For subsequent FAW control, the rate was increased to 20 ml per 15 liters knapsack sprayer. One week prior to sowing of maize seeds, the application of *Gliricidia sepium* biochar and chicken manure to plots according to treatments was done by incorporating into the soil at a depth of approximately 10 centimeters using a hoe. At two weeks after sowing, the NPK (15:15:15) fertiliser was applied by placing it 5-7 cm away from maize plants at a rate according to treatment and by using side placement method.

2.8 Harvesting

Harvesting was done when maize cobs were at dry stage. Lodging of plants, leaf and stalk senescence, drooping of both leaves and ears, brown colour of husk, tassel and silk as well as less than 20 to 25 percent moisture content in grain were observable signs of maturity at dry stage in both maize varieties before harvesting was done. Both maize varieties were manually harvested on the same day by using cutlass to cut the stalk just above the ground. After cutting the stalk, the maize ears were separated from the stalk by twisting.

2.9 Data Collection

Data were collected on vegetative growth, physiological growth, yield and yield components. The vegetative data collected was the number of leaves per plant, physiological growth parameters were, crop growth rate (CGR) and relative growth rate (RGR).Five plants were randomly selected and tagged from the two central rows of each plot for data collected on vegetative growth. The total number of leaves per plant was physically counted on the five tagged plants at two weeks intervalsfrom 4 to 12 weeks after planting (WAP) and the mean leaf number was estimated. To determine plant dry matter accumulation, four randomly selected plants from each plot were uprooted and separated into root and shoot. After determining the shoot fresh weight,200 g samples per plot were placed in a paper envelope and oven-dried at 72 ± 2 ºC for 72 hours to attain dry weights. Dried samples were then weighed using an electronic weighing scale and total dry weight for each treatment was subsequently estimated. The total biomass was computed between 0-28, 28-42, 42-56, 56-

70 days after planting (DAP) and 70 DAP to harvest. The mean crop growth rate (CGR) was determined from the formula below as used by Baumann *et al.* (2002).

$$CGR_{(\text{total biomass})} = \left(\frac{1}{GA}\right) X \left(\frac{W2-W1}{T2-T1}\right) \text{ g m}^{-2}/\text{day}^{-1} \quad (1)$$

Where CGR= Crop growth rate; GA= Ground Area; W_1=Initial Dry Weight of plant or plant part; W_2= Final Dry Weight of plant or plant part; T_1=Initial time (in terms of days after planting); T_2= Final time (in terms of days after planting).The classical approach by Anten & Ackerly (2001) was used to determine the relative growth rate (RGR).

$$RGR = \left(\frac{InW2-InW1}{T2-T1}\right) \text{ g m}^{-2}/\text{days}^{-1} \quad (2)$$

Where RGR = Relative growth rate; W_1= Initial dry weight of plant; W_2= Final dry weight of plant; T_1= Initial time (in terms of days after planting); T_2= Final time (in terms of days after planting), Ln = Natural logarithm.

The yield and yield components data collected were number of filled and unfilled cobs per plot, number of lodged plants per plot, husked cob weight per plot and grain yield (kg/ha). The number of lodged plants per plot, number of filled and unfilled cobs per plot were counted from the two central rows of each plot before and after harvest respectively and the mean was computed. The husked cob weight per plot was determined after harvest by weighing all cobs with husk intact from the two central rows of each plot and the means were computed and recorded. The weighing was done with a salter suspended weigher with model number 235. The grain yield was calculated in kg/ha using the formula as described below by Amanullah *et al*. (2019) as follows:

$$\text{Grain yield (kg/ha)} = \frac{Grain\ yield\ (kg)}{Harvestable\ \ area\ (m^2)} \times 10000m^2 \quad (3)$$

This was determined on all cobs from the two central rows of each plot after harvest, shelled and weighed using Westinghouse electronic weighing scale and the mean estimated.

2.10 Statistical Analysis

All data collected were analyzed using Analysis of Variance (ANOVA). The data obtained were analyzed using the GenStat Release 18.1 (PC/Windows 8) statistical package, Copyright 2015, VSN International Ltd. Registered to ICARDA. Tukey's Honestly Significant Difference (HSD) was used to separate the treatment means and compared at 5% level of probability.

3. RESULTS

3.1 Soil, Chicken manure, and *Gliricidia sepium* biochar analysis

Table 2 shows the chemical characteristics of chicken manure and *Gliricidia sepium* biochar used for both experiments. The P^H of the chicken manure was slightly alkaline. The total nitrogen and potassium levels were high and the organic carbon content was very high. However, the total P, Ca, and Mg levels were low in the chicken manure. The *Gliricidia sepium* biochar was alkaline. The biochar was observed to have moderate N and K levels, the organic carbon content was very high whereas available P, Ca, and Mg levels were low (SRI, 2007) (Table 2).
Table 3 shows the chemical and physical characteristics of the soils at the experimental site in the minor and major cropping seasons. The soil chemical characteristics for 2021 minor season experimental site was slightly acidic (6.05), Organic matter content (1.06) level was low, and Nitrogen (0.18) level was moderate (SRI, 2007). For the 2022 major season experimental site, the soil was slightly acidic (6.50), Organic matter content (1.75) was moderate, Total nitrogen levels (0.10) were low (Table 3). At both experimental sites for

2021 minor and 2022 major growing seasons, available P levels (7.45 and 6.24) were low, exchangeable bases (Ca, Mg, and Na) levels were also low and Total K levels were low. The physical characteristics of the soils at both experimental sites shows that the textural class were sandy-loam (Table 3).

Table 4 shows the chemical characteristics of the soils for both experimental sites after harvesting of maize. The soil was slightly acidic (6.51) and neutral (6.66) for the minor and major cropping seasons experimental sites respectively SRI (2007). All other soil properties were low at both experimental sites.

Table 2.Chemical properties of chicken manure and *Gliricidia sepium* biochar used for the experiment

Samples	Variables							
	pH (H_2O 1:1)	N (%)	P (%)	Org. C (%)	C:N ratio	Ca (%)	Mg (%)	K (%)
Chicken manure	7.84	4.02	3.41	38.2	9.50	2.89	1.09	2.93
Biochar	8.5	0.13	0.28	50.2	386.15	0.17	0.14	0.40

Table 3. Initial Chemical and physical properties of background soil at experimental sites before planting of maize

Soil Samples	**pH (H_2O 1:1)**	**P mg/kg**	**N (%)**	**Exch. Bases (cmol/kg)**				**Exch. Acidity**		**% Org. C**	**% Org. M**
				K	**Ca**	**Mg**	**Na**	**Al**	**H**		
								(cmol/kg)			
Exp. 1	6.05	7.45	0.18	0.13	1.65	0.53	0.02	0.40	0.53	0.82	1.06
Exp. 2	6.50	6.24	0.10	0.19	1.87	1.02	0.07	0.43	0.58	1.22	1.75
				Particle size analysis							
		% Sand		**% Clay**		**% Silt**			**Textural class**		
Exp. 1		79.07		9.98		10.95			Sandy loam		
Exp. 2		77.87		10.12		12.01			Sandy loam		

Table 4. Final Chemical and physical properties of soil at experimental sites after harvesting of maize

Soil Samples	**pH (H_2O 1:1)**	**P mg/kg**	**N (%)**	**Exch. Bases (cmol/kg)**				**Exch. Acidity**		**% Org. C**	**% Org. M**
				K	**Ca**	**Mg**	**Na**	**Al**	**H**		
								(cmol/kg)			
Exp. 1	6.51	6.25	0.14	0.10	1.01	0.20	0.02	0.21	0.32	0.54	0.85
Exp. 2	6.66	4.44	0.07	0.15	1.34	0.45	0.05	0.22	0.28	0.74	1.34
				Particle size analysis							
		% Sand		**% Clay**		**% Silt**			**Textural class**		
Exp. 1		75.25		11.47		13.28			Sandy loam		

Exp. 2	78.08	8.89	13.03	Sandy loam

3.2 Physiological Growth Parameters

3.2.1 Crop growth rate

There was no significant (P≥0.05) difference between the two maize varieties in crop growth rate (CGR) across the growing period except at 70 days after planting to harvest where Omankwa maize variety was significantly (P<0.05) different from Obatanpa in total crop growth rate (Table 5 and 6). The CGR increased linearly from 28 to 70 days after planting in maize plants that received biochar, organic and inorganic fertilisers either applied fully or in combination but decline during the latter growth stage of plants. Maize plants that received 10 t/ha CM had significantly higher CGR followed by 1.25 t/ha GB + 5 t/ha CM across the growing period than the control except at 28 to 42 DAP and 70 DAP to harvest (Table 6). Both maize varieties that received 10 t/ha CM and 1.25 t/ha GB + 5 t/ha CM increased CGR from 0-28 DAP to 70 DAP, however, it decreased sharply till harvest (Tables 5 and 6).

Table 5. Crop growth rate as affected by biochar, organic and inorganic fertilisers during 2021 minor cropping season

Treatment	Crop growth rate (g m^{-2}/day^{-1})				
	0-28 DAP	28-42 DAP	42-56 DAP	56-70 DAP	70 DAP to Harvest
Variety					
Omankwa	14.06	25.09	37.85	40.83	27.26
Obatanpa	13.10	25.09	38.02	41.59	25.17
HSD (P ≤ 0.05)	**NS**	**NS**	**NS**	**NS**	**NS**
Fertiliser rates					
10 t/ha CM	19.27a	27.08b	45.31a	49.35a	37.24a
300 kg/ha NPK 15:15:15	13.80abc	23.96b	35.16b	37.12b	26.03b
2.5 t/ha GB	9.11c	21.35b	36.98b	39.78b	22.40b
150 kg/ha NPK + 1.25 t/ha GB	13.28bc	22.14b	36.46b	39.87b	25.52b
1.25 t/ha GB + 5 t/ha CM	15.89ab	34.64a	43.23a	47.64a	25.52b
No fertiliser (Control)	10.16bc	21.35b	30.47c	33.52c	20.31b
HSD (P ≤ 0.05)	**5.79**	**7.54**	**3.90**	**3.56**	**7.82**
Interaction (V X F)					
Omank. **x** 10 t/ha CM	20.83a	27.08ab	43.23ab	47.29a	36.98a
Omank. **x** 300 kg/ha NPK 15:15:15	12.50abc	27.08ab	35.42cd	36.85bcd	28.65ab
Omank. **x** 2.5 t/ha GB	11.46abc	21.88b	36.98bc	39.39bc	21.88b
Omank. **x** 150 kg/ha NPK + 1.25 t/ha GB	12.50abc	21.35b	37.50bc	40.77b	25.00ab
Omank. **x** 1.25 t/ha GB + 5 t/ha CM	14.58abc	32.29ab	44.27a	47.56a	30.21ab
Omank. **x** No fertiliser (Control)	12.50abc	20.83b	29.69d	33.13d	20.83b
Obatan. **x** 10 t/ha CM	17.71a	27.05ab	47.40a	51.41a	37.50a
Obatan. **x** 300 kg/ha NPK 15:15:15	15.10abc	20.83b	34.90cd	37.39bcd	23.96b
Obatan. **x** 2.5 t/ha GB	6.77c	20.83b	36.98bc	40.17b	22.92b

Obatan. **x** 150 kg/ha NPK + 1.25 t/ha GB	14.06abc	22.92b	35.42cd	38.97bcd	26.04ab
Obatan. **x** 1.25 t/ha GB + 5 t/ha CM	17.19ab	36.98a	42.19ab	47.72a	20.83b
Obatan. **x** No fertiliser (Control)	7.81bc	21.88b	31.25cd	33.91cd	19.79b
HSD (P ≤ 0.05)	**9.57**	**12.44**	**6.43**	**5.57**	**12.91**
CV (%)	**23.73**	**16.71**	**5.71**	**4.80**	**16.59**

DAP- Days after planting; x – interaction; CM – Chicken manure; GB – *Gliricidia sepium* biochar; V-Variety; F- Fertilizer rates

Table 6. Crop growth rate as affected by biochar, organic and inorganic fertilisers during 2022 major cropping season

Treatment	Crop growth rate (g m^{-2}/day^{-1})				
	0-28 DAP	28-42 DAP	42-56 DAP	56-70 DAP	70DAP to Harvest
Variety					
Omankwa	9.93	14.52	25.95	36.45	23.86a
Obatanpa	7.55	15.78	26.32	35.38	21.19b
HSD (P ≤ 0.05)	**NS**	**NS**	**NS**	**NS**	**1.98**
Fertiliser rates					
10 t/ha CM	9.64ab	15.44ab	35.94a	44.79a	30.25a
300 kg/ha NPK 15:15:15	8.60ab	16.59ab	22.65b	30.99bc	18.43bc
2.5 t/ha GB	5.47b	11.68b	23.26b	33.42b	19.82b
150 kg/ha NPK + 1.25 t/ha GB	7.94ab	14.99ab	23.41b	33.19b	18.41bc
1.25 t/ha GB + 5 t/ha CM	13.43a	20.37a	34.58a	46.83a	33.62a
No fertiliser (Control)	7.38ab	11.85b	16.99b	26.27c	14.61c
HSD (P ≤ 0.05)	**6.65**	**7.74**	**9.82**	**6.42**	**5.16**
Interaction (V X F)					
Omank. **x** 10 t/ha CM	11.46	17.19	36.46ab	48.96a	32.54a
Omank. **x** 300 kg/ha NPK 15:15:15	10.94	16.50	21.34bcd	31.76cde	19.09c
Omank. **x** 2.5 t/ha GB	5.73	11.37	27.11abcd	34.92bcd	22.31bc
Omank. **x** 150 kg/ha NPK + 1.25 t/ha GB	10.86	11.75	22.34abcd	33.86cde	19.87bc
Omank. **x** 1.25 t/ha GB + 5 t/ha CM	11.75	18.87	30.98abcd	45.21ab	34.58a
Omank. **x** No fertiliser (Control)	8.86	11.46	17.49d	23.96e	14.75c
Obatan. **x** 10 t/ha CM	7.81	13.70	35.42abc	40.63abc	27.95ab
Obatan. **x** 300 kg/ha NPK 15:15:15	6.25	16.67	23.96abcd	30.21cde	17.77c
Obatan. **x** 2.5 t/ha GB	5.21	11.98	19.42cd	31.92cde	17.32c
Obatan. **x** 150 kg/ha NPK + 1.25 t/ha GB	5.02	18.23	24.48abcd	32.53cde	16.95c
Obatan. **x** 1.25 t/ha GB + 5 t/ha CM	15.11	21.87	38.17a	48.44a	32.65a
Obatan. **x** No fertiliser (Control)	5.91	12.23	16.48d	28.58de	14.46c
HSD (P ≤ 0.05)	**NS**	**NS**	**16.22**	**10.60**	**8.51**
CV (%)	**16.25**	**28.39**	**20.90**	**9.94**	**12.73**

DAP- Days after planting; x – interaction; CM – Chicken manure; GB – *Gliricidia sepium* biochar; V-Variety; F- Fertilizer rates

3.2.2 Relative growth rate

There was no significant (P≥0.05) difference both maize varieties in relative growth rate (RGR) from 0-28 DAP to 70 DAP-harvest across the growing period in both seasons except from 56 – 70 DAP in the major cropping season where Obatanpa recorded significantly higher (0.11 g m^{-2}/day^{-1}) RGR than Omankwa (0.09 g m^{-2}/day^{-1}) (Table 7 and 8). There was no significant difference between the fertilizer rates in RGR from 0. 28 DAP through to 42 – 56 DAP in the minor cropping season (Table 7). Maize plants that received 10 t/ha CM produced significantly higher RGR than 1.25 t/ha GB + 5 t/ha CM and the control from 56 to 70 DAP and from 70 DAP to harvest respectively during the minor cropping season whereas plants that received 1.25 t/ha GB + 5 t/ha CM produced significantly higher RGR than the control plot from 28 to 42 DAP and from 70 DAP to harvest in the major cropping season. Irrespective of treatments, RGR increased linearly at the early growth stage of plants, however showed a decreasing trend with the advancement of plant age in both maize varieties and their interaction with amendments and the control (Table 7 and 8).

Table 7. Relative growth rate as affected by biochar, organic and inorganic fertilisers during 2021 minor season

Treatment	Relative growth rate (g m^{-2}/day^{-1})				
	0-28 DAP	28-42 DAP	42-56 DAP	56-70 DAP	70 DAP to Harvest
Variety					
Omankwa	0.79	0.19	0.16	0.15	0.11
Obatanpa	0.79	0.20	0.15	0.15	0.11
HSD (P ≤ 0.05)	**NS**	**NS**	**NS**	**NS**	**NS**
Fertiliser rates					
10 t/ha CM	0.84a	0.18	0.18	0.16a	0.13a
300 kg/ha NPK 15:15:15	0.78b	0.19	0.17	0.15ab	0.11ab
2.5 t/ha GB	0.79b	0.19	0.11	0.14ab	0.10ab
150 kg/ha NPK + 1.25 t/ha GB	0.79b	0.19	0.16	0.15ab	0.12a
1.25 t/ha GB + 5 t/ha CM	0.83a	0.23	0.16	0.12b	0.11ab
No fertiliser (Control)	0.74c	0.21	0.14	0.14ab	0.07b
HSD (P ≤ 0.05)	**0.03**	**NS**	**NS**	**0.04**	**0.05**
Interaction (V X F)					
Omank. **x** 10 t/ha CM	0.83abc	0.19	0.19a	0.16a	0.13
Omank. **x** 300 kg/ha NPK 15:15:15	0.78def	0.22	0.15ab	0.13ab	0.11
Omank. **x** 2.5 t/ha GB	0.79cdef	0.19	0.14ab	0.13ab	0.08
Omank. **x** 150 kg/ha NPK + 1.25 t/ha GB	0.79bcde	0.18	0.14ab	0.13ab	0.13
Omank. **x** 1.25 t/ha GB + 5 t/ha CM	0.84ab	0.22	0.14ab	0.14ab	0.12
Omank. **x** No fertiliser (Control)	0.74g	0.20	0.18ab	0.14ab	0.08
Obatan. **x** 10 t/ha CM	0.85a	0.17	0.16ab	0.16a	0.14
Obatan. **x** 300 kg/ha NPK 15:15:15	0.78efg	0.17	0.15ab	0.15ab	0.12

Obatan. **x** 2.5 t/ha GB	0.79cdef	0.19	0.08b	0.15ab	0.12
Obatan. **x** 150 kg/ha NPK + 1.25 t/ha GB	0.78def	0.19	0.17ab	0.14ab	0.11
Obatan. **x** 1.25 t/ha GB + 5 t/ha CM	0.82abcd	0.24	0.17ab	0.10b	0.07
Obatan. **x** No fertiliser (Control)	0.75fg	0.22	0.11ab	0.10b	0.06
HSD (P ≤ 0.05)	**0.04**	**NS**	**0.11**	**0.07**	**NS**
CV (%)	**1.85**	**NS**	**25.11**	**15.70**	**25.76**

DAP- Days after planting; x – interaction; CM – Chicken manure; *GB – Gliricidia sepium* biochar; V-Variety; F- Fertilizer rates

Table 8.Relative growth rate as affected by biochar, organic and inorganic fertilisers during 2022 major season

Treatment	Relative growth rate (g m^{-2}/day^{-1})				
	0-28 DAP	28-42 DAP	42-56 DAP	56-70 DAP	70 DAP to Harvest
Variety					
Omankwa	0.66	0.37	0.16	0.09b	0.05
Obatanpa	0.69	0.34	0.15	0.11a	0.07
HSD (P ≤ 0.05)	**NS**	**NS**	**NS**	**0.02**	**NS**
Fertiliser rates					
10 t/ha CM	0.79a	0.46a	0.19ab	0.14ab	0.10a
300 kg/ha NPK 15:15:15	0.63b	0.35b	0.13bc	0.09bc	0.04b
2.5 t/ha GB	0.67ab	0.31bc	0.12c	0.08c	0.04b
150 kg/ha NPK + 1.25 t/ha GB	0.67ab	0.34b	0.12c	0.08c	0.03b
1.25 t/ha GB + 5 t/ha CM	0.70ab	0.48a	0.25a	0.16a	0.11a
No fertiliser (Control)	0.62b	0.22c	0.12bc	0.05c	0.03b
HSD (P ≤ 0.05)	**0.15**	**0.10**	**0.07**	**0.06**	**0.05**
Interaction (V X F)					
Omank. **x** 10 t/ha CM	0.79	0.46ab	0.21abc	0.14ab	0.10ab
Omank. **x** 300 kg/ha NPK 15:15:15	0.58	0.37abc	0.13bcd	0.07bc	0.03bc
Omank. **x** 2.5 t/ha GB	0.73	0.35abc	0.13bcd	0.07bc	0.03bc
Omank. **x** 150 kg/ha NPK + 1.25 t/ha GB	0.63	0.37abc	0.09d	0.04c	0.01c
Omank. **x** 1.25 t/ha GB + 5 t/ha CM	0.64	0.49a	0.26a	0.14ab	0.09abc
Omank. **x** No fertiliser (Control)	0.60	0.20c	0.12bcd	0.04c	0.03abc
Obatan. **x** 10 t/ha CM	0.78	0.47ab	0.18abcd	0.14ab	0.10ab
Obatan. **x** 300 kg/ha NPK 15:15:15	0.67	0.33abc	0.13bcd	0.09abc	0.06abc
Obatan. **x** 2.5 t/ha GB	0.62	0.27c	0.09cd	0.08abc	0.04abc
Obatan. **x** 150 kg/ha NPK + 1.25 t/ha GB	0.72	0.30bc	0.15abcd	0.11abc	0.05abc
Obatan. **x** 1.25 t/ha GB + 5 t/ha CM	0.77	0.48a	0.24ab	0.17a	0.13a
Obatan. **x** No fertiliser (Control)	0.63	0.23c	0.12bcd	0.07bc	0.03bc
HSD (P ≤ 0.05)	**NS**	**0.17**	**0.12**	**0.09**	**0.08**

CV (%)	12.32	15.96	25.96	32.01	23.21

DAP- Days after planting; x – interaction; CM – Chicken manure; GB – *Gliricidia sepium* biochar; V-Variety; F- Fertilizer rates

3.3 Vegetative Growth

3.3.1 Number of leaves per plant

Figures 1 and 2 show the effect of biochar, organic and inorganic fertilisers on number of leaves per plant of Omankwa and Obatanpa maize varieties. There was an increase trend in number of leaves per plant from 4 weeks after planting (WAP) to 8 WAP in both growing periods. However, leaf count declined sharply in both varieties from 10 to 12 WAP. Obatanpa had higher leaf count than Omankwa from 8 to 12 WAP and 6 to 10 WAP during the minor and major growing periods respectively. From Figures 3 and 4, leaf count for the different fertiliser rates increased steadily from 4 to 8 WAP and declined from 10 to 12 WAP across growing seasons. The highest leaf count was recorded by maize plants that received 10 t/ha CM followed by 1.25 t/ha GB + 5 t/ha CM whereas the least leaf count was recorded by the control plots from 4 to 12 WAP in both cropping seasons.

Similarly, the interaction of both maize varieties and amendments and the control substantially increased number of leaves per plant from 4 to 8 WAP, however, it decreased sharply from 10 to 12 WAP across cropping seasons (Figures 5,6, 7 and 8). Both maize varieties that received 10 t/ha CM and 1.25 t/ha GB + 5 t/ha CM recorded higher number of leaves per plant from 4 to 12 WAP across seasons whereas the control plot recorded the least leaf count during the same period (Figure 5, 6, 7 and 8).

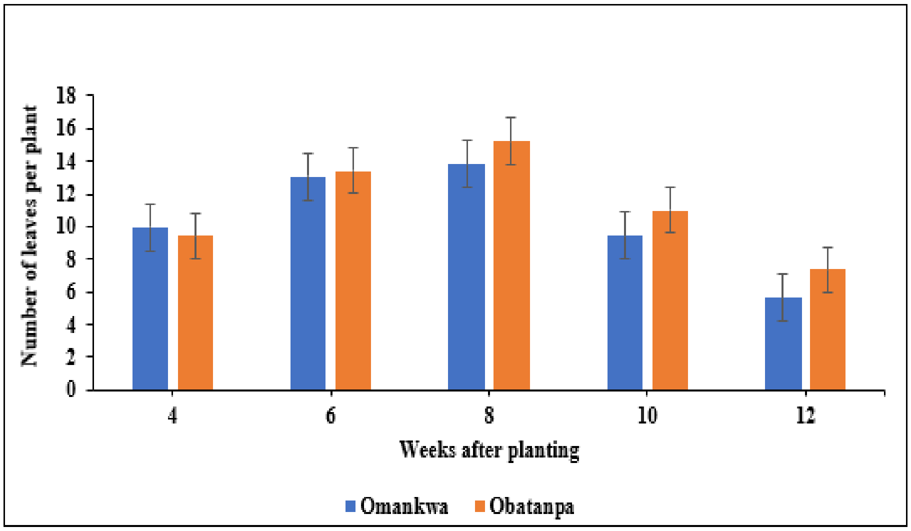

Fig. 1. Number of leaves per plant of Omankwa and Obatanpa maize varieties during 2021 minor cropping season

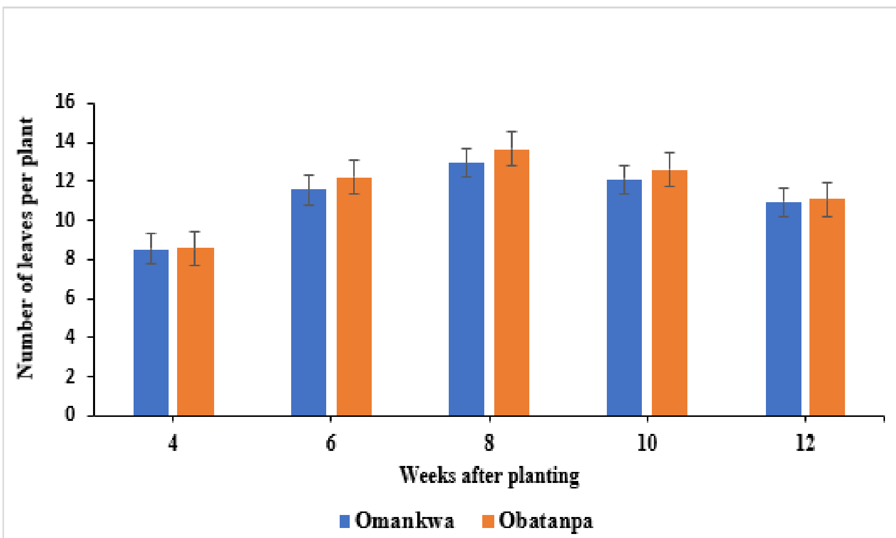

Fig. 2. Number of leaves per plant of Omankwa and Obatanpa maize varieties during 2022 major cropping season

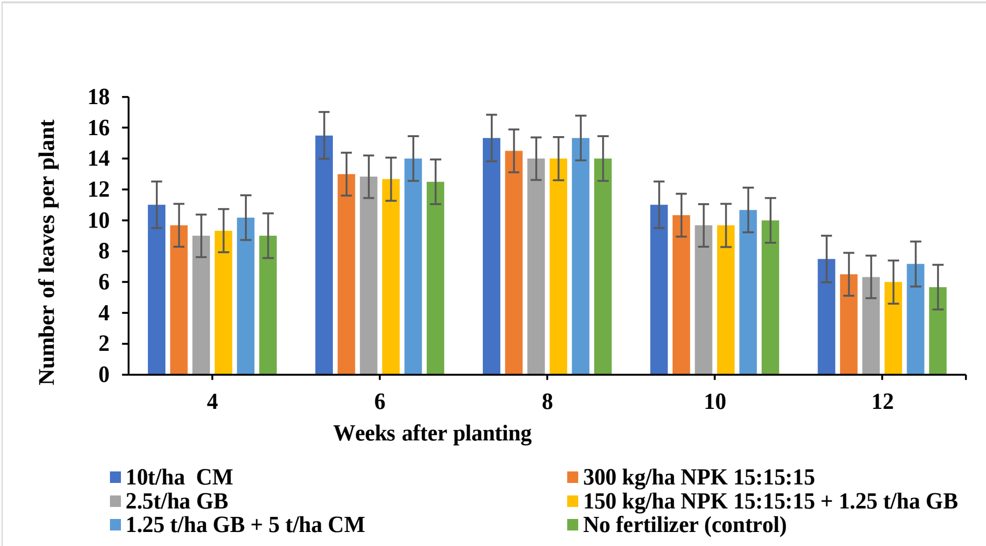

Fig. 3. Effect of fertiliser rates on number of leaves per maize plants during 2021 minor cropping season

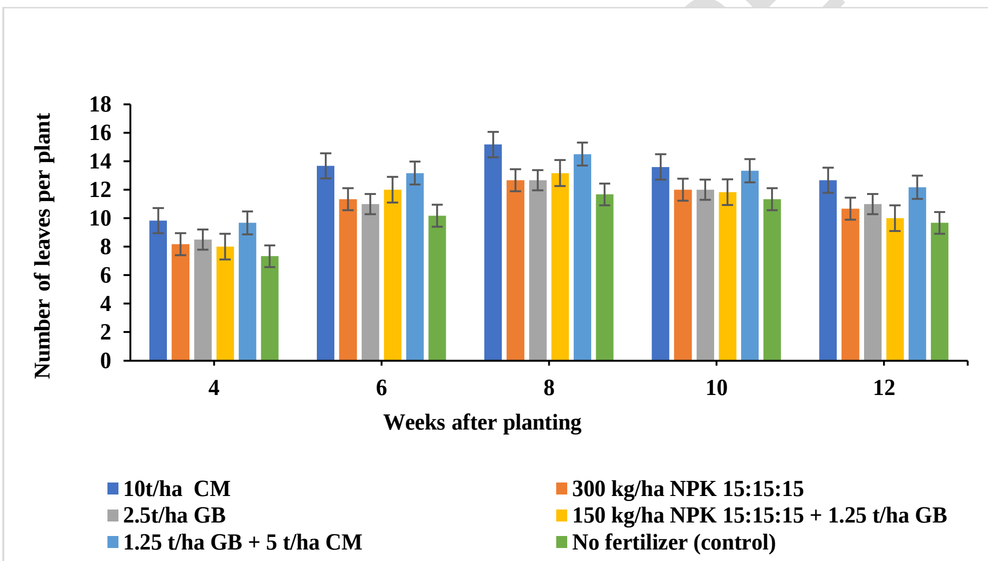

Fig. 4. Effect of fertiliser rates on number of leaves per maize plants during 2022 major cropping season

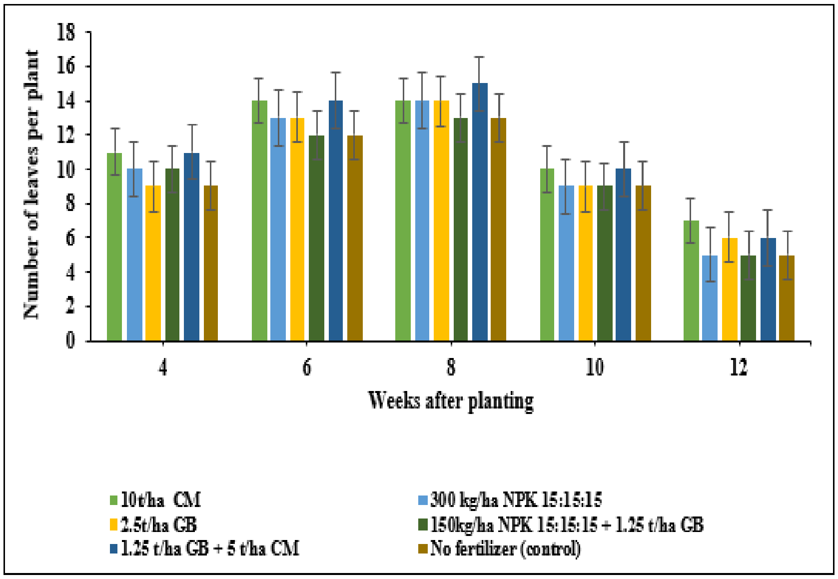

Fig. 5. Number of leaves per plant of Omankwa x fertiliser rates interaction during 2021 minor cropping season

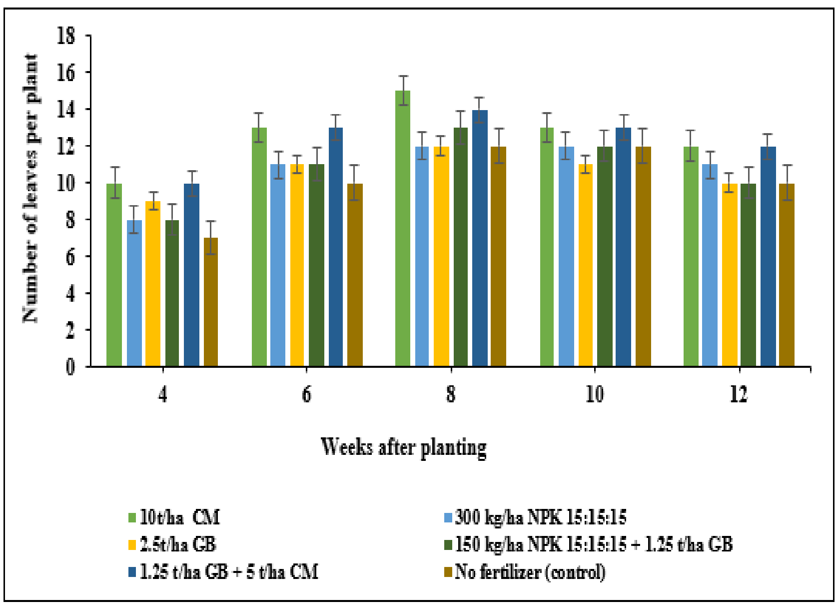

Fig. 6. Number of leaves per plant of Omankwa x fertiliser rates interaction during 2022 major cropping season

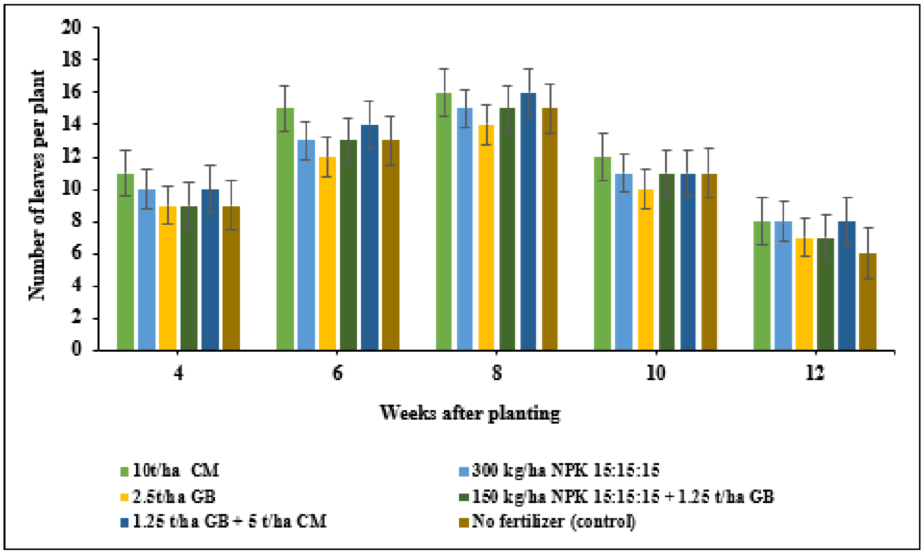

Fig. 7. Number of leaves per plant of Obatanpa x fertiliser rates interaction during 2021 minor cropping season

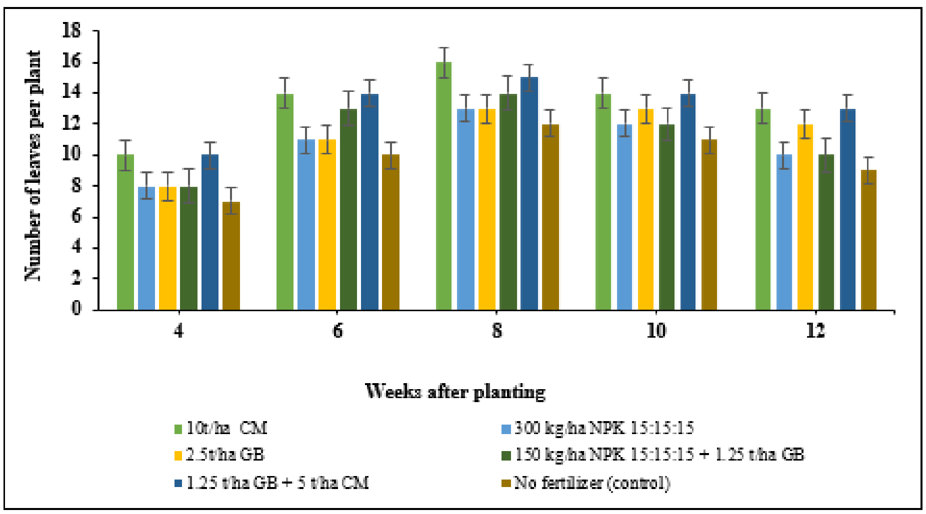

Fig. 8. Number of leaves per plant for Obatanpa x fertiliser rates interaction during 2022 major cropping season

3.3 Yield and Yield Traits

3.3.1 Number of lodged plants per plot

Table 9 shows number of lodged plants per plot as influenced by biochar, organic inorganic fertilisers. In 2021 minor cropping season, there was no significant (P≥0.05) difference between Omankwa and Obatanpa in number of lodged plants per plot (Table 9). The maize plants with no amendment produced significantly higher number of lodged plants per plot than plants that received 10 t/ha CM (Table 9). Omankwa maize planted on unamended plot differed significantly from the same variety that received 10 t/ha CM followed by 1.25 t/ha GB + 5 t/ha CM in number of lodged plants per plot. The interaction of Obatanpa and 150 kg/ha

NPK + 1.25 t/ha GB and 2.5 t/ha GB gave significantly higher number of lodged plants per plot than the same maize variety that received 10 t/ha CM (Table 9).

In 2022 major cropping season, Obatanpa produced significantly higher number of lodged plants per plot than Omankwa (Table 9). Maize plants without amendment produced significantly higher ($P \leq 0.05$) number of lodged plants per plot than plants that received 10 t/ha CM and 1.25 t/ha GB + 5 t/ha CM (Table 9). There was however no significant ($P \geq 0.05$) difference between plants that received amendments in number of lodged plants per plot. There was no significant ($P \geq 0.05$) difference between interaction of both maize varieties, amended and unamended plots in number of lodged plants per plot (Table 9). Similarly, no significant ($P \geq 0.05$) difference existed between seasons and season x variety x fertiliser rates interactions in number of lodged plants per plot (Table 9).

<u>3.3.2 Husked cob weight per plot</u>

Table 9 shows husked cob weight per plot as influenced by biochar, organic and inorganic fertilisers. In 2021 minor cropping season, there was no significant ($P \geq 0.05$) difference between Omankwa and Obatanpa in husked cob weight per plot (Table 9). The maize that received 10 t/ha CM produced the maximum husked cob weight per plot (3.23 kg) followed by 1.25 t/ha GB + 5 t/ha CM (2.92 kg) and the least with the control (1.83 kg) which was significantly different (Table 9). There was no significant ($P > 0.05$) difference between interaction of Omankwa, amended and unamended plots in husked cob weight per plot (Table 9). Interaction of Obatanpa and 10 t/ha CM had the maximum (3.29 kg) husked cob weight per plot which was significantly higher than interaction of Obatanpa and the control (1.54 kg) (Table 9).
In 2022 major cropping season, there was a significant ($P \leq 0.05$) difference between Obatanpa and Omankwa in husked cob weight plot. Obatanpa recorded significantly higher (6.73 kg) husked cob weight per plot than Omankwa which recorded the least (5.92 kg) (Table 9). The maize plants that received 10 t/ha CM had maximum husked cob weight per plot (7.62 kg) followed by maize plants that received 1.25 t/ha GB + 5 t/ha CM (7.60 kg) and were significantly different from the control (5.00 kg) which had least husked cob weight per plot (Table 9). There was no significant ($P > 0.05$) difference between interaction of Omankwa, amended and unamended plots in husked cob weight per plot (Table 9). Interaction of Obatanpa and 1.25 t/ha GB + 5 t/ha CM differed significantly ($P \leq 0.05$) from interaction of Obatanpa and 300 kg/ha NPK 15:15:15 and the control and in husked cob weight plot (Table 9). A significant ($P \leq 0.05$) difference exists between the two cropping seasons in husked cob weight per plot. The husked cob weight per plot for the 2022 major cropping season was significantly higher than those obtained in the 2021 minor cropping season. There was no significant ($P \geq 0.05$) difference between season x variety x fertiliser rates interaction in husked cob weight per plot (Table 9).

Table 9.Number of lodged plants per plot and husked cob weight per plot as affected by biochar, organic and inorganic fertilisers during 2021 minor and 2022 major cropping seasons

Treatment	Number of lodged plants per plot		Husked cob weight per plot (kg)	
	2021 minor season	2022 major season	2021 minor season	2022 major season
Variety				
Omankwa	4.83	4.28b	2.42	5.92b

Obatanpa	4.78	6.33a	2.23	6.73a
HSD (P ≤ 0.05)	**NS**	**0.97**	**NS**	**0.55**
Fertiliser rates				
10 t/ha CM	2.83b	3.67b	3.23a	7.62a
300 kg/ha NPK 15:15:15	4.67ab	5.83ab	2.04c	5.67b
2.5 t/ha GB	5.17ab	5.83ab	2.09bc	5.65b
150 kg/ha NPK + 1.25 t/ha GB	5.50a	5.33ab	1.79c	5.92b
1.25 t/ha GB + 5 t/ha CM	4.33ab	3.83b	2.92ab	7.60a
No fertiliser (Control)	6.33a	7.33a	1.87c	5.00b
HSD (P ≤ 0.05)	**2.35**	**2.52**	**0.86**	**1.44**
Interaction (V X F)				
Omank. **x** 10 t/ha CM	3.67bc	2.67c	3.17a	6.83ab
Omank. **x** 300 kg/ha NPK 15:15:15	4.33abc	4.33abc	1.91ab	5.60b
Omank. **x** 2.5 t/ha GB	4.33abc	5.00abc	2.09ab	4.93b
Omank. **x** 150 kg/ha NPK + 1.25 t/ha GB	4.67abc	4.00bc	1.94ab	5.67b
Omank. **x** 1.25 t/ha GB + 5 t/ha CM	4.00bc	3.33bc	3.17a	6.70ab
Omank. **x** No fertiliser (Control)	8.00a	6.33abc	2.20ab	5.80b
Obatan. **x** 10 t/ha CM	2.00c	4.67abc	3.29a	8.40a
Obatan. **x** 300 kg/ha NPK 15:15:15	5.00abc	6.67abc	2.16ab	5.73b
Obatan. **x** 2.5 t/ha GB	6.00ab	7.33ab	2.00ab	6.37ab
Obatan. **x** 150 kg/ha NPK + 1.25 t/ha GB	6.33ab	6.67abc	1.63b	6.17ab
Obatan. **x** 1.25 t/ha GB + 5 t/ha CM	4.67abc	4.33abc	2.69ab	8.50a
Obatan. **x** No fertiliser (Control)	4.67abc	8.33a	1.54b	5.20b
HSD (P ≤ 0.05)	**3.88**	**4.16**	**1.42**	**2.37**
CV (%)	**27.21**	**26.38**	**20.60**	**12.62**

x – interaction CM – Chicken manure GB – *Gliricidia sepium* biochar

Variety (V)	= NS	= 0.65**
Fertiliser rates (Fr.)	= 0.89**	= 1.67**
Season (S)	= 0.34**	= NS
S x V	= 0.64**	= 1.22**
Fr. x V	= NS	= NS
Fr. x S	= NS	= NS
S x Fr. x V	= NS	= NS

3.3.3 Number of filled cobs per plot

Table 10 shows number of filled cobs per plot as influenced by biochar, organic and inorganic fertilisers. In 2021 minor cropping season, Omankwa had significantly higher (30.11) number of filled cobs per plot than Obatanpa which recorded the least (24.61) (Table 10). For the individual effect of fertiliser on number of filled cobs per plot, maize plants the received 10 t/ha CM had significantly (P≤0.05) higher (34.67) number of filled cobs per plot than the control (24.50) (Table 10). The interaction of Omankwa and 10 t/ha CM had significantly (P≤0.05) higher number (36.33) of filled cobs per plot than the control plot (25.00) (Table 10). There was no significant (P≥0.05) difference between interaction of Obatanpa, amended and the unamended plots in number of filled cobs per plot (Table 10).

In 2022 major cropping season, Omankwa had significantly higher (33.00) number of filled cobs per plot than Obatanpa (30.28) (Table 10). For fertiliser rates, maize plants that received 10 t/ha CM followed by 1.25 t/ha GB + 5 t/ha CM had significantly (P≤0.05) higher number of filled cobs per plot than the control plot (Table 10). Both amended and the control plots with Omankwa and Obatanpa maize varieties did not differ significantly in number of cobs per plot during the 2022 cropping season (Table 10). The number of filled cobs per plot produced during the major cropping season was higher than in the minor cropping season. No significant (P≥0.05) difference occurred between interaction of season x variety x fertiliser rates (Table 10).

3.3.4 Number of unfilled cobs per plot

Table 10 shows number of unfilled cobs per plot as influenced by biochar, organic and inorganic fertilisers. In 2021 minor cropping season, there was no significant (P≥0.05) difference between Omankwa and Obatanpa in number of unfilled cobs per plot (Table 10). For the individual effect of fertiliser on number of unfilled cobs per plot, maize plants without amendments produced significantly higher (P≤0.05) number of unfilled cobs per plot than plants that received 10 t/ha CM and 1.25 t/ha GB + 5 t/ha CM (Table 10). Omankwa maize variety without amendments differed significantly from the same variety that received 10 t/ha CM in number of unfilled cobs per plot. There was no significant (P≥0.05) difference between interaction of Obatanpa, amended and unamended plots in number of unfilled cobs per plot (Table 10).

In 2022 major cropping season, there was a significant (P≤0.05) difference between maize varieties in number of unfilled cobs per plot. Omankwa had significantly higher number of unfilled cobs than Obatanpa (Table 9). For the individual effect of fertiliser in number of unfilled cobs per plot, the control plot produced significantly higher (P≤0.05) number of unfilled cobs per plot than plants that received 10 t/ha CM and 1.25 t/ha GB + 5 t/ha CM (Table 10). No significant (P≥0.05) difference exists between maize plants with amendments in number of unfilled cobs per plot. There was no significant (P≥0.05) difference between interaction of Omankwa, amended and the unamended plots in number of unfilled cobs per plot (Table 10). Similarly, no significant (P≥0.05) difference exists between Obatanpa planted on amended plots except 1.25 t/ha GB + 5 t/ha CM and the unamended plots in number of unfilled cobs per plot (Table 10). Generally, the number of unfilled cobs per plot for Omankwa and Obatanpa with and without amendments during the 2022 major cropping season was higher than during the 2021 minor cropping season. No significant (P≥0.05) difference occurred between season x variety x fertiliser rates interactions (Table 10).

Table 10.Number of filled and unfilled cobs per plot as affected by biochar, organic and inorganic fertilisers during 2021 minor and 2022 major cropping seasons

Treatment	Number of filled cobsper plot		Number of unfilled cobs per plot	
	2021 minor season	2022 major season	2021 minor season	2022 major season
Variety				
Omankwa	30.11a	33.00a	2.33	4.06a
Obatanpa	24.61b	30.28b	2.00	2.39b
HSD (P ≤ 0.05)	**2.38**	**1.94**	**NS**	**1.06**
Fertiliser rates				
10 t/ha CM	32.50a	34.67a	1.17b	2.17b

300 kg/ha NPK 15:15:15	26.50ab	31.83ab	2.17ab	2.83ab
2.5 t/ha GB	25.67b	29.67ab	2.33ab	3.83ab
150 kg/ha NPK + 1.25 t/ha GB	25.00b	30.17ab	2.50ab	3.83ab
1.25 t/ha GB + 5 t/ha CM	30.00ab	34.50a	1.50b	1.67b
No fertiliser (Control)	24.50b	29.00b	3.33a	5.00a
HSD (P ≤ 0.05)	**6.19**	**5.05**	**1.60**	**2.75**
Interaction (V X F)				
Omank. **x** 10 t/ha CM	36.33a	35.00a	1.00b	1.67b
Omank. **x** 300 kg/ha NPK 15:15:15	27.00abcd	33.33ab	2.00ab	2.33ab
Omank. **x** 2.5 t/ha GB	31.00abc	30.33ab	2.33ab	3.33ab
Omank. **x** 150 kg/ha NPK + 1.25 t/ha GB	29.00abcd	32.67ab	3.33ab	2.33ab
Omank. **x** 1.25 t/ha GB + 5 t/ha CM	32.33ab	35.67a	1.67ab	1.33b
Omank. **x** No fertiliser (Control)	25.00bcd	31.33ab	3.67a	3.33ab
Obatan. **x** 10 t/ha CM	28.67abcd	34.33ab	1.33ab	2.67ab
Obatan. **x** 300 kg/ha NPK 15:15:15	26.00bcd	30.33ab	2.33ab	3.33ab
Obatan. **x** 2.5 t/ha GB	20.33d	29.33ab	2.33ab	4.33ab
Obatan. **x** 150 kg/ha NPK + 1.25 t/ha GB	21.00cd	27.67ab	1.67ab	5.33ab
Obatan. **x** 1.25 t/ha GB + 5 t/ha CM	27.67abcd	33.33ab	1.33ab	2.00b
Obatan. **x** No fertiliser (Control)	24.00bcd	26.67b	3.00ab	6.67a
HSD (P ≤ 0.05)	**10.21**	**8.33**	**2.64**	**4.55**
CV (%)	**12.57**	**8.87**	**40.91**	**47.53**

x – interaction CM – Chicken manure GB – *Gliricidia sepium* biochar

Variety (V)	= 1.53**	0.61**
Fertiliser rates (Fr.)	= 3.92**	1.55**
Season (S)	= 1.53**	0.61**
S x V	= NS	1.13**
Fr. x V	= NS	NS
Fr. x S	= NS	NS
S x Fr. x V	= NS	NS

<u>3.3.5 Grain Yield (kg/ha)</u>

Table 11 shows maize grain yield as affected by biochar, organic and inorganic fertilizers during 2021 minor and 2022 major cropping seasons. In 2021 minor cropping season, Omankwa produced significantly maximum (2678.0 kg/ha) yield compared to Obatanpa (2232.6 kg/ha) whereas no significant (P≥0.05) difference occurred between the two maize varieties in the major cropping season (Table 11). The maize that received 10 t/ha CM and 1.25 t/ha GB + 5 t/ha CM produced significantly higher grain yield than the control in both cropping seasons. There was no significant (P>0.05) difference between the interaction of Omankwa and amended and unamended plots in grain yield in both cropping seasons although the interaction of Omankwa and 1.25 t/ha GB + 5 t/ha CM produced the highest grain yield in both cropping seasons (Table 11). The interaction of Obatanpa and 10 t/ha CM had the maximum grain yield (3473.4 kg/ha and 7474.0 kg/ha) during the minor and major cropping seasons respectively and was significantly (P≤0.05) different from interaction of Obatanpa and the control (Table 11). The grain yield produced in the 2022 major cropping season was significantly higher than those produced in the 2021 minor cropping season.

Table 11. Grain Yield (kg/ha) as affected by biochar, organic and inorganic fertilizers during 2021 minor and 2022 major cropping seasons

Treatment	Yield (kg/ha)	
	2021 minor season	2022 major season
Variety		
Omankwa	2678.0a	5142.4
Obatanpa	2232.6b	5520.8
HSD (P ≤ 0.05)	**345.34**	**NS**
Fertiliser rates		
10 t/ha CM	3400.5a	6648.4a
300 kg/ha NPK 15:15:15	2054.7c	4802.1b
2.5 t/ha GB	2465.9bc	4645.8b
150 kg/ha NPK + 1.25 t/ha GB	1872.7c	4953.1b
1.25 t/ha GB + 5 t/ha CM	3023.2ab	6447.9a
No fertiliser (Control)	1914.6c	4492.2b
HSD (P ≤ 0.05)	**898.01**	**1440.6**
Interaction (V X F)		
Omank. **x** 10 t/ha CM	3327.6a	5822.9abc
Omank. **x** 300 kg/ha NPK 15:15:15	2001.6ab	4906.3bc
Omank. **x** 2.5 t/ha GB	2829.7ab	4093.8c
Omank. **x** 150 kg/ha NPK + 1.25 t/ha GB	2125.0ab	4984.4bc
Omank. **x** 1.25 t/ha GB + 5 t/ha CM	3459.4a	6093.7abc
Omank. **x** No fertiliser (Control)	2324.5ab	4953.1bc
Obatan. **x** 10 t/ha CM	3473.4a	7474.0a
Obatan. **x** 300 kg/ha NPK 15:15:15	2107.8ab	4697.9bc
Obatan. **x** 2.5 t/ha GB	2102.1ab	5197.9abc
Obatan. **x** 150 kg/ha NPK + 1.25 t/ha GB	1620.3b	4921.9bc
Obatan. **x** 1.25 t/ha GB + 5 t/ha CM	2587.0ab	6802.1ab
Obatan. **x** No fertiliser (Control)	1504.7b	4031.2c
HSD (P ≤ 0.05)	**1482.4**	**2378.1**
CV (%)	**20.34**	**15.02**

x – interaction CM – Chicken manure GB – *Gliricidia sepium* biochar

Variety (V) = NS
Fertilizer rates (Fr.) = 849.74**
Season (S) = 331.92**
S x V = 622.10**
Fr. x V = NS
Fr. x S = NS
S x Fr. x V = NS

4.DISCUSSION

The soil at both experimental sites was slightly acidic (6.05 and 6.50). The slightly acidic condition of the soil might have afforded maize plants with good access to available nutrients in the soil for healthy plant growth and increased yield. The soil at both experimental sites was low in organic matter content, nitrogen, available phosphorus, potassium, calcium, and magnesium. The low soil nutrient levels could be attributed to prolong nutrient leaching and continuous agricultural activities on the same piece of land. This corroborates with Asante *et al.* (2019) who reported of moderately low levels of effective cation exchange capacity, available P, Ca, and Mg levels whereas the Organic carbon content, Total N and Potassium content were high in the chicken manure used in an experiment conducted with biochar and chicken manure on carrot. The handling, storage and management of the manure prior to application might have resulted in these differences. The nutrient composition of manure is influenced by various factors such as the type of animal, the animal's feed consumption and water intake, methods of manure storage and handling (Ahmad *et al.*, 2016). The *Gliricidia sepium* biochar exhibited high organic carbon content, moderate levels of total nitrogen, potassium, and exchangeable magnesium. Nevertheless, the levels of available phosphorus and exchangeable calcium were relatively low. Mosharrof *et al.* (2021) observed that the choice of raw materials and the pyrolysis temperatures utilized in biochar production had an impact on the ash content. The high nutrient requirement, as maize in known to be a heavy feeder crop or high nutrient uptake of maize from the soil for growth and development might have led to a substantial reduction in soil nutrients at both trial locations after harvesting.

Obatanpa consistently displayed a significantly ($P<0.05$) higher leaf count per plant compared to Omankwa in both cropping seasons. This difference highlights the genetic variability between the two varieties and their ability to leverage environmental factors such as soil moisture, rainfall, temperature, and nutrients. The application of 1.25 t/ha GB + 5 t/ha CM and 10 t/ha CM to maize significantly ($P<0.05$) enhanced plant growth and development, resulting in increased leaf count of maize. The notable increase in leaf count per plant observed in the plots amended with chicken manure and biochar is likely due to the elevated levels of nitrogen and potassium in the plants resulting from the chicken manure and *Gliricidia sepium* biochar application. This is in consonance with the findings of Abdulrazaq & Haneef (2022) that the use of chicken manure outperformed other amendments, leading to a higher leaf count in maize plants due to the increased presence of nitrogen, phosphorus, and potassium from the chicken manure. Additionally, Wang *et al.* (2017) highlighted that combining biochar with organic manure enhances soil carbon storage while reducing nitrate and ammonium leaching. Contrarily, the consistently lower performance of control plots and those with alternative amendments indicated that plants tend to reach their optimal growth potential when sufficient nutrients are available, potentially causing the observed distinctions (Eleduma *et al.,* 2020). Leaf number specifies photosynthetic potential and its major influence in determining grain yield of the crop.

The differences in genetic traits between the two maize varieties generally did not influence the total crop growth rate (CGR) and relative growth rate (RGR) during both cropping seasons. This contradicts the findings made by Islam *et al.* (2019) in Bangladesh, where they identified variations in CGR and RGR among eight maize varieties. The CGR and RGR notably surged from 0-28 DAP to 70 DAP, and sharply decreased thereafter until harvest. The reduction in CGR and RGR at 70 DAP till harvest could be attributed to the allocation of assimilates to the economically important part (grain) of maize during the grain-filling phase, resulting in leaf and stalk senescence and consequently decreasing CGR (Tanveer *et al.*, 2014). Pandey *et al.* (2017) further suggested that the decline in growth rate as plants aged might be linked to the cessation of vegetative growth, shading of older leaves, and subsequent senescence, resulting in reduced photosynthesis. Tajul *et al.* (2013) also asserted that the rise in metabolically active tissue played a smaller role in overall plant growth, contributing to the observed downward trend. The findings regarding CGR are consistent with those of Khan *et al.* (2012). Limpinuntana *et al.* (2010) noted a sharp increase in RGR during the early phase, particularly during 30 days after planting (DAP) until reaching 90 days after planting, followed by a gradual decrease. Differences in CGR and RGR among treatments were more evident during the initial plant growth phase rather than the later stage. Maize plants that received amendments with higher nitrogen content exhibited the highest CGR and RGR, while the control plot consistently showed the lowest values across both seasons. The amendments enriched with nitrogen might have enhanced photosynthetic tissues, and displayed elevated CGR and RGR, as opined by Azarpour *et al.*(2014).

The low nutrient levels in the unamended plots in both seasons, might have hindered the supply of essential nutrients for optimal plant growth probably the stalk to support the cobs during maize fruiting, and this might be attributable to the higher number of lodged plants in the control plot. This discovery aligns with the findings of Eleduma *et al.* (2020), who suggested that plant diameter plays a crucial role in lodging during fruiting, thicker stems reduce the likelihood of lodging due to the strain of carrying fruit or other factors such as wind.Omankwa consistently had fewer number of lodged plants, higher count of filled cobs per plot, and greater grain weight per plot compared to Obatanpa across both cropping seasons. However, during the 2022 major cropping season, Obatanpa produced heavier husked cob weight per plot than Omankwa. Additionally, Obatanpa recorded lower number of unfilled cobs per plot compared to Omankwa across both cropping seasons. These notable disparities between Omankwa and Obatanpa in terms of cob characteristics and yield attributes may stem from their distinct genetic compositions, responses to soil moisture and nutrients, as well as variations in climatic factors such as rainfall and temperature experienced during the growing period.

Sole application of 10 t/ha CM and 1.25 t/ha GB + 5 t/ha CM and their interaction to Omankwa and Obatanpa significantly increased yield compared to other amended plots and the control in both cropping seasons. The soil amended with chicken manure and biochar exhibited a rich macronutrient profile, ensuring a steady and accessible nutrient supply to the plants during the grain filling period resulting in high yield.

The presence of nutrients facilitated by manure and biochar likely enhanced the availability of N, P, K, Ca, and Mg in the soil, fostering vegetative growth and development, ultimately leading to increased yield (Olatunji *et al.,* 2020). Sufficient nitrogen (N) application significantly impacts grain filling in maize which translates into higher grain yield. Studies by Fernandez & Ciampitti (2019) showed that the application of nitrogen enhances both the duration and pace of grain filling, consequently augmenting maize yield. The continuous supply of nutrients from the chicken manure and the ability of the biochar to bind them together for effective plant absorption and utilization during grain filling period might have resulted in this. This was in tandem with Jenberu (2017) who highlighted that in the joint use of biochar and chicken manure, biochar acts as a reservoir for nutrients, slowly releasing them, akin to slow-release fertilizer, owing to its extensive surface area, negative surface charge, and density. Adekiya *et al.* (2020) further reported that the presence of macro nutrients in manure amended soils heightened the photosynthetic activity of plants hence optimizing yield.

In a research conducted by Wisnubroto *et al.* (2017) on integration of farmyard manure and biochar, the findings indicated a rapid and robust crop growth in red chili, this was attributed to the combination of biochar residue and farmyard manure (FYM), which also resulted in increased yields. Adekiya *et al.* (2020) emphasized that the combined application of 15 t/ha biochar (BC) with 15 t/ha poultry manure (BC+PM) notably enhanced soil physical and chemical properties, ginger growth, and yield compared to their individual applications and the unamended plot. Combining biochar with organic manure by Wang *et al.* (2017), boosts soil carbon storage, curtails nitrate and ammonium leaching, augments nutrient availability to plants, and fosters plant growth and agricultural yields (Kavitha *et al.,* 2018).

5.CONCLUSION

The results of this study conclusively reveal that the application of 10 t/ha chicken manure and combine application of chicken manure (CM) with *Gliricidia sepium* biochar (GB) notably enhanced soil physical and chemical properties. Maize plants that received 10 t/ha CM and/or 1.25 t/ha GB + 5 t/ha CM had increased plant growth in both cropping seasons. The study also indicated that Omankwa and Obatanpa maize varieties that received 10 t/ha CM and 1.25 t ha^{-1} GB + 5 t ha^{-1} CM enhanced husked cob weight per plot, number of filled cobs per plot and least number of lodged plants and unfilled cobs. The interaction of Obatanpa and 10 t/ha CM had increased grain yield in both cropping seasons than Obatanpa and Omankwa planted on the control plot. Farmers are to apply 10 t/ha CM or 1.25 t/ha GB + 5 t/ha CM to their maize for vigorous plant growth and optimized grain yield.

REFERENCES

Abdulrazaq, A. S., & Haneef, M. (2022). Analysis of Effect of Poultry Manure on Growth Parameters in Maize (Zea Maize). *African Scholar Journal of Biotechnology and Agricultural Research*, *26*(1), 163–174.

Adekiya, A. O., Agbede, T. M., Ejue, W. S., Aboyeji, C. M., Dunsin, O., Aremu, C. O., Owolabi, A. O., Ajiboye, B. O., Okunlola, O. F., & Adesola, O. O. (2020). Biochar, poultry manure and NPK fertilizer: Sole and combine application effects on soil properties and ginger (Zingiber officinale Roscoe) performance in a tropical Alfisol. *Open Journal of Soil Science*, *5*(1), 30–39. https://doi.org/10.1515/opag-2020-0004

Adekiya, A. O., Ogunboye, O. I., Ewulo, B. S., & Olayanju, A. (2020). Effects of Different Rates of Poultry Manure and Split Applications of Urea Fertilizer on Soil Chemical Properties, Growth, and Yield of Maize. *Scientific World Journal*. https://doi.org/10.1155/2020/4610515

Ahmad, A. A., Radovich, T. J. K., Nguyen, H. V., Uyeda, J., Arakaki, A., Cadby, J., Paull, R., & Sugano, J.; Teves, G. (2016). Use of Organic Fertilizers to Enhance Soil Fertility, Plant Growth, and Yield in a Tropical Environment. *In Organic Fertilizers—From Basic Concepts to Applied Outcomes*, 85–108.

Alam, M. J., Ahmed, K. S., Sultana, A., Firoj, S. M. and Hasan, I. M. (2018). Ensure food security of Bangladesh: Analysis of post-harvest losses of maize and its pest management in stored condition. *Journal of Agricultural Engineering and Food Technology*, *5*(1), 26–32.

Amanullah, Nangial, K., Muhammad, I. K., Shah, K., Asif, I., & Al-Tawaha, A. R. (2019). Wheat biomass and harvest index increases with integrated use of phosphurus, Zinc and beneficial microbes under searid climates. *Journal of Microbiology, Biotec. and Food Sciences*, *9*(2), 285–287. https://doi.org/10.1016/B978-0-323-60984-5.00062-7

Anten, N. P. R., & Ackerly, D. D. (2001). A new method of growth analysis for plants that experience periodic losses of leaf mass. *Functional Ecology*, *15*(6), 804–811. https://doi.org/10.1046/j.0269- 8463.2001.00582.x 13.

AOAC. (1975). *Official methods of analysis, Association of Official Agricultural Chemists.* 2nd ed, Washington D.C.

Arif, M., Ilyas, M., Riaz, M., Ali, K., Shah, K., Haq, I. U., & Fahad, S. (2017). Biochar improves phosphorus use efficiency of organic-inorganic fertilizers, maize- wheat productivity and soil quality in a low fertility alkaline soil. *Field Crop. Res*, *214*, 25–37.

https://doi.org/DOI: 10.1016/j.fcr.2017.08.018
Asante, K., Essilfie, M. E., & Manu-Aduening, J. (2020). Influence of Different Rates of Fertilizer and Biochar on Growth and Yield of Carrot (Daucus carota) in the Forest-Savannah Transitional Zone of Ghana. *Asian Journal of Research in Crop Science*, *5*(1), 21–39. https://doi.org/10.9734/AJRCS/2020/v5i130087
Asante, K., Manu-Aduening, J., & Essilfie, M. . (2019). . Nutritional quality response of carrot (Daucus carota) to different rates of inorganic fertilizer and biochar. *Asian Journal of Soil Science and Plant Nutrition*, 1–14.
Asfaw, M. D. (2022). Effects of animal manures on growth and yield of maize (Zea mays L.). *Journal of Plant Science and Phytopathology*, *6*(2), 033–039. https://doi.org/10.29328/journal.jpsp.1001071
Asiamah, R. D. (1988). *Soils and soil suitability of Ashanti region.*
Azarpour, E., Moraditochaee, M., & Bozorgi, H. R. (2014). Effect of nitrogen fertilizer management on growth analysis of rice cultivars. *International Journal of Bioscanes*, *4*(5), 35–47.
Aziz, A., Khan, B. ., Tahir, M. ., Nadeem, M. ., Amin, M. ., Qura, Adnan, M., Munawar, N., Hussain, A., Khisham, M., Danish, M. T., & Sultan, M. (2020). Effect of poultry manure on growth and yield of forage sorghum (Sorghum bicolor L.). *International Journal of Botany Studies*, *5*(3), 401–406. https://www.researchgate.net/publication/342231552
Baumann, D. T., Bastiaans, L., & Goudriaan, J. (2002). Analysing crop yield and plant quality in an intercropping system using an ecophysiological model for interplant competition. *Agricultural Systems.*, *73*(11), 173–203.
Biratu, G. K., Elias, E., Ntawuruhunga, P., & Nhamo, N. (2018). Effect of chicken manure application on cassava biomass and root yields in two agro-ecologies of Zambia. *Agriculture*, *8*(4), 45.
Bray, R. H., & Kutz, L. T. (1945). Determination of total, organic and available forms of phosphorus in soils. 1945. *Soil Science*, *59*, 39–45.
CSIR. (2019). *Catalogue of crop varieties released and registered in Ghana*.
Demeke, K. H. (2018). Nutritional quality evaluation of seven maizevarieties grown in Ethiopia. *Biochemistry & Molecular Biology*, *3*, 45–48. https://doi.org/doi:10.11648/j.bmb.20180302.11.
Eleduma, A., Aderibigbe, A., & Obabire, S. (2020). Effect of cattle manure on the performances of maize (Zea mays L) grown in forest-savannah transition zone Southwest Nigeria. *International Journal of Agricultural Science and Food Technology*, *6*(2), 110–114. https://doi.org/10.17352/2455-815x.000063
Erenstein, O., Moti, J., Prasanna, B. M., & Sonder, K. (2022). Global maize production, consumption and trade: trends and R&D implications. *Food Security*. https://doi.org/10.1007/s12571-022-01288-7
FAO/UNESCO. (2008). *FAO/UNESCO System of Soil Classification*.
FAO. (2020). *Food and Agriculture Organization of the United Nations.Rome, Italy: FAOSTAT database. Accessed May 15, 2020.http://www.fao.org/faostat/en/#home.*
Fernandez, J. A., & Ciampitti, I. A. (2019). Effect of late nitrogen fertilization on grain yield and grain filling in corn. *Kansas Agricultural Experiment Station Research Reports*, *5*(6), 4.
Geodatos. (2020). *Mampong Geographic coordinates. Retrieved at https://www.geodatos.net/en/coordinates/ghana/mampong.*
Islam, M. T., Islam, A. S., & Sharaf Uddin, M. (2019). Physiological growth indices of maize (Zea mays L.) Genotypes in Sylhet. *BioRxiv, 518993.*
Jahromi, N. B., Fulcher, A., Walker, F., & Altland, J. (2018). Photosynthesis, growth, and water use of Hydrangea paniculata ‘Silver Dollar’ produced with a physiologically based or a substrate physical properties-based irrigation schedule and biochar substrate amendment. Submitted to Irrigation Science. *Journal of Real Life Solutions*, *10*, 10–19.
Jenberu, G. A. (2017). *Biochar, compost and biochar-compost: effects on crop performance,*

soil quality and greenhouse gas emissions in tropical agricultural soils. – PhD thesis. James Cook University.
Kavitha, B., Reddy, P. V. L., Kim, B., Lee, S. S., Pandey, S. K., & Kim, K. H. (2018). Benefits and limitations of biochar amendment in agricultural soils: A review. *J.Environ. Manage*, *227*, 146–154.
Khan, M. B., Yousaf, F., Hussain, M., Haq, M. W., Lee, D. J., & Farooq, M. (2012). Influence of planting methods on root development, crop productivity and water use efficiency in maize hybrids. . 72:556-63. *Chilean J. Agric. Res*, *72*, 556–563.
Limpinuntana, V., Sitthaphanit, S., Toomsan, B., Panchaban, S., & Bell, R. W. (2010). Growth and yield responses in maize to split and delayed fertilizer applications on sandy soils under high rainfall regimes. *Kasetsart J. (Nat. Sci.)*, *44*, 991–1003.
Mensah, A. K., & Frimpong, A. K. (2018). Biochar and / or Compost Applications Improve Soil Properties , Growth , and Yield of Maize Grown in Acidic Rainforest and Coastal Savannah Soils in Ghana. *International Journal of Agronomy*. https://doi.org/10.1155/2018/6837404
MoFA. (2019). *Agriculture in Ghana facts and figures*.
Mosharrof, M., Uddin, M. K., Jusop, S., Sulaiman, M. F., Shamsuzzaman, S. M., & Haque, A. N. A. (2021). Integrated use of biochar and lime as a tool to improve maize yield and mitigate co2 emission: A review. *Chilean Journal of Agricultural Research*, *81*(1), 109–118. https://doi.org/10.4067/S0718-58392021000100109
MSD. (2017). *Meteorological Services Department. Annual Reports Mampong Municipal Assembly, Mampong-Ashanti, Ashanti Region, Ghana.15*, 9–12.
Olatunji, K. O., Adebayo, A. O., & Bolaji, G. E. (2020). Investigating Organic Manure and Inorganic Fertilizer for Sustainable Maize (Zea mays) Production in Southwestern Nigeria. *Asian Journal of Environment & Ecology*, *13*(4), 31–40. https://doi.org/10.9734/ajee/2020/v13i430188
Oluwagbemi, C. O., Oni, A. C., Adeegbe, J. F., & Ajakaye, A. S. (2021). Evaluation of Fertilizer Types on the Growth and Yield of Maize (Zea mays). *International Journal of Plant & Soil Science*, *33*(3), 53–60. https://doi.org/10.9734/IJPSS/2021/v33i330422
Pabi, O., Ayivor, J. S., & Ofori, B. D. (2019). Adaptive strategies of smallholder farming systems to changing climate conditions in the vicinity of kogyae strict nature reserve within the forest-savanna transitional zone of Ghana. *West African Journal of Applied Ecology*, *27*(2), 88–105.
Pandey, P., Bhambri, M. C., Agronomy, D., & Chhattisgarh, R. (2017). Growth response of maize to different crop arrangements and nutrient managements under maize (Zea mays l .) and soybean (Glycine max l .) intercropping system. *Plant Archives*, *17*(2), 967–972.
Rafii, M., Elango, R., Ball, R. O., Pencharz, P. B., & Courtney-Martin, G. (2018). Metabolic availability of the limiting amino acids lysine and tryptophan in cooked white African cornmeal assessed in healthy young men using the indicator amino acid oxidation technique. *The Journal of Nutrition*, *148*(6), 917-924.
SRI. (2007). *CSIR-Soil Research Institute: Guide to interpretation of soil analytical data in Ghana*.
Syuhada, A. B., Shamshuddin, J., Fauziah, C. I., Rosenani, A. B., & Arifin, A. (2016). Biochar as soil amendment: Impact on chemical properties and corn nutrient uptake in a Podzol. *Canadian Journal of Soil Science*, *96*, 400–412. https://doi.org/. doi:10.1139/CJSS-2015-0044
Tajul, M. . I., Alam, M. M., Hossain, S. M. M., Naher, K., Rafii, M. Y., & Latif, M. A. (2013). Influence of Plant Population and Nitrogen-Fertilizer at Various Levels on Growth and Growth Efficiency of Maize. *The Scientific World Journal*. http://dx.doi.org/10.1155/2013/193018
Tańczuk, M., Junga, R., Kolasa-Więcek, A., & Niemiec, P. (2019). Assessment of the energy potential of chicken manure in Poland. *Enegies*, *12*(7), 1244.

https://doi.org/10.3390/en12071244
Tanumihardjo, S. A., McCulley, L., Roh, R., Lopez-Ridaura, S., Palacios-Rojas, N., && Gunaratna, N. S. (2020). Maize agro-food systems to ensure food and nutrition security in reference to the Sustainable Development Goals. *Global Food Security*, *25*, 100327.
Tanveer, M., Anjum, S. A., & Sajjad, A. (2014). Growth and development of maize (Zea mays L.) in response to different planting methods. *Journal of Agricultural Research*, *52*(4). https://www.researchgate.net/publication/277786933
Walkey, A., & Black, I. A. (1934). An examination of the Degtjareff method of determining organic carbon in soils. Effect of variations in digestion conditions and of inorganic soil constituents. *Soil Sci*, *63*(22), 251-263.
Wang, Y., Liu, Y., Liu, R., Zhang, A., Yang, S., Liu, H., Zhou, Y., & Yanng, Z. (2017). Biochar amendment reduces paddy soil nitrogen leaching but increases net global warming potential in Ningxia irrigation, China. *Sci Rep-UK*, *7*, 1–10.
Wisnubroto, E. I., Utomo, W. H., & Indrayatie, E. . (2017). Residual effect of biochar on growth and yield of red chili (Capsicum Annum L.). *Journal of Advanced Agricultural Technologies.*, *4*(1), 28–31.
Wongnaa, C. A., Bakang, J.-E. A., Asiamah, M., Appiah, P., & Asibey, J. K. (2021). Adoption and compliance with Council for Scientific and Industrial Research recommended maize production practices in Ashanti region, Ghana. *World Journal of Science, Technology and Sustainable Development*, *18*(4), 438–456. https://doi.org/10.1108/wjstsd-03-2021-0035