



Effect of Biochar, NPK, and Poultry Manure on Yield Productivity of Maize under Rainfed Conditions

**Emmanuel Appiah ^{a*}, Margaret Esi Essilfie ^a,
Emmanuel Kwasi Asiedu ^a and Samuel Ebo Owusu ^a**

^a*Department of Crop and Soil Sciences Education, Faculty of Agriculture Education, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED), P.O. Box 40, Mampong-Ashanti, Ghana.*

Authors' contributions

This work was carried out in collaboration among all authors. Author EA wrote and prepared the original draft of the manuscript, did data curation, formal analysis and software development and data interpretation. Author MEE wrote, reviewed and edited the manuscript, conceptualized the study, supervised the work, performed the methodology development, did investigation. Author EKA supervised the work, conceptualized the study, did validation and visualization. Author SEO wrote, reviewed and edited the manuscript, did data validation, manage the literature searches, searched for resources management and did investigation. All authors read and approved the final manuscript.

Article Information

DOI: <https://doi.org/10.9734/jsrr/2025/v31i63199>

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://pr.sdiarticle5.com/review-history/137524>

Original Research Article

Received: 09/04/2025

Accepted: 11/06/2025

Published: 24/06/2025

ABSTRACT

The demand for maize continues to outstrip supply due to challenges such as low soil fertility, inappropriate agronomic practices, and infestations of pests and diseases. Hence, there is a need to explore sustainable solutions like *Gliricidia sepium* biochar and poultry manure as alternatives to improve maize yields while simultaneously enhancing soil chemical and physical properties. The

*Corresponding author: E-mail: eappiah25@aamusted.edu.gh, appiahemmanuel01@gmail.com;

study employed a 2 x 6 factorial experiment arranged in a Randomized Complete Block Design with twelve treatments and replicated three times. The treatments included; (i) two maize varieties (*Obatanpa* and *Omankwa*), and (ii) six fertiliser rates [10 t ha⁻¹ Poultry manure (PM), 300 kg ha⁻¹ NPK, 2.5 t ha⁻¹ *Gliricidia sepium* biochar (GB), 150 kg ha⁻¹ NPK + 1.25 t ha⁻¹ GB, 1.25 t ha⁻¹ GB + 5 t ha⁻¹ PM and No fertiliser (Control)]. The results showed that *Omankwa* and *Obatanpa* planted on 10 t ha⁻¹ PM tasseled (3 and 6 days) and silked (2 and 6 days) respectively earlier than the same varieties planted on the control during 2021. *Obatanpa* planted on 10 t ha⁻¹ PM and 1.25 t ha⁻¹ GB + 5 t ha⁻¹ PM produced significantly higher plant height and wider stem diameter respectively at 12 weeks after planting across 2021 and 2022 than the control and *Omankwa* planted on same amendments. *Obatanpa* produced a significantly wider cob diameter than *Omankwa* in 2022. *Obatanpa* grown on 10 t ha⁻¹ PM produced a significantly greater cob diameter than the control. *Omankwa* had a significantly higher total grain yield than *Obatanpa* in 2021. *Omankwa* and *Obatanpa* maize varieties planted on 1.25 t ha⁻¹ GB + 5 t ha⁻¹ PM were superior in grain yield which was 10.4% and 25.8% respectively higher than the same varieties planted on the control plot. For higher vegetative growth and total grain yield *Obatanpa* and *Omankwa* maize varieties planted on 10 t ha⁻¹ PM and 1.25 t ha⁻¹ GB + 5 t ha⁻¹ PM are recommended to farmers.

Keywords: Poultry manure; *omankwa*; *obatanpa*; *gliricidia sepium* biochar; grain yield.

1. INTRODUCTION

Industries play a significant role in the improvement of lifestyle and in the development of a country. However, the byproducts from these industries are a source of environmental pollution. The proper use of the byproducts of these industries can help to cope with environmental pollution. Some byproducts have high nutritional content and are good for crop plants. Under such a scenario, nitrogen-containing organic substances could be utilized as an effective and economic alternative to expensive synthetic N fertilizers, with a documented potential to improve crop yields and soil properties (Rasool *et al.*, 2023; Essilfie *et al.*, 2023). Maize (*Zea mays* L.) is a monocotyledonous crop classified under the genus *Zea* of the family *Poaceae* (Bizuneh, 2021). Due to its versatility, it is widely grown in a variety of climates around the world (Akinrinola & Fagbola, 2020). Maize is ranked third in terms of global production and consumption behind wheat and rice, covering an estimated total area of 197 million hectares (FAOStat, 2021). In Ghana, the southern sectors (Bono, Ahafo, Eastern, and Ashanti regions) produce 85% of the country's maize while the northern sectors produce 15% (Attipoe *et al.*, 2019). Maize contains vitamins A, C, and K, as well as a substantial amount of beta carotene and a moderate amount of selenium, all of which support the thyroid glands and immune system's good functioning (Azawei & Alapuba, 2022). Maize is prepared and eaten in Ghana as 'banku', 'apkle', and porridge (Bede *et al.*, 2020). The starchy component of the kernel is utilized in foods as well as a variety of other items like

adhesives, textiles, and pharmaceutical tablets (Ovharhe *et al.*, 2021). Soil degradation and poor soil fertility management practices are the major factors underlying poor agricultural productivity and its attendant low nutritional qualities of most crops (Dzomeku *et al.*, 2018). Severely degraded land is a major challenge that threatens the productivity and sustainability of crops worldwide, as a result of repeated use of the same land for cultivation. It has been reported that excessive use of synthetic fertilizers may lead to degradation of soil organic matter, nutrient imbalance, soil acidification and environmental pollution. Prolonged and exclusive use of chemical fertilizers can harm soil health by depleting organic matter, causing soil compaction, reducing water infiltration and retention, and contaminating natural resources (Agbede, 2025).

Despite its numerous importance in Ghana, the yield of maize has steadily declined as a result of low soil nutrient points, inappropriate agronomic practices, such as inadequate soil management practices to improve soil health (Awoonor *et al.*, 2025), disease and pest infestation and inability to identify high yielding maize varieties most adapted to each agroecological zone. This has led to the yield averages of 1.5 t ha⁻¹ below the achievable yield of between 5.4 - 6 t ha⁻¹ in Ghana (Boullouz *et al.*, 2022). Organic fertilisers are not fully absorbed and utilized by plants due to their slow release to crops which makes it difficult to supply crop nutrient demands during the growth period (Zhang *et al.*, 2020). According to Agbede (2021), the use of inorganic fertilisers is associated with high soil acidity, human health,

and environmental problems, as well as soil degradation as a means to increase crop yield in Ghana. Poultry manure has been used worldwide for crop improvement and yield. According to Jaja *et al.* (2022), poultry manure serves as a valuable organic fertiliser due to its high organic matter content, making it suitable for surface application to enhance soil quality and boost crop yields. Poultry manure is considered one of the most effective alternatives to synthetic fertilisers, often leading to improved crop production (Almunqedhi *et al.*, 2025).

Leguminous plants such as *Gliricidia sepium*, a versatile fast-growing tree can be used by farmers for living fences, shade, fodder, green manure, support for crops, fuel and as biochar. Leguminous plant wastes contain essential plant nutrients and can be recycled through biochar and used as amendments for maize production. Biochar enhances the crop productivity of many cereal crops, which include maize. Phares *et al.* (2022) discovered that maize grain yield and profitability significantly increased in sole biochar amended soils as compared to the control across the cropping seasons. Biochar usually contains ash, which is rich in macronutrients such as calcium, magnesium, and potassium, all of which are beneficial to soil health and crop production (Chausali *et al.*, 2021). To mitigate the adverse effects of both synthetic and organic fertilisers on soil health and the environment, it is essential to adopt more sustainable, safer, and alternative approaches to crop production. Such strategies should aim to balance crop nutrition, enhance nutrient availability, and function as liming agents to manage soil acidity, particularly in maize cultivation. Different plant varieties typically impact the micro-environmental conditions of crops, thereby affecting both growth and productivity (Hasan *et al.*, 2018). Maize variety have countless effects on yield and yield traits. The study was to determine the yield performance of maize as affected by biochar, NPK, and poultry manure amendments.

2. MATERIALS AND METHODS

2.1 Experimental Location

Two field experiments were conducted at different sites of the research field at the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED), Mampong campus, in the Ashanti Region of

Ghana during the minor cropping season (August -December 2021) and the major cropping season (March - July 2022). Mampong-Ashanti is located between latitudes 7° and 8° north of the Equator and longitudes 1° and 24° west of Greenwich. Mampong-Ashanti is located in the Forest Savannah transitional zone of Ghana with a bimodal rainfall distribution pattern (Amartey *et al.*, 2022). The major rainy season lasts from early April to July and the minor rainy season occurs from September to November (Pabi *et al.*, 2019). The experimental site has GPS coordinates of latitude 7°4'38.75196" North and longitude 1°23'43.45908" West. The experimental site is located at GPS coordinates AM-0078-0227. The soil at this location is classified under the Bediese series, part of the Savannah Ochrosol group, derived from Voltaian sandstone in the Afram Plains region. According to the FAO/UNESCO (2008) classification system, it is identified as Chromic Luvisol. The soil has a pH range between 6.5 and 7.0 and is characterized as sandy loam with good drainage. It contains a thin layer of organic matter, has a deep yellowish-red colour, is friable, stone-free, and exhibits high water retention capacity (Asiamah, 1988). During the 2021 minor cropping season (August to December), total rainfall was 676.7 mm, with the highest amounts recorded in September and October. Average monthly temperatures ranged from 23.1°C to 31.9°C. In the 2022 major cropping season (March to July), the area received a total of 694.6 mm of rainfall, with average monthly temperatures between 23.4°C and 32.2°C. Across both seasons, the average monthly relative humidity was recorded at 70.4%.

2.2 Poultry Manure and Biochar Preparation

The poultry manure used for the two field trials was collected from the poultry farm at the AAMUSTED-Asante Mampong. It was heaped under shade and shielded with leaves, allowing it to dry and cure for two weeks before use, while also helping to reduce nitrogen loss. Woody branches of *Gliricidia sepium* were collected from the AAMUSTED-Mampong campus, heaped and slowly pyrolyzed at about 500 °C in an anoxic pit reactor (Asante *et al.*, 2020) and prepared at the AAMUSTED-Mampong campus solely for the experiment. The biochar was later crushed and milled using a milling machine leaving it in a powdered form and packaged in a plastic bag until ready for use.

2.3 Land preparation, Field layout and Fertilization

The experimental field was marked out. The marked-out field was ploughed, harrowed, leveled, lined, pegged. The field was layout in three blocks with plot size of 3.2 m in length and 4.8 m long (15.36 m²). A path of 0.5 m was left between plots and 2 m between blocks. Background Soils were sampled for routine physical and chemical analyses before planting. A week before sowing of maize seeds, the *Gliricidia sepium* biochar and poultry manure were applied to the plots according to treatment and incorporated into the soil at about 10 cm deep using a hoe. The NPK (15:15:15) fertiliser was amended 2 WAS. Soils were sampled for routine physical and chemical analyses after harvest.

2.4 Soil, Poultry Manure and Biochar Sampling and Analysis

Before planting and after harvest, a representative soil sample from the Ap horizon was randomly collected at a consistent depth of 0-20 cm from the research field at AAMUSTED, Mampong campus for physical and chemical analysis. Poultry manure and *Gliricidia sepium* biochar were also sampled for analysis. The soil, poultry manure, and biochar samples were bulked, left to air dry, and subsequently, sub-samples were collected for standardized analysis at the Soil Science laboratory of the Department of Crop and Soil Sciences, KNUST, Kumasi. The analysis encompassed several characteristics: soil pH was measured through a 1:1 (soil: distilled water) ratio using a pH meter (Pracitronic pH meter) produced by Veb Pracitron in Dresden, Germany. Organic matter analysis followed the Walkey and Black method (Walkey & Black, 1934), while total nitrogen assessment utilized the micro Kjeldahl method (AOAC, 1975). Available phosphorus was extracted utilizing the Bray method and assessed colorimetrically (Bray & Kutz, 1945). Flame emission photometry was used to assess exchangeable cations (Bray & Kutz, 1945). The procedure included shaking the soil-extract mixture, and then separating the liquid phase through either filtration or centrifugation. After removing ammonium acetate and organic matter at a neutral pH of 7.0, the concentrations of calcium (Ca) and magnesium (Mg) were measured using atomic absorption spectrometry (AAS).

2.5 Experimental Design and Treatment

The experimental design used was a 2 x 6 factorial experiment laid in a Randomized Complete Block Design (RCBD) with twelve treatments and each replicated three times. The treatments were made up of factor (i) two maize varieties (Obatanpa and Omankwa), and (ii) six fertiliser rates: [(T1 = 10 t ha⁻¹ poultry manure (PM), T2 = 300 kg ha⁻¹ NPK 15:15:15, T3 = 2.5 t ha⁻¹ *Gliricidia sepium* biochar (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 PM) and T6 = No fertiliser (Control)]. Each block contained twelve plots, on which Omankwa and Obatanpa maize varieties were assigned to.

2.6 Planting Materials and Planting

The Omankwa and Obatanpa maize varieties were sourced at CSIR-CRI, Fumesua- Ghana. Omankwa is 90 to 95-day early maturing improved maize variety which tolerates drought and striga while Obatanpa is a 105 to 110-day medium maturing maize variety. Omankwa and Obatanpa are high-quality protein maize (QPM) varieties, excellent for enhanced nutrition and health of humans, poultry, and livestock. Obatanpa is suited for all agroecologies in Ghana while Omankwa is most suitable for Guinea and Sudan savannah zones in Ghana (NVRRC-CSIR, 2019). The grain of Omankwa is white flint/dent and it has a yield capacity of 4.5 t ha⁻¹ while the grain of Obatanpa is white/dent with a yield capacity of 4.6 t ha⁻¹ (Tetteh *et al.*, 2018). Seeds were planted at a spacing of 80 x 40 cm, with 3 seeds sown per hill. After one week, the seedlings were thinned to two per/stand. Each plot comprised 4 rows, with each row containing 24 plants, resulting in a total of 96 plants per plot. Out of these, 40 plants were situated within the harvestable area.

2.7 Agronomic Practices

Supplying was done at 7 days after planting by replacing about 2 to 3 vacant holes per plot with seeds that failed to germinate. Weeding started at 2 weeks after planting using hoe and where weeds were close to plants pulling out weeds by hand was used. Subsequent weed control was done at every two weeks by hand pulling and hoeing. Pest and disease occurrences were regularly monitored by visiting the experimental site to assess their presence. The incidence of Fall Armyworm (FAW) outbreak was controlled by spraying with 15 ml of Warrior super

insecticide with Emamectin benzoate as an active ingredient in 15 l of water equivalent to 9.77 l ha⁻¹ of insecticide in 9, 800 l of water per hectare.

2.8 Harvesting

The maturity of both maize varieties for harvesting at the dry stage was indicated by several visual cues, including plant lodging, senescence of leaves and stalks, drooping of leaves and ears, and the browning of husks, tassels, and silks. Additionally, grain moisture content of less than 20 to 25 percent signalled readiness for harvest. Harvesting was conducted manually on the same day for both varieties, using a cutlass to cut the stalks just above the ground. The maize ears were then separated from the stalks by twisting them off.

2.9 Data Collection

Field data was collected on phenology, vegetative growth, yield and yield components. The number of days to fifty percent tasseling and silking was determined by counting the number of days from sowing until half of the plants in the two central rows had produced tassels or silks.

Five plants were randomly selected and tagged from the two middle rows of each plot for data collection. Plant height was determined with a meter stick from the ground level to the tip of the apical leaf from 4 to 12 WAP and at two-week intervals and the mean plant height was estimated. The stem diameter was measured on the five randomly tagged plants from the two middle rows within each plot from the plant base to approximately 5 cm above ground level from 4 to 12 WAP and at two-week intervals with the aid of a digital Vernier caliper. The mean stem diameter was then computed and recorded.

Five cobs were randomly selected from the central rows of every treatment after harvest and the cob diameter was measured at the widest part of the cob using a digital Vernier caliper and the mean estimated. After shelling, the grains were weighed using an electronic scale, and the average weight was calculated. All maize stover from the central rows of every treatment after harvest was tied together and weighed using a salter suspended weigher with model number 235.

The harvest index (HI) was expressed as described below by Amanullah et al. (2019) as follows:

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

The total grain yield per plot was estimated in (t ha⁻¹) using the formula as described below by Amanullah et al. (2019) as follows:

$$\text{Grain yield (t ha}^{-1}\text{)} = \frac{\text{Grain yield (kg)}}{\text{Harvestable area (m}^2\text{)}} \times \frac{10,000\text{m}^2}{1,000} \quad (2)$$

2.10 Statistical Analysis

Analysis of Variance was used to analyze the data. The statistical package GenStat Release 18.1 (PC/Windows 8), Copyright 2015 by VSN International Ltd. and registered to ICARDA, was used for this analysis. Treatment means were separated using Tukey's Honestly Significant Difference (HSD) at 5% level of probability.

3. RESULTS

3.1 Soil, Poultry Manure, and Biochar Analysis

Table 1 presents the chemical properties of poultry manure and *Gliricidia sepium* biochar used in the experiments. The poultry manure had a slightly alkaline pH, with high levels of total nitrogen and potassium, and very high organic carbon content. However, it exhibited low levels of total P, Ca, and Mg. The *Gliricidia sepium* biochar was also alkaline, with moderate N and K levels, very high organic carbon content, and low available P, Ca, and Mg levels (SRI, 2007). Table 2 shows the initial chemical and physical properties of the soils at the experimental sites during the minor (2021) and major (2022) cropping seasons. In the 2021 minor season, the soil was slightly acidic (pH 6.05), with low organic matter content (1.06) and moderate nitrogen levels (0.18) (SRI, 2007). For the 2022 major season, the soil was slightly acidic (pH 6.50), with moderate organic matter content (1.75) and low total N levels (0.10). At both experimental sites, available P levels (7.45 and 6.24) were low, as were the levels of exchangeable bases (Ca, Mg, and Na) and total K. The soil texture at both sites was classified as sandy-loam. Table 3 shows the chemical properties of the soils at both experimental sites after maize harvest. The soil pH was slightly acidic (6.51) for the minor season and neutral (6.66) for the major season, according to SRI (2007). All other soil properties remained low at both sites after harvesting.

Table 1. Chemical properties of poultry manure and *Gliricidia sepium* biochar used for the study

Samples	Variables							
	pH (H ₂ O 1:1)	N (%)	P (%)	Org. C (%)	C:N ratio	Ca (%)	Mg (%)	K (%)
Poultry 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 2. Initial Chemical and physical properties of background soil at experimental sites before planting of maize

Soil Samples	pH (H ₂ O 1:1)	P mg/kg	N (%)	Exch. Bases (cmol/kg)				Exch. Acidity		% Org. C	% Org. M
				K	Ca	Mg	Na	Al (cmol/kg)	H		
2021	6.05	7.45	0.18	0.13	1.65	0.53	0.02	0.40	0.53	0.82	1.06
2022	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			
2021		79.07		9.98		10.95		Sandy loam			
2022		77.87		10.12		12.01		Sandy loam			

Table 3. Final Chemical and physical properties of soil at experimental sites after harvesting of maize

Sample	pH (H ₂ O 1:1)	P mg/kg	N (%)	Exch. Bases (cmol/kg)				Exch. Acidity		% Org. C	% Org. M
				K	Ca	Mg	Na	Al (cmol/kg)	H		
2021	6.51	6.25	0.14	0.10	1.01	0.20	0.02	0.21	0.32	0.54	0.85
2022	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			
2021		75.25		11.47		13.28		Sandy loam			
2022		78.08		8.89		13.03		Sandy loam			

3.2 Phenology

3.2.1 Days to 50% tasseling

The result on number of days to 50% tasseling as affected by biochar, poultry manure, and NPK fertiliser application is shown in Table 4. In the 2021 minor cropping season, a significant ($P \leq 0.05$) difference occurred between varieties, fertiliser rates and their interaction in number of days to 50% tasseling. Omankwa tasseled seven (7) days earlier than Obatanpa and was significantly different. Plot treated with 10 t/ha PM produced maize plants that tasseled earlier (47 days) than the control plot (59 days). Omankwa planted on 10 t/ha PM plot tasseled three days (44.67 days) earlier than plants planted on the control plot (48) days followed by those planted on 1.25 t/ha GB + 5 t/ha PM. Obatanpa planted on 10 t/ha PM plot tasseled six days (50 days) earlier than plants planted on the control plot (55.67 days). In the 2022 major cropping season, Omankwa tasseled five days (51 days) earlier than Obatanpa (56 days) (Table 4). Maize planted on plot treated with 10t/ha PM tasseled four days (51 days) earlier than the control plot (55 days). Omankwa grown on 10 t/ha PM soils had the least (49 days) number of days to 50% tasseling followed by interaction of Omankwa and 1.25 t/ha GB + 5 t/ha PM (50 days) which differed significantly from Obatanpa x control plot which tasseled 8 to 9 days later (58 days).

3.2.2 Days to 50% silking

In the 2021 minor cropping season there was a significant ($P \leq 0.05$) difference between Omankwa and Obatanpa in number of days to 50% silking (Table 5). Omankwa silked seven days earlier than Obatanpa. There was a significant ($P \leq 0.05$) difference between the fertiliser rates. The maize plant planted under 10 t/ha PM silked five days (52 days) earlier than the control plot (57 days). There was however no significant ($P > 0.05$) difference between interaction of Omankwa and amended and unamended plots in days to 50% silking. Interaction of Obatanpa and 10 t/ha PM showed significant differences from other treated plots except 1.25t/ha GB + 5 t/ha PM and the unamended plots and silked six days (55 days) earlier than the control (61 days).

In 2022 major cropping season, there was a significant ($P \leq 0.05$) difference between Omankwa and Obatanpa in number of days to 50% silking. Omankwa silked five days (56

days) earlier than Obatanpa (61 days). The maize plants grown on 10 t/ha PM was the earliest to silk followed by 1.25 t/ha GB + 5 t/ha PM which was not significantly different, but was significantly different from the no fertiliser plot (Table 5). Interaction of both maize varieties and 10 t/ha PM as well as 1.25t/ha GB + 5 t/ha PM was not significantly ($P \leq 0.05$) different in days to 50% silking, but significantly different from the control with a maximum number of days to 50% silking in all cases.

3.3 Vegetative Growth

3.3.1 Plant height

Tables 6 and 7 show the impact of biochar, poultry manure, and NPK fertiliser application on plant height. Obatanpa had significantly higher plant height than Omankwa across the entire growing period in both cropping seasons except at 4 WAP where no significant difference exists between varieties and at 6 WAP where Omankwa produced significantly higher plant height than Obatanpa during 2021 minor cropping season (Tables 6 and 7). In the 2021 minor cropping season, application of 10 t/ha PM to maize plants produced significantly higher plant height than other amended plots and the control followed by 1.25 t/ha GB + 5 t/ha PM across the growing period (Table 6). The interaction of Omankwa and Obatanpa maize varieties and 10 t/ha PM as well as 1.25 t/ha GB + 5 t/ha PM produced higher plant height than other amended treatments and the control and was significantly ($P \leq 0.05$) different across the entire growing period. The interaction of Omankwa and Obatanpa and no fertiliser plots had the lowest plant height at 4 and 6 WAP respectively. However, the interaction of Omankwa and 300 k/ha NPK 15:15:15 produced the shortest plants from 8 to 12 WAP. In the 2022 major season, applying 10 t/ha PM followed by 1.25 t/ha GB + 5 t/ha PM to maize plants produced significantly higher plant height than other amended plots and the control across the growing period except at 4 WAP (Table 7). The interaction of both Omankwa and Obatanpa maize varieties and 10 t/ha PM as well as 1.25 t/ha GB + 5 t/ha PM produced higher plant height than the control and was significantly ($P \leq 0.05$) at 6 WAP. The interaction of Obatanpa maize variety and 10 t/ha PM produced tallest plants followed by same maize variety planted on 1.25 t/ha GB + 5 t/ha PM and was significantly ($P \leq 0.05$) different from the control from 10 to 12 WAP.

Table 4. Days to 50% tasseling as affected by biochar, poultry manure and NPK fertiliser application during 2021 minor and 2022 major cropping seasons

Fertiliser rates	Days to 50% Tasseling					
	2021			2022		
	Variety			Variety		
	Omank.	Obatan.	Mean	Omank.	Obatan.	Mean
10 t/ha PM	44.67 ^e	50.00 ^c	47.33 ^c	49.33 ^d	53.33 ^{abcd}	51.33 ^b
300 kg/ha NPK	48.00 ^{cd}	54.33 ^{ab}	51.17 ^a	52.67 ^{abcd}	56.00 ^{ab}	54.33 ^{ab}
2.5 t/ha GB	48.00 ^{cd}	55.33 ^a	51.67 ^a	52.00 ^{bcd}	56.00 ^{ab}	54.00 ^{ab}
150 kg/ha NPK +1.25 t/ha GB	48.67 ^{cd}	55.33 ^a	52.00 ^a	50.67 ^{cd}	56.67 ^{ab}	53.67 ^{ab}
1.25 t/ha GB + 5 t/ha PM	46.33 ^{de}	52.67 ^b	49.50 ^b	50.33 ^{cd}	55.00 ^{abc}	52.67 ^{ab}
No fertiliser (control)	48.00 ^{cd}	55.67 ^a	51.83 ^a	53.00 ^{abcd}	57.67 ^a	55.33 ^a
Mean	47.28 ^b	53.89 ^a		51.33 ^b	55.78 ^a	
CV (%)	1.59			3.17		
Variety (V)	HSD (0.05) = 0.56			HSD (0.05) = 1.17		
Fertiliser rates (F)	HSD (0.05) = 1.44			HSD (0.05) = 3.05		
V x F	HSD (0.05) = 2.38			HSD (0.05) = 5.04		

CV = Coefficient of variation; HSD = Highest significant difference at 5%; PM = Poultry manure; GB = *Gliricidia sepium* biochar; Omank = Omankwa; Obatan: Obatanpa

Table 5. Days to 50% silking as affected by biochar, poultry manure and NPK fertiliser application during 2021 minor and 2022 major cropping seasons

	Days to 50% Silking					
	2021			2022		
	Variety			Variety		
Fertiliser rates	Omank.	Obatan.	Mean	Omank.	Obatan.	Mean
10 t/ha PM	50.00 ^e	54.67 ^{cd}	52.33 ^b	51.33 ^d	57.67 ^{bcd}	54.50 ^c
300 kg/ha NPK	52.00 ^{de}	59.00 ^{ab}	55.50 ^a	58.67 ^{abc}	61.67 ^{ab}	60.17 ^{ab}
2.5 t/ha GB	51.33 ^{de}	60.00 ^a	55.67 ^a	58.33 ^{abc}	60.67 ^{ab}	59.50 ^{ab}
150 kg/ha NPK +1.25 t/ha GB	52.67 ^{cde}	60.00 ^a	56.33 ^a	56.33 ^{bcd}	62.33 ^{ab}	59.33 ^{ab}
1.25 t/ha GB + 5 t/ha PM	50.33 ^e	56.00 ^{bc}	53.17 ^b	53.00 ^d	60.33 ^{ab}	56.67 ^{bc}
No fertiliser (control)	52.00 ^{de}	61.00 ^a	56.50 ^a	59.00 ^{abc}	64.67 ^a	61.83 ^a
Mean	51.39 ^b	58.44 ^a		56.11 ^b	61.22 ^a	
CV (%)	2.29			3.85		
Variety (V)	HSD (0.05) = 0.86			HSD (0.05) = 1.56		
Fertiliser rates (F)	HSD (0.05) = 2.26			HSD (0.05) = 4.06		
V x F	HSD (0.05) = 3.73			HSD (0.05) = 6.70		

CV = Coefficient of variation; HSD = Highest significant difference at 5%; PM = Poultry manure; GB = *Gliricidia sepium* biochar; Omank = Omankwa; Obatan: Obatanpa

Table 6. Plant height as affected by biochar, poultry manure and NPK fertiliser application during 2021 minor cropping season

Treatment	Plant height (cm)				
	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP
Variety					
Omankwa	24.05	96.08 ^a	156.85 ^b	158.33 ^b	159.84 ^b
Obatanpa	25.32	79.65 ^b	174.48 ^a	190.55 ^a	192.66 ^a
HSD ($P \leq 0.05$)	NS	6.40	6.61	5.89	5.86
Fertiliser rates					
10 t/ha PM	34.32 ^a	128.63 ^a	196.72 ^a	197.47 ^a	200.40 ^a
300 kg/ha NPK 15:15:15	21.78 ^b	78.17 ^c	156.62 ^b	166.70 ^b	168.83 ^b
2.5 t/ha GB	20.73 ^b	68.90 ^c	149.05 ^b	162.63 ^b	164.13 ^b
150 kg/ha NPK + 1.25 t/ha GB	21.32 ^b	71.88 ^c	153.07 ^b	165.28 ^b	166.78 ^b
1.25 t/ha GB + 5 t/ha PM	30.75 ^a	111.32 ^b	187.28 ^a	188.27 ^a	190.25 ^a
No fertiliser (Control)	19.22 ^b	68.30 ^c	151.25 ^b	166.30 ^b	167.12 ^b
HSD ($P \leq 0.05$)	4.67	16.64	17.20	15.32	15.24
Interaction (V x F)					
Omank. x 10 t/ha PM	33.90 ^a	134.97 ^a	175.03 ^{bcd}	174.97 ^{bcd}	177.03 ^{bc}
Omank. x 300 kg/ha NPK 15:15:15	17.77 ^c	83.03 ^{cd}	141.37 ^f	147.20 ^e	149.70 ^d
Omank. x 2.5 t/ha GB	21.57 ^c	79.13 ^{cd}	150.50 ^{cdef}	150.47 ^{de}	151.37 ^d
Omank. x 150 kg/ha NPK + 1.25 t/ha GB	20.77 ^c	78.10 ^{cd}	145.40 ^{ef}	147.20 ^e	148.87 ^d
Omank. x 1.25 t/ha GB + 5 t/ha PM	31.03 ^{ab}	125.73 ^a	176.63 ^{bc}	177.30 ^{bc}	179.00 ^b
Omank. x No fertiliser (Control)	17.27 ^c	75.53 ^{cd}	152.17 ^{cdef}	152.87 ^{cde}	153.10 ^{cd}
Obatan. x 10 t/ha PM	34.73 ^a	122.30 ^{ab}	218.40 ^a	219.97 ^a	233.77 ^a
Obatan. x 300 kg/ha NPK 5:15:15	23.80 ^{bc}	73.30 ^{cd}	171.87 ^{bcde}	186.20 ^b	187.97 ^b
Obatan. x 2.5 t/ha GB	19.90 ^c	58.67 ^d	147.60 ^{def}	174.80 ^{bcd}	176.90 ^{bc}
Obatan. x 150 kg/ha NPK + 1.25 t/ha GB	21.87 ^c	65.67 ^d	160.73 ^{cdef}	183.37 ^b	184.70 ^b
Obatan. x 1.25 t/ha GB + 5 t/ha PM	30.47 ^{ab}	96.90 ^{bc}	197.93 ^{ab}	199.23 ^{ab}	201.50 ^{ab}
Obatan. x No fertiliser (Control)	21.17 ^c	61.07 ^d	150.33 ^{cdef}	179.73 ^b	181.13 ^b
HSD ($P \leq 0.05$)	7.71	27.47	28.39	25.29	25.17
CV (%)	10.52	10.53	5.77	4.88	4.81

x – Interaction

PM – Poultry manure

WAP– Weeks after planting

GB – Gliricidia sepium biochar

Table 7. Plant height as affected by biochar, poultry manure and NPK fertiliser application during 2022 major cropping season

Treatment	Plant height (cm)				
	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP
Variety					
Omankwa	19.65 ^b	65.31	157.60 ^b	169.19 ^b	171.05 ^b
Obatanpa	22.13 ^a	68.04	172.79 ^a	201.73 ^a	204.08 ^a
HSD (P ≤ 0.05)	1.72	NS	13.29	6.24	5.70
Fertiliser rates					
10 t/ha PM	24.22 ^a	88.00 ^a	193.53 ^a	204.92 ^a	206.73 ^a
300 kg/ha NPK 15:15:15	19.92 ^{abc}	59.87 ^b	154.59 ^{bc}	181.01 ^b	183.29 ^{bc}
2.5 t/ha GB	21.00 ^{abc}	58.88 ^b	158.67 ^{bc}	175.60 ^b	178.17 ^{bc}
150 kg/ha NPK + 1.25 t/ha GB	19.48 ^{bc}	59.72 ^b	160.45 ^{abc}	182.84 ^b	184.79 ^b
1.25 t/ha GB + 5 t/ha PM	23.75 ^{ab}	80.70 ^a	183.70 ^{ab}	200.80 ^a	202.01 ^a
No fertiliser (Control)	16.97 ^c	52.90 ^b	140.26 ^c	167.59 ^b	169.60 ^c
HSD (P ≤ 0.05)	4.49	18.96	34.55	16.24	14.81
Interaction (V x F)					
Omank. x 10 t/ha PM	22.77 ^{ab}	84.37 ^{ab}	174.48 ^{abc}	186.09 ^{cd}	187.79 ^{cd}
Omank. x 300 kg/ha NPK 15:15:15	18.27 ^{ab}	56.80 ^{bcd}	152.34 ^{bc}	165.95 ^{def}	167.59 ^{de}
Omank. x 2.5 t/ha GB	20.03 ^{ab}	51.30 ^{cd}	145.69 ^c	155.28 ^f	158.80 ^e
Omank. x 150 kg/ha NPK + 1.25 t/ha GB	18.27 ^{ab}	61.57 ^{abcd}	158.87 ^{abc}	167.17 ^{def}	168.59 ^{de}
Omank. x 1.25 t/ha GB + 5 t/ha PM	23.17 ^a	82.00 ^{abc}	163.82 ^{abc}	183.12 ^{cde}	184.45 ^{cd}
Omank. x No fertiliser (Control)	15.40 ^b	55.88 ^{bcd}	150.43 ^{bc}	157.54 ^{ef}	159.41 ^e
Obatan. x 10 t/ha PM	25.67 ^a	91.63 ^a	212.59 ^a	223.75 ^a	225.68 ^a
Obatan. x 300 kg/ha NPK 5:15:15	21.57 ^{ab}	62.93 ^{abcd}	156.83 ^{abc}	196.07 ^{bc}	198.99 ^{bc}
Obatan. x 2.5 t/ha GB	21.97 ^{ab}	66.47 ^{abcd}	171.65 ^{abc}	195.92 ^{bc}	197.54 ^{bc}
Obatan. x 150 kg/ha NPK + 1.25 t/ha GB	20.70 ^{ab}	57.87 ^{bcd}	162.02 ^{abc}	198.50 ^{abc}	201.29 ^{abc}
Obatan. x 1.25 t/ha GB + 5 t/ha PM	24.33 ^a	79.40 ^{abcd}	203.59 ^{ab}	218.49 ^{ab}	221.17 ^{ab}
Obatan. x No fertiliser (Control)	18.53 ^{ab}	49.97 ^d	130.08 ^c	177.64 ^{cdef}	179.78 ^{cde}
HSD (P ≤ 0.05)	7.60	31.31	57.03	26.80	24.45
CV (%)	11.94	15.81	11.63	4.87	4.39

x – Interaction PM – Poultry manure WAP– Weeks after planting GB – *Gliricidia sepium* biochar

3.3.2 Stem diameter

Tables 8 and 9 show the impact of biochar, poultry manure, and NPK fertiliser application on stem diameter. In the 2021 minor cropping season, Obatanpa produced significantly wider stem diameter than Omankwa from 6 to 12 WAP (Table 8). The application of 10 t/ha PM to maize plants produced significantly wider stem diameter than other treated plots and the unamended plot from 4 WAP to 12 WAP except 1.25 t/ha GB + 5 t/ha PM which was not significantly different from 10 t/ha PM at 12 WAP in stem diameter. The interaction of both Omankwa and Obatanpa maize varieties and 10 t/ha PM produced widest stem diameter followed by 1.25 t/ha GB + 5 t/ha PM at 12 WAP and significantly varied from other treated plots and the unamended plot except interaction of Obatanpa and 300 kg/ha NPK 5:15:15. In the 2022 major cropping season, Obatanpa differed significantly from Omankwa in stem diameter across the entire growing period (Table 9). The application of 10 t/ha PM to maize plants produced the widest stem diameter followed by 150 kg/ha NPK + 1.25 t/ha GB from 4 to 10 WAP and differed significantly from other amended plots except 300 kg/ha NPK 15:15:15 at 4 WAP and the control. The 10 t/ha PM applied to maize gave the widest stem diameter at 12 WAP and was significantly ($P \leq 0.05$) different from other amended plots and the control. The interaction of Omankwa and Obatanpa and 10 t/ha PM produced significantly wider stem diameters from 4 to 6 WAP and from 8 to 12 WAP respectively than the control which produced the least stem diameters across the entire growing period (Tables 8 and 9).

3.4 Yield and Yield Components

3.4.1 Cob diameter

Table 10 shows cob diameter as affected by biochar, poultry manure, and NPK fertiliser application. In the 2021 minor cropping season, no significant ($P \geq 0.05$) difference occurred between maize varieties in cob diameter. The application of 10 t/ha PM plot had the widest (4.56 cm) cob diameter which was significantly ($P \leq 0.05$) different from the unamended plot which recorded the least (4.03 cm). There was no significant ($P \geq 0.05$) difference between the interaction of Omankwa and amended and unamended plots in cob diameter. The interaction of Obatanpa and 10 t/ha PM gave significantly ($P \leq 0.05$) wider cob diameter than the control.

In the 2022 major cropping season, Obatanpa produced significantly ($P \leq 0.05$) wider (5.07 cm) cob diameter than Omankwa (4.79 cm). The application of 10 t/ha PM to maize had the widest (5.21 cm) cob diameter which was significantly ($P \leq 0.05$) different from the unamended plot which recorded the least (4.70 cm). There was no significant ($P \geq 0.05$) difference between the interaction of Omankwa and amended and unamended plots in cob diameter. The interaction of Obatanpa and 10 t/ha PM produced significantly ($P \leq 0.05$) wider (5.45 cm) cob diameter than the unamended plot (4.71 cm). Omankwa grown on 10 t/ha PM was not significantly different from interaction of both maize varieties and 1.25 t/ha GB + 5 t/ha PM. In all cases the interaction of Obatanpa and Omankwa maize varieties and amended and unamended plots produced significantly wider cob diameter in the 2022 major cropping season than in the 2021 minor cropping season (Table 10).

3.4.2 Harvest index

Table 11 shows harvest index as influenced by biochar, poultry manure, and NPK fertiliser application. In the 2021 minor cropping season, Omankwa had significantly higher (0.44) harvest index than Obatanpa (0.31). There was no significant ($P \geq 0.05$) difference between the different fertiliser rates applied to treatments in harvest index. There was no significant ($P \geq 0.05$) difference between the interaction of Omankwa and amended and unamended plots in harvest index. However, the interaction of Omankwa and 2.5 t/ha GB had significantly higher harvest index than interaction of Obatanpa and other amended plots except interaction of Obatanpa and 2.5 t/ha GB and the unamended plot.

In the 2022 major cropping season, Omankwa had significantly higher (0.44) harvest index than Obatanpa (0.38). There was no significant ($P \geq 0.05$) difference between the different fertiliser rates applied to treatments in harvest index. There was no significant ($P \geq 0.05$) difference between the interaction of both Omankwa and Obatanpa maize varieties and amended and unamended plots in harvest index although the interaction of Omankwa and 2.5 t/ha GB had a maximum (0.49) harvest index whilst the interaction of Obatanpa and 2.5 t/ha GB and the unamended plot had the least and same mean value (0.36) in harvest index.

Table 8. Stem diameter as affected by biochar, poultry manure and NPK fertiliser application during 2021 minor cropping season

Treatment	Stem diameter (cm)				
	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP
Variety					
Omankwa	1.61	1.94 ^b	2.11 ^b	2.27 ^b	1.94 ^b
Obatanpa	1.59	2.10 ^a	2.24 ^a	2.38 ^a	2.05 ^a
HSD ($P \leq 0.05$)	NS	0.07	0.06	0.06	0.09
Fertiliser rates					
10 t/ha PM	2.20 ^a	2.48 ^a	2.62 ^a	2.75 ^a	2.45 ^a
300 kg/ha NPK 15:15:15	1.48 ^c	1.93 ^c	2.13 ^c	2.33 ^c	2.00 ^b
2.5 t/ha GB	1.32 ^c	1.85 ^{cd}	2.02 ^{cd}	2.18 ^d	1.70 ^c
150 kg/ha NPK + 1.25 t/ha GB	1.38 ^c	1.85 ^{cd}	2.00 ^{cd}	2.18 ^d	1.85 ^{bc}
1.25 t/ha GB + 5 t/ha PM	1.90 ^b	2.28 ^b	2.42 ^b	2.52 ^b	2.35 ^a
No fertiliser (Control)	1.30 ^c	1.72 ^d	1.88 ^d	1.98 ^e	1.63 ^c
HSD ($P \leq 0.05$)	0.24	0.19	0.17	0.14	0.24
Interaction (V x F)					
Omank. x 10 t/ha PM	2.13 ^{ab}	2.37 ^{ab}	2.50 ^{ab}	2.67 ^{ab}	2.40 ^{ab}
Omank. x 300 kg/ha NPK 15:15:15	1.40 ^{cd}	1.77 ^e	2.00 ^{cd}	2.30 ^{def}	1.97 ^{cde}
Omank. x 2.5 t/ha GB	1.37 ^d	1.83 ^{de}	2.03 ^{cd}	2.17 ^{efgh}	1.60 ^{ef}
Omank. x 150 kg/ha NPK + 1.25 t/ha GB	1.33 ^d	1.77 ^e	1.93 ^d	2.10 ^{fgh}	1.77 ^{def}
Omank. x 1.25 t/ha GB + 5 t/ha PM	2.03 ^{ab}	2.20 ^{bc}	2.37 ^b	2.47 ^{bcd}	2.37 ^{ab}
Omank. x No fertiliser (Control)	1.37 ^d	1.70 ^e	1.83 ^d	1.93 ^h	1.57 ^f
Obatan. x 10 t/ha PM	2.27 ^a	2.60 ^a	2.73 ^a	2.83 ^a	2.50 ^a
Obatan. x 300 kg/ha NPK 5:15:15	1.57 ^{cd}	2.10 ^{bcd}	2.27 ^{bc}	2.37 ^{cde}	2.03 ^{bcd}
Obatan. x 2.5 t/ha GB	1.27 ^d	1.87 ^{de}	2.00 ^{cd}	2.20 ^{efg}	1.80 ^{def}
Obatan. x 150 kg/ha NPK + 1.25 t/ha GB	1.43 ^{cd}	1.93 ^{cde}	2.07 ^{cd}	2.27 ^{defg}	1.93 ^{def}
Obatan. x 1.25 t/ha GB + 5 t/ha PM	1.77 ^{bc}	2.37 ^{ab}	2.47 ^{ab}	2.57 ^{bc}	2.33 ^{abc}
Obatan. x No fertiliser (Control)	1.23 ^d	1.73 ^e	1.93 ^d	2.03 ^{gh}	1.70 ^{def}
HSD ($P \leq 0.05$)	0.39	0.31	0.28	0.24	0.39
CV (%)	8.19	5.09	4.26	3.43	6.55

x – Interaction *PM* – Poultry manure *WAP*– Weeks after planting *GB* – *Gliricidia sepium* biochar

Table 9. Stem diameter as affected by biochar, poultry manure and NPK fertiliser application during 2022 major cropping season

Treatment	Stem diameter (cm)				
	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP
Variety					
Omankwa	1.45 ^b	1.80 ^b	2.01 ^b	2.18 ^b	2.02 ^b
Obatanpa	1.62 ^a	1.91 ^a	2.13 ^a	2.34 ^a	2.16 ^a
HSD (P ≤ 0.05)	0.13	0.10	0.07	0.07	0.07
Fertiliser rates					
10 t/ha PM	1.83 ^a	2.22 ^a	2.43 ^a	2.72 ^a	2.57 ^a
300 kg/ha NPK 15:15:15	1.55 ^{abc}	1.77 ^{cd}	2.00 ^b	2.15 ^b	1.97 ^c
2.5 t/ha GB	1.45 ^{bc}	1.72 ^{cd}	1.95 ^b	2.08 ^{bc}	1.92 ^{cd}
150 kg/ha NPK + 1.25 t/ha GB	1.43 ^{bc}	1.82 ^{bc}	1.97 ^b	2.13 ^b	1.95 ^{cd}
1.25 t/ha GB + 5 t/ha PM	1.63 ^{ab}	2.03 ^{ab}	2.30 ^a	2.55 ^a	2.35 ^b
No fertiliser (Control)	1.30 ^c	1.57 ^d	1.75 ^c	1.92 ^c	1.78 ^d
HSD (P ≤ 0.05)	0.33	0.25	0.19	0.18	0.17
Interaction (V x F)					
Omank. x 10 t/ha PM	1.67 ^{ab}	2.07 ^{ab}	2.30 ^{abc}	2.60 ^{ab}	2.47 ^{ab}
Omank. x 300 kg/ha NPK 15:15:15	1.40 ^b	1.73 ^{bc}	1.93 ^{def}	2.10 ^{de}	1.93 ^{de}
Omank. x 2.5 t/ha GB	1.33 ^b	1.67 ^{bc}	1.87 ^{ef}	1.97 ^{de}	1.80 ^e
Omank. x 150 kg/ha NPK + 1.25 t/ha GB	1.37 ^b	1.77 ^{bc}	1.93 ^{def}	2.07 ^{de}	1.80 ^e
Omank. x 1.25 t/ha GB + 5 t/ha PM	1.63 ^{ab}	2.00 ^{ab}	2.23 ^{bcd}	2.40 ^{bc}	2.30 ^{bc}
Omank. x No fertiliser (Control)	1.30 ^b	1.57 ^c	1.77 ^{ef}	1.93 ^{de}	1.80 ^e
Obatan. x 10 t/ha PM	2.00 ^a	2.37 ^a	2.57 ^a	2.83 ^a	2.67 ^a
Obatan. x 300 kg/ha NPK 5:15:15	1.70 ^{ab}	1.80 ^{bc}	2.07 ^{bcde}	2.20 ^{cd}	2.00 ^{de}
Obatan. x 2.5 t/ha GB	1.57 ^{ab}	1.77 ^{bc}	2.03 ^{cdef}	2.20 ^{cd}	2.03 ^{cde}
Obatan. x 150 kg/ha NPK + 1.25 t/ha GB	1.50 ^{ab}	1.87 ^{bc}	2.00 ^{cdef}	2.20 ^{cd}	2.10 ^{cd}
Obatan. x 1.25 t/ha GB + 5 t/ha PM	1.63 ^{ab}	2.07 ^{ab}	2.37 ^{ab}	2.70 ^a	2.40 ^{ab}
Obatan. x No fertiliser (Control)	1.30 ^b	1.57 ^c	1.73 ^f	1.90 ^e	1.77 ^e
HSD (P ≤ 0.05)	0.54	0.41	0.31	0.30	0.29
CV (%)	11.80	7.50	5.07	4.43	4.63

x – interaction PM – Poultry manure WAP– Weeks after planting GB – Gliricidia sepium biochar

Table 10. Cob diameter as affected by biochar, poultry manure and NPK fertiliser application during 2021 minor and 2022 major cropping seasons

Fertiliser rates	Cob diameter (cm)					
	2021			2022		
	Variety			Variety		
	Omank.	Obatan.	Mean	Omank.	Obatan.	Mean
10 t/ha PM	4.45 ^{ab}	4.67 ^a	4.56 ^a	4.96 ^{bc}	5.45 ^a	5.21 ^a
300 kg/ha NPK	4.04 ^{ab}	4.34 ^{ab}	4.19 ^{ab}	4.66 ^c	5.08 ^{abc}	4.87 ^b
2.5 t/ha GB	3.99 ^b	4.11 ^{ab}	4.05 ^b	4.64 ^c	4.93 ^{bc}	4.79 ^b
150 kg/ha NPK +1.25 t/ha GB	4.08 ^{ab}	4.18 ^{ab}	4.13 ^b	4.70 ^c	4.96 ^{bc}	4.83 ^b
1.25 t/ha GB + 5 t/ha PM	4.43 ^{ab}	4.61 ^{ab}	4.52 ^a	5.07 ^{abc}	5.28 ^{ab}	5.18 ^a
No fertiliser (control)	4.07 ^{ab}	3.99 ^b	4.03 ^b	4.70 ^c	4.71 ^c	4.70 ^b
Mean	4.18	4.32		4.79 ^b	5.07 ^a	
CV (%)	5.06			3.30		
Variety (V)	HSD (0.05) = NS			HSD (0.05) = 0.11		
Fertiliser rates (F)	HSD (0.05) = 0.39			HSD (0.05) = 0.29		
V x F	HSD (0.05) = 0.64			HSD (0.05) = 0.48		

CV = Coefficient of variation; HSD = Highest significant difference at 5%; PM = Poultry manure; GB = *Gliricidia sepium* biochar; Omank = Omankwa; Obatan: Obatanpa

Table 11. Harvest index as influenced by biochar, poultry manure and NPK fertiliser application during 2021 minor and 2022 major cropping seasons

Harvest index						
	2021			2022		
	Variety			Variety		
Fertiliser rates	Omerk.	Obatan.	Mean	Omerk.	Obatan.	Mean
10 t/ha PM	0.39 ^{abcd}	0.32 ^{bcd}	0.36	0.42	0.39	0.41
300 kg/ha NPK	0.43 ^{ab}	0.32 ^{bcd}	0.38	0.45	0.43	0.44
2.5 t/ha GB	0.50 ^a	0.36 ^{abcd}	0.43	0.49	0.36	0.43
150 kg/ha NPK +1.25 t/ha GB	0.45 ^{ab}	0.28 ^{cd}	0.37	0.41	0.37	0.39
1.25 t/ha GB + 5 t/ha PM	0.41 ^{abc}	0.33 ^{bcd}	0.37	0.43	0.38	0.41
No fertiliser (control)	0.44 ^{ab}	0.27 ^d	0.36	0.46	0.36	0.41
Mean	0.44 ^a	0.31 ^b		0.44 ^a	0.38 ^b	
CV (%)	12.66			14.88		
Variety (V)	HSD (0.05) = 0.03			HSD (0.05) = 0.04		
Fertiliser rates (F)	HSD (0.05) = NS			HSD (0.05) = NS		
V x F	HSD (0.05) = 0.14			HSD (0.05) = NS		

CV = Coefficient of variation; HSD = Highest significant difference at 5%; PM = Poultry manure; GB = Gliricidia sepium biochar; Omerk = Omerkwa; Obatan: Obatanpa

Table 12. Total grain yield as influenced by biochar, poultry manure and NPK fertiliser application during 2021 minor and 2022 major cropping seasons

Fertiliser rates	Total grain yield (t/ha)					
	2021			2022		
	Variety			Variety		
	Omank.	Obatan.	Mean	Omank.	Obatan.	Mean
10 t/ha PM	3.33 ^a	3.47 ^a	3.40 ^a	5.82 ^{abc}	7.47 ^a	6.65 ^a
300 kg/ha NPK	2.00 ^{ab}	2.11 ^{ab}	2.05 ^c	4.91 ^{bc}	4.70 ^{bc}	4.80 ^b
2.5 t/ha GB	2.83 ^{ab}	2.10 ^{ab}	2.47 ^{bc}	4.09 ^c	5.20 ^{abc}	4.65 ^b
150 kg/ha NPK +1.25 t/ha GB	2.13 ^{ab}	1.62 ^b	1.92 ^c	4.98 ^{bc}	4.92 ^{bc}	4.95 ^b
1.25 t/ha GB + 5 t/ha PM	3.46 ^a	2.59 ^{ab}	3.02 ^{ab}	6.09 ^{abc}	6.80 ^{ab}	6.45 ^a
No fertiliser (control)	2.33 ^{ab}	1.50 ^b	1.87 ^c	4.96 ^{bc}	4.03 ^c	4.50 ^b
Mean	2.68 ^a	2.23 ^b		5.14	5.52	
CV (%)	20.36			15.03		
Variety (V)	HSD (0.05) = 0.35			HSD (0.05) = NS		
Fertiliser rates (F)	HSD (0.05) = 0.90			HSD (0.05) = 1.44		
V x F	HSD (0.05) = 1.48			HSD (0.05) = 2.38		

CV = Coefficient of variation; HSD = Highest significant difference at 5%; PM = Poultry manure; GB = *Gliricidia sepium* biochar; Omank = Omankwa; Obatan: Obatanpa

Table 13. Correlation matrix analysis during 2021 minor and 2022 major cropping seasons

	2021 minor cropping season						
	1	2	3	4	5	6	7
1. Days to 50% tasseling	1	0.96***	-0.09ns	-0.27ns	-0.12ns	-0.65ns	-0.61ns
2. Days to 50% silking		1	-0.07ns	-0.27ns	-0.12ns	-0.72ns	-0.61ns
3. Plant height			1	0.92***	0.78***	-0.36ns	0.63***
4. Stem diameter				1	0.73***	-0.16ns	0.69***
5. Cob diameter					1	-0.18ns	0.65***
6. Harvest index						1	0.37*
7. Total grain yield per plot							1
	2022 major cropping season						
	1	2	3	4	5	6	7
1. Days to 50% tasseling	1	0.87***	-0.04ns	-0.15ns	0.08ns	-0.41ns	-0.22ns
2. Days to 50% silking		1	-0.18ns	-0.41ns	-0.15ns	-0.26ns	-0.42ns
3. Plant height			1	0.83***	0.88***	-0.14ns	0.82***
4. Stem diameter				1	0.84***	-0.21ns	0.78***
5. Cob diameter					1	-0.16ns	0.84***
6. Harvest index						1	-0.07ns
7. Total grain yield per plot							

Numbers against the parameters in columns correspond with variables in rows; NS – Not significant ($p > 0.05$) * = Significant at $p \leq 0.05$; ** = Significant at $p \leq 0.01$; *** = Significant at $p \leq 0.001$

3.4.3 Total grain yield

Table 12 shows total grain yield as influenced by biochar, poultry manure, and NPK fertiliser application. In 2021 minor cropping season (2021), there was a significant ($P \leq 0.05$) difference between Omankwa and Obatanpa in total grain yield. Omankwa produced significantly higher (2.68 t/ha) total grain yield than Obatanpa which recorded the least (2.23 t/ha). The maize planted on 10 t/ha PM treated plots produced the highest grain yield (3.40 t/ha) followed by 1.25 t/ha GB + 5 t/ha PM (3.02 t/ha) and the least with the control (1.87 t/ha) and was significantly different. The interaction of Obatanpa and 10 t/ha PM had the maximum total grain yield (3.47 t/ha) followed by the interaction of Omankwa and 1.25 t/ha GB + 5 t/ha PM (3.46 t/ha) which was significantly ($P \leq 0.05$) different from the interaction of Obatanpa and the control which recorded the least total grain yield (1.50 t/ha).

In the 2022 major cropping season, there was no significant ($P \geq 0.05$) difference between Omankwa and Obatanpa in total grain yield although differences exist between mean values. The maize planted on 10 t/ha PM treated plot had the highest total grain yield (6.65 t/ha) followed by maize planted on 1.25 t/ha GB + 5 t/ha PM (6.45 t/ha) and was significantly different from the control (4.50 t/ha) with the least total grain yield. There was no significant ($P \geq 0.05$) difference between maize planted on other amended plots in total grain yield. There was no significant ($P > 0.05$) difference between interaction of Omankwa and amended and unamended plots in total grain yield. Interaction of Obatanpa and 10 t/ha PM had the maximum (7.47 t/ha) total grain yield followed by interaction of same maize variety and 1.25 t/ha GB + 5 t/ha PM (6.80 t/ha) which were significantly higher than interaction of Obatanpa and the control (4.03 t/ha) (Table 12).

3.5 Correlation Matrix Analysis

Table 13 shows the correlation matrix analysis between phenology, growth, yield and yield components as affected by biochar, poultry manure and NPK fertiliser application across both seasons. In 2021 minor cropping season, 40% of the parameters showed a strong, positive and significant relationship specifically days to 50% tasseling and silking ($r=0.96$), plant height and stem diameter ($r=0.92$), plant height and cob diameter ($r=0.78$), stem diameter and

cob diameter ($r=0.73$), stem diameter and total grain yield ($r=0.69$), cob diameter and total grain yield per plot ($r=0.65$), plant height and total grain yield per plot ($r=0.63$). 57% of the traits showed no significant difference. In 2022 major cropping season, there was a strong, positive and significant correlation between 40 % of the characteristics ranging from cob diameter and grain weight per plant ($r=0.89$), plant height and cob diameter ($r=0.88$), days to 50% tasseling and silking ($r=0.87$) cob diameter and total grain yield per plot ($r=0.84$), stem diameter and cob diameter ($r=0.84$), plant height and stem diameter ($r=0.83$), plant height and total grain yield per plot ($r=0.82$) and stem diameter and total grain yield per plot ($r=0.78$). 60% of the traits showed no significant difference (Table 13).

4. DISCUSSION

4.1 Effect of *Gliricidia sepium* Biochar, Poultry Manure and NPK Fertiliser on Soil Chemical Properties

The slightly acidic nature of the soil at both experimental sites showed the capability of soil to support crop growth and development since most crops do well in slightly to moderately acidic soils. At both experimental sites, total N, available P, Potassium content, exchangeable bases such as Ca and Mg and organic matter content was low (SRI, 2007). This indicates that the soil has inadequate nutrients and hence needed to be amended. The poultry manure had high total N and organic carbon content as well as high available K. Total P, Ca, and Mg levels were moderately low. This might be attributable to how the poultry manure used for the experiment was handled, managed and stored. According to Joseph *et al.* (2025), nutrient composition of poultry manure is influenced by several factors, including the bird species, type of litter material, nutritional quality of the feed, and various management practices. Maruthamuthu *et al.* (2024) also reported that bird's type and type of litter influences the physicochemical attributes of poultry manure. The *Gliricidia sepium* biochar used for both experiments had high organic carbon content, moderate Total N, K and exchangeable Mg levels. However, available P and exchangeable Ca levels were low. The ash content, elemental composition (C, Ca, P), soil pH, EC, CEC, and surface area of biochar are all influenced by the feedstock variety and production conditions (Kaur & Sharma, 2021). After harvesting of

maize, the chemical analysis of soil showed a substantial reduction in soil nutrients at both experimental sites. The decline in soil nutrient levels may be attributed to maize being a heavy feeder plant with a high demand for nutrient uptake. Similar observations were made by Essilfie et al. (2023).

4.2 Effect of *Gliricidia sepium* Biochar, Poultry Manure and NPK Fertiliser on Phenology of Maize

The delay in tasseling and silking in Obatanpa compared to Omankwa in both growing seasons could be attributed to the variations in the hereditary composition of the cultivars and their potential to respond to available nutrients present in the soil. This aligns with the findings of Meydane & Ismael (2025), who observed significant differences in number of days to reach 50% tasseling and silking among different maize varieties. The shorter time to 50% tasseling and silking observed in plots treated with either sole poultry manure (PM), PM combined with *Gliricidia sepium* biochar (PM + GB), and their interactions with Obatanpa and Omankwa in both growing seasons may be attributed to the high organic carbon levels in the organic amendments. This likely enhanced the soil's moisture-holding capacity and improved its ability to regulate and supply nutrients to the plants. Furthermore, the higher levels of essential macro- and micronutrients in the poultry manure, along with the capacity of biochar to improve soil structure by binding soil particles, likely made nutrients more accessible to the plants. This facilitated earlier tasseling and silking. Agbede (2025) also asserted that applying organic fertilisers improves soil moisture retention, increases pH and porosity, lowers soil temperature, reduces nutrient loss through leaching, and overall supports early reproductive growth in plants.

The delay in tasseling and silking in unamended soils compared to amended soils could be due to low soil nutrients. This corroborates with findings of Gurmu & Mintesnot (2020). Previous studies have demonstrated the effectiveness of biochar in increasing soil water holding capacity (WHC), enhancing soil pH and reducing nutrient leaching (N, P, Mg, and Si) (Sharma et al., 2025) and that plants have better access to nutrients e.g. N for effective growth and development. Biochar application in combination with organic manure increases soil C storage and minimizes nitrate and ammonium

leaching, increasing nutrient availability to plants and improving plant development (Wang et al., 2017; Kavitha et al., 2018). This reflection may perhaps also be ascribed to the inability of the soil to supply essential plant nutrients for effective growth. This agrees with Olatunji et al. (2020) that unamended soils supply little or no nutrient that are essentially desirable for reproductive growth.

4.3 Effect of *Gliricidia sepium* Biochar, Poultry Manure and NPK Fertiliser on Vegetative Growth of Maize

The significantly higher plant height and wider stem diameter produced by Obatanpa than Omankwa in both years is sign of variations in the hereditary characteristics of the two maize varieties and their ability to exploit environmental conditions such as soil moisture, temperature and nutrients. Maize planted on 10 t/ha PM significantly improved vegetative growth, thus taller plant and wider stem diameter than the other treated and unamended plots. This could be due to the greater supply of essential plant nutrients and the improvement of the soil physicochemical properties by the poultry manure applied. According to Jindaluang et al. (2025), poultry manure enhances soil fertility by supplying essential nutrients and increasing organic matter, which improves soil structure, microbial activity, maintain a stable pH and nutrient retention. In addition to 10 t/ha PM the application of GB + PM was significantly advanced as compared to the control plot and other amendments in both cropping seasons. The supply of macronutrients, especially N and other micronutrients from poultry manure and biochar application might have contributed to the observed condition. This agrees with Alubiagba et al. (2021), who observed that poultry manure stands out among organic fertilisers due to its rapid mineralization rate, which enables quicker release of essential macro- and micronutrients for efficient crop absorption and use. Similarly, Asfaw (2022) asserted that effective vegetative growth and hence higher plant height was due to nitrogen in the poultry manure, which increased the number of nodes and the length of the internodes and consequently the plant height. Biochar enhances soil physicochemical properties which influenced the growth of groundnut over the control (Pandian et al., 2016). The underperformance of control plots (non-fertilized) and other amended plots consistently demonstrated that optimal plant

growth occurs when nutrients are sufficiently available. This phenomenon likely contributed to the observed increase in stem diameter of both maize varieties planted on poultry manure and biochar-treated soils (Eleduma et al., 2020).

4.4 Effect of *Gliricidia sepium* Biochar, Poultry Manure and NPK Fertiliser on Yield and Yield Components of Maize

The significantly ($P \leq 0.05$) wider cob diameter produced by Obatanpa grown on sole PM than the control plot across years could be attributable to the genetic composition of the maize variety and the extent to which it is able to exploit soil nutrients and weather components like sunlight, humidity, and temperature that prevailed within the experimental period for successful crop growth and development. This aligns with Satish et al. (2022), indicating that the productivity of maize variety relies on the effective completion of crop development, maximizing their inherited capabilities and harmonizing with the micro environmental factors of their cultivation. This finding is in accordance with Ansa (2022), who indicated that the use of poultry manure at a rate of 40 g per plant resulted in the thickest cob diameter.

A significantly higher harvest index (HI) in Omankwa than Obatanpa in both seasons might be attributed to the variation in genotypic makeup and the impact of environmental conditions like soil nutrition. This enhances interception of sunlight, assimilate production and high yield. The higher harvest index of Omankwa produced on amended and unamended plots compared to Obatanpa on the same treatments might be linked to higher grain yield potential of Omankwa. This is a more favourable attribute in crop cultivation as a higher harvest index, signifies an increased efficiency in converting plant biomass into grain yield. Similarly, Hembram et al. (2025) reported significant variations in the harvest index (HI) among different chickpea varieties. The interaction of Omankwa and 2.5 t/ha GB had significantly higher harvest index than the interaction of Obatanpa and 150 kg/ha NPK + 1.25 t/ha GB amended plot in the 2021 cropping season. This might be linked to the advanced carbon - nitrogen ratio and the organic carbon content in *Gliricidia sepium* biochar than in poultry manure. The high C:N ratio of the biochar might have resulted in a

faster rate of decomposition and release of N making it available for plant uptake. Alternatively, the increased organic carbon content may have contributed to improved soil physicochemical characteristics of the soil treated with 2.5 t/ha of GB. Such enhancements could include improved water intrusion, higher water retention, greater nutrient accessibility, and increased microbial activity in the soil contributing to higher grain yield and subsequent higher harvest index.

The significant differences in total grain yield as influenced by variety could be due to the genetic variation between the two maize varieties. Factors such yield potential and maturity periods might have contributed to the differences in total grain yield. For fertiliser rate, the significantly heavier total grain yield observed in maize planted on 10 t/ha PM followed by maize planted on GB + PM as compared to the control across both 2021 and 2022 could be attributed to the fact that the combined application of biochar with poultry manure had the potential to prevent the leaching of the essential macronutrients by binding the soil particles together for optimum absorption of water and macro and micro nutrients. This agrees with Ibrahim et al. (2025) who reported that the enhanced vegetative growth and yield of globe artichoke were due to the application of biochar combined with poultry manure in a 1:1 ratio.

Also, this corroborates with Adekiya et al. (2020) who indicated that organic manure provides vital macronutrients, fostering heightened photosynthetic activities in plants. These nutrients ultimately move toward the sink and contribute to higher yield production. Furthermore, this rapid utilization of nitrogen could lead to the transformation of carbohydrates into reproductive sugars through hydrolysis, ultimately contributing to the increased yield (Yoldas et al., 2019). The heavier total grain yield observed between the interaction of Obatanpa and 10 t/ha PM as well as 1.25 t/ha GB + 5 t/ha PM in both 2021 and 2022 compared to the interaction of Obatanpa and the control is attributable to the increased quantities of macronutrients (N, P, K) and the ability of the biochar to minimize leaching of the essential macro nutrients through binding of soil particles together for optimum absorption of nutrients and soil moisture that translated into higher yield (Essilfie et al., 2023). The boost in both macro and micronutrients in soils amended

with poultry manure and biochar facilitated nutrient absorption and augmented the transfer of photosynthetic constituents from source to sink, which could be linked to the maximum grain yield recorded by both varieties grown on sole PM and GB +PM (Massaquoi *et al.* 2021).

4.5 Effect of *Gliricidia sepium* Biochar, Poultry manure and NPK Fertiliser on correlation between Phenology, Growth, Yield and Yield Components

The result obtained in both cropping seasons were similar to those found by Asfaw (2020) and Kandil *et al.*, (2020) that a significant positive correlation occurred between plant height, stem girth, grains per row and grain yield. This outcome might be a result of the significant contribution made by the macronutrients present in the amended soil, which might enhance soil qualities and boost the availability of nutrients to maize plants (Agbede, 2025). According to Ion *et al.* (2015) when soil conditions are less favourable for growing maize, a higher harvest index tends to correlate negatively with plant height. However, under more favourable conditions particularly with optimal soil quality, the harvest index generally shows a positive correlation, increasing up to a certain threshold.

5. CONCLUSION

The study has shown that Omankwa maize variety tasseled and silked earlier than Obatanpa planted on 10 t/ha PM and 1.25 t/ha GB + 5 t/ha PM in both cropping seasons. Farmers would have to plant Omankwa maize variety to avoid unexpected bad weather that may affect crop growth, development and yield and to also harvest early. Planting Obatanpa maize variety using 10 t ha⁻¹ PM produced a thicker cob diameter than the control. The study showed that Omankwa and Obatanpa maize varieties planted on 10 t/ha PM and 1.25 t ha⁻¹ GB + 5 t ha⁻¹ PM was most productive, with 10.4-25.8% yield advantage over the control. The interaction of Obatanpa and 10 t/ha PM and with 1.25 t/ha GB + 5 t/ha PM was superior in grain yield over Omankwa planted on same and the unamended treated plots. Amendment of soil with 10 t/ha PM and/or 1.25 t/ha GB + 5 t/ha PM and planting Obatanpa maize variety could provide farmers with maximum yield hence recommended.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

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

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

- Adekiya, A. O., Ogunboye, O. I., Ewulo, B. S., & Olayanju, A. deniy. (2020). Effects of different rates of poultry manure and split applications of urea fertiliser on soil chemical properties, growth, and yield of maize. *The Scientific World Journal*, 2020(1), 4610515. <https://doi.org/10.1155/2020/4610515>
- Agbede, T. M. (2021). Effect of tillage, biochar, poultry manure and NPK 15-15-15 fertilizer, and their mixture on soil properties, growth and carrot (*Daucus carota* L.) yield under tropical conditions. *Heliyon*, 7(6), e07391. <https://doi.org/10.1016/j.heliyon.2021.e07391>
- Agbede, T. M. (2025). Poultry manure improves soil properties and grain mineral composition, maize productivity and economic profitability. *Scientific Reports*, 15(1), 1–12. <https://doi.org/10.1038/s41598-025-00394-8>
- Akinrinola, T., & Fagbola, O. (2020). Influences of organomineral and NPK 15-15-15 fertilisers on the yield of maize and weed infestation. *IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)*, 13(6), 41–46. <https://doi.org/10.9790/2380-1306014146>
- Almunqedhi, B. M., Alfarhan, A., Muharram, A. A., & Mohammed, N. (2025). Sustainable potato farming: The impact of poultry manure on growth and yield. *Applied Ecology and Environmental Research*, 23(3), 3929–3937. http://dx.doi.org/10.15666/aeer/2303_39293937
- Alubiagba, D. O., Ovharhe, O. J., & Akparobi, S. O. (2021). Effects of moringa leaf extract and poultry manure on the growth parameters of sweet maize. *Asian Journal*

- of Agriculture and Rural Development, 11(1), 10–18. <https://doi.org/10.22004/ag.econ.342311>
- 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 phosphorus, zinc and beneficial microbes under arid climates. *Journal of Microbiology, Biotech and Food Sciences*, 9(2), 285–287. <https://doi.org/10.1016/B978-0-323-60984-5.00062-7>
- Amartey, J. N. A., Sarkodie-Addo, J., Essilfie, M. E., & Dapaah, H. K. (2022). Growth and yield of carrots affected by integrated nutrient management of organic and inorganic fertilizers. *African Journal of Agricultural Research*, 18(7), 576–585. <https://doi.org/10.5897/AJAR2022.15967>
- Ansa, J. (2022). Comparative effects of poultry manure and poultry manure biochar on the performance of maize (*Zea mays*) in River State, Southern, Nigeria. *International Journal of Novel Research in Life Sciences*, 6(5), 66–70. www.noveltyjournals.com
- AOAC. (1975). *Official methods of analysis*. Association of Official Agricultural Chemists. 2nd ed., Washington D.C.
- Asante, K., Essilfie, M. E., & Manu-Aduening, J. (2020). Influence of different rates of fertiliser 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>
- Asfaw, M. D. (2020). Impact of some animal manures on growth and yield of maize (*Zea mays* L.). *Journal of Natural Sciences Research*, 11(23), 17–25. <https://doi.org/10.7176/jnsr/11-23-04>
- 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.jpssp.1001071>
- Asiamah, R. D. (1988). *Soils and soil suitability of Ashanti region*. Soil Research Institute (SRI). Tech. Report No. 193 SRI, Kwadaso, Kumasi, Ghana.
- Attipoe, S. G., Jianmin, C., & Yaa, O.-K. (2019). A profit analysis of small-scale maize farmers: A case study in the Brong Ahafo Region of Ghana, West Africa. *RJOAS*, 12(96), 18–26. <https://doi.org/10.18551/rjoas.2019-12.03>
- Awoonor, J. K., Amoakwah, E., Buri, M. M., Dogbey, B. F., & Gyamfi, J. K. (2025). Impact of land use on soil quality: Insights from the forest-savannah transition zone of Ghana. *Heliyon*, 11(1). <https://doi.org/10.1016/j.heliyon.2024.e41183>
- Azawei, A., & Alapuba, N. J. B. (2022). Evaluation on the effect of cost-effective cow dung (in bio-fertilizers form) on the growth and yield of maize (*Zea mays*) production in the Niger Delta Area (Bayelsa State) of Nigeria. *European Journal of Agriculture and Forestry Research*, 10(1), 1–24. <https://doi.org/10.37745/ejafr.2013/vol10n01pp.1-24>
- Bede, D., Zaixiang, L., & Yahui, G. (2020). Food safety concerns due to presence of aflatoxins of common maize based food consumed in Ghana and the need to implement Hazard Analysis and Critical Control Point (HACCP) systems. *Acta Scientific Biotechnology*, 1(2).
- Bizuneh, G. K. (2021). The chemical diversity and biological activities of phytoalexins. *Advances in Traditional Medicine*, 21, 31–43. <https://doi.org/10.1007/s13596-020-00442-w>
- Boullouz, M., Bindraban, P. S., Kissiedu, I. N., Kouame, A. K., Devkota, K. P., & Atakora, W. K. (2022). An integrative approach based on crop modeling and geospatial and statistical analysis to quantify and explain the maize (*Zea mays*) yield gap in Ghana. *Frontiers in Soil Science*, 2, 68. <https://doi.org/10.3389/fsoil.2022.1037222>
- Bray, R. H., & Kutz, L. T. (1945). Determination of total, organic and available forms of phosphorus in soils. *Soil Science*, 59, 39–45.
- Chausali, N., Saxena, J., & Prasad, R. (2021). Nano biochar and biochar-based nanocomposites: Advances and applications. *Journal of Agriculture and Food Research*, 5, 100191. <https://doi.org/10.1016/j.jafr.2021.100191>
- Dzomeku, I. K., Iliasu, O., & Amegbor, I. K. (2018). Effects of biochar, rice husk and rice straw on productivity of maize (*Zea mays* L.) and sustainable soil fertility restoration. *Journal of Experimental Agriculture International*, 20(6), 1–11. <https://doi.org/10.9734/JEAI/2018/39346>

- Eleduma, A. F., 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*, 110–114. <https://doi.org/10.17352/2455-815x.000063>
- Essilfie, M. E., Appiah, E., Asiedu, E. K., & Owusu, S. E. (2023). Growth and yield response of maize (*Zea mays* L.) to integrated nutrient management of biochar, organic and inorganic fertilisers. *Asian Journal of Advances in Agricultural Research*, 23(4), 69–91. <https://doi.org/10.9734/AJAAR/2023/v23i4481>
- FAO/UNESCO. (2008). *FAO/UNESCO system of soil classification*.
- FAOStat. (2021). *FAO Stat*. FAO, Rome. <http://www.fao.org/faostat>
- Gurmu, S., & Mintesnot, A. (2020). Effect of combined application of NPS fertilizer and compost on phenology and growth of quality protein maize (*Zea mays* L.) at Jimma, South Western Ethiopia. *International Journal of Research Studies in Science, Engineering and Technology*, 7(1), 18–28.
- Hasan, M. R., Rahman, M. R., Hasan, A. K., Paul, S. K., & Alam, A. H. M. J. (2018). Effect of variety and spacing on the yield performance of maize (*Zea mays* L.) in old Brahmaputra floodplain area of Bangladesh. *Archives of Agriculture and Environmental Science*, 3(3), 270–274. <https://doi.org/10.26832/24566632.2018.0303010>
- Hembram, A., Saren, B. K., Barat, S., Jaiswal, D., Chowdhury, A., & Ghosh, S. K. (2025). Varietal performance of chickpea (*Cicer arietinum* L.) under different dates of sowing in red and lateritic soil of West Bengal. *International Journal of Research in Agronomy*, 8(3), 33–38. <https://doi.org/10.33545/2618060X.2025.v8.i3a.2629>
- Ibrahim, N. M., Ismail, S. A., Abd-Elatif, A. A., & Ganzour, S. K. (2025). Biochar and chicken manure impact on growth and yield of globe artichoke. *Egyptian Journal of Soil Science*, 65(1).
- Ion, V., Dicu, G., Dumbravă, M., Temocico, G., Alecu, I. N., Băşa, A. G., & State, D. (2015). Harvest index at maize in different growing conditions. *Romanian Biotechnological Letters*, 20, 10951–10960. <https://www.researchgate.net/publication/309187091>
- Jaja, N., Codling, E. E., Rutto, L. K., & Timlin, D. (2022). Poultry litter and inorganic fertilization: Effects on biomass yield, metal and nutrient concentration of three mixed-season perennial forages. *Agronomy*, 12, 570. <https://doi.org/10.3390/agronomy12030570>
- Jindaluang, W., Somarsa, W., Darunsontaya, T., Anusontpornperm, S., & Jaroenchasri, R. (2025). Effect of chicken manure and cassava starch manufacturing wastes on aggregate stability and yield of cassava grown on sandy soil. *Journal of Soil Science and Plant Nutrition*, 25, 291–302. <https://doi.org/10.1007/s42729-024-02133-w>
- Joseph, P. O., Ojomah, F. O., & Abioye, J. B. (2025). Poultry manure-induced influence on soil properties of coarse-textured tropical soil. *Journal of Wastes and Biomass Management (JWBM)*, 7(1), 01–05. <http://doi.org/10.26480/jwbm.01.2025.01.05>
- Kandil, E. E., Abdelsalam, N. R., Mansour, M. A., Ali, H. M., & Siddiqui, M. H. (2020). Potentials of organic manure and potassium forms on maize (*Zea mays* L.) growth and production. *Scientific Reports*, 10(1), 1–12. <https://doi.org/10.1038/s41598-020-65749-9>
- Kaur, V., & Sharma, P. (2021). Effect of mixed wood biochar on physico-chemical properties of sandy soil, Haryana region, India. *An International Journal of Science & Technology*, 16, 25–39. www.ewijst.org
- 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. *Journal of Environmental Management*, 227, 146–154. <https://doi.org/https://doi.org/10.1016/j.jenvman.2018.08.082>
- Maruthamuthu, T., Karuppusamy, S., Veeramalai, R., Nagarajan, M. M., Ragavan, P., Santiago, M., & Aranganoor, T. K. (2024). Physicochemical characterization of broiler poultry litter from commercial broiler poultry operation in semiarid. *Tropics of India. Agriculture*,

- 14(10), 1708.
<https://doi.org/https://doi.org/10.3390/agriculture14101708>
- Massaquoi, F. B., Bangura, S., Kabbia, F. H., & Conteh, K. S. (2021). The effect of palm kernel cake, chicken manure, *Gliricidia sepium* as compared to inorganic manures (Npk15:15:15 & urea) fertilization on growth, yield component and yield of irrigated maize. *International Journal of Research in Education Humanities and Commerce*, 02(05), 13–22. www.ijrehc.com
- Meydane, A. H., & Ismael, M. A. (2025). Yield performance of improved hybrid maize (*Zea mays* L.) varieties under rainfed conditions in Golohajo, Gursum District, Fafan Zone, Somali Region, Ethiopia. *Journal of Agriculture, Aquaculture, and Animal Science*, 2(1), 171–175.
<https://doi.org/10.69739/jaaas.v2i1.482>
- NVRRC-CSIR. (2019). *National Variety Release and Registration Committee: Catalogue of crop varieties released and registered in Ghana*.
- 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>
- Ovharhe, O. J., Emaziye, P. O., Okpara, O., Agoda, S., & Benson, C. O. (2021). Strategies adopted by maize farmers to minimize post-harvest losses in Delta State, Nigeria. *International Journal of Agricultural Technology*, 17(1), 237–256.
<http://www.ijat-aatsea.com>
- 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.
- Pandian, K., Subramaniyan, P., Gnasekaran, P., & Chitraputhirapillai, S. (2016). Effect of biochar amendment on soil physical, chemical and biological properties and groundnut yield in rainfed Alfisol of semi-arid tropics. *Archives of Agronomy and Soil Science*, 62(9), 1293–1310.
<https://doi.org/10.1080/03650340.2016.1139086>
- Phares, C. A., Amoakwah, E., Danquah, A., Akaba, S., Frimpong, K. A., & Mensah, T. A. (2022). Improved soil physicochemical, biological properties and net income following the application of inorganic NPK fertilizer and biochar for maize production. *Acta Ecologica Sinica*, 42(4), 289–295.
<https://www.sciencedirect.com/science/article/pii/S1872203221001499>
- Rasool, A., Ghani, A., Nawaz, R., Ahmad, S., Shahzad, K., Rebi, A., ... & Ercisli, S. (2023). Effects of poultry manure on the growth, physiology, yield, and yield-related traits of maize varieties. *ACS Omega*, 8(29), 25766–25779.
- Satish, P., Kumar, V., Singh, S., Singh, A., & Kumar, A. (2022). Growth, yield attributes and nutrient uptake of maize (*Zea mays*) as affected by balanced nutrition under western up conditions. *The Pharma Innovation Journal*, 11(4), 1344–1347.
- Sharma, S., Mukherjee, S., Bolan, S., de Figueiredo, C., Fachini, J., Chang, S. X., ... & Bolan, N. (2025). Biochar as a potential nutrient carrier for agricultural applications. *Current Pollution Reports*, 11(1), 1–36.
<https://doi.org/10.1007/s40726-025-00349-7>
- SRI. (2007). *CSIR-Soil Research Institute: Guide to interpretation of soil analytical data in Ghana*.
- Tetteh, A. Y., Ayibor, W. G., & Agyemang-Duah, E. (2018). Quantifying the albumin content of 14 tropical maize varieties in Ghana. *International Journal of Nutrition & Food Science*, 6(1), 1–3.
<https://doi.org/10.19080/nfsij.2018.06.555680>
- 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. *Scientific Reports*, 7(1), 1592.
- Yoldas, F., Ceylan, S., & Mordogan, N. (2019). Effect of chicken manure on yield and yield criteria of onion (*Allium cepa* L.) as second crop. *Applied Ecology & Environmental Research*, 17(5), 12639–12647.

https://doi.org/http://dx.doi.org/10.15666/aer/1705_1263912647
Zhang, Z., Dong, X., Wang, S., & Pu, X. (2020). Benefits of organic manure combined with biochar amendments to cotton root growth and yield under continuous cropping systems in Xinjiang, China. *Scientific Reports*, 10(1), 1–10. <https://doi.org/10.1038/s41598-020-61118-8>

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). This publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

© Copyright (2025): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

The peer review history for this paper can be accessed here:
<https://pr.sdiarticle5.com/review-history/137524>