World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

Check for updates

Effects of Plantain Peel Biochar on the General Growth Characteristics of Selected Vegetables in Effurun, Okpe Local Government Area, Delta State, Nigeria

Awolowo FA.[1,*], Osakwe JA.[2], Gobo AE [1] and Tudararo-Aherobo LE [3]

[1] *Institute of Geosciences and Environmental Management, Rivers State University, Nkpolu-Oroworukwo, Port Harcourt, Nigeria.*
[2] *Department of Crop Science, Faculty of Agriculture, Rivers State University, Nkpolu-Oroworukwo, Port Harcourt, Nigeria.*
[3] *Integrated Institute of Environment and Development, Federal University of Petroleum Resources, Delta State, Nigeria.*

World Journal of Advanced Research and Reviews, 2025, 28(02), 1323–1335

Publication history: Received on 06 October 2025; revised on 13 November 2025; accepted on 15 November 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.28.2.3851

Abstract

The study examined the effects of plantain peel biochar on the general growth characteristics of selected vegetables in Effurun, Okpe Local Government Area, Delta State, Nigeria. Complete Randomized Design (CRD) was adopted for this research. Plantain peels were sourced from food vendors around Warri metropolis. Over 385kg of plantain peels was used for this study, a very huge amount of waste that has been repurposed to value and ensured towards a cleaner environment. These peels served as the primary material (organic waste) for this study. Pots used were of 6kg capacity and uniform in size and shape. Produced plantain peel biochar was applied in ranges of 250g, 125g, 62.5g and control. The experimental size was 3 replicates of each vegetable which gave a total of 48 pots. The vegetables of choice planted included Telfair occidentalis; Amaranthus spy, Talinum triangular, and Vernonia amygdalina. Descriptive statistics were used for the data analysis. Findings revealed that the presence of Nitrogen in biochar as against soil is 1.162mg/kg to 0.123mg/kg. The soil has a nitrate value of 43.44mg/kg as against biochar with 103.10mg/kg. The value of phosphate in the soil is 18.48mg/kg, while that of the biochar is 30.51mg/kg. This difference shows the abundance of phosphorus that will be available for crop use even over time. The pH of the soil was 7.10, while the biochar recorded value of 8.50. Furthermore, the value of Iron (Fe) and Arsenic in soil was 700.00mg/kg and ≤ 0.01mg/kg. Biochar recorded values of 1223mg/kg and ≤ 0.01mg/kg of Iron (Fe) to Arsenic. The value of Arsenic is still below acceptable limits of 2mg/kg according to FAO and WHO. The maximum level of iron (Fe) taken up by plants is 386.20mg/kg, which is still below acceptable limits of 425.5mg/kg by FAO and WHO. It is concluded that vegetables treated with plantain peel biochar exhibited increased shoot height, leaf area and good root development compared to control groups. It is thus recommended among others that the long-term impacts of plantain peel biochar on soil health and crop productivity needs further investigation and also, future research should focus on optimizing pyrolysis conditions, understanding the mechanisms of nutrient release and evaluating the economic feasibility of large-scale plantain peel biochar production and application.

Keywords: Biochar; Plantain Peels; Vegetables; Soil Health; Heavy Metals

1. Introduction

Ever since man gathered into large communities there has been growing concerns about effective and safe disposal of liquid and solid wastes (Priestly, 1991). Africa, specifically Nigeria, has witnessed a dramatic increase in population over the last century, prompting efforts to ensure sustainable food production and quality. Nigeria is experiencing a severe food insecurity crisis despite having a growing economy, which is exacerbated by factors like high population growth, climate change, insecurity and conflict. This crisis negatively impacts economic growth by hindering

* Corresponding author: Awolowo F.A.

Copyright © 2025 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution Liscense 4.0.

agricultural output and productivity, leading to challenges like high food prices, malnutrition, and reduced labor productivity. To address this, the Nigerian government is focusing on increasing domestic food production, and international organizations are providing humanitarian assistance (Idisi, 2022).

To meet up with the high demand for food and vegetables, the use of chemical fertilizers have been widely used by local farmers to boost growth and production of crops. But the overuse of these chemical fertilizers can lead to soil infertility through acidification and nutrient imbalances. Excessive application can also cause problems like soil salinity and runoff, causing surface and groundwater pollution. The high cost and lack of soil-specific knowledge among farmers are significant challenges that contribute to this issue, as many rely on compound fertilizers without understanding the specific nutrient needs of their soil.

Concerns for soil sustainability and food security have led to the exploration of cost-effective methods, such as use of organic waste as manure to enhance soil quality. Soil fertility depletion is a significant challenge in agricultural systems, particularly in tropical regions where intensive farming and soil erosion contribute to declining crop yields (Lal, 2015). Vegetable production, which is crucial for food security and nutrition, is highly dependent on soil quality and nutrient availability. However, the excessive use of synthetic fertilizers has led to adverse environmental effects, including soil acidification, nutrient leaching, greenhouse gas emission, and groundwater contamination (Lehmann and Joseph, 2015). As a result, researchers and policy makers are increasingly advocating for sustainable soil management practices, including the use of biochar as a soil amendment. Sustainable agriculture is crucial for ensuring global food security while mitigating environmental degradation.

As a result, the growing demand for sustainable agricultural practices has led to the exploration of organic waste materials as potential soil amendments. One of such material is plantain peel, which is often discarded as agricultural waste but holds significant promise as a valuable resource. Plantain peel biochar, produced through pyrolysis process, has garnered attention for its potential role as a soil conditioner and fertilizer for vegetable cultivation. It has been recognized for its potential to enhance soil fertility, improve nutrient retention and promote plant growth (Jeffery et al., 2017).

Biochar is a type of charcoal produced from organic materials, such as plant waste, agricultural waste, or other biomass sources. It is created through a process called pyrolysis (thermal decomposition) where the organic material is heated in the absence of oxygen, resulting in a stable, carbon-rich material that has various applications, particularly in agriculture (Akinola et al., 2022). Among the various feedstocks used for Biochar production, plantain peels represent an abundant yet underutilized resource. Plantain (Musa paradisiaca) is a staple crop in many tropical and subtropical regions, generating significant amounts of peel waste. These peels are rich in essential nutrients such as potassium, phosphorus and calcium, making them a promising raw material for biochar production (Akinyemi et al., 2020).

Biochar has been widely studied for its ability to enhance soil properties, including water retention, cation exchange capacity, and microbial activity, making it a promising soil amendment in sustainable agriculture (Lehmann et al., 2011). Among the various biomass sources available for biochar production, agricultural waste materials such as plantain peels present a viable and environmentally friendly option. Plantains generate large quantities of peel waste that are often discarded indiscriminately and leading to environmental concerns (Oladele et al., 2019). Converting plantain peels into biochar for use as a soil amendment could provide dual benefits: improving soil fertility and promoting sustainable waste management.

Despite the well-documented benefits of biochar, research on the specific effects of plantain peel biochar as a fertilizer for vegetable crops remains limited. Studies have shown that biochar amendments can enhance soil fertility, increase microbial activity, and improve crop yield (Agegnehu et al., 2015), but the extent to which plantain peel biochar influences vegetable growth, nutrient dynamics, and soil health requires further investigation. Understanding its long-term impact on soil properties and its interaction with other organic and inorganic fertilizers is essential for optimizing its application in sustainable agricultural practices.

Plantain (Musa spp.) is a significant crop cultivated for its fruits, which are a staple in many tropical regions. However, the peel, which constitutes a large portion of the plantain fruit (approximately 30-40% of its weight), is often discarded as waste. This has led to environmental challenges, as the disposal of large amounts of plantain peel in landfills can contribute to pollution and greenhouse gas emissions (Woolf et al., 2010).

Plantain peel is often discarded after the fruit is consumed, leading to a significant amount of waste. In many tropical countries where plantain is grown, such as in parts of West Africa, especially Nigeria, the disposal of plantain peel is a major concern. Traditionally, these peels are either composted or left to decay in open spaces, contributing to pollution and more often a sore sight. However, recent studies have explored alternative methods to valorize this waste, such as converting it to biochar for agricultural purposes. While the research on plantain peel biochar for soil amendment in Nigeria is limited, other regions like Australia, Asia and China have done extensive studies and research on the use of biochar produced from different organic sources like rice husk, coconut shell, wood and banana peels. Its effectiveness as a direct fertilizer is not fully understood. While biochar from different biomass sources has been studied, the potential benefits of plantain peel biochar on these selected vegetables remain unexplored. More research is needed to evaluate its effects on soil nutrients, microbial activity, and vegetable yield to validate its effectiveness as a fertilizer. Thus, the present study examined the effects of plantain peel biochar on the general growth characteristics of selected vegetables in Effurun, Warri, Okpe LGA, Delta State, Nigeria.

2. Materials and Methods

The study was carried out in Effurun, Warri, Okpe LGA, Delta State, Nigeria. Warri is located on the Longitude 5 36' 05" E and Latitude 5 35' 22" N with an altitude of about 50m above sea level. Delta State is generally low-lying without remarkable hills and lies roughly between Longitude 50 00 and 60 45' East and Latitude 50 00 and 60 30' North. The state has a wide coastal belt inter-locked with rivulets and streams, which forms part of the Niger-Delta (Fig. 3.1). The area has Tropical Climate marked by two distinctive Seasons, the Dry and Raining Seasons. The Dry Season occurs between November and April while the Rainy Season begins in April and lasts till October. Occasional rainfall may be experienced during the dry season and at the month of August, there is an occurrence of a brief dry season spell commonly referred to as August – break. The month of July witnesses the heaviest rainfall. The average annual rainfall in the coastal area is about 266.5cm and 190.5cm in the Northern Fringes of the state. The temperature is high, ranging between 28°C and 34°C with an average temperature of 30°C. The vegetation of Delta State varies from the mangrove Swamps along the coast to Evergreen Forests and Savanna in the North (Uyigue and Agbo, 2007; Delta State Ministry of Culture and Tourism Bulletin, 2003). Complete Randomized Design (CRD) was adopted for this research. CRD is the statistical analysis used to analyze data. A research design using CRD for potted plants is suitable for homogeneous environments, like in a greenhouse where all pots are treated equally and variables can be controlled. This research was conducted using pots, and ratio of soil, biochar mix at various measurements was used. Planting of the vegetables was done in April 2025 and harvested in August 2025. Laboratory analysis was done in August in a reputable laboratory. To implement CRD, determine the total number of pots needed

- n = rt
- where n = number of pots
- r = replications
- t = treatment

3. Collection of Plantain Peels and planting materials

3.1. Plantain peel

Plantain peels were sourced from food vendors around Warri metropolis. Over 385kg of plantain peels was used for this study, a very huge amount of waste that has been repurposed to value and ensured towards a cleaner environment. These peels served as the primary material (organic waste) for this study. Pots used were of 6kg capacity and uniform in size and shape. Produced plantain peel biochar was applied in ranges of 250g, 125g, 62.5g and control. The experimental size was 3 replicates of each plant which gave a total of 48 pots.

3.2. Sample Preparation

The organic waste (plantain peel) obtained underwent a series of preparation and subsequent charring that was used for this study. Upon collection of the plantain peels, they were subjected to a thorough washing process. This is vital to remove dirt, contaminants or residues present on the peels. The plantain peels used were the popularly called 'show ripe'. Following the washing stage, the plantain peels was air dried in a well-ventilated shed. They were uniformly spread to ensure even and uniform drying. Complete drying was achieved after 5 days. After drying of the plantain peels, they were subjected to a controlled charring process in an oven with temperature range of 3000c and 10000c. The oven was regulated at 3500C for 30 mins per set to achieve complete and efficient charring of the peels. After the charring process, the peels were immediately transferred to the mortar for the grinding process. Grinding was done using mortar and pestle in an open space. Due to the smoke from the charred plantain peels, it was done in the open using safety precautions like nose mask, safety goggles and long-sleeved jacket. A very important point to note during the production of biochar from plantain peels is that if allowed to cool down before grinding, the peels harden and crushing will be difficult. But while still hot and fresh out of the oven, the charred plantain peels are very brittle and easy to crush to fine powder. After the grinding process, the resulting material was allowed to cool completely then sieved to ensure a uniformity of size. Proper storage of the resulting product was done. Air tight containers were used to protect it from direct sunlight and dust and additionally storing in a cool and dry environment will minimize degradation and ensure its long-term preservation.

The vegetables of choice planted are fluted pumpkin, (Telfair occidentalis) (Plate 1); Green (Amaranthus conoids) (Plate 2), Water leaf (Talinum triangular) (Plate 3) and Bitter leaf (Vernonia amygdalina) (Plate 4). These vegetables and seeds were locally sourced from the open market. Harvesting was done manually by hand. Precautions taken while harvesting the leaves included wearing of hand gloves while plucking the leaves. Leaves were placed in a paper bag for onward procedure to the laboratory for analysis.

Figure 1 Fluted Pumpkin (Source: Author's work, 2025)

Figure 2 Green Vegetable

Figure 4 Water leaf

Figure 4 Bitter leaf

- Laboratory Analysis of Soil, Plantain peel Biochar and vegetable leaves
- Standard methods were used to analyze soil, biochar and plants at harvest.
- The analysis done included and not limited to the following parameters:

3.3. PH (of biochar and soil)

The pH meter method was used. A standard ratio of soil-to-water (15.0 g of soil and 15 ml of distilled water) and (12 g of soil and 15 ml of 0.01M $CaCl_2$) was used to obtain results. Soil to be tested was put into a beaker with equal milliliter of water. pH meter control switch is set at the neutral or standby position. Electrodes are cleaned and ready for measuring. pH meter was warmed for about 30 mins before use. The electrodes were placed in the slurry in the beaker and reading was taken as soon as the meter stabilizes (about 30 seconds).

3.4. Organic Matter

Weight loss-on-ignition is the procedure used for the routine estimation of soil organic matter by the loss of weight in a sample heated at a temperature high enough to burn organic matter but not so high as to decompose carbonates. A sample of soil was dried at 1050 C to remove moisture. The sample was weighed, heated at 3600 C for 2 hours and weighed again after the temperature drops below 1500 C.

To calculate percent weight loss-on-ignition (LOI)

LOI = (wt. at 1050 C) – (wt. at 3600 C) x 100

Wt. at 1050 C

3.5. Total Nitrogen (of soil and biochar)

The Total / Kjeldahl method covers the digestion of samples for Nitrogen. Soil and plant samples are dried at 550 C and 650 C respectively. The dried soil was grounded to pass a 12-mesh screen and plant tissue was ground to pass a 2 mm screen. Water sample used were stored at 40 C. 0.15 – 0.20 g of dried plant tissue and 0.45 – 0.5 g of soil and produced biochar was weighed out into a clean, dry digestion tube.

For Total Kjeldahl N (Org N + NH4 – N): to each tube, add 1 (metal catalyst) digestion tablet and 3.5 ml of concentrated H2SO4

For Total N (Org N + NH4-N + NO3-N + NO2-N): To each tube add 1 (metal catalyst) digestion tablet and 3.5 ml of H2SO4 with Salicylic acid.

The tubes were placed in a block digestor. Temperature was set at 1600 C and time to 20 minutes. The samples were removed from the block and allowed to cool for 15 minutes. Then filled with deionized water to 50.0 ml. Then determined the ammonium concentration by Flow Injection Analysis (FIA).

Calculation

- Ppm N = 50/WSX CD (For soil sample)
- % N = 50/ WSX CD / 10,000 (for plant sample)
- Where WS = Weight of sample (g)
- CD = Concentration in the digest (mg N/I)

3.6. Exchangeable Cations (Ca ++, Mg ++, K+, Na+)

Exchangeable cations are extracted from the soil using an extraction solution (1 N NH4O Ac) at pH 7.0. The extracted solution was then analyzed by AA (Atomic Absorption) for the soil cations. These exchangeable cations are partially ionized in the nitrous oxide – acetylene or air acetylene flame of AA. To suppress ionization, cesium nitrate or chloride solution is added to give final concentration of 1000 ppm in all solutions including the standards and blank. The purest available cesium compound must be used to avoid potassium contamination.

A 1.5 g scoop of soil was placed into a 50 ml Erlenmeyer flask. 15 ml of extracting solution of (1 N NH4O Ac, pH 7.0) by constant suction pipette. The suspension is the agitated on an oscillating shaker for 15 minutes. Then it was filtered through a Whatman No. 2 filter paper into 15 ml funnel tubes. Acid washed filter papers should be used for Na extractions. Ca, Mg, K and Na were determined in the filtered extract via AA Spectrophotometry, using a bulk standard containing 40 ppm of Ca / Mg (run simultaneously); 15 ppm of K; or 15 ppm of Na respectively; which is diluted by the AA to make as many standards as specified.

Results are reported as ppm of exchangeable Ca, Mg, K and Na in soil. If the results are to be used to estimate cation exchange capacity (CEC), convert ppm of each cation to meq/100 g of soil, then sum the values for the four cations

Estimated CEC = (Ca (ppm)/200 + Mg (ppm)/122 + K (ppm)/391) x (soil + tare) – tare/4.25

- (Soil + tare) – tare/4.25 = soil density.

If soil density is not given:

Estimated CEC = (Ca (ppm)/200 + Mg (ppm)/122 + K (ppm)/391) x 5-g scoop/default wt

- Where default WT = 5 for texture code 2 (medium + fine) and 4 (red) soils
- WT = 6.25 for texture code 1 soils (sands)
- WT = 3.5 for texture code 3 soils (mucks)

3.7. Potassium

To determine potassium in soil and plant samples, both involve an extraction or digestion step followed by instrumental analysis. For soil, this usually means extracting plant-available potassium with an ammonium acetate solution, while for plants, it involves digesting the biomass to break it down. The extracted or digested solution is then analyzed using methods like Atomic Absorption Spectrometry (AAS). For soil sample, it was mixed with a neutral ammonium acetate solution (1N) and shaken to extract the plant-available potassium. The mixture was then filtered to separate the liquid extract from the solid soil particles. The concentration of potassium in the filtered extract was measured using an AAS. The reading was used to determine the potassium concentration in the original soil sample, often reported as parts per million (ppm). For plant samples, plant tissue was dried, weighed and prepared for digestion. The plant material was broken down using a strong acid, in a microwave digestion system, to release all the potassium in a liquid solution. The digested solution was filtered to remove any solid particles. The potassium concentration in the clear liquid was measured using AAS.

Available phosphorus involved in an extraction step followed by a colorimetric analysis. For soil, the extraction method used was the Olsen method for neutral to alkaline soils and the Bray-1 method for acidic soils. The extracted solution, containing phosphorus, then reacts with a reagent to form a blue complex whose intensity is measured with a colorimeter to quantify the phosphorus concentration. For plant samples, a similar extraction and colorimetric process is used after the plant tissue has been digested or ached. Plant samples are typically dried and ground before analysis.

For particle size, the analysis involves breaking soil aggregates into individual particles and then separating them by size using methods like sieving and sedimentation. The sedimentation method was used. The hydrometer method was used, which relies on Stoke's Law to determine the settling velocity of silt and clay particles. The density of the suspension was measured over time to calculate the portions of silt and clay.

For organic matter, the analysis was done using the Walkley-Black method. Individual samples of Soil and Biochar was mixed with a known amount of potassium dichromate (K2Cr2O7) and concentrated sulphury acid (H2SO4). Organic matter in the soil oxidizes the dichromate, the remaining excess dichromate is then titrated with a solution of ferrous ammonium sulphate to determine how much was consumed by the organic carbon. Results are reported as a percentage or converted to an organic matter value using a standard factor. Nitrate was carried out using the laboratory method used was the UV spectroscopy (Sempere et al, 1993). Phosphate analysis involves extracting the phosphate, then using a colorimetric method to quantify it. For soils, sample was extracted with a solution (Sodium bicarbonate) for Olsen's Method, and the liquid extract was then analyzed. For the vegetables, the plant material was digested or extracted, and the resulting liquid was analyzed using a similar colorimetric reaction where the intensity of the blue color was measured to determine phosphate concentration. Analysis for heavy metals in soil and plants involves a two-step process: sample preparation, which involves digestion and instrumental analysis which uses techniques like AAS. Digestion uses strong acids to breakdown samples, making the metals detectable.

Figure 5 Plantain peel biochar

Descriptive statistics were used for the data analysis and tables and graphs were used for data presentation.

4. Results and Discussions

Table 1 and Table 2 present the physicochemical properties of the soil and plantain. Plantain peel biochar provides beneficial nutrients such as nitrogen, (N), phosphorus (P), potassium (K), sodium (Na), calcium (Ca), Magnesium (Mg) which are essential for plant growth and endow biochar with its fertilizing properties. It also improves soil nutrient by increasing productivity, reducing nutrient leaching, and also offering a sustainable way to utilize agricultural waste.

The presence of Nitrogen in biochar as against soil is 1.162mg/kg to 0.123mg/kg. The soil has a nitrate value of 43.44mg/kg as against biochar with 103.10mg/kg. These values indicated that biochar has a good amount of Nitrogen, which is an important soil nutrient and can be used to boost the nitrogen level in the soil and make this nutrient available for vegetable use. Soil nitrogen provides essential plant nutrition, while biochar's nitrogen content contributes to nutrient retention and organic matter enrichment within the soil. Soil nitrogen is an inherent component of the soil, while biochar's nitrogen level is a specific characteristic of the added material, which is often used to enrich soil.

Phosphorus is vital to plant growth and is found in every living plant cell. It is involved in several key plant functions, including energy transfers, photosynthesis, transformation of sugars and starches, nutrient movement within the plant and transfer of genetic characteristics from one generation to the next and root development. The importance of phosphorus in biochar lies in its ability to release phosphorus gradually, increase soil pH and improve soil structure which enhances the availability of phosphorus from the soil itself. Unlike direct soil application, biochar acts as a slow-release fertilizer and a soil amendment, providing both a source of phosphorus and a more favourable environment for plant uptake. The value of phosphate in the soil is 18.48mg/kg, while that of the biochar is 30.51mg/kg. This difference shows the abundance of phosphorus that will be available for crop use even over time.

Potassium is the third major plant nutrient coming after nitrogen and phosphorus. Potassium plays vital role as a plant macronutrient and it is essential for carbohydrate, water and nutrient movement within the plant tissues, photosynthesis and disease resistance. Potassium also helps plants resist drought, improves water use efficiency. Biochar when applied to soil, acts as a soil amendment that enhances potassium availability by increasing its exchangeable content and promoting plant uptake through direct and indirect mechanisms, leading to better plan growth and resilience, especially under drought conditions. In essence, biochar improves a soil's potassium supply capacity, whereas potassium in a soil sample is about the baseline availability of this essential nutrient for plant life. The soil has potassium level of 40.10mg/kg while the biochar has values of 67.80mg/kg. The biochar is richer in exchangeable potassium than the soil with values of 41.06mg/kg as against soil with 37.10mg/kg. The deficiency of K in the soil was evidenced in the control samples with stunted and delayed growth as against the other experiments that experienced normal and fast growth.

Sulphate is classified as a secondary element, along with Magnesium and Calcium. As the most important sulphur source in the soil, sulphate is taken up by the roots and translocated to the leaves. It is used in the formation of amino acids, proteins and oils. It is also necessary for chlorophyll formation, promotes nodulation in legumes, helps develop and activate certain enzymes and vitamins and is a structural component of two of the 21 amino acids that form protein. The sulphate level in biochar was 36.35mg/kg while that of the soil was 42.33mg/kg. This is due to the fact that suphate is abundant in biochar and is available for slow-release to the vegetable over a period of time. This slow-release mechanism helps to prevent Sulphur deficiency in plants, leading to better growth and higher crop yields.

Calcium is one of the nutrients present in soil for plant use but often limited depending on the soil type and condition which makes biochar a good source of calcium for plant growth as it enhances soil properties by providing concentrated nutrient source for plants, stabilizing its carbon structure for improved soil carbon sequestration, improving soil aggregation, and contributing to pH management, especially in acidic soils. The value of calcium in the soil was 31.60mg/kg which was low compared to 288.10mg/kg in the biochar. This large difference indicates the availability and abundance of calcium in biochar and its potential to support plant growth and development.

The organic matter content in the biochar is 22.76mg/kg. This relatively high level of organic matter makes biochar a good potential to be used as a soil conditioner and amendment to improve the physical properties of the soil thereby enabling the plants to get maximum support for growth. The organic matter content of the soil is 2.44mg/kg. This is low compared to the value of the biochar. Organic content in a soil makes it more porous, improves the circulation of air and water and provides space for plant roots. Biochar offers a long-term release of organic matter for plant's use and this improves the water holding capacity of soil, improves soil health and allows for sustained agricultural productivity.

Soil pH is important for good nutrient availability and crop growth. pH is a measure of the quantity of hydrogen present in the soil. The pH of the soil was 7.10, while the biochar recorded value of 8.50. This level of pH in the biochar makes it ideal to use in acidic soils as it will greatly improve soil pH and allow for optimum crop growth and development.

Iron (Fe) and Arsenic were the main focus of this study. Iron (Fe) is an essential nutrient, but excess of it can still pose a serious risk while arsenic is a highly toxic, non-essential heavy metal that causes serious health problems including cancer, cardiovascular disease and neurological damage, even at low levels of chronic exposure. Vegetables can absorb these metals from contaminated soil or water, with arsenic's transfer into edible parts being particularly sensitive to soil concentrations. Consumption of contaminated vegetables leads to bioaccumulation, increasing the risk of acute and chronic health issues in humans. Iron (Fe) is a vital nutrient required for many bodily functions and trace levels are necessary for plant growth as well. While essential, excessive levels in the human body can be hazardous. Elevated iron levels can affect the immune system, potentially leading to fragile immunological mechanisms. These heavy metals can be present in humans through diet and they can bioaccumulate in organs over time, leading to long term health problems. The value of Iron (Fe) and Arsenic in soil was 700.00mg/kg and ≤ 0.01mg/kg. Biochar recorded values of 1223mg/kg and ≤ 0.01mg/kg of Iron (Fe) to Arsenic. The value of Arsenic is still below acceptable limits of 2mg/kg according to FAO and WHO. The maximum level of iron (Fe) taken up by plants is 386.20mg/kg, which is still below acceptable limits of 425.5mg/kg by FAO and WHO. The physicochemical analysis of the soil before application of the Biochar was carried out to determine the initial soil nutrient. The result of the analysis is shown in Table 1.

Table 1 Physicochemical properties of the soil

Parameters	Results
pH	7.30
Nitrogen (%)	0.123
Organic Matter (%)	2.44
Potassium (mg/kg)	40.10
Phosphate (mg/kg)	18.48
Sulphate (mg/kg)	42.33
Nitrate (mg/kg)	103.10
Chloride Ion (mg/kg)	42.54
Available Phosphorus (mg/kg)	5.54
Exchangeable Potassium (mg/kg)	37.10
Sodium (mg/kg)	43.30
Calcium (mg/kg)	31.60
Magnesium (mg/kg)	18.80
Total Exchangeable Acidity (mg/kg)	1.36
Cation Exchange Capacity(mg/kg)	8.84
Iron (mg/kg)	700.00
Chromium (mg/kg)	9.20
Zinc (mg/kg)	22.30
Arsenic (mg/kg)	< 0.01

The physicochemical analysis of the biochar was carried out to determine the nutrient content. Heavy metal analysis was also carried out. The results of the analysis are shown in Table 2.

Table 2 Physic-chemical properties of the Biochar

Parameters	Results (mg/kg)
pH	9.70
Nitrogen (%)	1.162
Organic Matter (%)	22.76
Potassium (mg/kg)	67.80
Phosphate (mg/kg)	30.51
Sulphate (mg/kg)	36.35
Nitrate (mg/kg)	43.44
Chloride Ion (mg/kg)	418.40
Available Phosphorus (mg/kg)	9.15
Exchangeable Potassium (mg/kg)	41.06
Sodium (mg/kg)	361.30
Calcium (mg/kg)	288.10

Magnesium (mg/kg)	108.00
Total Exchangeable Acidity (mg/kg)	6.42
Cation Exchange Capacity (mg/kg)	16.03
Iron (mg/kg)	1223
Chromium	4.40
Zinc (mg/kg)	73.80
Arsenic (mg/kg)	< 0.01

Table 3 Effect of Biochar weight on Carbohydrate (mg/kg) (Mean values)

Treatment	Bitter leaf	UGU	Green	Water leaf
250g	40.10	33.70	37.00	38.50
125g	38.50	38.00	36.60	35.80
62.5g	35.20	35.00	35.20	32.70
Control	35.00	33.10	33.50	35.20

Table 4 Effect of Biochar weight on Protein (mg/kg) (Mean Values)

Treatment	Bitter leaf	UGU	Green	Water leaf
250g	30.10	28.20	28.00	28.20
125g	24.20	25.60	26.50	25.30
62.5g	22.60	24.80	24.00	24.20
Control	20.50	33.10	32.10	33.10

Table 5 Effect of Biochar weight on Fat (mg/kg) (Mean values)

Treatment	Bitter leaf	UGU	Green	Water leaf
250g	5.80	5.30	5.60	5.30
125g	4.40	5.10	5.00	4.80
62.5g	5.60	4.80	4.50	4.30
Control	4.20	4.20	4.20	4.20

Table 6 Effect of Biochar weight on Iron (mg/kg) (Mean values)

Treatment	Bitter leaf	UGU	Green	Water leaf
250g	386.20	301.10	298.20	320.20
125g	342.10	296.30	285.30	280.30
62.5g	298.20	290.30	286.30	280.40
Control	265.50	260.30	268.30	258.40

Table 7 Effect of Biochar weight on Arsenic (mg/kg) (Mean values)

Treatment	Bitter leaf	UGU	Green	Water leaf
250g	< 0.001	< 0.001	< 0.001	< 0.001
125g	< 0.001	< 0.001	< 0.001	< 0.001
62.5g	< 0.001	< 0.001	< 0.001	< 0.001
Control	< 0.001	< 0.001	< 0.001	< 0.001

5. Conclusions

It is concluded that vegetables treated with plantain peel biochar exhibited increased shoot height, leaf area and good root development compared to control groups. This suggests that biochar improved nutrient retention and microbial activity, promoting better plant growth. Also, biochar amended soils showed higher water retention, reduced soil acidity which enhanced nutrient availability. Biochar's slow-release nutrient properties decreased the need for frequent synthetic/chemical fertilizer application, making it a cost-effective and sustainable option for small-scale and urban farming. Converting plantain peels into biochar provides an eco-friendly alternative to chemical fertilizers, reducing agricultural waste while improving soil fertility. In conclusion, this study confirms that plantain peel biochar is an effective and sustainable organic fertilizer for potted vegetable cultivation. Its ability to enhance soil fertility, promote plant growth and reduce waste aligns with circular economy principles. Plantain peel biochar is a potent multi-functional tool for sustainable vegetable production. Its application goes beyond mere nutrient supplementation, offering a holistic approach to enhancing the soil-plant system.

Recommendations

It is thus recommended that despite its potential, the use of plantain peel biochar as a fertilizer faces several challenges. The variability in the quality of biochar produced from different pyrolysis conditions and process can affect its effectiveness. Moreover, the long-term impacts of plantain peel biochar on soil health and crop productivity needs further investigation. Future research should focus on optimizing pyrolysis conditions, understanding the mechanisms of nutrient release and evaluating the economic feasibility of large-scale plantain peel biochar production and application.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Agegnehu, G.; Bass, A.M.; Nelson, P.N.; Muirhead, B.; Wright, G.; and Bird, M.I. (2015). Biochar and biochar-compost as soil amendments: Effects on peanut yield, soil properties and greenhouse gas emissions in tropical North 1 Queensland, Australia. Agric. Ecosyst. Environ. 213, 72–85.

[2] Akinola, F.O., Osunde, A.O., and Bala, A. (2022). Biochar Amendments for sustainable Soil Management: A Review of Tropical Studies. Journal of Sustainability, 14(13), 7892.

[3] Akinyemi, B.A., Akinlua, A., and Enitan, O.S. (2020). Properties and Agronomic Potential of Biochar from plantain peel and poultry manure. Journal of Environmental Science and Agriculture, 15(3), 45-52.

[4] Idisi, P.O. (2022). Food Security, Economic Growth and Price Stability Nexus and Conceptual Issues. Economic and Financial Review, 59(4), 9-31.

[5] Jeffery, S., Verheijen, F.G., Van Der Velde, M., and Bastos, A.C (2011). A Quantitative review of the Effects of Biochar Application to Soils on Crop Productivity using Meta-analysis. Journal of Agricultural Ecosysytems and Environment, 142(3-4) 235-246.

[6] Lal, R. (2015). Restoring Soil Quality to Mitigate Soil Degradation. Sustainability, 7(5), 58875-5895.

[7] Lehmann, J., and Joseph, S. (2015). Biochar for Environmental Management: Science, Technology and Implementation. Earthscan/Routeledge

[8] Priestly, A.T. (1991). 'Report on Sewage Sludge Treatment and Disposal – Environment Programmes and Research Needs from an Australian Perspective'. CSIRO, Division of Chemicals and Polymers. Pp. 1-44.

[9] Woolf, D., Amonette, J.E., Street-Perrott, F.A., and Joseph, S. (2010). Sustainable Biochar to Mitigate Global Climate Change. Nature Comms. 1 (5), 1-9.