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## Effect of Rice Husk Biochar and Inorganic Fertilizer on Growth and Yield of Lettuce (*Lactuca sativa* L.)

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### ABSTRACT

A field experiment was conducted from July to September 2024 at the Multipurpose crop nursery field of Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Mampong Campus, to evaluate the influence of rice husk biochar and inorganic fertilizer on soil properties, growth and yield of lettuce. The experimental design used was a Randomized Complete Block Design (RCBD) with seven treatments and three replications. The treatments were [(i) No fertilizer (control), (ii) 5 t/ha Rice husk biochar (RHB), (iii) 300 kg/ha NPK, (iv) 2.5 t/ha RHB + 150 kg/ha NPK, (v) 2.5 t/ha RHB + 100 kg/ha NPK, (vi) 1.25 t/ha RHB + 150 kg/ha NPK, and (vii) 1.25 t/ha RHB + 100 kg/ha NPK]. The results showed that 5 t/ha RHB and 1.25 t/ha RHB + 150 kg/ha NPK significantly enhanced the soil chemical properties (pH, P, N, K, Ca, Mg, OM and OC contents) as compared to the unamended plot and 300 kg/ha NPK treated soils. Lettuce plants that received 1.25 t/ha RHB + 150 kg/ha NPK and 5 t/ha RHB recorded significantly taller plants and higher number of leaves per plant than plants that received 300 kg/ha NPK from 2 to 5 WAT. The combination of 1.25 t/ha RHB and 150 kg/ha NPK showed significantly wider leaf area, canopy spread, highest shoot development, and overall yield (16.49 t/ha) as compared to the control (7.63 t/ha) and 300 kg/ha NPK (9.52 t/ha) treated soils. It is recommended that for enhanced soil fertility and higher yield, lettuce farmers should apply 1.25 t/ha RHB + 150 kg/ha NPK.

**Keywords:** Lettuce, rice husk biochar, inorganic fertilizer, yield, *Lactuca sativa*

## 1. INTRODUCTION

Lettuce (*Lactuca sativa* L.), a member of the Asteraceae family, commonly known as the daisy family, is a temperate annual or biennial plant native to the Mediterranean region. It is the most extensively cultivated and widely consumed green leafy salad vegetable globally (Mulyati & Wulandari, 2019). Lettuce plants typically reach a height of 15 to 30 cm. They feature a thin taproot and an erect stem that branches in its upper portion. The root system consists of a main taproot accompanied by smaller secondary roots, which contribute to the plant's nutrient uptake and stability. The crop is considered one of the most important salad crops in the world and is also used as a garnish for other food preparations. Lettuce is usually used as a salad with tomato, carrot, cucumber, or other salad vegetables and is often served alone or with dressing, and represents a good source of minerals (Hasan *et al.*, 2017). Leaves of lettuce are very good antioxidants, and it is an important component of the human diet with a significant amount of minerals, proteins, and vitamins A, C, and K, folates, and carotenoids, all of which play crucial roles in human health (Bhatta, 2022).

Globally, lettuce and chicory are cultivated on approximately 1.27 million hectares, yielding around 27.25 million tonnes annually (Thakur *et al.*, 2019). Historically, Europe and North America were the primary producers of lettuce, but since the 20<sup>th</sup> century, its cultivation and consumption have expanded worldwide. Today, China leads global lettuce production, followed by the USA. India ranks third in commercial lettuce production, accounting for 4% of the world's total, with Spain, Italy, Japan, and Iran also being significant producers. In Ghana, lettuce is cultivated across various regions, but yields remain relatively low due to challenges such as poor soil nutrient levels and inappropriate agronomic practices, including insufficient soil amendments. Ensuring adequate soil fertility is recognized as a key management practice that significantly impacts plant growth, development, and yield.

Lettuce yields per hectare in Ghana have declined due to production challenges such as low soil nutrient levels and inadequate agronomic practices. Over-cultivation of the same land without replenishing lost nutrients has depleted the soil of essential macro and micronutrients necessary for proper growth and yield (Tsado *et al.*, 2020). While chemical fertilizers can boost soil fertility, they lack humus, which is crucial for binding soil particles. Additionally, the rising cost of chemical fertilizers makes them unaffordable for many resource-poor farmers. According to the World Reference Base, Ghana's southern lands are predominantly covered by andosol, making the region a potential area for agricultural production. However, poor agricultural practices such as nutrient loss through water and soil erosion, continuous cultivation with minimal or no soil amendments, removal of crop residues, and insufficient knowledge of soil fertility management have further depleted the soil of the essential nutrients needed for plant growth and development.

The indiscriminate use of inorganic fertilizers in lettuce production has harmful effects on both soil and human health. However, the supplemental use of biochar has emerged as an effective approach to soil fertility management (Kilic *et al.*, 2021). Biochar is an innovative material that has garnered significant research interest due to its porous structure and high carbon content, resulting from the controlled heating of organic matter at temperatures ranging from 300 °C to 1000 °C in an oxygen-limited or oxygen-free environment (Kilic *et al.*, 2021). The application of biochar has garnered significant research attention because of its various advantages, such as improved soil water and nutrient retention, enhanced crop growth and yield, and its role in sequestering carbon in the soil (Ramlow *et al.*, 2019). Vaccari *et al.* (2015)

demonstrated that biochar treatments increased vegetative plant growth metrics like plant height, stem diameter, root dry weight, and root length in tomatoes. Biochar has demonstrated positive effects on soil fertility and plant growth, but there is limited information on its impact when combined with inorganic fertilizers, especially concerning vegetable crop growth, yield, and soil chemical properties. Therefore, the study aimed to evaluate the growth and yield response of lettuce to the combination of rice husk biochar and inorganic fertilizer.

## **2. MATERIALS AND METHODS**

### **2. 1. Study Area**

The field experiment was conducted from July to September 2024 at the multipurpose crop nursery of Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED), Mampong Campus. The study site was located in Mampong-Ashanti, which lies in Ghana's Forest-Savannah Transition Zone at an elevation of 135 meters above sea level. Mampong-Ashanti experiences a bimodal rainfall pattern, with an average annual precipitation of approximately 1,270 mm. The major rainy season occurs from April to July, while the minor rainy season begins in September and continues through November. Although there is a brief dry spell in August, the main dry season extends from December to March. The area has an average annual temperature of 27 °C, with temperatures ranging from 22 °C to 30 °C. The soil is part of the Savannah Ochrosol class and belongs to the Bediase Series. According to the FAO/UNESCO (2008) classification system, the soil is characterized as a Chromic Luvisol derived from Voltaian Sandstone. It is classified as a sandy loam soil with favourable properties, including good water holding capacity, texture, and structure. Additionally, the soil is well-drained and friable, making it suitable for agricultural purposes. The soil in the area has a pH of approximately 6.5, making it suitable for a wide range of crops.

### **2. 2. Experimental Design and Treatments**

The study used a Randomized Complete Block Design (RCBD) with seven treatments and three replications. The treatments used in the study were:- No Fertilizer (Control), 5 t/ha Rice husk biochar (RHB), 300 kg/ha NPK, 2.5 t/ha RHB + 150 kg/ha NPK, 2.5 t/ha RHB + 100 kg/ha NPK, 1.25 t/ha RHB + 150 kg/ha NPK and 1.25 t/ha RHB + 100 kg/ha NPK.

### **2. 3. Preparation of Biochar, Raising of Seedlings, and Construction of Wooden Frames**

The biochar used in this study was derived from rice husks. The production process involved slow pyrolysis of rice straws at approximately 500 °C in an anoxic pit reactor as used by Asante *et al.* (2020). After production, the biochar was collected and stored appropriately until it was needed for experimental use. The lettuce seedlings were raised at the multi-purpose crop nursery of AAMUSTED, Mampong campus. The nursery area was manually cleared using a cutlass, and the seedbed was prepared with a hoe to create optimal soil conditions for seedling growth. To eliminate harmful soil pathogens, dried palm fronds were burned on the seedbed before sowing. The Eden variety of lettuce seeds was purchased from a recognized and registered Agrochemical shop known as Kyeiwaa Agrochemical shop in Asante Mampong. After nursery establishment, the seedbed was covered with palm fronds for protection. Three days later, the palm fronds were removed and replaced with a raised shade structure. Watering was conducted twice daily, in the morning and evening, adjusted according to daily rainfall

patterns. The experiment utilized 21 squared wooden frames, each measuring 0.6 m × 0.6 m with a depth of 0.12 m. Each frame was filled with 50 kg of soil collected from the dumping site at AAMUSTED, Mampong Campus, after removing all debris.

## **2. 4. Soil and Biochar Sampling and Analysis**

Before fertilizer application, a representative soil sample used to fill the wooden frame was collected using a core sampler for analysis. Additionally, a rice husk biochar sample was taken for chemical analysis. After harvesting, soil samples were collected from each of the treatment plots and dried and bulked into composite samples. The soil samples were air-dried and sieved through a 2.00 mm mesh for both physical and chemical analysis. Both the soil and rice husk biochar samples were sent to the Department of Crop and Soil Science Laboratory, KNUST-Kumasi, for testing.

## **2. 5. Land Preparation and Transplanting of Seedlings**

An experimental area of 41.76 m<sup>2</sup> (5.8 m × 7.2 m) was designated and prepared by ploughing and leveling. To minimize weed growth, the area was covered with a polyethylene sheet. The experimental area was divided into three blocks, each consisting of seven wooden frames, with 2 m between blocks and 0.5 m between frames. Three weeks after nursery establishment, robust and disease-free seedlings were carefully transplanted into the wooden frames, spaced 15 cm apart in both rows and within rows. To minimize transplant shock and prevent damage, the seedlings were gently uprooted from the nursery bed in the evening and relocated to their new positions. There were four rows per plot with four plants per row.

## **2. 6. Agronomic practices**

The powdered biochar was applied to respective treatment plots and incorporated into the soil using a hand trowel, one week before transplanting. The NPK (15:15:15) fertilizer was applied 5-7 cm from the plants through side placement based on the treatment combinations, one week after transplanting. One week after transplanting, gap filling was performed to ensure an optimal plant population for the study. To prevent transplant shock, the seedlings were watered immediately after transplanting. Subsequent watering was carried out twice daily (morning and evening) using a watering can, unless rainfall occurred, in which case watering was reduced. Weed control measures were implemented one week after transplanting, utilizing the hand-pulling method. Throughout the crop growth period, plots were maintained weed-free through regular hand-pulling. Regular visits were made to the experimental sites to monitor for pests and diseases, ensuring prompt action could be taken if necessary.

## **2. 7. Data Collected and Statistical Analysis**

### **2. 7. 1. Soil Analysis**

Some of the parameters examined included soil texture, pH, organic matter content, total nitrogen, exchangeable calcium, potassium, and sodium, effective cation exchange capacity, and organic carbon. The soil's texture was determined using the Hydrometer method, while its pH level in water was measured with a Veb Pracitron glass electrode pH meter from Dresden, Germany. The amount of soil organic matter was determined using the wet combustion method (Walkey & Black, 1934). The total nitrogen in the soil was determined by using the micro

Kjeldahl technique for. The available phosphorus was extracted by the Bray P-1 method and analyzed for color using the method developed by Bray & Kutz (1945). The amount of potassium present was determined through flame emission photometry. The calcium, magnesium, potassium, and sodium exchangeable cations were extracted using a 0.1N Ammonium Acetate solution at pH level 7 and determined via EDTA Titration as recommended by IITA (1979).

## **2. 7. 2. Plant Growth and Yield Parameters**

Three plants were randomly selected and tagged from the two central rows of each plot for data collection. The height of the tagged plants was measured using a meter rule from the soil surface to the tip of the longest leaf at weekly intervals from 2 to 5 WAT, and the average plant height was estimated. The total number of leaves per plant was counted on the tagged plants at weekly intervals from 2 to 5 WAT, and the average number was then calculated from these counts. For leaf area determination, one leaf was randomly selected from each of the three tagged plants. The length and width of the selected leaves were measured at their longest and widest points using a meter rule at weekly intervals from 2 to 5 WAT. The leaf area was then calculated by multiplying the length and width of each leaf. The tagged plant's canopy width was measured at the widest points using a meter rule at weekly intervals from 2 to 5 WAT, and the mean canopy spread was estimated. For the determination of dry matter accumulation, a lettuce plant was randomly uprooted from the two border rows of each treatment for shoot fresh weight assessment. After uprooting, the plant was destructively sampled, and the shoot was weighed separately for the fresh weight using an electronic weighing scale, and the means were recorded in grams. Following sampling, the shoots were placed in paper envelopes and oven-dried at 72 °C for 72 hours, and the dry weight was measured using an electronic weighing scale. The yield from the harvestable area of each plot was calculated and then scaled up to determine the yield per hectare. The yield calculation formula used was based on the method described by Amanullah *et al.* (2019).

$$\text{Yield} \left( \frac{\text{t}}{\text{ha}} \right) = \frac{\text{Yield (kg)}}{\text{Harvestable area (m}^2\text{)}} \times \frac{10000 \text{ m}^2}{1000}$$

## **2. 8. Statistical Analysis**

The data collected were subjected to statistical analysis using the Analysis of Variance (ANOVA) technique with GenStat Release 18.1 software package. The treatment means were separated and compared using Tukey's Honestly Significant Difference (HSD) at 5% level of probability. Correlation matrix analysis was also performed among some vegetative growth parameters and yield.

# **3. RESULTS**

## **3. 1. Background Soil Analysis**

The initial chemical and physical properties of the soil sample used in the study are summarized in Table 1. According to the classification guide from the CSIR-Soil Research Institute, the soil was moderately acidic with a pH of 5.81. The soil had moderate levels of

available phosphorus (18.13 ppm), total nitrogen (0.11%), and potassium (0.27 cmol/kg), as shown in Table 1. Additionally, calcium (2.29 cmol/kg) and organic matter (1.96%) contents were also moderate. In contrast, the levels of magnesium (0.78 cmol/kg), sodium (0.06 cmol/kg), aluminum (0.25 cmol/kg), hydrogen (0.27 cmol/kg), and organic carbon (1.14%) were considered low. The soil was classified as sandy loam in texture.

**Table 1.** Initial chemical and physical properties of the background soil.

| Soil Sample | pH (H2O) | Aval. P ppm            | N (%) | Exch. Bases (cmol/kg) |      |        |      | Exch. Acidity  |      | % Org. C. | % Org. M. |
|-------------|----------|------------------------|-------|-----------------------|------|--------|------|----------------|------|-----------|-----------|
|             |          |                        |       | K                     | Ca   | Mg     | Na   | Al             | H    |           |           |
|             |          |                        |       |                       |      |        |      | (cmol/kg)      |      |           |           |
|             | 5.81     | 18.13                  | 0.11  | 0.27                  | 2.29 | 0.78   | 0.06 | 0.25           | 0.27 | 1.14      | 1.96      |
|             |          | Particle size analysis |       |                       |      |        |      |                |      |           |           |
|             |          | % Sand                 |       | % Clay                |      | % Silt |      | Textural class |      |           |           |
|             |          | 73.40                  |       | 16.80                 |      | 9.80   |      | Sandy loam     |      |           |           |

### 3. 2. Chemical properties of rice husk biochar used for the study

The initial chemical properties of the rice husk biochar used in the study are shown in Table 2. The biochar was highly alkaline with a pH of 10.2. It had a high organic carbon content of 16.3% and a total nitrogen content of 0.59%. However, the available phosphorus, potassium, and calcium levels were low, with values of 0.14 cmol/kg, 0.22 cmol/kg, and 1.34 cmol/kg, respectively. Magnesium content was also low at 0.43%. The biochar had an ash content of 220 g/kg and a carbon-to-nitrogen (C:N) ratio of 27:1.

**Table 2.** Chemical properties of rice husk biochar used for the study.

| Nutrient Composition        | Rice Husk Biochar |
|-----------------------------|-------------------|
| pH (1:2.5) H <sub>2</sub> O | 10.2              |
| Available P (ppm)           | 0.14              |
| Total nitrogen (%)          | 0.59              |
| Organic carbon (%)          | 16.3              |
| Ash (g kg <sup>-1</sup> )   | 220               |
| C:N Ratio                   | 27:1              |

| Exch. Bases (cmol/kg) |      |
|-----------------------|------|
| K                     | 0.22 |
| Ca                    | 1.34 |
| Mg                    | 0.43 |

### 3. 3. Final Chemical Properties of the Soil after Harvesting

The application of rice husk biochar (5 t/ha RHB) significantly increased soil pH as compared to the other amendments, making the soil less acidic or neutral (Table 3). Phosphorus levels increased with the application of fertilizers. The highest available P (38.14 ppm) and N (0.13%) content was found in the 1.25 t/ha RHB + 100 kg/ha NPK treatment, significantly higher than the control (18.13 ppm and 0.11% for P and N, respectively) and the other amended plots. The highest K value (0.45 cmol/kg) was observed in the 2.5 t/ha RHB + 150 kg/ha NPK treatment, while the control recorded the lowest (0.27 cmol/kg). Calcium content varied significantly across treatments, with the highest concentration (5.67 cmol/kg) in the 5 t/ha RHB treatment, which was much higher than the control (2.29 cmol/kg). Magnesium levels were moderate to low across treatments. The 5 t/ha RHB treatment had the highest Mg content (1.49 cmol/kg), while the control had a lower value (0.78 cmol/kg). Sodium levels were relatively stable across all treatments, with only slight variation. The highest Na content was found in the 2.5 t/ha RHB + 150 kg/ha NPK treatment (0.09 cmol/kg). The exchangeable aluminum and hydrogen levels remained relatively constant across treatments, with no significant changes observed compared to the control. Organic carbon and organic matter were significantly improved with biochar application. The highest organic carbon (1.39%) and organic matter (2.40%) contents were recorded in the 2.5 t/ha RHB + 100 kg/ha NPK treatment, while the control had the lowest values (1.14% OC and 1.96% OM).

**Table 3.** Final chemical properties of the soil after harvesting.

| Samples                           | pH    | Avail.<br>P ppm | N<br>(%) | Exch. Bases<br>(cmol/kg) |       |       |       | Exch.<br>Acidity<br>(cmol/kg) |      | %<br>Org.<br>C. | %<br>Org.<br>M. |
|-----------------------------------|-------|-----------------|----------|--------------------------|-------|-------|-------|-------------------------------|------|-----------------|-----------------|
|                                   |       |                 |          | K                        | Ca    | Mg    | Na    | Al                            | H    |                 |                 |
| No Fertilizer<br>(Control)        | 5.81e | 18.13f          | 0.11e    | 0.27f                    | 2.29f | 0.78d | 0.06c | 0.25                          | 0.27 | 1.14e           | 1.96e           |
| 5 t/ha Rice husk<br>biochar (RHB) | 6.84a | 21.30e          | 0.12c    | 0.42b                    | 5.67a | 1.49a | 0.06c | 0.27                          | 0.25 | 1.38a           | 2.37a           |
| 300 kg/ha NPK                     | 6.27b | 27.84d          | 0.13b    | 0.41cd                   | 2.77e | 0.70d | 0.07b | 0.27                          | 0.27 | 1.13e           | 1.94e           |

|                               |        |        |       |        |       |       |       |                    |                    |       |       |
|-------------------------------|--------|--------|-------|--------|-------|-------|-------|--------------------|--------------------|-------|-------|
| 2.5 t/ha RHB + 150 kg/ha NPK  | 6.17cd | 33.42b | 0.12c | 0.45a  | 4.29b | 1.11b | 0.09a | 0.27               | 0.27               | 1.35b | 2.33b |
| 2.5 t/ha RHB + 100 kg/ha NPK  | 6.25bc | 31.57c | 0.12c | 0.40d  | 3.88c | 0.99c | 0.08a | 0.28               | 0.27               | 1.39a | 2.40a |
| 1.25 t/ha RHB + 150 kg/ha NPK | 6.14d  | 34.32b | 0.12c | 0.38e  | 3.07d | 0.93c | 0.07b | 0.28               | 0.27               | 1.26c | 2.17c |
| 1.25 t/ha RHB + 100 kg/ha NPK | 6.18cd | 38.14a | 0.13a | 0.42bc | 2.95d | 0.79d | 0.06c | 0.28               | 0.28               | 1.22d | 2.11d |
| HSD ( $P \leq 0.05$ )         | 0.08   | 0.84   | 0.003 | 0.01   | 0.15  | 0.11  | 0.009 | 0.04 <sup>NS</sup> | 0.04 <sup>NS</sup> | 0.03  | 0.04  |
| CV (%)                        | 0.74   | 1.81   | 1.39  | 1.50   | 2.30  | 6.60  | 7.57  | 6.22               | 5.98               | 1.12  | 1.12  |

### 3. 4. Vegetative Growth

#### 3. 4. 1. Plant height

Table 4 shows the results on plant height of lettuce as affected by rice husk biochar and NPK fertilizer from 2 weeks after transplanting (WAT) to 5 WAT. There were significant ( $P \leq 0.05$ ) differences between the treatments in plant height throughout the entire growing period. Generally, lettuce plants that received 1.25 t/ha RHB + 150 kg/ha NPK recorded the tallest plants and were significantly ( $P \leq 0.05$ ) different from lettuce plants that received 300 kg/ha NPK from 2 to 5 WAT. Lettuce plants that received 300 kg/ha NPK recorded the shortest plant height from 2 to 3 WAT, whereas lettuce plants grown on the unamended plot recorded the shortest plant height from 4 to 5 WAT (Table 4).

**Table 4.** Effect of rice husk biochar and NPK fertilizer on the height of lettuce.

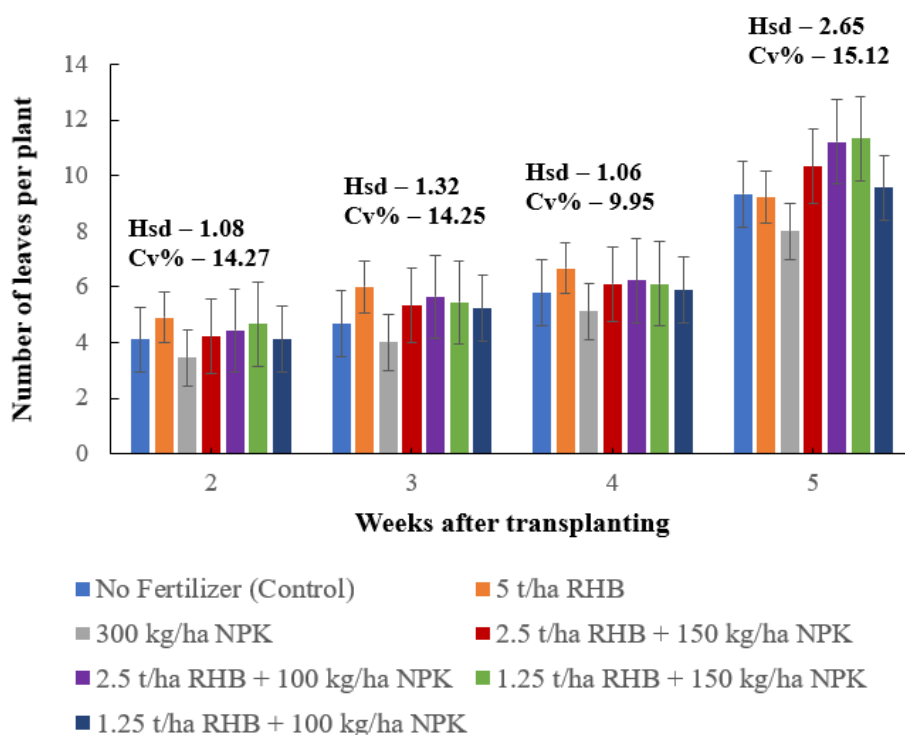
| Treatment                    | Plant height (cm) |        |        |        |
|------------------------------|-------------------|--------|--------|--------|
|                              | 2 WAT             | 3 WAT  | 4 WAT  | 5 WAT  |
| No Fertilizer (Control)      | 5.23ab            | 5.82ab | 7.00b  | 8.67b  |
| 5 t/ha RHB                   | 6.12ab            | 7.10ab | 8.85ab | 9.89b  |
| 300 kg/ha NPK                | 4.29b             | 5.33b  | 7.03b  | 9.52b  |
| 2.5 t/ha RHB + 150 kg/ha NPK | 5.77ab            | 6.90ab | 10.19a | 13.70a |
| 2.5 t/ha RHB + 100 kg/ha NPK | 5.58ab            | 7.19a  | 10.02a | 13.12a |

|                               |              |              |              |              |
|-------------------------------|--------------|--------------|--------------|--------------|
| 1.25 t/ha RHB + 150 kg/ha NPK | 6.44a        | 7.36a        | 10.66a       | 14.09a       |
| 1.25 t/ha RHB + 100 kg/ha NPK | 6.42a        | 6.63ab       | 10.00a       | 13.30a       |
| <b>HSD (0.05)</b>             | <b>1.87</b>  | <b>1.82</b>  | <b>2.54</b>  | <b>2.78</b>  |
| <b>CV (%)</b>                 | <b>18.31</b> | <b>15.42</b> | <b>16.70</b> | <b>13.29</b> |

Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD = Tukey's Honestly significant difference at 5%; RHB = Rice husk biochar; WAT = Weeks after transplanting.

### 3. 4. 2. Number of leaves per plant

There were significant ( $P \leq 0.05$ ) differences between the treatments in the number of leaves per plant from 2 WAT to 5 WAT. Generally, there was an increase in the number of leaves per plant from 2 to 5 WAT. Lettuce plants that received 5 t/ha RHB recorded the highest number of leaves per plant from 2 to 4 WAT and was significantly ( $P \leq 0.05$ ) different from lettuce plants that received 300 kg/ha NPK during the same period (Fig. 1). At 5 WAT, lettuce plants that received 1.25 t/ha RHB + 150 kg/ha NPK recorded the highest (11.33) number of leaves per plant and differed insignificantly ( $P \geq 0.05$ ) from the lettuce plants grown on the other amended plots and the control plot except lettuce plants grown on 300 kg/ha NPK which produced the least (8.00) number of leaves per plant (Fig. 1).



**Figure 1.** Effect of rice husk biochar and NPK fertilizer on number of leaves per plant.

### 3. 4. 3. Leaf area

The results on the leaf area of lettuce as affected by rice husk biochar and NPK fertilizer are shown in Table 5. At 2 WAT, there was no significant ( $P \geq 0.05$ ) difference between the treatment means in leaf area. Lettuce plants that received 1.25 t/ha RHB + 150 kg/ha NPK recorded the widest leaf area (48.37 cm<sup>2</sup>) which differed insignificantly ( $P \geq 0.05$ ) from the lettuce plants grown on the other amended plots and the control plot except lettuce plants grown on 300 kg/ha NPK which produced the least leaf area (18.13 cm<sup>2</sup>) at 3 WAT. There was no significant difference between the treatment means in leaf area at 4 WAT. At 5 WAT, lettuce plants grown on 2.5 t/ha RHB + 150 kg/ha NPK had the widest leaf area (209.40 cm<sup>2</sup>) and were significantly different from lettuce plants grown on 5 t/ha RHB (112.80 cm<sup>2</sup>), 300 kg/ha NPK (78.23 cm<sup>2</sup>), and the control plot (62.33 cm<sup>2</sup>) (Table 5).

**Table 5.** Effect of rice husk biochar and NPK fertilizer on leaf area of lettuce.

| Treatment                                                                                                                                                                                                                  | Leaf area (cm <sup>2</sup> ) |              |                           |              |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|--------------|---------------------------|--------------|
|                                                                                                                                                                                                                            | 2 WAT                        | 3 WAT        | 4 WAT                     | 5 WAT        |
| No Fertilizer (Control)                                                                                                                                                                                                    | 19.61                        | 27.50ab      | 50.03                     | 62.33d       |
| 5 t/ha RHB                                                                                                                                                                                                                 | 27.58                        | 47.27a       | 66.50                     | 112.80bcd    |
| 300 kg/ha NPK                                                                                                                                                                                                              | 12.73                        | 18.13b       | 39.67                     | 78.23cd      |
| 2.5 t/ha RHB + 150 kg/ha NPK                                                                                                                                                                                               | 22.17                        | 35.70ab      | 86.63                     | 209.40a      |
| 2.5 t/ha RHB + 100 kg/ha NPK                                                                                                                                                                                               | 24.51                        | 39.33ab      | 87.03                     | 154.23abc    |
| 1.25 t/ha RHB + 150 kg/ha NPK                                                                                                                                                                                              | 25.80                        | 48.37a       | 87.53                     | 190.93ab     |
| 1.25 t/ha RHB + 100 kg/ha NPK                                                                                                                                                                                              | 25.00                        | 37.67ab      | 84.57                     | 203.27a      |
| <b>HSD (0.05)</b>                                                                                                                                                                                                          | <b>17.32<sup>NS</sup></b>    | <b>23.61</b> | <b>50.19<sup>NS</sup></b> | <b>79.62</b> |
| <b>CV (%)</b>                                                                                                                                                                                                              | <b>23.30</b>                 | <b>26.58</b> | <b>19.34</b>              | <b>20.98</b> |
| Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD = Tukey's Honestly significant difference at 5%; RHB = Rice husk biochar; WAT = Weeks after transplanting. |                              |              |                           |              |

### 3. 4. 4 Canopy spread

The results on canopy spread as affected by rice husk biochar and NPK fertilizer are shown in Table 6. At 2 WAT, there were no significant ( $P \geq 0.05$ ) differences between the treatments in canopy spread. However, there were significant differences between the treatments in canopy spread from 3 to 5 WAT. At 3 WAT, lettuce plants that received 5 t/ha RHB recorded significantly ( $P \leq 0.05$ ) wider canopy spread than lettuce plants that received

300 kg/ha NPK and lettuce plants grown on the unamended plot. From 4 to 5 WAT, lettuce plants that received 1.25 t/ha RHB + 150 kg/ha NPK recorded the widest canopy spread (17.44 cm and 23.63 cm) respectively, and were significantly ( $P \leq 0.05$ ) different from plants that received 300 kg/ha NPK and those grown on the unamended plot during the same period. The unamended plot recorded the least canopy spread from 4 to 5 WAT that differed insignificantly from lettuce plants grown on 300 kg/ha NPK (Table 6).

**Table 6.** Effect of rice husk biochar and NPK fertilizer on canopy spread of lettuce.

| Treatment                                                                                                                                                                                                                  | Canopy spread (cm)       |              |              |              |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|--------------|--------------|--------------|
|                                                                                                                                                                                                                            | 2 WAT                    | 3 WAT        | 4 WAT        | 5 WAT        |
| No Fertilizer (Control)                                                                                                                                                                                                    | 7.98                     | 9.17bc       | 11.56b       | 13.56c       |
| 5 t/ha RHB                                                                                                                                                                                                                 | 8.83                     | 13.46a       | 15.38a       | 19.22ab      |
| 300 kg/ha NPK                                                                                                                                                                                                              | 7.04                     | 7.89c        | 11.68b       | 15.37bc      |
| 2.5 t/ha RHB + 150 kg/ha NPK                                                                                                                                                                                               | 10.23                    | 12.46ab      | 16.11a       | 21.16a       |
| 2.5 t/ha RHB + 100 kg/ha NPK                                                                                                                                                                                               | 8.63                     | 11.70abc     | 16.90a       | 20.99a       |
| 1.25 t/ha RHB + 150 kg/ha NPK                                                                                                                                                                                              | 9.74                     | 11.19abc     | 17.44a       | 23.63a       |
| 1.25 t/ha RHB + 100 kg/ha NPK                                                                                                                                                                                              | 8.82                     | 10.92abc     | 16.22a       | 20.33ab      |
| <b>HSD (0.05)</b>                                                                                                                                                                                                          | <b>5.17<sup>NS</sup></b> | <b>4.20</b>  | <b>3.57</b>  | <b>5.50</b>  |
| <b>CV (%)</b>                                                                                                                                                                                                              | <b>23.17</b>             | <b>21.52</b> | <b>13.34</b> | <b>16.11</b> |
| Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD = Tukey's Honestly significant difference at 5%; RHB = Rice husk biochar; WAT = Weeks after transplanting. |                          |              |              |              |

### 3. 4. 5. Shoot fresh weight per plant

**Table 7.** Effect of rice husk biochar and NPK fertilizer on shoot fresh weight of lettuce.

| Treatment               | Shoot fresh weight per plant (g) |       |        |         |
|-------------------------|----------------------------------|-------|--------|---------|
|                         | 2 WAT                            | 3 WAT | 4 WAT  | 5 WAT   |
| No Fertilizer (Control) | 2.27c                            | 5.97  | 9.55b  | 18.03c  |
| 5 t/ha RHB              | 2.83bc                           | 6.53  | 13.95b | 13.83c  |
| 300 kg/ha NPK           | 4.60abc                          | 7.97  | 17.32b | 43.01bc |

|                                                                                                                                                                                                                            |              |                          |              |              |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|--------------------------|--------------|--------------|
| 2.5 t/ha RHB + 150 kg/ha NPK                                                                                                                                                                                               | 3.30abc      | 7.90                     | 21.57b       | 71.55a       |
| 2.5 t/ha RHB + 100 kg/ha NPK                                                                                                                                                                                               | 3.57abc      | 7.43                     | 24.94ab      | 64.80a       |
| 1.25 t/ha RHB + 150 kg/ha NPK                                                                                                                                                                                              | 5.47a        | 9.73                     | 41.21a       | 73.54a       |
| 1.25 t/ha RHB + 100 kg/ha NPK                                                                                                                                                                                              | 5.03ab       | 9.76                     | 23.06b       | 69.58a       |
| <b>HSD (0.05)</b>                                                                                                                                                                                                          | <b>2.61</b>  | <b>5.81<sup>NS</sup></b> | <b>16.85</b> | <b>25.38</b> |
| <b>CV (%)</b>                                                                                                                                                                                                              | <b>27.91</b> | <b>41.33</b>             | <b>43.73</b> | <b>26.82</b> |
| Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD = Tukey's Honestly significant difference at 5%; RHB = Rice husk biochar; WAT = Weeks after transplanting. |              |                          |              |              |

Lettuce plants that received 1.25 t/ha RHB + 150 kg/ha NPK recorded significantly higher shoot fresh weight per plant than plants that received 5 t/ha RHB and plants grown on the unamended plot from 2 WAT to 5 WAT, except at 3 WAT, where treatments had no significant effect on shoot fresh weight per plant (Table 7). Generally, lettuce plants grown on the unamended plot had the least shoot fresh weight per plant throughout the entire growing period and differed insignificantly from lettuce plants that received 300 kg/ha NPK.

#### 4. 4. 6. Shoot dry weight per plant

The results on the shoot dry weight per plant as affected by rice husk biochar and NPK fertilizer are presented in Table 8. It was observed that 1.25 t/ha RHB + 150 kg/ha NPK-treated plot recorded the highest shoot dry weight per plant from 2 to 5 WAT and differed insignificantly from all the amended plots, but differed significantly from the unamended plot during the same period. Throughout the entire growing period, plants grown on the unamended plot recorded the least shoot dry weight per plant (Table 8).

**Table 8.** Effect of rice husk biochar and NPK fertilizer on shoot dry weight of lettuce.

| Treatment                    | Shoot dry weight per plant (g) |         |        |        |
|------------------------------|--------------------------------|---------|--------|--------|
|                              | 2 WAT                          | 3 WAT   | 4 WAT  | 5 WAT  |
| No Fertilizer (Control)      | 0.37b                          | 0.97c   | 1.16b  | 2.15b  |
| 5 t/ha RHB                   | 1.17ab                         | 1.53bc  | 2.50ab | 3.56ab |
| 300 kg/ha NPK                | 1.30a                          | 1.85bc  | 2.16ab | 3.25ab |
| 2.5 t/ha RHB + 150 kg/ha NPK | 0.83ab                         | 2.33abc | 3.06a  | 4.40a  |
| 2.5 t/ha RHB + 100 kg/ha NPK | 0.80ab                         | 2.03bc  | 2.83a  | 4.73a  |

|                                                                                                                                                                                                                            |              |              |              |              |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|--------------|--------------|--------------|
| 1.25 t/ha RHB + 150 kg/ha NPK                                                                                                                                                                                              | 1.70a        | 3.60a        | 3.79a        | 5.32a        |
| 1.25 t/ha RHB + 100 kg/ha NPK                                                                                                                                                                                              | 1.67a        | 2.53ab       | 2.67ab       | 4.61a        |
| <b>HSD (0.05)</b>                                                                                                                                                                                                          | <b>0.92</b>  | <b>1.38</b>  | <b>1.66</b>  | <b>2.18</b>  |
| <b>CV (%)</b>                                                                                                                                                                                                              | <b>35.96</b> | <b>36.65</b> | <b>35.96</b> | <b>30.65</b> |
| Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD = Tukey's Honestly significant difference at 5%; RHB = Rice husk biochar; WAT = Weeks after transplanting. |              |              |              |              |

### 3. 5. Yield (t/ha)

There were significant differences in yield (t/ha) between the treatments ( $P \leq 0.05$ ). The highest yield was observed in plants treated with 1.25 t/ha RHB + 150 kg/ha NPK, producing 16.49 t/ha, which significantly exceeded ( $P \leq 0.05$ ) the yields of 300 kg/ha NPK (9.52 t/ha) and the unamended control plot (7.63 t/ha) (Table 9). No significant differences in lettuce yield were observed between treatments of 5 t/ha RHB, 2.5 t/ha RHB + 150 kg/ha NPK, 2.5 t/ha RHB + 100 kg/ha NPK, 1.25 t/ha RHB + 150 kg/ha NPK, and 1.25 t/ha RHB + 100 kg/ha NPK. The control plot recorded the lowest yield (7.63 t/ha), which was significantly lower ( $P \leq 0.05$ ) than all amended treatments except the 300 kg/ha NPK treatment.

**Table 9.** Effect of rice husk biochar and NPK fertilizer on the yield of lettuce.

| <b>Treatment</b>                                                                                                                                                                          | <b>Yield (t/ha)</b> |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| No Fertilizer (Control)                                                                                                                                                                   | 7.63c               |
| 5 t/ha RHB                                                                                                                                                                                | 16.15a              |
| 300 kg/ha NPK                                                                                                                                                                             | 9.52bc              |
| 2.5 t/ha RHB + 150 kg/ha NPK                                                                                                                                                              | 12.36ab             |
| 2.5 t/ha RHB + 100 kg/ha NPK                                                                                                                                                              | 15.56a              |
| 1.25 t/ha RHB + 150 kg/ha NPK                                                                                                                                                             | 16.49a              |
| 1.25 t/ha RHB + 100 kg/ha NPK                                                                                                                                                             | 13.92a              |
| <b>HSD (0.05)</b>                                                                                                                                                                         | <b>3.86</b>         |
| <b>CV (%)</b>                                                                                                                                                                             | <b>26.70</b>        |
| Means bearing the same letters within a column are not significantly different at 5% level of significance; HSD = Tukey's Honestly significant difference at 5%; RHB = Rice husk biochar. |                     |

### 3. 6. Correlation matrix analysis between vegetative and yield of lettuce

Most vegetative traits and yield components in lettuce were strongly and positively correlated, with about 85.71% of correlations showing high significance. Plant height had strong positive associations with canopy spread, number of leaves per plant, leaf area, root weight, shoot weight, and overall yield. Similarly, canopy spread was positively correlated with nearly all key growth and yield measures. Leaf area, root weight, and shoot weight independently showed strong relationships with yield, with shoot fresh weight per plant especially exhibiting an almost perfect positive correlation ( $r = 0.98$ ). The number of leaves per plant was moderately linked with fresh root and shoot weights, and less strongly but still positively associated with yield ( $r = 0.48$ ).

**Table 10.** Correlation matrix analysis between vegetative and yield and yield components of lettuce.

|                                                                                                                                                                                         | 1 | 2       | 3       | 4       | 5       | 6       |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|---------|---------|---------|---------|---------|
| 1. Plant height                                                                                                                                                                         | 1 | 0.89*** | 0.83*** | 0.93*** | 0.79*** | 0.78*** |
| 2. Canopy spread                                                                                                                                                                        |   | 1       | 0.84*** | 0.89*** | 0.73*** | 0.72*** |
| 3. Number of leaves per plant                                                                                                                                                           |   |         | 1       | 0.76*** | 0.53**  | 0.48*   |
| 4. Leaf area                                                                                                                                                                            |   |         |         | 1       | 0.79*** | 0.76*** |
| 5. Shoot fresh weight per plant                                                                                                                                                         |   |         |         |         | 1       | 0.98*** |
| 6. Yield (t/ha)                                                                                                                                                                         |   |         |         |         |         | 1       |
| Numbers against the parameters in columns correspond with variables in rows; * = Significant at $P \leq 0.05$ ; ** = Significant at $P \leq 0.01$ ; *** = Significant at $P \leq 0.001$ |   |         |         |         |         |         |

## 4. DISCUSSION

### 4. 1. Effect of rice husk biochar and inorganic fertilizer on soil chemical properties

The application of rice husk biochar (RHB) and NPK fertilizer significantly improved several soil chemical properties compared to the control and sole 300 kg/ha NPK. The increase in soil pH with 5 t/ha RHB was attributed to the alkaline minerals (Ca, K, Mg) present in biochar, which neutralize soil acidity. This agrees with findings by Mbah *et al.* (2017) and Juriga & Šimanský (2018), who observed higher soil pH and cation exchange capacity (CEC) in biochar-amended soils. Although NPK fertilizers also raised soil pH, their effect was less pronounced, possibly due to basic fillers like calcium carbonate. A marked improvement in available phosphorus was observed, particularly in the 1.25 t/ha RHB + 100 kg/ha NPK treatment, indicating a synergistic effect between biochar and NPK. Biochar minimizes phosphorus fixation by binding with aluminum and iron oxides while releasing phosphorus slowly, complementing the readily available P from NPK. Adekiya *et al.* (2019) similarly

reported improved soil nutrient status with combined biochar and NPK applications. Nitrogen content was highest in NPK-treated plots due to direct nitrogen supply, while RHB + NPK treatments showed slightly higher N levels owing to biochar's role in reducing nitrogen losses and enhancing microbial nitrogen fixation. Soil potassium levels increased significantly in the 2.5 t/ha RHB + 150 kg/ha NPK treatment, attributed to potassium retention in biochar during pyrolysis and direct supply from NPK fertilizer.

Similarly, calcium and magnesium contents increased in biochar treatments due to their presence in biochar ash, enhancing soil structure and reducing acidity (Karamina & Fikrinda, 2020). Sodium levels remained stable across treatments, with minor variations possibly due to incidental contributions from inputs or soil factors. Exchangeable aluminum and hydrogen levels showed no significant changes, indicating minimal alteration of soil acidity pools. However, biochar's pH-raising effect may help mitigate aluminum toxicity over time. Organic carbon and organic matter significantly increased in biochar-treated plots, particularly at 2.5 t/ha RHB + 100 kg/ha NPK, due to biochar's high and stable carbon content. This improvement enhances soil health by promoting nutrient retention, water-holding capacity, and microbial activity.

#### **4.2. Effect of rice husk biochar and inorganic fertilizer on vegetative growth of lettuce**

Generally, lettuce plants that received 1.25 t/ha RHB + 150 kg/ha NPK recorded significantly taller plants and heavier shoot fresh and dry weight per plant than the unamended plot from 2 to 5 WAP. The combination of RHB and NPK fertilizer likely improves several physiological processes in lettuce plants. Rice husk biochar is known to enhance soil structure, increase water retention, and improve nutrient availability (Kameyama *et al.*, 2014).

The porous nature of biochar allows for better aeration and root penetration, facilitating root development, which is crucial for nutrient uptake. Improved root systems can lead to enhanced shoot growth, resulting in taller plants and increased biomass. The application of NPK fertilizer provides essential macro-nutrients—nitrogen (N), phosphorus (P), and potassium (K) that are vital for plant growth. Nitrogen is particularly important for vegetative growth, as it is a key component of chlorophyll and amino acids. Phosphorus plays a critical role in energy transfer and root development, while potassium is essential for regulating various physiological processes, including water uptake and enzyme activation (Wang *et al.*, 2013). The synergistic effect of these nutrients from the NPK fertilizer, combined with the benefits of biochar, likely contributed to the observed increases in plant height and biomass.

The significantly higher number of leaves per plant and wider canopy spread observed in plants treated solely with rice husk biochar (5 t/ha) than 300 kg/ha NPK from 2 to 4 WAP and 3 WAP, respectively, may be attributed to the biochar's capacity to aggregate soil particles effectively. This aggregation not only improves soil structure but also enhances water retention and reduces nutrient leaching, which are critical for plant growth. By creating a stable environment in the soil, rice husk biochar increases the availability of essential nutrients, such as nitrogen, phosphorus, and potassium, which are vital for leaf development. Increased microbial populations can lead to improved soil fertility and better nutrient uptake, contributing to enhanced vegetative growth. Jabborova *et al.* (2020) demonstrated that biochar enhances soil nutrient contents such as total nitrogen, potassium, and phosphorus. At 5 WAP, 1.25 t/ha RHB + 150 kg/ha NPK recorded a significantly higher number of leaves per plant and wider canopy spread than 300 kg/ha. Rice husk biochar improves soil structure and enhances water retention, which helps support plant growth by providing a more favourable environment for root

development and nutrient uptake, while NPK fertilizers complement this by supplying necessary nutrients (NPK) that may be lacking in biochar alone. The combination improves nutrient availability, stimulates soil microbial communities, and can lead to synergistic effects, resulting in better plant growth (Kumar *et al.*, 2020). The significantly wider leaf area observed in plants treated with 5 t/ha RHB at 3 WAP and 1.25 t/ha RHB + 150 kg/ha NPK at 5 WAP compared to the unamended plot can be attributed to biochar's ability to improve soil structure through effective particle aggregation.

This improved structure enhances water retention and reduces nutrient leaching, which are crucial for plant growth. Additionally, the stable soil environment created by rice husk biochar increases the availability of essential nutrients, such as nitrogen, phosphorus, and potassium supplied by NPK fertilizer, which are critical for promoting vegetative growth and expanding leaf area and heavier root weight (Selvarajh *et al.*, 2020). This combination enhances nutrient availability, stimulates soil microbial activity, and creates synergistic effects, leading to improved plant growth and increased yields.

#### **4. 3. Effect of rice husk biochar and inorganic fertilizer on the yield of lettuce**

Although the yields in treatments with 5 t/ha RHB and combinations of biochar and NPK fertilizers did not differ significantly from each other, they all performed significantly better than the control, which had the lowest yield (2.63 t/ha). The highest yield was observed in the treatment with 1.25 t/ha RHB + 150 kg/ha NPK, producing 16.49 t/ha. These results demonstrate the positive interaction between biochar and chemical fertilizers, particularly in enhancing soil fertility and crop growth. Biochar improves soil structure, nutrient retention, and water-holding capacity, which can enhance plant growth, especially when combined with NPK fertilizers. The 1.25 t/ha RHB + 150 kg/ha NPK treatment likely provided optimal conditions for lettuce growth by improving soil nutrient availability, particularly nitrogen, phosphorus, and potassium, which are essential for vegetative and reproductive development in plants and subsequently higher yield. This agreed with Adekiya *et al.* (2019), who reported that while biochar alone did not positively affect radish yield due to its recalcitrant nature, the combination of 50 t/ha biochar with 100 kg/ha NPK resulted in the highest radish yield. Research shows that biochar can increase the efficiency of applied fertilizers, reduce nutrient leaching, and make more nutrients available to plants over time. A study by Jindo *et al.* (2020) found that applying biochar along with inorganic fertilizers resulted in substantial yield increases in rice and maize, particularly in soils with low fertility. This synergistic interaction between biochar and inorganic fertilizers contributes to enhanced nutrient use efficiency, allowing plants to access a broader range of nutrients essential for their growth and partitioning of assimilate to the economically important plant part. Trupiano *et al.* (2017) highlighted that applying biochar and NPK fertilizer in nutrient-poor soils could effectively enhance soil fertility, promoting better plant growth and biomass yields.

#### **4. 4. Correlation matrix analysis**

The strong and positive correlation between plant height and the key growth characteristics and yield indicates that they collectively contribute to improved photosynthetic efficiency and nutrient uptake, ultimately enhancing shoot biomass and yield. Taller plants with broader canopies and larger leaves tend to be more productive, as they intercept more sunlight and support better overall growth. Similarly, Wilkinson *et al.* (2020) also reported that there

was a significantly positive correlation between plant height and other vegetative and yield components of sweet potato. The positive correlation between root weight per plot and shoot weight per plot suggests that a healthy root system ensures efficient nutrient and water uptake, supporting vigorous shoot growth and higher yields.

This suggests that root development plays a critical role in determining yield, as plants with more extensive root systems can access more resources, leading to greater shoot biomass and productivity (Sathiyavani *et al.*, 2017). Shoot weight per plot emerged as the most influential factor in determining yield, as greater above-ground biomass reflects better plant vigour, resource acquisition, and energy storage, which translate into higher yields.

## 5. CONCLUSIONS

From the findings of the study, it can be concluded that sole application of 5 t/ha RHB and combination of biochar and NPK fertilizer at different rates specifically 1.25 t/ha RHB + 150 kg/ha NPK significantly enhanced the soil chemical properties (pH, P, N, exchangeable bases and acidity, OM and OC contents) as compared to the unamended plot and 300 kg/ha NPK treated soils. Lettuce plants that received 1.25 t/ha RHB + 150 kg/ha NPK and 5 t/ha RHB recorded significantly taller plants and a higher number of leaves per plant than plants that received 300 kg/ha NPK from 2 to 5 WAT. Treatments combining biochar and NPK fertilizer at different rates showed significantly wider leaf area, canopy spread, highest shoot development, and overall yield as compared to the control and 300 kg/ha NPK-treated soils.

The combination of 1.25 t/ha RHB and 150 kg/ha NPK, as well as sole 5 t/ha RHB, produced the highest yields and most robust vegetative growth compared to 300 kg/ha NPK-treated soils. It is therefore recommended that lettuce farmers should use 1.25 t/ha RHB + 150 kg/ha NPK and or 5 t/ha RHB for enhanced soil fertility and higher yield.

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