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Influence of Rice Husk Ash Application Rates on Growth, Yield, and Soil Fertility of Maize (Zea mays) in Ishiagu, Ebonyi State, Nigeria

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ABSTRACT

Declining land productivity due to low soil fertility, resulting from continuous cultivation and inadequate use of organic and inorganic fertilizers, is a major cause of reduced crop productivity. To address this issue, a field experiment was conducted at the Research and Teaching Farm of the Department of Crop Production Technology at the Federal College of Agriculture Ishiagu (FCAI) during the 2024 cropping season. The aim was to determine the influence of different rice husk ash (RHA) application rates on the growth, yield, and soil fertility of maize (Zea mays). The experiment was designed as a completely randomized block design (CRBD) with four treatments (0, 4.2, 8.3, and 12.5t/ha of RHA) and three replications, resulting in a total of twelve plots. Soil samples were collected at a depth of 0-20 cm before treatment application and after crop harvest, and analyzed following standard laboratory procedures. Data were analyzed using SAS software (version 9.0). The results indicated that the 12.5t/ha rate of RHA showed the greatest improvement in maize growth, grain yield, and soil fertility. Significant ($p<0.05$) increases in maize growth and grain yield were observed with the application of 8.3t/ha and 12.5t/ha rates of RHA compared to the control. From the results, it can be concluded that applying different rates of RHA led to short-term improvements in maize growth and grain yield. The control plots, which did not receive any RHA, exhibited poor performance in both growth and yield, highlighting the positive effect of RHA on maize production.

KEY WORDS: Maize yield, Rice husk ash, Soil fertility, Crop production, Soil amendments, Organic fertilizer.

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INTRODUCTION

Maize *(Zea mays)* is a globally cultivated cereal crop, serving as a major traditional food source for people in tropical regions since the 19th century. Its usage has expanded, making it a prime source of grains for monogastric animals like poultry and pigs. Maize can be consumed in forms of maize powder, maize meal, and in confectionaries like bread, biscuits, and cake. Additionally, it is a crucial human nutrient and a basic element of animal feed. It is also a raw material for many industrial products, including livestock feeds, corn starch, corn oil, corn syrup, alcohol, and products from fermentation and distillation industries (John *et al.,* 2010).

Originating from Mexico (Central America), maize was introduced to West Africa. Among cereals, it ranks third in global importance after wheat and rice due to its extensive use in agro-industries. It is recognized for its great agro-economic value (Robel *et al.,* 2019). Maize ranks second to wheat in world cereal production and holds the distinction of being the most important cereal in sub-Saharan Africa. It is one of the three most important food crops globally, alongside rice *(Oryza sativa)* and wheat *(Triticum aestivum)* (John *et al.,* 2010). Maize is high-yielding, easy to process, readily digested, and costs less than other cereals. Its uses extend beyond human food to vitamins, chemical medicine, biofuel, ornamental purposes, and more. When eaten in its immature state, maize provides valuable of vitamins, making it an important source of carbohydrates (Ekwere *et al.,* 2021).

Ojienyi *et al.,* (2001) found that the yield of vegetable crops and nutrient content were improved by rice husk ash in southeast Nigeria. John *et al.,* (2011) evaluated the effects of rice husk ash, wood ash, and leaf ash on soil properties and maize yield. Their findings indicated that rice husk ash significantly improved soil pH, nutrient content, and maize yield. The improved performance of maize due to added manure is attributed to the supply of essential nutrient elements to the plants. As maize is a crop that exhausts soil nutrients, it requires the supply of necessary elements in the correct proportions to produce a satisfactory yield. Nitrogen, phosphorus, potassium, and other nutrients play significant physiological roles in the formation of chlorophyll, nucleotides, phosphatides, alkaloids, enzymes, hormones, and vitamins (John *et al.,* 2011; Ayinde *et al.,* 2024).

Despite the economic importance of maize, its maximum yield has not been attained due to the continuous cultivation on specific plots of land, which leads to a decline in yield output. Efforts to improve yield and increase soil fertility using inorganic fertilizers are limited by high cost of purchase and the detrimental effects on soil properties with continuous use. As a result, there has been a shift towards using solid organic fertilizers such as wood ash, neem ash, and rice husk to achieve sustainable crop production. Organic manure provides a continuous source of energy that revitalizes depleted soil, enhances the survival of microorganisms, supplies essential minerals to plants, and reduces the need for inorganic fertilizer while increasing crop productivity (Kaith and Bhardwaj, 2009). The water retention capacity of sandy soil and the drainage of clay soil significantly depend on the presence of organic manure (Ojeniyi, 2000). Crops produced with organic manure is globally accepted and enjoyed, with increasing demand. They offer a more palatable taste, extends the shelf life of crops, and help avoid toxic accumulation in the body due to pesticide residues (Ayinde *et al.,* 2024).

Nwokoro, (2021) reported that maize is the most widely cultivated cereal and the most common intercropping component crop in Nigeria. In southeast Nigeria, soil conditions limit crop production (Eifediyi and Remison, 2010), necessitating the addition of lime and fertilizer to the soil. Although these issues can be addressed using inorganic manure and commercial liming materials, organic alternatives are being explored.

MATERIALS AND METHODS

Study Location and Experimental Duration

The study was conducted at the Research and Teaching Farm of the Department of Crop Production Technology at the Federal College of Agriculture Ishiagu, Ebonyi State, Nigeria. The study spanned four months, from June to September 2024

Sources of Experimental Materials

A high-yielding hybrid variety of maize seeds, Oba Super 11 (variety number M0926-7), was used as the test crop. These seeds were sourced from the National Root Crops Research Institute (NRCRI) in Umudike, Abia State. The rice husk ash (RHA) used for the treatment was obtained from a rice mill in Ishiagu, Ebonyi State. The rice husks were burnt and allowed to cool before measuring out the different levels of RHA required for the experiment. The materials used for planting, measuring, and cultivation included a measuring tape, rope, pegs, hoe, and cutlass.

Experimental Design and Field Layout

The experiment followed a completely randomized block design (CRBD) with four (4) treatments: T_1 (Control, no treatment applied), T_2 (4.2t/ha of RHA), T_3 (8.3t/ha of RHA), and T_4 (12.5t/ha of RHA). Each treatment was replicated three (3) times, resulting in a total of twelve (12) plots. The total land area used was 11m x 11m (121m^2). Each plot measured 3m x 2m, with a spacing of 0.5m between plots and 1m between blocks. There were 4 plots per row and 3 plots per column, totaling 12 plots. Each planting hole had 2 maize plants, resulting in 16 plants per plot and a total plant population of 192.

Field Preparation and Agronomic Practices

The field was cleared, ploughed, and harrowed by tractor before being manually prepared into seed beds. Seeds were sown by hand drilling at each row. Plant spacing was 50 x 70cm with 3 seeds per hole, later thinned to 2 seedlings per hole. A composite auger sample was collected from 0-20 cm soil depth before treatment application to determine initial soil characteristics. At harvest, another soil sample was taken from all plots to assess changes due to treatment application. Weeding was performed manually. The first weeding occurred three weeks after planting, and the second weeding took place seven weeks after planting. All other cultural practices were applied uniformly to all plots as per recommendations for maize production in the study area.

Data Collection and Measurement Procedures

Data were taken on, Germination count, Plant height, Leaf number, Leaf Area, Weight of fresh cobs with husk, Weight of fresh cobs without husk, Weight of dried cobs, and Weight of 1000 seeds after drying.

Establishment Count: Recorded at 1, 2, and 3 weeks after planting, Plant Height, Leaf Area, and Number of Leaves: Measured, and Counted at 2, 4, 6, 8, 10, and 12 weeks after planting, respectively. Weight of Fresh Cobs with and without Husk: Recorded after harvesting and dehusking, respectively.

Soil Sampling and Laboratory Analysis

The collected soil samples were air-dried, ground, and sieved through a 2.00mm mesh before undergoing laboratory analysis. Parameters analysed included soil pH, organic carbon (OC), total nitrogen (TN), available phosphorus (P), cation exchange capacity (CEC), and exchangeable acidity (EA), as described by Teneille, (2021) and Bitew *et al.,* (2024).

Statistical Analysis

All data collected were subjected to analysis of variance (SAS 9.0 version) applicable to a completely randomized block design as outlined by Statistical analysis systems (SAS, 2009). The treatment means were separated and compared using the Least Significant Difference (LSD) at 5% level of significance. All Statistical analysis was performed with SAS Software Procedure 2009.

RESULTS

Initial Physical and chemical characteristics of the studied soil before planting or treatment application

The physical and chemical properties of the soil analysis before treatment application are presented in Table 1. The soil composition included 8% clay, 7% silt, 42% fine sand, and 43% coarse sand. The chemical analysis showed an organic carbon (OC) content of 0.309%, total nitrogen (TN) of 0.280%, pH of 5.4, cation exchange capacity (CEC) of 14.80 cmol/kg, and exchangeable acidity (EA) of 1.40 cmol/kg. Additionally, available phosphorus (AP) was 14.92 mg/kg, with exchangeable bases totaling 20.68 cmol/kg, including 0.02 cmol/kg of sodium, 2.40 cmol/kg of calcium, 0.04 cmol/kg of potassium, and 0.60 cmol/kg of magnesium.

Table 1: Initial physical and chemical characteristics of the studied soil before planting

Soil Properties	Values
Clay (%)	8
Silt (%)	7
Fine sand (%)	42
Coarse sand (%)	43
Organic carbon (%)	0.309
Total Nitrogen (%)	0.280
pH (H_2O)	5.4
Exchangeable bases (cmol/kg)	20.68
Sodium (Na^+)	0.02
Calcium (Ca^+)	2.40
Potassium (K^+)	0.04
Magnesium (Mg^{2+})	0.60
Cation exchange capacity (cmol/kg)	14.80
Exchangeable acidity (cmol/kg)	1.40
Available phosphorus (mg/kg)	14.92

Influence of RHA application on soil chemical properties after harvest

The influence of different rates of RHA application on selected soil chemical properties after harvest is presented in Table 2. The RHA application significantly ($P<0.05$) improved all measured soil chemical parameters, except for EA. As the levels of RHA increased, the improvements were more pronounced. Laboratory analysis confirmed the soil chemical properties with the following mean values: pH (6.88), OC (0.47%), TN (0.53%), AP (53.36 mg/kg), CEC (46.4 cmol/kg), and EA (1.54 cmol/kg). Plots treated with 12.5t/ha of RHA consistently showed higher values throughout the experimental period, while the control group recorded lowest values.

Table 2: Influence of different rates of RHA application on the selected soil chemical properties after harvest

Treatment	pH	TN	CEC	EA	AP	OC
Control	5.3	0.110	13.42	1.93	10.59	0.3003
RHA 4.2t/ha	7.2	0.176	16.80	1.37	33.57	0.3760
RHA 8.3t/ha	7.3	1.162	17.73	1.47	71.93	0.4780
RHA 12.5t/ha	7.7	0.643	19.47	1.40	97.36	0.7227
Mean	**6.88**	**0.523**	**16.86**	**1.54**	**53.36**	**0.4693**
LSD	**0.1970**	**0.2753**	**1.886**	**NS**	**1.169**	**0.02292**

RHA= Rice husk ash; TN= total nitrogen; CEC= cation exchange capacity; EA= exchangeable acidity; AP= available phosphorus; OC= organ carbon.

The chemical characteristics of the used RHA

Table 3 presents the chemical characteristics of the rice husk ash (RHA) used in the study. The results indicate that the RHA had a pH value of 8.4, a total nitrogen (TN) content of 0.981%, available phosphorus (AP) of 0.20%, and organic carbon (OC) of 6.86%. The exchangeable calcium (Ca) and magnesium (Mg) were 2.0 meq/100g and 2.88 meq/100g, respectively.

Table 3: The chemical characteristics of the used RHA

RHA Property	Values
Ash pH (H_2O)	8.4
Total Nitrogen (%)	0.981
Organic Carbon (%)	6.86
Available Phosphorus (mg/kg)	0.02
Calcium (Ca^+) (cmol/kg)	2.0
Magnesium (Mg^{2+}) (cmol/kg)	2.88

RHA=Rice husk ash

Influence of different rates of RHA application on establishment count at various ages of maize

Table 4 presents the influence of different rates of RHA application on the establishment count (cm) of maize at various ages. The results revealed that the effect of RHA on maize establishment count was not significant ($P<0.05$) at 1, 2, and 3 weeks after planting (WAP).

At 1-3 WAP, the highest values were observed in plots treated with 8.3t/ha of RHA. The lowest and similar values were recorded in plots treated with 4.2t/ha of RHA and the control plots at 1 WAP (94.79); 12.5t/ha of RHA, 8.3t/ha of RHA, and the control plots at 2 WAP (98.96); and 12.5t/ha of RHA and the control plots at 3 WAP (98.96).

Table 4: Influence of different rates of RHA application on establishment count at various ages of maize.

Treatment	1WAP	2WAP	3WAP
Control	94.79	98.96	98.96
RHA 4.2t/ha	94.79	96.88	97.92
RHA 8.3t/ha	97.92	98.96	100
RHA 12.5t/ha	97.82	98.96	98.96
LSD	**NS**	**NS**	**NS**

RHA=Rice husk ash, WAP= week after planting

Influence of RHA Application on Maize Plant Heights

Table 5 shows the maize plant heights as influenced by different levels of RHA at various growth stages. The results indicated that the application of treatments significantly ($P<0.05$) affected the plant heights, with values increasing as the treatment levels increased.

At 2 WAP, the maximum plant height value (19.63 cm) at harvest stage was observed in plots treated with 12.5t/ha of RHA, while the control plots had the lowest value (11.03 cm). This trend continued at 4, 8, 10, and 12 WAP, with higher treatment levels consistently resulting in greater plant heights (68.6 cm, 114.37 cm, 165.47 cm, 166.47 cm and 166.47 cm) and control treatment consistently resulting in lower plant heights (24.53 cm, 60.53 cm, 90.83 cm, 99.63 cm and 99.63 cm), respectively.

Table 5: Maize plant heights as influenced by different levels of RHA at various growth stages

Treatment	2WAP	4WAP	6WAP	8WAP	10WAP	12WAP
Control	11.03	24.53	60.53	90.83	99.63	99.63
RHA 4.2t/ha	12.27	35.77	73	108.27	109.47	109.47
RHA 8.t/ha	15.23	53.97	90.57	124.97	126.13	126.13
RHA 12.5t/ha	19.63	68.6	114.37	165.47	166.47	166.47
LSD (0.05)	**2.58**	**10.03**	**13.64**	**14.39**	**11.65**	**11.65**

RHA= Rice husk Ash, WAP= Week after planting, LSD= Least significant difference

Table 6 presents the number of leaves of maize as influenced by different levels of rice husk ash (RHA) at various growth stages. Significant ($P<0.05$) differences were observed among all treatment groups throughout the experimental period, except at 8 weeks after planting (WAP). The results obtained indicate that the control plots had the lowest number of leaves (3.47cm) at 2 WAP. The highest number of leaves (12.56cm) was observed in plots treated with 12.5t/ha of RHA at 12 WAP.

Table 6: Number of leaves of maize as influenced by different levels of RHA at various ages of growth

Treatment	2WAP	4WAP	6WAP	8WAP	10WAP	12WAP
Control	3.47	4.77	8.13	9.1	9.76	9.1
RHA 4.2t/ha	4.2	5.87	9.22	9.76	10.16	10.1
RHA 8.3t/ha	5.6	7.17	10.57	11.2	11.63	11.63
RHA 12.5t/ha	5.67	7.8	11.27	11.6	12.56	12.56
LSD (0.05)	**1.58**	**4.01**	**1.15**	**NS**	**1.74**	**1.67**

RHA= Rice husk ash, WAP= Week after planting, LSD= Least significant difference

Influence of RHA application on leaf area of maize

Table 7 reveals the leaf area of maize as influenced by different levels of rice husk ash (RHA) at various growth stages. The results show that the leaf area at 6WAP was significant ($P<0.05$) at 261.97 cm^2 among the treatments within the sampling periods. The highest leaf area (795.21 cm^2) was observed at 8, 10, and 12 WAP in plots treated with 12.5t/ha of RHA, while the lowest leaf area (10.81 cm^2) was recorded at 2 WAP in the control plots. The results indicate that different rates of RHA application affect the leaf area of maize.

Table 7: Leaf area of maize as influenced by different levels of RHA at Various Ages of Growth.

Treatment	2WAP	4WAP	6WAP	8WAP	10WAP	12WAP
Control	10.81	53.58	273.05	616.68	616.68	616.68
RHA 4.2t/ha	20.17	80.19	445.75	761.29	761.29	761.29
RHA 8.3t/ha	33.08	114.10	675.07	784.25	784.25	784.25
RHA 12.5t/ha	30.69	111.99	790.85	795.21	795.21	795.21
LSD (0.05)	**NS**	**NS**	**261.97**	**NS**	**NS**	**NS**

RHA= Rice husk Ash, WAP= Week after planting, LSD= Least significant difference

Influence of RHA Application on Maize Plant Stem Girth

Table 8 presents the maize plant stem girth (cm) as influenced by different levels of rice husk ash (RHA) at various growth stages. Significant ($P<0.05$) differences were observed among all treatments throughout the experimental period. The results indicate that the treatment plot with 12.5t/ha of RHA had the highest stem girth (7.47 cm) at 8 weeks after planting (WAP). The lowest stem girth (1.1 cm) was recorded in the control plot at 2 WAP.

Table 8: Maize plant stem girth (cm) as influence by different levels of rice husk ash at various ages of growth.

Treatment	2WAP	4WAP	6WAP	8WAP	10WAP	12WAP
Control	1.1	2.87	3.73	4.87	4.67	4.27
RHA 4.2t/ha	1.2	4.5	5.17	5.93	4.67	5.5
RHA 8.3t/ha	1.3	4.93	5.5	6.37	6.17	5.7
RHA 12.5t/ha	1.8	5.2	6.7	7.47	7.27	6.73
LSD (0.05)	**0.33**	**0.62**	**1.18**	**0.14**	**0.86**	**0.96**

RHA= Rice husk ash, WAP= Week after planting, LSD= Least significant difference

Influence of RHA on Yield and Yield Component of Maize.

Table 9 presents the influence of rice husk ash (RHA) on maize yield and yield components. Maize treated with 12.5t/ha of RHA yielded the highest weight of fresh cobs with husk (7.17t/ha) and without husk (5.73t/ha) at harvest, followed by maize treated with 8.3t/ha of RHA, which yielded 4.27t/ha of fresh cobs. The lowest yields (3.85t/ha with husk and 3t/ha without husk) were obtained from the control plots. Significant ($P<0.05$) differences of 1.46t/ha and 1.14t/ha were observed among the treatments.

Table 9: Influence of rice husk ash (RHA) on maize yield and yield components.

Treatment	Weight of fresh cobs with husk	Weight of fresh cobs without Husk	Weight of dried cobs	Weight of 1000 seeds
Control	3.85	3	2	0.67
RHA 4.2t/ha	5.33	3.93	2.87	0.87
RHA 8.3t/ha	5.5	4.27	3	1.13
RHA 12.5t/ha	7.17	5.73	3.87	1.07
LSD (0.05)	**1.46**	**1.14**	**0.92**	**NS**

RHA= Rice husk ash, WAP= Week after planting, LSD= Least significant difference

DISCUSSION

The physical and chemical properties of the soil before treatment application. According to Bockheim, (2024) and Hazelton and Murphy (2007), the soil is classified as sandy loam, consisting of 8% clay, 7% silt, 42% fine sand, and 43% coarse sand. The soil pH is 5.4, indicating moderate acidic, as per the ratings of Sharma *et al.,* (2025). The TN value obtained in this study was (0.280%), which falls within the ideal range of 0.25% - 0.75% for crop production, as reported by Horneck *et al.,* (2011). The TN content in this study was higher than the value (0.097%) reported by Bitew *et al.,* (2024).

The AP content of the study area (14.92 mg/kg), slightly lower than the ideal range of (20 – 40 mg/kg) reported by Bitew *et al.,* (2024). The low AP contents could be attributed to intensive cultivation and low levels of soil organic matter in the study area. The values of soil OC, EA, exchangeable bases, exchangeable sodium, potassium, calcium, magnesium, and CEC were 0.309%, 1.40%, 20.68%, 0.02%, 0.04%, 2.40%, 0.60%, and 14.80%, respectively.

Sarkar *et al.,* (2024) examined the physico-chemical properties of initial soil at a depth of 0–15 cm, reporting significantly higher values for clay (40.5%), silt (6.0%), sand (53.5%), OC (0.87%), pH (6.93), TN (220 mg/kg), AP (52.64 mg/kg), and available potassium (167 mg/kg) compared to this current study. Also, John *et al.,* (2011) reported some properties of the topsoil (0 -20 cm) before tilling and amendment (clay 10%, silt 21%, total sand 69%, OC 1.42%, TN 0.09%, and pH 3.7), Exchangeable bases cmol/kg (sodium, potassium, calcium, Magnesium, cation exchange capacity, exchange acidity and available phosphorus at 0.40, 0.80, 1.0, 3.5, 8.22, 2.52 and 4.30 cmol/kg), respectively. These discrepancies can likely be attributed to differences in soil depth, timing, and location of the analysis.

The influence of different rates of RHA application on selected soil chemical properties after harvest. The application of RHA showed significant ($P<0.05$) improvements in all measured soil chemical parameters, except for EA. As the levels of RHA increased, the improvements were more pronounced. This observation aligns with Bitew *et al.* (2024), who assessed the effects of farmyard manure (FYM) on lowland rice production. Inorganic fertilizers like RHA are known for enhancing soil fertility, as they are robust sources of various nutrients. There is renewed interest in using burnt organic residues from plants as sources of phosphate and potash fertilizers (Bente, 2019). These materials are often considered less likely to have detrimental effects on soil physicochemical properties compared to mineral fertilizers (Gudeta *et al.,* 2025).

The application of RHA significantly ($P<0.05$) improved soil pH. The mean pH value was neutral (6.88), with the highest value in plots treated with 12.5t/ha (7.7) of RHA, followed by plots treated with 8.3t/ha (7.3) of RHA. The increased soil pH in T_4

(12.5t/ha) could be attributed to the increased microbial activity during the decomposition of inorganic residues, releasing more exchangeable cations or bases that might have increased the soil pH. The decrease in pH value at T_1 (control, 0t/ha) plots may have been due to absence of RHA application. Treated plots had significantly higher ($P<0.05$) pH levels compared to the control (5.3), indicating that RHA has a significant effect on soil pH and other chemical properties. The RHA was slightly acidic to neutral and was used to improve soil fertility and crop yields. These results align with Khater (2015), who reported optimum pH values ranging from 6.3 – 7.8 for different FYM types used to amend soil fertility and increase crop production. However, the pH value obtained in this study (6.88) was lower than the value (7.84) reported by Bitew *et al*., (2024).

Soil OC is a crucial factor in soil health and productivity, storing nutrients and providing energy for soil organisms. According to Arif *et al.,* (2014), OC in the soil is an indicator of soil fertility, improving soil structure, nutrient exchange, and maintain soil physical conditions. Adding nutrients like RHA to the soil enhances soil OC content, which is an important indicator of soil quality and crop productivity. In post-harvest soil, the balance of OC was found to be high in amended plots due to the integration of RHA. This supports the findings of Singh *et al.,* (2017), who explained that the conjunctive use of organic and or inorganic sources of nutrients significantly improved the carbon content of the soil. Plots amended with 12.5t/ha of RHA showed the highest soil OC value (0.72), while the control plot recorded the lowest value (0.30). The OC balance values in the control plot remained the same before treatment and after harvest, whereas treated plots exhibited an increase in OC balance compared to initial values. This outcome is probably because soil physical properties tend to remain stable and do not undergo significant changes over short-term experimental conditions. (Gorde *et al.,* 2022). Similar results were observed for all other soil physico-chemical properties measured. These findings align with the reports of Bitew *et al.,* (2024) and Sarkar *et al*., (2024).

Nitrogen is one of the most limiting nutrients in plant growth and is the most critical element obtained by plants from the soil. Its deficiency is a bottleneck in plant growth (Gebremedhn and Dereje, 2015; Bitew *et al*., 2024). The analysis of variance after maize harvest showed a significant ($P<0.05$) difference in soil TN percentage among treatments due to the main effects of RHA. This result agrees with Dragan *et al. (*2010), who reported evaluated that soil TN content constantly increased corresponding to the applied urea fertilizer rate, showing statistical significance difference between four nitrogen fertilizer rates of treated plots. Amended plots generally had significantly higher ($P<0.05$) TN than the control. Plots treated with 8.3t/ha of RHA recorded the highest TN, while the control plots had the lowest values throughout the experimental period. The availability of nitrogen in the post-harvest soil is greatly influenced by the addition of RHA. Incorporating natural and inorganic inputs, such as RHA, into the crop enhances the soil's carbon pool, nutrient availability and productivity (Farooqi *et al.,* 2024). These findings highlight the importance of nutrient application for sustainable crop productivity and overall soil health.

The application of RHA significantly ($P<0.05$) improved CEC. Plots amended with 12.5t/ha of RHA had the highest CEC, followed by plots treated with 8.3t/ha and 4.2t/ha of RHA. Generally, amended plots had significantly higher ($P<0.05$) CEC compared to the control. The increase in CEC values among the treated plots might be due to the addition of RHA, which increases the negative surface charges on soil colloids. Soils with larger amounts of organic matter typically have more negative charges and, therefore, a higher CEC than those with lower amounts. High CEC might lead to more nutrients being held in the soil, reducing their mobility and contributing to slow release (Bitew *et al.,* 2024).

According to Bitew *et al.,* (2024), the soil of the experimental site after the maize harvest showed high level of CEC for most treatments. In conformity with this result, Alem and Fassil (2016) reported that the CEC of the soil was greatly raised by FYM's primary effect and its interactional effect with inorganic fertilizers. Similar findings were made by Schoebitz and Vidal (2016), who found that the applying an optimum level of organic and inorganic fertilizer improved the organic matter and CEC content, making the soil fertile. Correspondingly, Getachew Agegnehua *et al.* (2016) confirmed that the CEC values increased after the integrated applications of organic and inorganic fertilizers on wheat and *tef* crop-cultivated soils in the highland environment of Ethiopia. The CEC results obtained in this study align with Sarkar *et al.* (2024), who reported that organic material can serve as an alternative nutrient input.

Phosphorus is the second most limiting nutrient next to nitrogen for producing healthy plants with profitable yields (Bitew *et al.,* 2024). After crop harvest, the value of AP for all treatments was higher than the AP before planting due to the residual effect of RHA applications during planting. In contrast, plots without RHA addition yielded the lowest AP (10.59 mg/kg). Therefore, all treatment plots significantly ($P<0.05$) increased AP compared to the control plots. This suggests that an alternative to inorganic fertilizers is the application of organic soil amendments, which, according to Manuel *et al.* (2024), are locally available and more cost-effective for maintaining soil fertility. Significant ($P<0.05$) improvements were observed due to the amendment application. The best improvement in OC was recorded in plots amended with 12.5t/ha of RHA, followed by those treated with 8.3t/ha of RHA. The lowest improvement was seen in plots without amendment. Thus, the availability of phosphorus rise with increasing RHA application rates. The increase in AP using RHA might be attributed to the high phosphorus content of the experimental material (RHA), as confirmed by the sample analysis of RHA. This idea aligns with Kunj *et al.,* (2018).

The result of the chemical characteristics of the RHA used in the study showed that the RHA was of good quality, with a higher pH (8.4), and OC (6.86%). The experimental material (RHA) was moderately alkaline and used to improve soil fertility and crop yields. These findings are in line with the report of Bitew *et al.,* (2024), who found an optimum pH value of 7.84 and other chemical properties (TN 1.302%, AP 289.9 mg/kg, exchangeable calcium 22.5 cmol/kg, and magnesium 8.71 cmol/kg) that were used to amend soil fertility and increase crop production. The values observed by Bitew *et al.,* (2024) for TN, AP, Ca^+ and Mg^{2+} were significantly higher than those reported in this present study. In contrast, John et al. (2011) reported lower values of RHA amendments (pH 6.9, OC 3.89%, TN 0.056%, exchangeable calcium 1.0 cmol/kg, magnesium 1.4 cmol/kg, sodium 0.33 cmol/kg, potassium 0.65 cmol/kg, and phosphorus 11.94 cmol/kg) when comparing the contributions of different ash sources to the improvement of a degraded Ultisol and maize production in southeastern Nigeria, compared to the values recorded in this study.

The maize plant heights were significantly ($P<0.05$) affected by different levels of RHA at various growth stages, with values increasing as the treatment levels increased. The genetic composition of a crop, along with environmental factors, significantly influences plant growth, as reported by Joseph *et al.,* (2023). The maximum plant height at the harvest stage was observed in plots treated with 12.5t/ha of RHA, while the control plots had the lowest value. This trend continued throughout the experimental period, with higher treatment levels consistently resulting in greater plant heights. The increase in height may result from nutrient variation in the soil and light interception, which determine the rate of photosynthesis in plants. This observation aligns with Umesh *et al.* (2022), who studied the influence of planting systems and nutrient management on maize growth, yield and light interception in a maize-soybean intercropping system. They stated that nutrient availability and plant competition influence photosynthetic interception in plants. Kumar *et al.,* (2018) reported that integrated use of fertilizers significantly enhanced average plant height and plant biomass in mustard. Ayinde *et al.,* (2024) assessed the effects of different substrates on the growth and yield of tomato plants. They found that plants grown on a mixture of topsoil and rice husk ash were the tallest, reaching 83.42 cm. This height increase was attributed to the high potassium content and organic matter provided by the rice husk ash, which supported the growth rate. Their findings align with the report of this study as RHA significantly influenced Maize plant heights.

The number of maize leaves at various growth stages was significantly ($P<0.05$) influenced by different levels of rice husk ash (RHA) application among all treatment groups throughout the experimental period. According to Kumar et al. (2018), the quantity of leaves on plants is a major yield-contributing factor. The maximum number of maize leaves was found in T4 (12.5t/ha) compared to T1 (0t/ha), which had fewer leaves per plant. This indicates that higher inclusion of RHA as an inorganic source significantly increased the number of maize leaves per plant.

The present study corroborates the findings of Ayinde et al. (2024), who determined that the effects of substrates on the number of leaves at harvest per plant of tomato showed significantly higher leaf counts (142.67) among plants grown on soil mixed with rice husk ash. This may be due to variations in photosynthetic interception, water, and nutrient uptake, which enhance leaf development in plants. Aicha *et al.,* (2022) stated that the number of leaves per plant increases with plant development.

The application of 12.5t/ha of RHA after soil testing might have increased the availability of nitrogen, an essential constituent of nucleic acid, protoplasm, and protein, playing a fundamental role in metabolism, growth, development, and transmission of heritable traits. Therefore, the number of maize leaves also increased under this condition. These results are in conformity with those of Nagdive *et al.,* (2007).

Leaf area a key indicator for evaluating the growth structure of individual plant or entire populations (Hammond *et al.,* 2023). According to Wang *et al.,* (2022), who proposed that leaf water content (LWC) inherently affects other leaf traits. Their analyses showed that mass-based photosynthetic capacity and specific leaf area increase nonlinearly with LWC. When the effects of temperature and LWC are controlled, the numerical values for the leaf area-mass scaling exponents converge onto 1.0 across plant functional groups, ecosystem types, and latitudinal zones. Their findings also indicate that leaf water mass is a better predictor of whole-leaf photosynthesis and leaf area than whole-leaf nitrogen and phosphorus masses.

The maize plant stem girth at various growth stages was significantly ($P<0.05$) influenced by different levels of rice husk ash (RHA) application throughout the experimental period. The highest stem girth (7.47 cm) was observed in plots treated with 12.5t/ha of RHA at 8 weeks after planting (WAP), while the lowest stem girth (1.1 cm) was recorded in the control plot at 2 WAP. However, the observations varied during the sampling periods. The reduction in stem girth at 10 and 12 WAP may be attributed to stem shrinking due to maturity and cob bearing. This aligns with the findings of Jiale et al. (2023), who stated that maturity tends to affect the size of the stem of a crop.

Additionally, Ayinde et al. (2024) reported the longest stem girth (7.54 mm) in plants grown on a mixture of soil and rice husk ash, compared to soil and poultry manure (6.78 mm). This result supports the similarity in nutrient compositions of the two substrates. Similarly, Olubanjo and Alade (2018) found that rice husk ash produced the highest stem girth when tomatoes were irrigated on different substrates.

There were significant ($P<0.05$) differences in maize yield and yield components due to the application of rice husk ash (RHA). Maize treated with 12.5t/ha of RHA yielded the highest weight of fresh cobs with husk (7.17t/ha) and without husk (5.73t/ha) at harvest. The lowest yields (3.85t/ha with husk and 3t/ha without husk) were obtained from the control plots.

For dried cobs, the highest weight (3.87t/ha) was recorded in plots treated with 12.5t/ha of RHA, while the lowest weight (2t/ha) was observed in the control plots, showing a significant ($P<0.05$) difference of 0.92t/ha among the treatments.

In terms of the weight of 1000 seeds, the highest value (1.13t/ha) was obtained in plots treated with 8.3t/ha of RHA, while the lowest value (0.67t/ha) was recorded in the control plots. There were no significant ($P>0.05$) differences among the treatments, suggesting that maize yield increased with higher nutrient application. The higher yield at 8.3t/ha of RHA compared to 12.5t/ha may be due to variations in the decomposition of soil amendments, which improved nitrogen availability for crop production.

The yield of all treatments was significantly influenced by different rates of RHA amendments. The highest maize yield throughout the experiment was observed in the 12.5t/ha treatment, followed by 8.3t/ha, 4.2t/ha, and the control with the lowest values. The increase in cob yield of maize might be due to the production of more effective grains per cob and cobs per stem/stalk as influenced by the treatment amendments. Manure (plant residue) provides essential plant nutrients in a steady and synchronized form, leading to better availability throughout the growth stages, resulting in more vigorous growth and higher production (Sathiyabama *et al.,* 2021). The increased maize yield with 12.5t/ha may be due to the consistent availability of macro-nutrients in plant-available ionic forms and essential plant growth-promoting hormones, which overall increased growth parameters and yield components (Kumar *et al.,* 2018).

The data pertaining to 1000 seed weight (test weight) are given in Table 9. Results revealed that variations in 1000 seed weight among different treatments were non-significant. However, the maximum test weight (1.13%) was recorded in treatment T_3 (RHA 8.3t/ha), closely followed by T_4 (1.07%) and T_2 (0.87%). The lowest test weight (0.67%) was recorded in treatment T_1. Similar results have been reported by Kumar *et al.,* (2018) and John *et al.,* (2011).

Growth-promoting substances like silicon, calcium, potassium, and beneficial trace elements such as magnesium, iron, and zinc in RHA are essential for various plant metabolic processes. They promote better root development, enhance leaf area, photosynthesis, and nutrient flow, boost yield, improve soil fertility, and enhance overall plant growth and productivity (Thakare *et al.,* 2023; Kumar *et al.,* 2018). Applying RHA enhances nutrient availability and supply to plants, promoting flowering, seed formation, and increased yield components such as cobs, plant height, and plant stem girth.

CONCLUSION

The study highlights that both organic and inorganic amendments, such as rice husk ash (RHA), are essential for combating soil degradation and enhancing soil quality. The application of RHA significantly improved maize growth and yield, with the highest results observed at 12.5t/ha and 8.3t/ha. These improvements include better root development, increased leaf area, enhanced photosynthesis, and improved soil fertility. Consequently, RHA proves to be a valuable soil amendment for sustainable maize production. The positive effects of RHA on soil properties and nutrient availability underscore its potential for achieving sustainable agriculture and preserving soil health for future generations. Future research should focus on the long-term interactions between soil management and soil amendments to maximize their effectiveness.

Conflict of Interest Declaration

The Authors declare that no conflict of interest exists.

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Author's contributions

We reviewed the results and approved the final version of the manuscript.

Contributions to the study were made by the authors as follows: Conceptualization, methodology, data curation, formal analysis, investigation, validation, software, resources, project administration, visualization, writing – original draft, and writing – review and editing: Onya Godswill Uzoma, Essen Paulinus Ogbonnaya, Njoku Godwin Nnamdi, Okoro Damian Chukwunyerem, Essen Joshua Ifeanyi, and Edeh Ernest Chukwuka

Data and materials availability

All data associated with this study are present in the paper.

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