Nitrogen

Article

Co-Application of Biochar Compost and Inorganic Nitrogen Fertilizer Affects the Growth and Nitrogen Uptake by Lowland Rice in Northern Ghana

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Abstract: Inherent low soil fertility status limits productivity of rice in the lowland ecologies in Northern Ghana. Combining organic and inorganic nitrogen fertilizers could help to maintain the fertility of lowland soils for rice production. A screen house pot experiment was carried out to investigate the combined effect of biochar compost and inorganic nitrogen fertilizer on the nitrogen uptake and agronomic performance of rice plants grown on an eutric gleysol lowland soil. Inorganic nitrogen fertilizer alone and its combinations with different types of biochar compost (based on the proportions of biochar and compost) were used as treatment. A control (unamended soil) was also included. The incorporation of biochar compost and inorganic nitrogen fertilizer improved the growth parameters and yield components of rice plants. The combination of biochar compost and inorganic nitrogen fertilizer was also found to improve nitrogen uptake in rice plants. This practice could be the most likely viable option for alleviating lowland soil fertility issues and increasing rice productivity in Northern Ghana.

Keywords: nitrogen uptake; biochar compost; inorganic nitrogen fertilizer; soil fertility issues; rice productivity

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1. Introduction

Rice is the second most important food staple in Ghana, West Africa, after maize, and its consumption is increasing as a result of population growth, urbanization, and changes in consumer habits [1]. However, because the country is not self-sufficient in rice production, it is unable to meet its ever-increasing domestic demand and must rely heavily on imported rice [2]. In order for the country to achieve self-sufficiency in rice production and meet its increasing local demand, it will require sustainable production systems. The northern part of Ghana is one of the major rice producing areas in the country [3]. There are abundant poorly drained lowlands and floodplains which are suitable for rice cultivation in the region [4]. Despite their suitability, the soils in the area have a low fertility status [5]. Small-scale farmers dominate rice cultivation in the area. They grow rice on as little as two hectares, yielding 1.2 tons per hectare on average [6]. Additionally, farmers cannot afford expensive chemical fertilizers. They use low fertilizer application rates to cut input costs, which contributes to low rice yield in the area. The soils in the area also have a low cation exchange capacity (CEC) as a result of low organic matter content and relatively low clay concentration. Low soil CEC reduces soil nutrient retention [7]. Low CEC may enhance the leaching potential of plant nutrients in soil such as K^+, Ca^{2+} and Mg^{2+}. There is also risk of N loss by ammonia volatilization in low CEC soils particularly when nitrogen is applied due to their low pH buffering capacity [8].

Nitrogen (N) is typically the main limiting nutrient in lowland rice cropping systems. Soil N supply is a critical component of soil quality, but the effective soil N supply is influenced by anaerobic N mineralization–immobilization processes that are unique to flooded soils [9]. Efficient ways to use nitrogen fertilizer and alternative amendments to maximize crop productivity, minimize nitrogen losses and maintain soil fertility without economically constraining farmers remain significant challenges that must be addressed.

Compost is an important amendment for increasing soil organic matter levels and sustaining soil fertility. In addition to being a source of plant nutrients including nitrogen, it improves the physicochemical and biological properties of the soil [10]. Biochar, a carbon-based by-product of biomass pyrolysis [11], also has great potential for improving rice production and maintaining lowland soil fertility in Northern Ghana [12–14]. Biochar has been shown to offer a range of agricultural benefits, such as reduced nutrient leaching [15] and increased soil cation exchange capacity [16]. Local organic input sources, especially rice husk and cow manure, abound in the northern region of Ghana. Burning of rice husk is a common practice by farmers to get rid of the waste products; however, this has serious environmental repercussions. The direct use of fresh organic materials as soil amendment may not be sufficient to meet the nutrient requirement of high-yielding rice. Adding fresh organic materials such as rice husk and cow manure to flooded soils may develop toxic soil conditions for plants [17,18]. Therefore, converting these materials into compost or biochar would apparently make them more suitable as soil amendments. Converting rice husk into rice husk biochar (RHB) can be an effective solution in rice waste management. Using RHB as a soil amendment could also provide multiple benefits such as carbon sequestration, soil quality improvement and better plant growth [16]. Composting with biochar has been investigated as a method to produce effective biochar-based slow-release organic fertilizers [19]. Co-composting of cow manure and rice husk with rice husk biochar could therefore be an excellent way to improve the compost nutrient composition and make it suitable for use as an amendment in the flooded lowland soils.

The supply of N from organic and inorganic fertilizer sources is vital to the rice crop's N requirements. Extensive research has been conducted to show the importance of integrated nutrient management on the yield of rice and nutrient status of soils [20–23]. Improved application and targeting of inorganic and organic fertilizer could conserve soil nutrients and increase their efficiency of uptake [24]. In this regard, an integrated approach to soil nutrient management must be part of the overall strategy for increasing rice yield. The objective of this work was to examine the combined effect of biochar compost and inorganic N fertilizer on the growth and nitrogen uptake by rice grown on a lowland soil, eutric gleysol. We hypothesized that combining biochar compost and inorganic N fertilizer would result in increased N uptake by rice and, as a result, increase growth and other yield attributes.

2. Materials and Methods

2.1. Soil and Soil Sampling

The soil for this study was collected from Wulugu, located at 10°28′29.0″ N and 0°47′55.5″ W in the West Mamprusi District in the northern region of Ghana, belonging to the Guinea Savannah Agro-Ecological Zone. The area is characterized by a single rainy season with an annual average rainfall of about 870 mm. The mean daily atmospheric temperature ranges from 24 °C to 32 °C [25]. The soil is locally known as Lima series and classified as eutric gleysol according to the FAO/UNESCO classification [25]. The soil is one of the dominant lowland soils of the interior savanna of Ghana used for rice cultivation. It occurs at the lowest part of a catena of Lima association and developed over shale or mudstone and sandstone [12]. The soil sample used for the pot experiment was randomly taken from the ploughed layer (0–20 cm), bulked and homogenized, and the subsamples were subsequently taken for routine characterization.

2.2. Soil Analysis

Bulk density of the soil was determined by the core method [26]. Particle size distribution of the soil samples was determined by the Bouyoucos hydrometer method modified by Day [27] and the moisture content at field capacity was estimated. Soil pH was determined in water and 1M KCl in a 1:1 soil–water and soil–salt ratio, respectively, using a glass electrode pH meter (Oakton Instruments, Vernon Hills, IL, USA). Total carbon content and total nitrogen content of the soils were determined by dry combustion [28] using a Leco Trumac Carbon Nitrogen Sulphur version 1.3 Analyser (LECO Corporation, St. Joseph, MI, USA). Available phosphorus was determined using the method of Bray and Kurtz [29]. Total phosphorus was determined using the molybdate ascorbic acid method of Watanabe and Olsen [30]. Exchangeable bases were determined by the ammonium acetate method [31] after which the concentration of bases was read on a Perkin Elmer Analyst 800 Atomic Absorption Spectrometer (PerkinElmer, Waltham, MA, USA). The exchangeable acidity was determined by the KCl extraction method [32]. The effective cation exchange capacities (ECEC) were determined by summation of the respective exchangeable bases and exchangeable acidities.

2.3. Biochar Compost Preparation and Characterization

Rice husk served as feedstock for the biochar used in the study. The rice husk was charred at an approximate pyrolysis temperature of 450 °C based on the recommendations of Chan and Xu [33] for optimal pyrolysis conditions of maintaining high nutrient contents and availability. A locally manufactured Kuntan kiln was used for the charring of the feedstock at the University of Ghana school farm, Legon-Accra. Cow manure (CM) and rice husk (RH) in the ratio of 1:1 and 2:1 (*v*/*v*) served as the materials for the preparation of base compost mixture. The base compost (with no biochar) was mixed with the rice husk biochar (RB) to achieve a compost–biochar ratio for the two compost types prepared on a volume basis. The rice husk biochar was mixed with the 1:1 type compost to achieve compost–biochar mixture in ratios of 9:1, 8:2 and 6:4 (*v*/*v*). The 2:1 type compost was also mixed with the rice husk biochar to achieve compost–biochar mixture ratios of 8:2 and 6:4 (Table 1). The composting piles were located under a shed to control the environmental conditions. The piles were turned periodically to aerate and homogenize the composting materials. Enough water was also added during the turns to stimulate microbial activity. The temperature of the pile was monitored periodically during the process (data not shown). The composting lasted for approximately 3 months. Samples were collected on maturing and then air-dried, ground and sieved prior to analysis. Biochar compost pH was determined in water. Total carbon and total nitrogen content of the composts was determined by dry combustion [28] using a Leco Trumac Carbon Nitrogen Sulphur version 1.3 Analyzer. Available phosphorus was determined using the method of Bray and Kurtz [29]. Total phosphorus was determined using the molybdate ascorbic acid method of Watanabe and Olsen [30].

2.4. Experimental Setup

The pot experiment was conducted in a screen house at the University of Ghana school farm. The experiment started in November 2019 and ended in March 2020. The maximum and minimum temperatures in the screen house throughout the experiment were 29 °C and 33 °C, respectively. Plastic containers of diameter 18 cm and height 16 cm were used as pots in the study. The pots were filled with soil to a predetermined height to attain the field bulk density of 1.32 Mg m^{-3}. Ammonium sulphate fertilizer alone or in combination with five different biochar–compost mixtures (based on the proportions of biochar and compost) were used as treatments. There were eight treatments in total with three replicates making a total of twenty-four experimental units. A parallel experiment with the same treatments and experimental units was set up and terminated seven weeks after transplanting for dry matter yield and nitrogen uptake analysis. The whole experiment was set up in a completely randomized design. Biochar composts were applied at single rate of 150 kg N ha^{-1}. Details concerning the treatments used are given in Table 2. The treated soils were then filled with water to the field capacity of the soil and incubated for 2 weeks. Basal P and K fertilizers were applied to all the experimental treatments at rates of 40 kg K_2O ha^{-1} and 45 kg P_2O_5 ha^{-1}, respectively, from muriate of potash and TSP (triple super phosphate). The rice variety used for this experiment was Jasmine 85. The seeds were obtained from Soil and Irrigation Research Centre, (SIREC-Kpong, Eastern Region, Ghana). The seeds were air-dried for three (3) days, sieved and cleaned of debris. The seeds had a germination rate of about 90%. The seeds were nursed and transplanted 12 days after sowing using 3 seedlings per pot. The inorganic fertilizers were applied in two equal splits in respective treatments at 7 and 42 days after transplanting. The fertilizers were pulverized to a fine particle size before being applied by ring placement. A water head between 3 to 5 cm was maintained throughout the experimental period.

Table 1. Description of the compost types.

Compost Type	Mix Ratio	Description
C1	CM:RH 1:1 (9:1RB)	Compost was formed using one part of cow manure and one part of rice husk. After making the compost, nine parts of it were mixed with one part of biochar.
C2	CM:RH 1:1 (8:2RB)	Compost was formed using one part of cow manure and one part of rice husk. After making the compost, eight parts of it were mixed with one part of biochar.
C3	CM:RH 2:1 (9:1RB)	Compost was formed using two parts of cow manure and one part of rice husk. After making the compost, nine parts of it were mixed with one part of biochar.
C4	CM:RH 2:1 (8:2RB)	Compost was formed using two parts of cow manure and one part of rice husk. After making the compost, eight parts of it were mixed with two parts of biochar.
C5	CM:RH 2:1 (6:4RB)	Compost was formed using two parts of cow manure and one part of rice husk. After making the compost, six parts of it were mixed with four parts of biochar.

Table 2. Various treatment combinations used for the pot experiment.

Treatment Code	Compost Type	Compost N Rate	Inorganic N Rate
		kg ha^{-1}	kg ha^{-1}
T1	-	0	0
T2	-	0	100
T3	C1	150	70
T4	C2	150	70
T5	C3	150	70
T6	C3	150	100
T7	C4	150	70
T8	C5	150	70

AS = Ammonium sulphate fertilizer.

2.5. Estimation of Agronomic Characteristics of Rice Plant

Rice growth parameters including plant height, leaf greenness index (SPAD), and the number of tillers were monitored weekly after transplanting. The plant height was measured from the arch of the uppermost leaf to the surface of the soil using a tape measure. The number of tillers was recorded by counting the total number of tillers for each of the pots and the average taken to represent each treatment. SPAD readings were taken using a chlorophyll meter (SPAD-502 Plus, Konica Minolta, Tokyo, Japan). The measurement was carried out in the morning between 9 o'clock and 11 o'clock on the flag leaf of the rice plants. Rice plants were randomly and destructively sampled for dry matter yield analysis seven weeks after transplanting. The roots of the uprooted rice samples were carefully washed with tap water to remove soil debris. The dry weights of the straw and root were recorded after oven drying at a temperature of 70 °C for 3 to 5 days. The root volume was also estimated by volume displacement. Data on growth parameters and yield components, including plant height, number of tillers, number of panicles, aboveground biomass, and thousand grain weight were also taken on the remaining plants samples during and after harvesting.

2.6. Nitrogen Uptake by Rice Plants

The tissue N of the plant shoot was determined using a Leco Trumac Carbon Nitrogen Sulphur version 1.3 Analyzer (LECO Corporation, St. Joseph, MI, USA). Nitrogen uptake was estimated as follows:

$$\text{Shoot N uptake (mg pot}^{-1}) = \text{shoot dry weight} \times \frac{Shoot\ N\%}{100} \times 1000\ \text{mg} \quad (1)$$

2.7. Statistical Analysis

The data were evaluated using analysis of variance (ANOVA). The means were compared by Fisher's Protected LSD test at the 5% level of significance. The analyses were carried out using GENSTAT software (12th edition) and graphs created using Sigma Plot version 14.5.

3. Results

3.1. Soil Physicochemical Properties

The soil bulk density was 1.32 Mg m^{-3}. The particle size gave 330 g sand kg^{-1}, 380 g silt kg^{-1}% and 290 g clay kg^{-1}. The soil was clay loam based on USDA texture classification. The soil pH in water and 1M KCl were 5 and 4.1, respectively. Soil total C and N were 13 g kg^{-1} and 0.8 g kg^{-1}, respectively. Soil total P was 124.5 mg kg^{-1} and the available P was 10.76 mg kg^{-1}. The exchangeable bases consisted of 1.8 cmol Ca^{2+} kg^{-1}, 0.32 cmol Mg^{2+} kg^{-1}, 0.49 cmol K^+ kg^{-1} and 0.22 cmol Na^+ kg^{-1}, respectively. The exchangeable acidity (Al^{3+} and H^+) was 0.62 cmol kg^{-1}. The effective cation exchange capacity (ECEC) of the soil was very low with a value of 3.42 cmol kg^{-1}

3.2. Biochar Compost Characterization

The results obtained from the characterization of the biochar compost are presented in Table 3. Total N was higher in 1:1 compost (C1 and C2) than for those of the 2:1 type (C3, C4 and C5). Highest available N occurred in C1 followed by C4. The C:N ratio of the samples ranged between 15.2 and 18.9 and lower for samples with small biochar doses. The C:N ratio values were appropriate for a matured compost (C:N < 21) [34].

Table 3. Chemical properties of the biochar compost.

Sample ID	pH	TC	TN	TP	Av. P	Av. N	C:N
	(H_2O)	g kg^{-1}			mg kg^{-1}		
C1	7.89	277.58	17.06	4333	2357.5	689.6	16.3
C2	7.90	296.11	15.65	3933	1345	333.0	18.9
C3	7.77	264.37	17.37	4000	2533	320.4	15.2
C4	7.81	268.75	17.12	4100	1970	438.8	15.7
C5	7.78	279.67	15.03	2438	2087	297.0	18.6

TC = Total carbon; TN = Total nitrogen; TP = Total phosphorus; Av. P = Average phosphorus; Av. N = Average nitrogen; C:N = Carbon-to-nitrogen ratio.

3.3. Effects of Various Treatments on Rice Growth

The effects of biochar compost and inorganic N on weekly growth parameters are presented in Figures 1–3. Plant height increased continuously with the advancement of crop growth stages. T7 recorded the highest plant height at week 3, 4 and 5. T2 recorded the highest plant height of 107.53 cm at week 6 and this was highly significant ($p < 0.001$)

relative to all the other treatments. The lowest plant height was observed for T1 throughout the weeks. Number of tillers increased continuously and attained a maximum value at week 4, after which it decreased towards maturity due to side tiller mortality and initiation of panicle primordia. The highest number of tillers was 53 and this was recorded for T7 at week 3. T1 recorded the lowest tiller number from week 3 through to week 6 followed by T2. Increasing the N fertilizer rate to 100 kg N ha^{-1} did not cause any greater change in the number of tillers in T6 compared with T5.

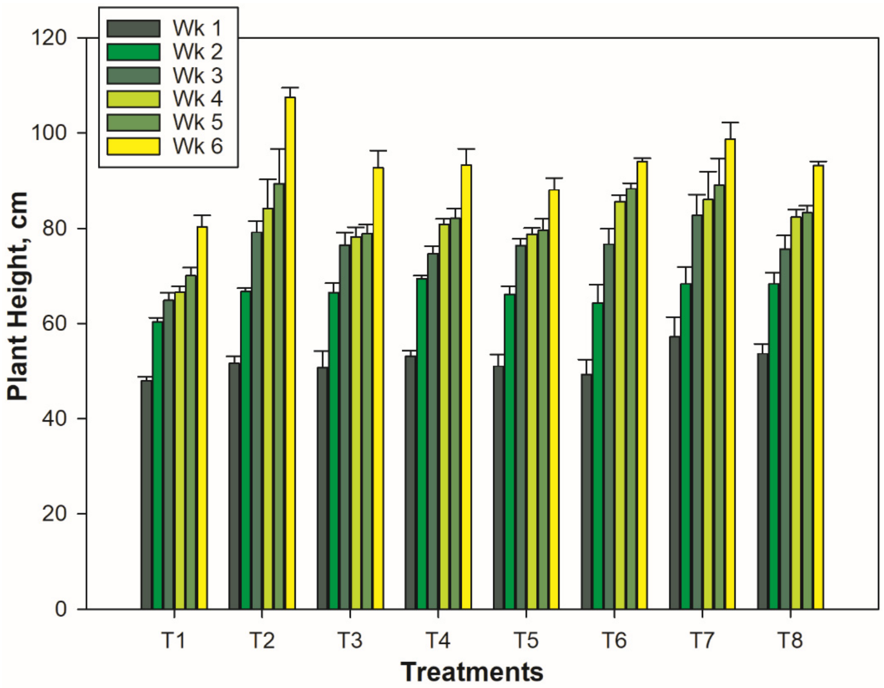

Figure 1. Effect of biochar compost and nitrogen fertilization on the weekly plant height. Wk = Week. (Error bars represent the standard deviation of means, n = 9).

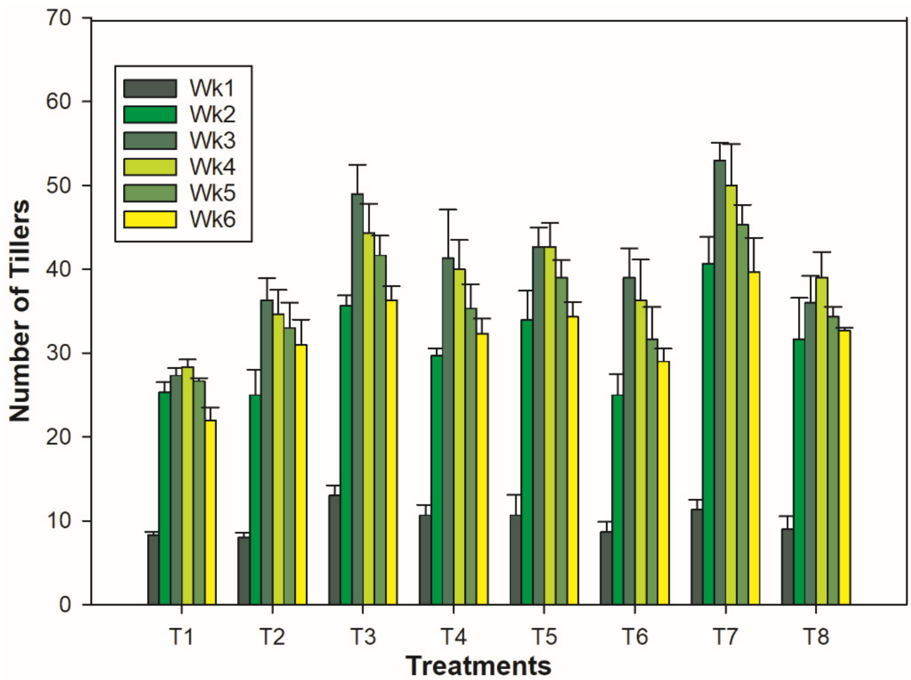

Figure 2. Effect of biochar compost and nitrogen fertilization on the weekly number of tillers of rice. Wk = Week. (Error bars represent the standard deviation of means, n = 9).

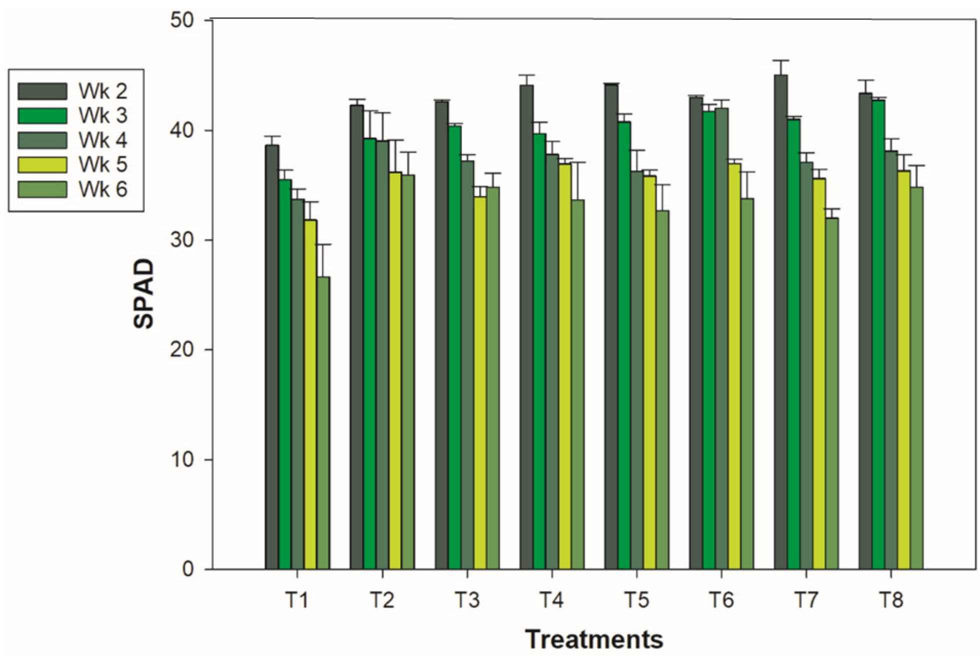

Figure 3. Effect of biochar compost and nitrogen fertilization on the weekly SPAD. Wk = Week. (Error bars represent the standard deviation of means, $n = 9$).

SPAD measurements may be useful in the observation of changes in plant pigments (chlorophylls) [35] and are particularly useful in precision agriculture for determining the plant's need for nitrogen fertilization, which is directly related to yield [36]. High SPAD readings were recorded for rice plants grown in amended soils, but a gradual decrease occurred for all treatments over time. There was no significant difference in the SPAD reading among the treatments at week 5 and week 6. The highest SPAD value (45.03) was recorded for T7 at week 2. The lowest SPAD value (26.67) was observed in T1 at week 6.

3.4. Effects of Various Treatments on Dry Matter Weight of Shoots and Roots, Root Volume and Shoot N Uptake at Vegetative Stage

The results of the dry matter weight of the shoots and roots and root volumes are presented in Table 4. The dry matter weight of rice shoots was significantly higher for the various treatments than for the unamended soil (i.e., T1). The highest shoot dry matter weight of 58.03 g was obtained by T7. The soil with no amendment recorded the lowest root dry weight of 11.77 g, followed by soil amended with only inorganic N, T2, 35.79 g.

Table 4. Effect of biochar compost and nitrogen fertilization on the dry weight of shoots and roots and on root volume at the vegetative stage.

Treatment	Shoot Dry wt. (g)	Root Dry wt. (g)	Root Volume (cm^3)	Shoot N Uptake (mg pot^{-1})
T1	29.32 a	11.77 a	64.0 a	241.10 a
T2	49.52 b	35.79 b	71.70 ab	534.60 b
T3	54.31 b	50.03 bcd	143.30 c	529.10 b
T4	53.08 b	41.79 bc	120.70 bc	523.00 b
T5	53.48 b	56.07 cd	126.70 c	585.50 b
T6	50.47 b	42.35 bc	121.70 bc	577.60 b
T7	58.03 b	61.81 d	128.30 c	602.00 b
T8	52.48 b	41.95 bc	101.70 abc	520.70 b
Fpr	0.006	<0.001	0.038	0.002
CV%	14.3	21.5	26.4	16.3

Fpr = Fisher's probability; CV% = Coefficient of variation. Means with same alphabets are statistically similar ($p < 0.05$, $n = 9$).

A significantly higher (p < 0.001) root dry weight of 61.81 g was recorded when 150 kg N ha^{-1} Compost C4 was applied along with 70 kg N ha^{-1} AS (i.e., T7), which was 5.2 times higher than T1 (control). Overall, 150 kg N ha^{-1} Compost C3 applied together with 70 kg N ha^{-1} AS, i.e., T5 produced a higher root dry matter weight of about 1.3 times higher than 150 kg N ha^{-1} Compost C3 applied together with 100 kg N ha^{-1} AS, T6. In the same manner, the combined application of biochar compost and inorganic N fertilizer significantly influenced the root volume of the rice plant. T3 recorded the highest root volume of 143.3 cm^3 followed by T7 and T5 with 128.30 cm^3 and 126.70 cm^3, respectively. The root volumes of T1, T2 and T8 were not significantly different from each other. The unamended soil recorded the lowest root volume of 64 cm^3 followed by soil only amended with ammonium sulphate fertilizer, 71.7 cm^3. Amending the soil with biochar compost and inorganic N fertilizer significantly increased shoot N uptake by the rice plants (p < 0.05). T7 had the highest shoot N uptake (602 mg pot^{-1}), representing a 2.5-fold increase over the unamended soil. Shoot N uptake in soil only amended with ammonium sulphate was statistically similar to soil amended with combinations of biochar–compost and ammonium sulphate fertilizer (p = 0.05).

3.5. Yield Components

Table 5 summarizes the results of combined application of biochar compost and inorganic N fertilizer on the rice growth parameters and yield components at harvest. Plant height, aboveground biomass (straw and grain weight), number of tillers, number of panicles and 1000 grain weight were significantly affected by the soil amendments used. Grain weight ranged from 23.03 g to 29.20 g. T2 and T7 had the highest and statistically similar grain weight, reflecting a 1.3-fold increase over the control.

Table 5. Effect of biochar compost and nitrogen fertilization on rice growth and yield component after harvest.

Treatment	Plant Height (cm)	Aboveground Biomass Weight (g pot^{-1})	Number of Tillers (pcs pot^{-1})	Number of Panicles (pcs pot^{-1})	1000 Grain Weight (g)
T1	102.70 a	131.20 a	14.00 a	14.00 a	23.03 a
T2	105.70 ab	209.80 b	23.67 cd	21.67 bcd	29.20 c
T3	111.20 bc	248.40 c	20.00 b	19.67 b	27.00 b
T4	117.80 c	266.80 c	21.67 bc	20.50 bc	26.17 b
T5	108.50 ab	245.40 c	22.33 bc	23.33 cd	26.30 b
T6	109.00 ab	273.30 c	26.00 d	24.33 d	26.80 b
T7	108.80 ab	260.00 c	19.67 b	19.00 b	29.20 c
T8	106.30 ab	255.40 c	21.33 bc	21.33 bcd	26.50 b
Fpr	0.03	<0.001	<0.001	<0.001	<0.001
CV%	4.10	6.9	9.4	9.9	4.3

Fpr = Fisher's probability; CV% = Coefficient of variation. Means with same alphabets are statistically similar (p < 0.05, n = 9).

4. Discussion

4.1. Characteristics of Biochar Compost

The biochar compost characterization revealed a slightly alkaline pH within a range ideal for a matured compost. This can be attributed to the addition of biochar during the composting process. The total carbon content of the compost was found to increase with increasing biochar content. The functional groups available on biochar surfaces are known to favor the retention of nutrients and prevent losses from compost. Biochar is also rich in highly aromatic carbon and can even offer physical protection to carbon and hence the high total carbon concentration in the compost with high biochar content. Gasco et al. [37] pointed out a synergistic effect of biochar on compost which promotes carbon stabilization through the formation of organo-complexes. Addition of biochar during the composting process changes the compost properties and quality and can lead to improved physicochemical properties (organic carbon content (OC), pH, moisture content) and nutrient availability (nitrogen, phosphorus and other important nutrients) in the final product [38,39]. The co-composting process also results in an organic coating on the biochar particles that reduces their hydrophobicity and increases nutrient retention for improved agronomic performance [40,41].

4.2. Rice Crop Growth and Nitrogen Uptake

The results of this study show that both combined application of biochar compost and inorganic N fertilizer and inorganic N fertilizer alone had a marked positive effect on rice growth characters at the vegetative stage. T2, T6 and T7 showed significantly higher plant height at later crop growth stages (Figure 2). Increasing plant height with increasing N levels has been associated with the greater availability of nitrogen in soil and higher uptake by plants [42]. There was greater formation of tillers when 150 kg N ha^{-1} biochar compost was applied along with 70 kg N ha^{-1} from ammonium sulphate fertilizer. Other studies also reported high tiller formation in rice when both organic and inorganic N sources were combined [43,44]. This was attributed to the availability of adequate nitrogen provided by both amendments during plant growth. The steady improvement in plant height and tiller count observed in T3 and T7 (Figure 2) could possibly be due to the enhanced N status of the soil. Their better performances may also be explained by the high N content (total and available N) of their biochar compost (Table 4). Ideally, inorganic N fertilizer provides more immediate plant available N unlike compost. However, compost may ensure a longer-term release of plant available N at the same time reducing nutrient leaching [45]. The control produced the least number of tillers and this is because of the low N content of the soil. Some signs and symptoms of N deficiency (e.g., very thin and slender tillers, yellowing of leaves and early senescence of older leaves) appeared in the plants from the unamended soil.

SPAD units reflect relative crop N status and yield level [46]. High and well-balanced fertilization affect the growth of aerial components, including the assimilating leaf area, as expressed by the leaf green area (LAI) or the green area index (GAI), as well as the synthesis of plant pigments in leaves responsible for photosynthesis. Higher SPAD values were obtained in amended soils during the initial development stage of rice. The development of plant aerial mass, which is responsible for photosynthesis, is significantly influenced by the high availability of nitrogen (N), which in turn ensures a high yield. [47]. Lower SPAD values observed in the control could be attributed to the low nitrogen content of the soil. The temporal decline observed for SPAD values would also have been caused by diminishing the availability of fertilizer N in the soil.

Nitrogen is important for the growth and development of the aboveground and belowground structures of the rice plant [48]. Low biomass production as observed in the control can be attributed to lack of N in native soil. Plants respond to nitrogen availability by changing their root–shoot ratio [49]. Dry matter accumulation of rice plants in the integrated treatments was on par with the treatment using only inorganic N (T2) at the vegetative stage (Table 5). High shoot–root ratio in T2 reflects high N availability provided by the inorganic N fertilizer which caused more biomass to be allocated to the shoots rather than the roots. T3, T5 and T7 outperformed other integrated treatments in terms of biomass production (Table 5). This could be associated with their superior biochar compost chemical properties (Table 3). Another factor could be the potential of both amendments especially compost to improve the soil's characteristics such as pH, exchangeable cation and availability of other nutrient elements.

Adequate nutrient uptake and balanced nutrition are essential prerequisites for increasing crop yields. Similarly, distribution of absorbed or accumulated nutrients in shoot and grain (higher N in grain) is associated with yield improvement [50]. Co-application of biochar compost and inorganic fertilizer increased the nitrogen uptake by the rice plant. This could imply that the application of the two nitrogen sources improved nitrogen retention and bioavailability in the soil. High N uptake in amended soils could be related to the split method of application of the inorganic N fertilizer. This might have decreased N losses in the soil as the element was supplied to the plant at the critical development stages of the rice plants. Organic and inorganic N sources may interact positively, increasing N uptake by the rice plant [20]. The use of biochar compost and inorganic N fertilizer may have resulted in improved N mineralization and decreased N losses, resulting in high N availability for rice uptake.

4.3. Influence of Soil Amendment on Yield Components

Nitrogen is important in rice yield because plant nitrogen status influences the development of the grain yield component [51]. Rice plant growth parameters and yield components were enhanced by the incorporation of biochar compost and ammonium sulphate fertilizer (Table 5). Plant height was maximized with T3 and T4. This could be attributed to higher N uptake by rice due to adequate nitrogen provided by both soil amendments and the gradual release of nitrogen from the compost all through the cultivation period. The significant increase in 1000 grain weight in response to the application of soil amendments as seen in all treatments is probably due to enhanced availability of nitrogen. Finally, grain weight in T7 was on par with that in T2, implying that mixing biochar composts with inorganic N could promote grain production.

5. Conclusions

It was demonstrated that co-applying biochar compost produced from cow manure, rice husk and rice husk biochar at various mix ratios with inorganic N fertilizer improved lowland rice growth and yield components. The results of rice growth parameters and yield components also corresponded well with nitrogen uptake across the treatments. The integrated use of biochar compost and inorganic N fertilizer has the potential to significantly improve the suitability of lowland soils for sustainable rice production in Northern Ghana. Further research will evaluate the full effect of the soil amendments on long-term soil conditions as well as rice productivity in field paddy environments in Northern Ghana.

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References

1. Anang, B.T.; Adjetey, S.; Abiriwe, S. Consumer Preferences for Rice Quality Characteristics and the Effects on Price in the Tamale Metropolis, Northern Region, Ghana. *Int. J. AgriScience* **2011**, *1*, 67–74.
2. Donkor, E.; Matthews, N.; Ogundeji, A.A. Efficiency of Rice Farming in Ghana: Policy Implications for Rice Sector Development. *Afr. Dev. Rev.* **2018**, *30*, 149–161. [CrossRef]
3. Tanko, M.; Ismaila, S.; Sadiq, S.A. Planting for Food and Jobs (PFJ): A Panacea for Productivity and Welfare of Rice Farmers in Northern Ghana. *Cogent Econ. Financ.* **2019**, *7*, 1693121. [CrossRef]
4. Buri, M.M.; Issaka, R.N.; Senayah, J.K.; Fujii, H.; Wakatsuki, T. Lowland Soils for Rice Cultivation in Ghana. In *Crop Production Technologies*; Sharma, P., Ed.; InTech: London, UK, 2012; ISBN 978-953-307-787-1.
5. Buri, M.M.; Issaka, R.N.; Wakatsuki, T.; Kawano, N. Improving the Productivity of Lowland Soils for Rice Cultivation in Ghana: The Role of the "Sawah" System. *J. Soil Sci. Environ. Manag.* **2011**, *2*, 304–310.
6. Abdul-Rahaman, A.; Abdulai, A. Do Farmer Groups Impact on Farm Yield and Efficiency of Smallholder Farmers? Evidence from Rice Farmers in Northern Ghana. *Food Policy* **2018**, *81*, 95–105. [CrossRef]
7. Sollins, P.; Robertson, G.P.; Uehara, G. Nutrient Mobility in Variable- and Permanent-Charge Soils. *Biogeochemistry* **1988**, *6*, 181–199. [CrossRef]

8. Ohnemus, T.; Spott, O.; Thiel, E. Spatial Distribution of Urea Induced Ammonia Loss Potentials of German Cropland Soils. *Geoderma* **2021**, *394*, 115025. [CrossRef]
9. Cassman, K.G.; Dobermann, A.; Cruz, P.C.S.; Gines, G.C.; Samson, M.I.; Descalsota, J.P.; Alcantara, J.M.; Dizon, M.A.; Olk, D.C. Soil Organic Matter and the Indigenous Nitrogen Supply of Intensive Irrigated Rice Systems in the Tropics. *Plant Soil* **1996**, *182*, 267–278. [CrossRef]
10. Adugna, G. A Review on Impact of Compost on Soil Properties, Water Use and Crop Productivity. *Acad. Res. J. Agric. Sci. Res.* **2016**, *4*, 93–104.
11. Lehmann, J.; Rondon, M. Bio-Char Soil Management on Highly Weathered Soils in the Humid Tropics. In *Biological Approaches to Sustainable Soil Systems*, 1st ed.; Uphoff, N., Ball, A.S., Fernandes, E., Herren, H., Husson, O., Laing, M., Palm, C., Pretty, J., Sanchez, P., Sanginga, N., et al., Eds.; CRC Press: Boca Raton, FL, USA, 2006; pp. 518–537. [CrossRef]
12. Yang, Y.; Ma, S.; Zhao, Y.; Jing, M.; Xu, Y.; Chen, J. A Field Experiment on Enhancement of Crop Yield by Rice Straw and Corn Stalk-Derived Biochar in Northern China. *Sustainability* **2015**, *7*, 13713–13725. [CrossRef]
13. Abukari, A. Influence of Rice Husk Biochar on Water Holding Capacity of Soil in The Savannah Ecological Zone of Ghana. *Turk. J. Agric. Food Sci. Technol.* **2019**, *7*, 888–891. [CrossRef]
14. Avornyo, V.K. Increasing Rice Productivity in the Lowland Soils of the Interior Savanna of Ghana: The Role of Rice Husk Biochar and Phosphate Rock. Ph.D. Thesis, Iowa State University, Ames, IA, USA, 2019.
15. Laird, D.; Fleming, P.; Davis, D.; Horton, R.; Wang, B.; Karlen, D. Impact of Biochar Amendments on the Quality of a Typical Midwestern Agricultural Soil. *Geoderma* **2010**, *158*, 443–449. [CrossRef]
16. Kartika, K.; Sakagami, J.-I.; Lakitan, B.; Yabuta, S.; Akagi, I.; Widuri, L.I.; Siaga, E.; Iwanaga, H.; Nurrahma, A.H.I. Rice Husk Biochar Effects on Improving Soil Properties and Root Development in Rice (*Oryza glaberrima* Steud.) Exposed to Drought Stress during Early Reproductive Stage. *AIMS Agric. Food* **2021**, *6*, 737–751. [CrossRef]
17. Rao, D.N.; Mikkelsen, D.S. Effect of Rice Straw Incorporation on Rice Plant Growth and Nutrition 1. *Agron. J.* **1976**, *68*, 752–756. [CrossRef]
18. Oh, W.K. Effects of Incorporation of Organic Materials on Paddy Soils. In *Nitrogen and Rice Symposium Proceedings*; IRRI: Los Banos, Philippines, 1979; pp. 435–449.
19. Antonangelo, J.A.; Sun, X.; Zhang, H. The Roles of Co-Composted Biochar (COMBI) in Improving Soil Quality, Crop Productivity, and Toxic Metal Amelioration. *J. Environ. Manag.* **2021**, *277*, 111443. [CrossRef] [PubMed]
20. Moe, K.; Mg, K.W.; Win, K.K.; Yamakawa, T. Effects of Combined Application of Inorganic Fertilizer and Organic Manures on Nitrogen Use and Recovery Efficiencies of Hybrid Rice (Palethwe-1). *Am. J. Plant Sci.* **2017**, *8*, 1043. [CrossRef]
21. Ullah, M.; Islam, M.; Islam, M.; Haque, T. Effects of Organic Manures and Chemical Fertilizers on the Yield of Brinjal and Soil Properties. *J. Bangladesh Agric. Univ.* **1970**, *6*, 271–276. [CrossRef]
22. Nyalemegbe, K.K.; Oteng, J.W.; Asuming-Brempong, S. Integrated Organic-Inorganic Fertilizer Management for Rice Production on the Vertisols of the Accra Plains of Ghana. *West Afr. J. Appl. Ecol.* **2010**, *16*. [CrossRef]
23. Sulemana, N.; Nartey, E.K.; Abekoe, M.K.; Adjadeh, T.A.; Darko, D.A. Use of Biochar-Compost for Phosphorus Availability to Maize in a Concretionary Ferric Lixisol in Northern GHANA. *Agronomy* **2021**, *11*, 359. [CrossRef]
24. Bimbraw, A.S. *Established and Emerging Practices for Soil and Crop Productivity*; CRC Press: Boca Raton, FL, USA, 2021; ISBN 1-00-320034-6.
25. Ahmed, G. The Influence of Rice Husk Biochar and Nitrogen Sources on the Growth of Lowland Rice on an Eutric Gleysol from Walewale. Master's Thesis, University of Ghana, Legon, Accra, Ghana, 2018.
26. Blake, G.R.; Hartge, K.H. Bulk Density. In *Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods*; American Society of Agronomy: Madison, WI, USA, 1986; Volume 5, pp. 363–375.
27. Day, P.R. Particle Fractionation and Particle-size Analysis. In *Methods of Soil Analysis: Part 1 Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling*; American Society of Agronomy: Madison, WI, USA, 1965; Volume 9, pp. 545–567.
28. Nelson, D.W.; Sommers, L.E. Total Carbon, Organic Carbon, and Organic Matter. In *Methods of Soil Analysis*; John Wiley & Sons, Ltd.: Hoboken, NJ, USA, 1983; pp. 539–579. ISBN 978-0-89118-977-0.
29. Bray, R.H.; Kurtz, L.T. Determination of Total, Organic, and Available Forms of Phosphorus in Soils. *Soil Sci.* **1945**, *59*, 39–46. [CrossRef]
30. Watanabe, F.S.; Olsen, S.R. Test of an Ascorbic Acid Method for Determining Phosphorus in Water and $NaHCO_3$ Extracts from Soil. *Soil Sci. Soc. Am. J.* **1965**, *29*, 677–678. [CrossRef]
31. Chapman, H. Cation-exchange Capacity. In *Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties*; American Society of Agronomy: Madison, WI, USA, 1965; Volume 9, pp. 891–901.
32. Thomas, G.W. Exchangeable Cations. In *Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties*; American Society of Agronomy: Madison, WI, USA, 1983; Volume 9, pp. 159–165.
33. Chan, K.Y.; Xu, Z. Biochar: Nutrient Properties and Their Enhancement. In *Biochar for Environmental Management: Science, Technology and Implementation*, 2nd ed.; Lehmann, J., Joseph, S., Eds.; Routledge: London, UK, 2015; ISBN 1-134-48953-6.
34. USDA, U. *Test Methods for the Examination of Composting and Compost*; United States Department of Agriculture, United States Composting Council: Washington, DC, USA, 2002.
35. Żołnowski, A.C.; Wyszkowski, M.; Rolka, E.; Sawicka, M. Mineral Materials as a Neutralizing Agent Used on Soil Contaminated with Copper. *Materials* **2021**, *14*, 6830. [CrossRef] [PubMed]

36. Zhang, K.; Liu, X.; Ma, Y.; Zhang, R.; Cao, Q.; Zhu, Y.; Cao, W.; Tian, Y. A Comparative Assessment of Measures of Leaf Nitrogen in Rice Using Two Leaf-Clip Meters. *Sensors* **2019**, *20*, 175. [CrossRef]
37. Gasco, G.; Paz-Ferreiro, J.; Cely, P.; Plaza, C.; Mendez, A. Influence of Pig Manure and Its Biochar on Soil CO_2 Emissions and Soil Enzymes. *Ecol. Eng.* **2016**, *95*, 19–24. [CrossRef]
38. Agegnehu, G.; Bass, A.; Nelson, P.; Bird, M. Benefits of Biochar, Compost and Biochar–Compost for Soil Quality, Maize Yield and Greenhouse Gas Emissions in a Tropical Agricultural Soil. *Sci. Total Environ.* **2016**, *543*, 295–306. [CrossRef] [PubMed]
39. Prost, K.; Borchard, N.; Siemens, J.; Kautz, T.; Séquaris, J.; Möller, A.; Amelung, W. Biochar Affected by Composting with Farmyard Manure. *J. Environ. Qual.* **2013**, *42*, 164–172. [CrossRef] [PubMed]
40. Kammann, C.I.; Schmidt, H.-P.; Messerschmidt, N.; Linsel, S.; Steffens, D.; Müller, C.; Koyro, H.-W.; Conte, P.; Joseph, S. Plant Growth Improvement Mediated by Nitrate Capture in Co-Composted Biochar. *Sci. Rep.* **2015**, *5*, 1–13.
41. Hagemann, N.; Joseph, S.; Schmidt, H.-P.; Kammann, C.; Harter, J.; Young, R.; Varga, K.; Taherymoosavi, S.; Elliott, K.; Mckenna, A.; et al. Organic Coating on Biochar Explains Its Nutrient Retention and Stimulation of Soil Fertility. *Nat. Commun.* **2017**, *8*, 1089. [CrossRef]
42. Saha, B.; Panda, P.; Patra, P.S.; Panda, R.; Kundu, A.; Roy, A.K.S.; Mahato, N. Effect of Different Levels of Nitrogen on Growth and Yield of Rice (*Oryza Sativa* L.) Cultivars under Terai-Agro Climatic Situation. *Int. J. Curr. Microbiol. App. Sci.* **2017**, *6*, 2408–2418. [CrossRef]
43. Tetteh, Z.V. Effect of Compost and Inorganic Nitrogen Fertilizer on Nutrient Uptake, Growth and Grain Yield of Nerica Rice. Master's Thesis, University of Ghana, Legon, Accra, Ghana, 2009.
44. Buri, M.; Issaka, R.; Zoromi, A.; Adjei, E.; Wakatsuki, T. Improving Soil Productivity and Increasing Lowland Rice Yields through the Integration of Organic and Inorganic Fertilizers in the Savannah and Forest Agro-Ecological Zones of La Cote d'Ívoire. *West Afr. J. Appl. Ecol.* **2022**, *30*, 35–47.
45. Rynk, R.; Cooperband, L.; Oshins, C.; Wescott, H.; Bonhotal, J.; Schwarz, M.; Sherman, R.; Brown, S. Chapter 1—Why Compost? In *The Composting Handbook*; Rynk, R., Ed.; Academic Press: Cambridge, MA, USA, 2022; pp. 1–26. ISBN 978-0-323-85602-7.
46. Chapman, S.; Barreto, H. Using a Chlorophyll Meter to Estimate Specific Leaf Nitrogen of Tropical Maize during Vegetative Growth. *Agron. J.* **1997**, *89*, 557–562. [CrossRef]
47. Ciećko, Z.; Żołnowski, A.; Mierzejewska, A. Impact of Foliar Nitrogen and Magnesium Fertilization on Concentration of Chlorophyll in Potato Leaves. *Ecol. Chem. Engineering. A* **2012**, *19*, 525–535.
48. Fageria, N.; Baligar, V. Lowland Rice Response to Nitrogen Fertilization. *Commun. Soil Sci. Plant Anal.* **2001**, *32*, 1405–1429. [CrossRef]
49. Agren, G.I.; Franklin, O. Root: Shoot Ratios, Optimization and Nitrogen Productivity. *Ann. Bot.* **2003**, *92*, 795–800. [CrossRef] [PubMed]
50. Baligar, V.C.; Fageria, N.K. Agronomy and Physiology of Tropical Cover Crops. *J. Plant Nutr.* **2007**, *30*, 1287–1339. [CrossRef]
51. Yoshida, S. *Fundamentals of Rice Crop Science*; International Rice Research Institute: Los Baños, Philippines, 1981; ISBN 19886768384.