Can soil amendment with or without fertiliser benefit the soil and upland rice?

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Abstract

Crop production is being threatened by poor soil quality and nutrient loss. An avenue to enhance soil quality for sustainable crop production is to explore the appropriate soil amendment with or without chemical fertiliser. A pot experiment was used to investigate the effects of biochar at 5tha^{-1}(BC5), sawdust at 5tha^{-1}(SD5), biochar at 5tha^{-1} with fertiliser (BC5-F), sawdust at 5tha^{-1} with fertiliser (SD5-F), biochar at 50t ha^{-1} (BC50), sawdust at 50tha^{-1} (SD50), biochar at 50tha^{-1}with fertiliser (BC50-F), sawdust at 50tha^{-1} with fertiliser (SD50-F) and control on soil quality, growth, and yield of upland rice. BC50-F or BC50 increased the soil pH, but SD5-F reduced the soil pH. Also, SD50-F or SD50 enhanced soil organic carbon and total nitrogen. The BC50, BC5-F and SD5-F treatments enhanced available P in Akim Oda soil (Ferric Acrisol). In the Winneba soils (Haplic Lixisol), all treatments enhanced available P except SD5. Furthermore, all treatments with fertiliser enhanced rice tiller numbers and plant height in Akim Oda, except BC50, which decreased height. Compared to the Winneba soil, BC5-F and SD5-F enhanced rice tiller numbers. However, plant height was maintained for all treatments except for BC50-F. Similarly, straw yield in the Akim Oda and Winneba soils was improved by all treatments except BC50-F in Winneba soil. Grain yield in the Akim Oda soil was enhanced in BC50-F, SD50-F and SD5-F, but only in SD50-F for Winneba soil. Biochar or sawdust with inorganic fertiliser could enhance soil properties and crop yield, depending on the soil type.

Keywords: biochar, sawdust, fertiliser, soil, upland rice

Introduction

There is a greater need for food due to the increased human population (Lau et al., 2021). However, climate change and its impacts on soil quality threaten food production through agriculture. According to Pozza and Field (2020), the gradual deterioration of soil quality can result in crop failure and a subsequent decrease in the amount of food required to feed the world's population. FAO (2019) noted that once soils start deteriorating, they fail to offer the projected ecosystem services for users. Human land use activities that affect soil organic matter, leaching, nutrient imbalance, and erosion are frequently linked to soil deterioration (Fahad et al., 2020).

The agricultural sector has adopted various strategies to enhance crop production in response to the growing food demand (Ngumbela et al., 2020). Agricultural intensification to enhance food production has led to environmental challenges, including global warming, water pollution, and land degradation (Beltran-Pea et al., 2020). Enhancing soil quality to boost crop yields is a key strategy in food production systems. The utilisation of biochar is increasingly favoured among various soil amendments employed in sustainable farming practices. The acceptance of this method stems from its effectiveness in increasing soil pH levels. Moreover, its resistant characteristics allow for the prolonged retention of nutrients within the soil. The availability of these nutrients is ensured for the upcoming cropping season. The addition of biochar to soil influences various properties, including total organic carbon, pH, cation exchange capacity, surface area, bulk density, water-holding capacity, available phosphorus, total nitrogen, and nutrient use efficiency (Seleiman et al., 2020;

Wang et al., 2020). Biochar is utilised in soils for climate change management, aiding in storing carbon within the soil and preventing the release of CO_2 into the atmosphere. Therefore, incorporating biochar presents a beneficial approach to combat climate change, enhance soil quality, and help reduce environmental pollution. Although multiple studies demonstrate that biochar increases pH and liming the soil to address acidity, hence improving soil quality, some argue that biochar's effectiveness is not straightforward (Jeffery et al., 2017). For instance, the effects of biochar on soil and plant yield may differ depending on the temperature of its production and application. Yang et al. (2022) reported that irrespective of soil type, the fraction of carbon in the biochar that mineralised diminished as pyrolysis temperature increased. Consequently, selecting the appropriate biochar type, the rate at which it is applied and evaluating soil and environmental conditions is essential for its application. However, the impact of the uncharred feedstock on the soil and plant has not been adequately studied. Thus, further investigation is required to elucidate the impact of biochar from different feedstocks and applied at different rates on crop development, yield, and, more especially, to comprehend the mechanisms that govern plant responses. This comprehension is crucial for the large-scale use and adoption of biochar as a soil amendment. We hypothesised that the application of sawdust or biochar with or without chemical fertiliser to soils would have different effects on soil quality, growth and yield of upland rice. Therefore, the aim of this study was to evaluate the effects of biochar or sawdust applied alone, and biochar or sawdust applied with chemical fertilisers on soil quality, growth and yield of upland rice in soils from two agroecological zones in Ghana. Specifically, we employed an incubation study and a pot experiment to ascertain:

1) If the application of biochar to soil will enhance the soil quality more than the application of sawdust.
2) If the application of biochar to the soil will enhance the growth and yield of upland rice more than the application of sawdust.

Materials and Methods

Sites and soil sampling

The soils for the experiment were collected from arable lands at Akim Oda (05° 57' 25.9" N and 000 ° 58' 44.6" W) in the Birim Central Municipality and at Winneba (05° 23' 44.0" N and 000° 35' 44.4" W) in the Effutu

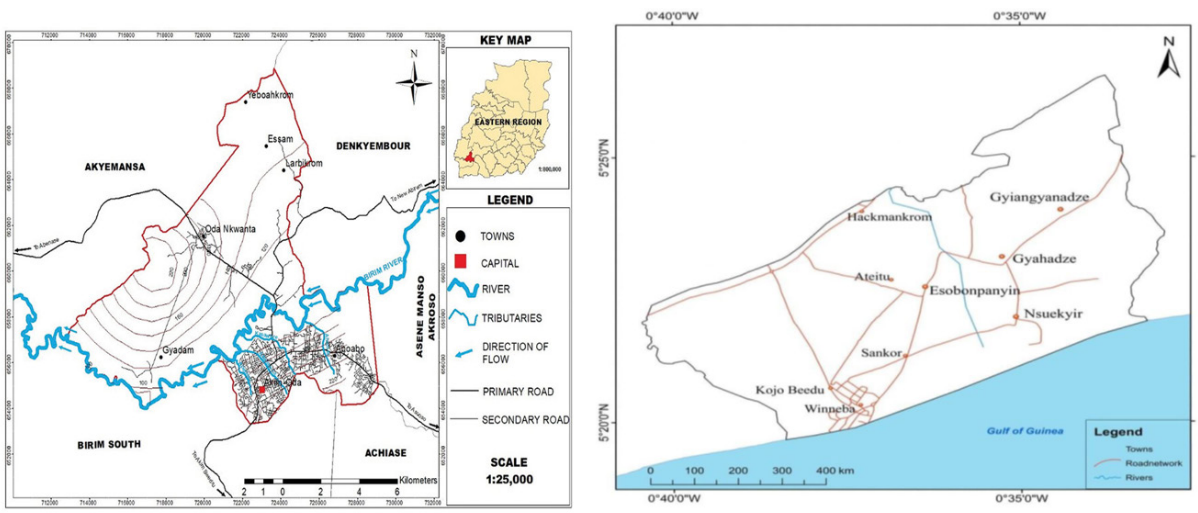

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Figure 1 Map of (A) Birim Central Municipality and (B) Effutu Municipality showing the locations of Akim Oda and Winneba . Source (B): Geographic Information Systems, Remote Sensing and Cartography Section of the University of Education, Winneba

TABLE 1

Treatments and rates of biochar, sawdust, and inorganic fertilisers used in the experiment

Treatment	Rate
Control-Soil only (C)	0 % (w/w)
Biochar only (BC5)	0.25 % (5 t ha^{-1} equivalent)w/w)
Biochar only (BC50)	2.5 % (50 t ha^{-1} equivalent) w/w)
Sawdust only (SD5)	0.25% (5 t ha^{-1} equivalent) w/w)
Sawdust only (SD50)	2.5 % (50 t ha^{-1} equivalent) w/w)
Biochar + Fertilizer (BC5-F)	0.25 % (5 t ha^{-1} equivalent) w/w) + 90N: 60P: 60K (Kg/ha)
Biochar + Fertilizer (BC50-F)	2.5 % (50 t ha^{-1} equivalent) w/w)+ 90N: 60P: 60K (Kg/ha)
Sawdust + Fertilizer (SD5-F)	0.25 % (5t ha^{-1} equivalent) w/w)+ 90N: 60P: 60K (Kg/ha)
Sawdust + Fertilizer (SD50-F)	2.5 % (50 t ha^{-1} equivalent) w/w)+ 90N: 60P: 60K (Kg/ha)

Municipality of Ghana (Figure 1). The Akim Oda site has been cultivated continuously for three years with no history of biochar application. The Winneba site has been left uncultivated with any major crop for about four years. The agroecological zone of Akim Oda is a semi-deciduous rainforest, and that of Winneba is the Coastal Savanna (Klutse et al., 2014; MoFA, 2019).

Akim Oda has a mean annual rainfall of 1400 mm and a mean annual temperature of 26°C (Ghana Statistical Service, 2014). *Triplochiton scleroxylon*, *Antaris africana*, *Clorophora excelsa*, and *Ceiba pentandra* are common trees in Akim Oda. Winneba has a mean annual rainfall of 800 mm (Klutse et al., 2014), and an average temperature between 22 and 28 °C. Trees like *Eucalyptus* and *Cassia*, shrubs notably *Borrelia*, *Abutilon*, and *Gymnema*, as well as grasses and sedges such Vetiver sp., *Fimbristylis* sp., *Brachiaria* sp., *Sporobolus pyramidalis*, and *Setaria* are also in Winneba (Ankrah, 2020). The Akim Oda and Winneba soils are classified as Ferric Acrisol and Haplic Lixisol, respectively (FAO, 1998).

Soil samples were taken within a depth of 0 - 30 cm and analysed for pH, total organic carbon, available phosphorous, total nitrogen, exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}), exchangeable acidity ((H^{+} and Al^{3+}), bulk density and texture (sand, silt, and clay). The soils' pH was measured using a glass electrode pH metre at a ratio of 1: 2.5 (w/v) soil to water (10g of sample in 25 ml of deionized water) (Anderson & Ingram, 1993). The total organic carbon (TOC) of the soil was determined by the Walkley–Black method (Black, 1965) Available P was determined by the Olsen's method (Olsen, 1954), and total nitrogen by the Kjeldahl method (Landon, 1984). Soil extraction for exchangeable cations was analysed using the NH_4OAc method at pH 7 and determined using an Atomic Absorption Spectrophotometer(Thomas,1982). Exchangeable acidity was determined by the titration method described by Robertson et al. (1999). The effective cation exchange capacity (ECEC) was also determined by summing the exchangeable cations and acidity. Soil texture was determined using the hydrometer method (Anderson and Ingram, 1993), and bulk density by the cylindrical core method (Arshad et al.,1996). Table 2 presents the initial properties of the soils.

Biochar production

A top-lit updraft (TLUD) gasifier, built using a barrel, was used to produce the biochar (Steiner et al., 2018). The biochar's feedstock was softwood (*Triplochiton scleroxylon*) sawdust and was provided by Tony Toffey Wood Processing Company Limited in Akim Oda. The biochar and uncharred sawdust were packaged separately for characterisation.

Characterisation of the amendments

The biochar and sawdust were analysed for pH, total organic carbon, total nitrogen, total phosphorus, calcium, magnesium and potassium. The ash content, fixed carbon, and volatile matter were analysed for the biochar only, while lignin was also analysed for the

TABLE 2

Physico-chemical properties of the Akim Oda and Winneba soils before treatment application used in the study

Parameter	Akim Oda		Winneba	
	0-15cm	15-30cm	0-15cm	15-30cm
Available P (mg kg^{-1})	4.42	1.92	12.27	11.01
OM (%)	2.10	1.23	2.23	1.39
pH (1:2.5)	5.33	5.2	7.39	7.13
TN (%)	0.09	0.08	0.12	0.06
Exch. Mg^{2+} ($cmol_c \cdot kg^{-1}$)	1.28	1.07	1.70	1.49
Exch. Ca^{2+} ($cmol_c \cdot kg^{-1}$)	2.13	2.77	5.75	5.11
Exch. K^+ ($cmol_c \cdot kg^{-1}$)	0.11	0.14	0.63	0.37
Exch. Na^+ ($cmol_c \cdot kg^{-1}$)	0.01	0.01	0.06	0.01
H^++Al^{3+} ($cmol_c \cdot kg^{-1}$)	0.65	0.70	0.05	0.05
ECEC $cmol_c \cdot kg^{-1}$)	4.18	4.69	8.19	7.03
ESP (%)	0.28	0.25	0.74	0.14
BD (g/cm^3)	1.53	1.65	1.59	1.64
Clay (%)	4.20	4.20	4.10	4.10
Silt (%)	4.10	4.10	3.80	3.80
Sand (%)	91.7	91.70	92.10	92.10
Texture	Sand	Sand	Sand	Sand

OM = Organic matter : TN = Total Nitrogen BS = Base saturation : BD = Bulk density, CEC = Cation Exchange Capacity, ESP= Exchangeable Sodium Percentage, ECEC= Effective Cation Exchange Capacity

sawdust only. The ashing method was used to determine the TOC (Mclaughlin, 2010). Using a glass electrode pH metre, the pH was determined in a suspension of the sample (1:10) (w/v) . The Kjeldahl method was used to determine the total nitrogen, and the Autoanalyser was used to estimate the total phosphorus (Gupta, 2006). Additionally, Ca^{2+}, K^+ and Mg^{2+} were determined using an Atomic Absorption Spectrophotometer (Thomas, 1982). The proximate analysis method (ASTM, 2009) was used to prepare and determine the biochar's ash, volatile matter and fixed carbon. The lignin content of sawdust was determined gravimetrically using the ADF Method (Rowland and Roberts, 1999). The chemical characteristics of the sawdust and biochar are presented in Table 3.

Experimental setup

The study employed an incubation and an outdoor pot experiment with upland rice

TABLE 3

Chemical characteristics of the amendments used in the study

Parameter	Unit	Biochar	Sawdust
TOC	%	44	48
pH (1:10)	-	9.04	6.05
Ash	%	17	Nd
Volatile matter	%	31.5	Nd
Fixed carbon	%	14.11	Nd
Lignin	%	nd	35.59
Mg	%	0.46	0.19
Ca	%	1.8	0.58
K	%	0.63	0.22
P	%	0.03	0.01
TN	%	0.54	0.42
C:N	-	81.48	114.28

TOC = Total Organic Carbon, TN = Total Nitrogen, C: N = Carbon to Nitrogen Ratio as a test crop. There were five different treatments, three levels, and three replications each. The treatments were: Control with no soil amendments (C), Biochar only (BC), Sawdust only (SD), Biochar with inorganic fertilisers (BCF), and Sawdust with inorganic fertiliser (SDF) (Table 1). Biochar and sawdust were each applied at the rates of 0, 0.25 and 2.5% (w/w) while fertilisers were applied at the rates of 90, 60 and 60 Kg/ha for urea, muriate of potash and triple superphosphate, respectively. Thus, there were nine treatments and twenty-seven experimental setups.

Addition of soil amendments and soil incubation

The biochar and sawdust were each thoroughly mixed in proportion with 4kg of air-dried soil (<2 mm). The mixtures were filled into plastic pots with a diameter of 20 cm and a height of 18 cm. The mixtures were gently tapped to approximate a bulk density of 1.53 g/cm^3 for the Akim Oda soil and 1.59 g/cm^3 for the Winneba soil among the experimental units to reflect the respective soil bulk densities in the field. The plastic pots' bottoms were perforated to drain excess water and to prevent easy soil loss. The proportion of treatment-soil mixture of 0.25 % biochar or sawdust to soil means 2.5 to 1000 g of soil, while a 2.5 % biochar or sawdust to soil means 25 to 1000 g of soil. Deionised water was added to all pots to saturate the soils and was then left to drain for 24 hours to reach field capacity. The pots were covered with perforated parafilm to facilitate air circulation and prevent water loss from evaporation. They were then kept in a dark room at 25°C for two weeks at 20% field capacity. After two weeks, soil samples were taken from each pot, air-dried and analysed.

Pot Experiment

The pot experiment was conducted after incubation in an experimental screen garden at the Soil Research Institute's field in Kwadaso, Ashanti Region, Ghana. The area lies between latitudes 06^0.39' and 06^0.43' N and longitudes 1^0.39' and 1^0.42' W. It is located in Ghana's moist deciduous forest zone (Taylor, 1952) and is characterised by bimodal rainfall. The mean annual precipitation is about 1500 mm, while the mean monthly temperature ranges from 24 to 28°C

The upland rice variety (CRI-KAFACI) was used for this study. The rice grains were nursed on a nursery bed, and two rice seedlings were transplanted into each pot from a 21-day nursery. The seedlings were planted 1 cm deep into the soil. After 14 days, the seedlings were reduced to one by eliminating the less robust ones. Throughout the experiment, each pot received an equal amount of water every three days.

Urea, triple superphosphate, and muriate of potash were used to fertilise the soil at the rate of 90 N: $60P_2O_5$: and $60K_2O$ (kg/ha), respectively. Before the two weeks of incubation, all the 60% P, all the 60% K, and half (45%) of N were added as a basal dose to BC5-F, BC50-F, SD 5-F and SD50-F treatments by mixing them with soil. 21 days after transplanting (DAT), the remaining half of the N fertiliser was applied by dibbling.

The number of tillers and plant height were measured every 14 days starting from 30 days after transplanting (DAT) till maturity. The tillers of rice plants in a pot were counted while plant height was measured using a tape measure from the soil surface to the tip of the topmost leaf of the young plants, and the tip of the longest panicle of mature plants. At maturity, the rice in each pot was harvested by cutting the stalk directly on the soil surface and threshed by hand to separate the grains from the straw. The grains and the straw were dried in an oven at 70°C. until a constant dry weight was attained for the determination of grain and straw biomass.

Data Analysis

A one-way ANOVA was performed between the treatments for each soil type to determine the effects of the amendments and amendments with fertiliser on soil quality, growth and yield of rice. Duncan LSD was used to separate means at a 5% level of probability. Statistical analysis was performed using R Statistical Software, and the results were displayed using bar charts and tables.

Results

Initial soil properties

At the depths of 0-15 and 15-30cm, respectively, the total nitrogen (0.12 and 0.06 %,), available phosphorus (12.27 and 11.01 mg kg^{-1}), and organic matter content (2.23 and 1.39%) of the Winneba soil (*Adawso series*, Haplic Lixisol) was higher than that of Akim Oda soil (*Nzema series*, Ferric Acrisol) with total nitrogen of 0.09 and 0.08%, avail P (4.42 and 1.92 mg kg^{-1}) and organic matter (2.10 and 1.30%) for top- and sub-soils (Table 2). The Akim Oda soil was strongly acidic (pH, 5.33 and 5.20) while the Winneba soil was slightly alkaline (pH, 7.39 and 7.13).

Generally, the exchangeable cations of the Akim Oda soils (Exch. Mg^{2+}, 1.28 and 1.07 cmolc·kg^{-1}, Exch Ca^{2+}, 2.13 and 2.77 cmolc·kg^{-1} Exch. K^+, 0.11 and 0.14 cmolc·kg^{-1}, Exch. Na^+, 0.01 and 0.01 cmolc·kg^{-1}) with ECEC of, 4.18 and 4.69 cmolc·kg^{-1}) were relatively lower than those of the Winneba soils (Exch.Mg^{2+}, 1.70 and 1.49 cmolc·kg^{-1}, Exch Ca^{2+}, 5.75 and 5.11 cmolc·kg^{-1}, Exch. K^+, 0.63 and 0.37 cmolc·kg^{-1}, Exch. Na^+, 0.63 and 0.37 cmolc·kg^{-1}) with ECEC of 8.19 and 7.03 cmolc·kg^{-1}. Also, the exchangeable sodium percentage (ESP) in Winneba soils (0.74 and 0.14%) was higher than that of Akim Oda soil (0.28 and 0.25%), respectively, for the top and subsoils. and was within the permissible range. Texturally, both the Akim Oda (91,7% sand,4.2% clay and 4.1% silt) and Winneba (92.10 % sand, 4.1% clay and 3.8 % silt) soils were sand (Table 2) with a bulk density of 1.53 and 1.59 g/cm^3, respectively.

Amendments' effects on the soil quality

Soil pH and carbon

The application of biochar alone, sawdust alone and applications with fertiliser to the Akim Oda and Winneba soils significantly (P < 0.05) affected the soil pH and TOC (Figures 2 and 3). In the Akim Oda soil, the BC50 and SD5-F treatments had the highest (8.20) and lowest (5.13) pH values, respectively. The pH of the soil increased in the following decreasing order; SD5-F < BC5-F < C < SD50-F < SD 50 < SD5 < BC5 < BC50-F < BC50. In the Winneba soil, the highest pH (9.12) was recorded in the BC50 treatment, while the lowest (6.90) was recorded in the SD5-F treatment. pH increased in the following order; SD5-F < C < SD5 < BC5-F <BC5 < SD50-F < SD50 < BC50-F < BC50. The highest TOC (2.36%) was recorded in the treatment SD50-F whereas the lowest (1.09%)

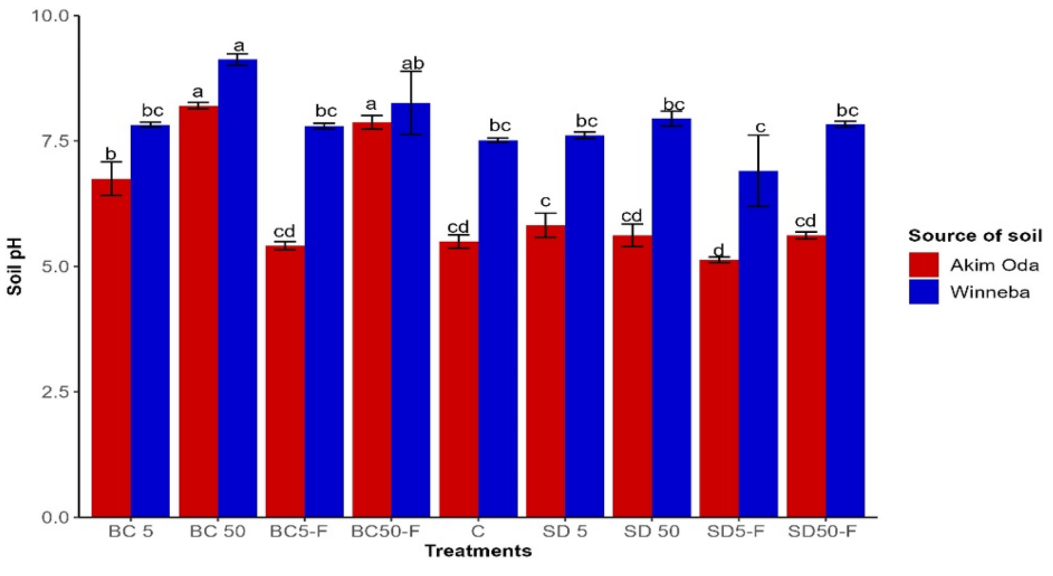

Figure 2 Soil pH of Akim Oda and Winneba soils following the applications of the treatments and 14 days of incubation. Means with the same letters on the same soil type are not significantly different from each other. (ANOVA, P < 0.05)

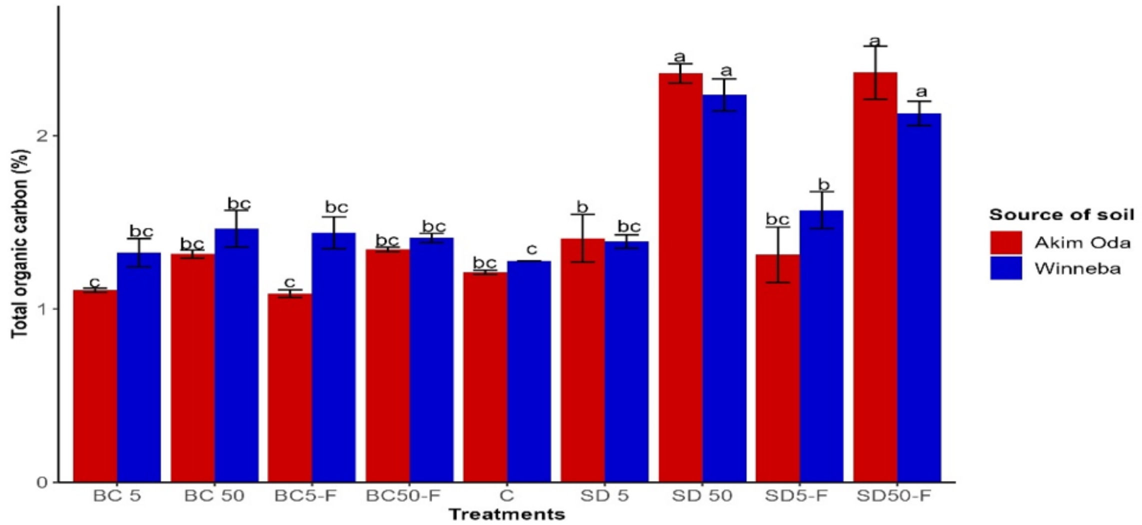

Figure 3 Total organic carbon (TOC) of Akim Oda and Winneba soils following the application of treatments and 14 days of incubation. Means with the same letters on the same soil type are not significantly different from each other (ANOVA, P < 0.05)

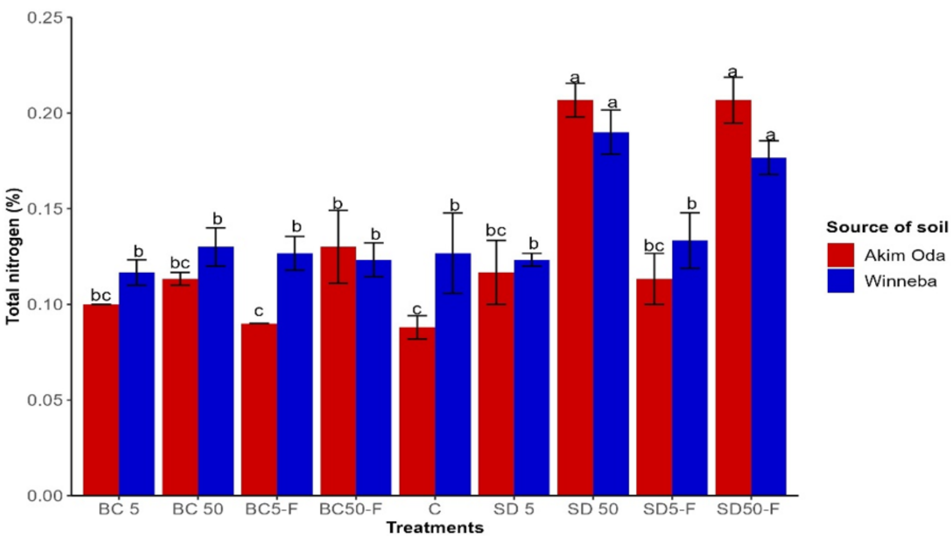

Figure 4 Total nitrogen of Akim Oda and Winneba soils following the application of treatments and 14 days of incubation. Means with the same letters on the same soil type are not significantly different from each other (ANOVA, P < 0.05)

was measured in BC5-F. TOC increased in the order: BC5-F < BC5 < C < SD5-F < BC 50 < BC50-F < SD5 < SD50 < SD50-F.

Total nitrogen and available phosphorus

The total nitrogen and available phosphorus content of the soil in Akim Oda and Winneba differed significantly ($P < 0.05$) with the application of biochar treatment, sawdust treatment and treatments with fertiliser (Figure 4). The order of the TN in the Oda soil was: C< BC 5 -F < BC 5 <BC 50= SD 5-F< SD 5 <BC 50 -F < SD 50= SD 50 -F, while that of the Winneba soil, which ranged from 0.12 to 0.18% was BC5 < SD5 <BC50-F<BC5-F< C<BC50<SD5-F<SD50-F<SD50. The available P concentration in the Akim Oda soil was lowest (2.94 mg kg^{-1}) in the SD5 treatment and highest (11.62 mg kg^{-1}) in the BC50-F treatment, and was in the increasing order: SD5<BC5<C<SD50<SD50-F<BC5-F<BC50<SD5-F<BC50-F. The SD5 treatment on the Winneba soil also had the lowest (11.48 mg kg^{-1}) available P, with BC50-F having the greatest (30.66 mg kg^{-1}) available P. The increase in the soil available P were following

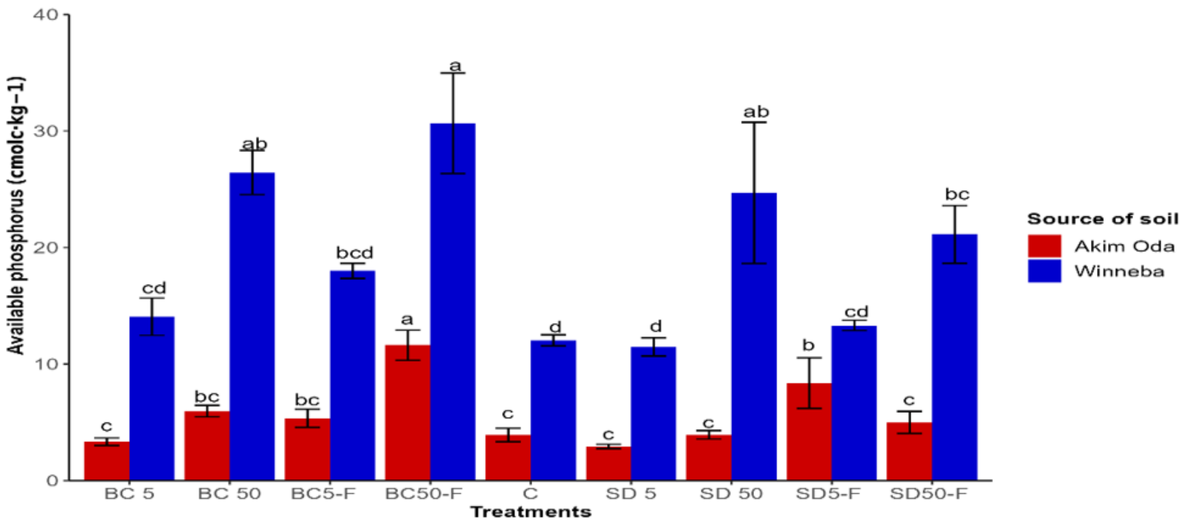

Figure 5 Available P of Akim Oda and Winneba soils following the application of treatments and 14 days of incubation. Means with the same letters on the same soil type are not significantly different from each other (ANOVA, P < 0.05)

the order: SD 5<C<SD5-F<BC5<BC5-F<SD50-F<SD50<BC50<BC50-F (Figure 5).

Cation exchange capacity (CEC) and Effective Cation Exchange Capacity (ECEC)

At the end of the incubation period, the addition of the soil amendment significantly (P<.05) increased the CEC and ECEC for both the Akim Oda soil and the Winneba soils (Table 4). The highest CEC value was recorded in BC50 treatment for both Akim Oda soil (7.23 cmol·kg^{-1}) with 103.1% increment and Winneba soil (10.55 cmol·kg^{-1}) with 64.1% increment (Tables 4 and 5). The lowest values of 3.56 and 6.46 cmol·kg^{-1} were recorded in the control for Akim Oda and Winneba, respectively (Table 4).

The addition of biochar at 2.5 % without fertiliser resulted in the highest ECEC for the Akim Oda soils (7.28 cmol·kg^{-1}) and Winneba soil (10.60 cmol·kg^{-1}), which translated into an increment of 71.13% and 63.58% respectively. The addition of biochar at 0.25 and 2.5% with or without fertiliser to the Akim Oda soil decreased exchangeable acidity between 41 and 91%. However, the addition of sawdust at 2.5 % without fertiliser resulted in a significantly lower ECEC for the Akim

TABLE 4

The effects of soil amendments and amendments with fertiliser on soil exchangeable bases, CEC and ECEC after 14 days of incubation

Treatments	Exch. Mg^{2+}		Exch. Ca^{2+}		Exch. K^{+}		Exch. Na^{+}		CEC		H^{+}+Al 3^{+}		ECEC	
	(cmol·kg-1)													
	AO	WB	AO	WB	AO	WB	AO	WB	AO	WB	AO	WB	AO	WB
C														
BC5	1.17c	1.28b	2.27c	4.76b	0.11e	0.38c	0.01b	0.01c	3.56f	6.43e	0.55ab	0.05b	4.11e	6.48d
	2.41a	3.20a	3.41bc	6.18b	0.20cd	0.55b	0.10a	0.22a	6.12bc	10.14abc	0.08c	0.05b	6.20bc	10.19ab
BC50	0.78c	1.46b	5.82a	8.31a	0.61a	0.77a	0.02b	0.01c	7.23a	10.54a	0.05c	0.05b	7.28a	10.59a
BC5-F	1.21bc	3.34a	3.26bc	5.96b	0.27bc	0.62b	0.11a	0.14ab	4.85bc	10.06abc	0.29bc	0.05b	5.14d	10.11ab
BC50-F	0.82c	1.31b	5.54a	8.31a	0.67a	0.80a	0.01b	0.01c	7.04ab	10.43a	0.05c	0.05b	7.08ab	10.48a
SD5	2.42a	2.91a	3.20bc	5.47b	0.14de	0.56b	0.13a	0.09bc	5.89cd	9.03abcd	0.43b	0.05b	6.32abc	9.08abc
SD50	1.03c	1.56b	3.69b	6.04b	0.28bc	0.56b	0.02b	0.01c	5.02de	8.17cde	0.53ab	0.05b	5.56cd	8.22bcd
SD5-F	1.70b	2.84a	2.77bc	4.83b	0.23bc	0.57b	0.13a	0.17ab	4.84de	8.40abc	0.87a	0.23a	5.70cd	8.64abc
SD50-F	1.24bc	1.28b	2.73bc	5.54b	0.30b	0.52b	0.01b	0.01c	4.28ef	7.35de	0.62ab	0.05b	4.90de	7.40cd

Exch= Exchangeable, AO= Akim Oda, WB= Winneba, CEC = Cation Exchange Capacity, and ECEC= Effective Cation Exchange Capacity
C=control, BC5= Biochar treatment at 0.25%, BC50= Biochar treatment at 2.5%, BC5-F BC5= Biochar treatment at 0.25% with fertiliser at 90N: 60P: 60K (Kg/ha), BC50-F= Biochar treatment at2.5% with fertiliser at 90N: 60P: 60K (Kg/ha), SD= Sawdust treatment at 0.25%, SD50= Sawdust treatment at 2.5%, SD5-F= Sawdust treatment at 0.25% with fertiliser at 90N: 60P: 60K (Kg/ha), SD50-F= treatment at 2.5% with fertiliser at 90N: 60P: 60K (Kg/ha). Values represent means of three replicates Values within one column followed by the same letter are not significantly different from each other (ANOVA, P < 0.05)

TABLE 5

Percentage change of exchangeable bases, CEC and ECEC after the addition of soil amendments and amendments with fertilizer and 14 days of incubation

Treatments	Exch. Mg^{2+}		Exch. Ca^{2+}		Exch. K^{+}		Exch. Na^{+}		CEC		H^{+}+Al 3^{+}		ECEC	
	(cmol·kg-1)													
	AO	WB	AO	WB	AO	WB	AO	WB	AO	WB	AO	WB	AO	WB
C	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BC5	105	150	50.22	29.83	81.82	115.79	900	2100	71.91	57.9	-84	0	50.85	57.4
BC50	-33	14.06	156.38	74.58	454.6	102.63	100	0	103.1	64.1	-91	0	77.13	63.58
BC5-F	3.4	157	44.05	25.21	145.5	63.16	1000	1300	36.52	56.5	-47	0	25.3	56.02
BC50-F	-30	2.34	144.05	74.58	509.1	110.53	0	0	97.75	62.2	-91	0	72.51	61.73
SD5	107	126.6	40.97	14.92	27.27	47.37	1200	800	65.45	40.4	-22	0	53.77	40.12
SD50	-12	21.88	62.56	26.89	154.5	47.37	100	0	41.01	27.1	-3.6	0	35.28	26.85
SD5-F	45	121.9	22.03	1.47	109.1	50	1200	1600	35.67	30.8	58.2	360	38.69	33.33
SD50-F	6	0	20.26	16.39	172.7	36.84	0	0	20.22	14.3	12.7	0	19.22	14.2

Exch= Exchangeable, AO= Akim Oda, WB= Winneba, CEC = Cation Exchange Capacity, and ECEC= Effective Cation Exchange Capacity
C=control, BC5= Biochar treatment at 0.25%, BC50= Biochar treatment at 2.5%, BC5-F BC5= Biochar treatment at 0.25% with fertilizer at 90N: 60P: 60K (Kg/ha), BC50-F= Biochar treatment at2.5% with fertilizer at 90N: 60P: 60K (Kg/ha), SD= Sawdust treatment at 0.25%, SD50= Sawdust treatment at 2.5%, SD5-F= Sawdust treatment at 0.25% with fertilizer at 90N: 60P: 60K (Kg/ha), SD50-F= treatment at 2.5% with fertilizer at 90N: 60P: 60K (Kg/ha).
(-) , means percentage decrease as compared to the control, (+) , means percentage increase as compared to the control

Oda soil 5.56 cmol·kg^{-1}) and Winneba soil (8.22 cmol·kg^{-1}) with an increment of 35.28 and 26.85% respectively (Table 5).

$$\text{Percentage increase or decrease at the end of incubation} = \frac{\text{Measured value in the treatment sample} - \text{Measured value in the control sample}}{\text{Measured value in the control sample}} \times 100$$

Effects of the amendment on the growth and yield of rice

Tiller number and plant height

Application of soil amendments significantly ($P < 0.05$) affected the number of tillers and height of upland rice grown on Akim Oda and Winneba soils (Figures 6 and 7). The mean tiller number for Akim Oda soil ranged from 3 to 8 tillers per pot. The addition of biochar at 0.25% without fertiliser (BC5) produced the lowest tiller number while biochar at 0.25% with fertiliser (BC5-F) produced the highest (Figure 6). The mean tiller number for Winneba soil ranged from 1 to 5 tillers per pot. The highest was observed upon the addition of sawdust at 0.25% with fertiliser (SD5-F) while the addition of sawdust at 2.5% without fertiliser (SD50) produced the lowest tiller number (Figure 6). In the Akim Oda soils, the addition of biochar at 0.25% with fertiliser (BC5-F) produced the highest height (90.63 cm) while biochar at 2.5% without fertiliser (BC50) had the lowest (77.07cm) (Figure 7). In the Winneba soils, however, the application

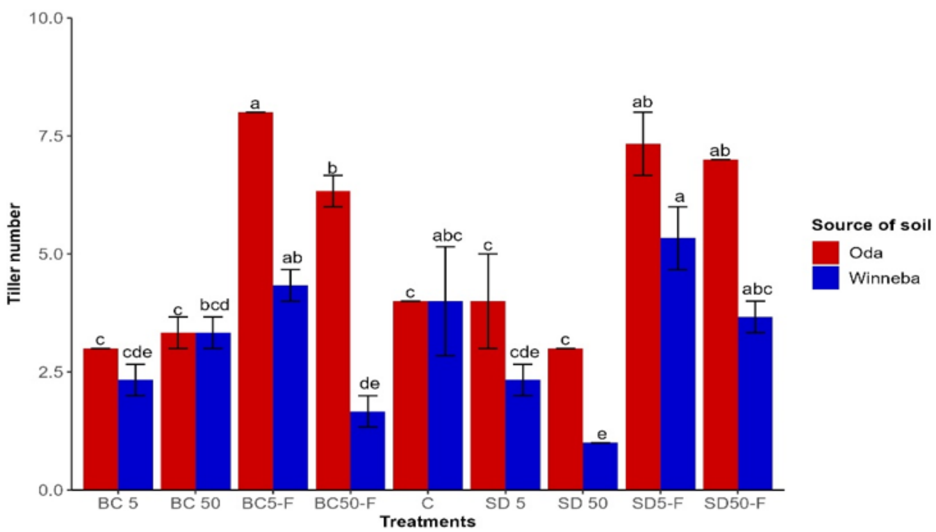

Figure 6 The mean number of tiller of rice plant at maturity on Akim Oda and Winneba soils following the applications of the treatments and 14 days of incubation. Means with the same letters on the same soil type are not significantly different from each other. (ANOVA, P < 0.05)

of sawdust at 0.25% with fertiliser (SD5-F) produced the highest height (84.67 cm) while the lowest (30 cm) was observed when biochar was applied at 2.5% with fertiliser (BC 50-F).

Straw and grain yield

After harvest, the application of the soil amendments significantly ($P < 0.05$) affected the straw and grain yield of rice on both the Akim Oda and Winneba soils (Figures 8 and 9). The addition of biochar at 0.25% with fertiliser (BC5-F) to the Akim Oda soils produced the highest straw yield of 12.65 g/pot, while the application of biochar at 2.5% without fertiliser (SD50) resulted in the lowest 3.90 g/pot (Figure 8).

The highest (10.72 g/pot) grain yield from Akim Oda soil was produced from the application of sawdust at 2.5% with fertiliser (SD 50 -F) while the lowest (2.77 g/pot) was produced from the addition of biochar at 2.5%. Also, the application of sawdust at 2.5% with fertiliser to the Winneba soils resulted in a grain yield of 6.36 g/pot but no rice grain

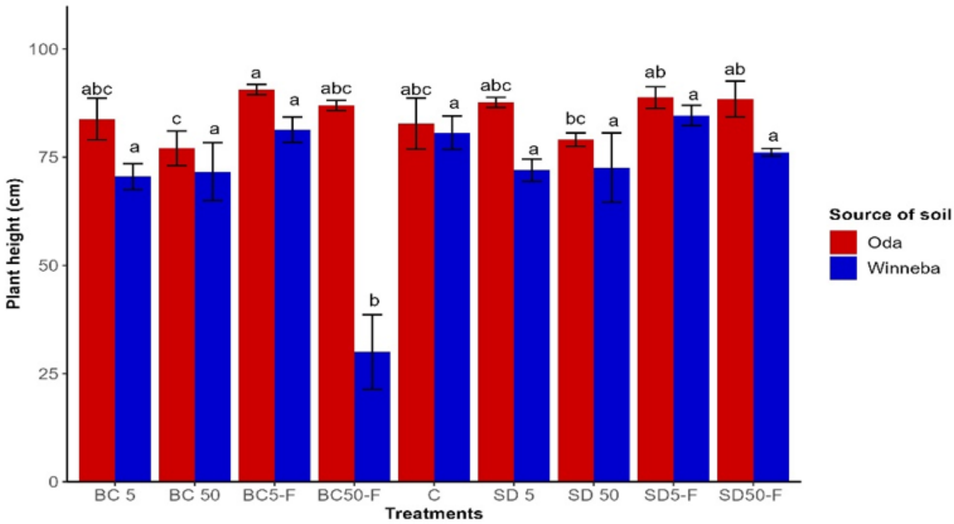

Figure 7 The mean final height of rice plant at maturity on Akim Oda and Winneba soils following the applications of the treatments and 14 days of incubation. Means with the same letters on the same soil type are not significantly different from each other. (ANOVA, $P < 0.05$)

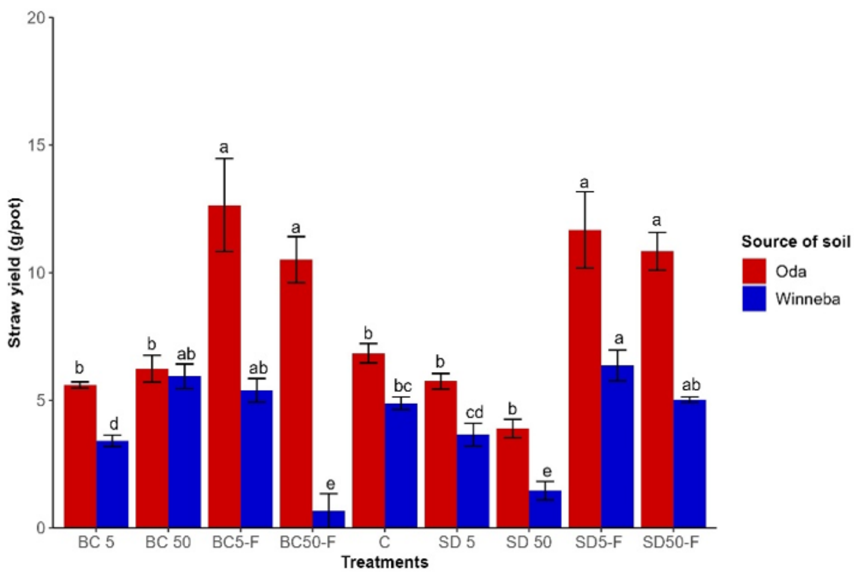

Figure 8 The mean straw yield of rice plants at harvest on Akim Oda and Winneba soils following the applications of the treatments and 14 days of incubation. Means with the same letters on the same soil type are not significantly different from each other. (ANOVA, $P < 0.05$)

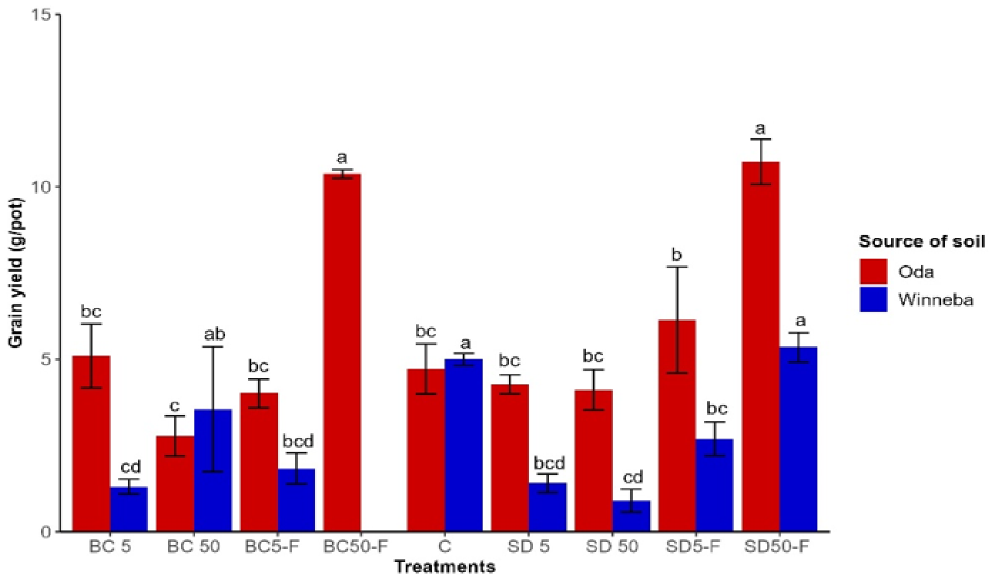

Figure 9 The mean grain yield of rice plant at harvest on Akim Oda and Winneba soils following the applications of the treatments and 14 days of incubation. Means with the same letters on the same soil type are not significantly different from each other. (ANOVA, P < 0.05)

(0 g/pot) was observed from the application of biochar at 2.5% with fertiliser (BC50-F) (Figure 9).

Discussion

Initial soil properties

The higher total nitrogen and available P content of the Winneba soil than the Akim Oda soil may be due to the high organic matter content of the Akim Oda soil (2.10 and 1.30%) and the Winneba soil (2.23 and 1.39%). The significant amount of organic matter in soils could be attributed to the decomposition and accumulation of plant remains and other dead soil organisms (Opeyemi et al., 2020). The acidic nature of the Akim Oda soil (pH, 5.33 and 5.2) and the alkaline nature of Winneba soil are not ideal for crop cultivation and therefore require an amendment to correct the pH.

The lower concentration of exchangeable cations in Akim Oda soils may be attributed to soil nutrient loss through climatic factors leading to leaching that can prompt mobilisation and immobilisation of these cations (Anderson et al., 2017; Suleiman et al., 2017). The higher ESP in the Winneba soils is probably because of the closeness of the Winneba soil to the coast. The ESP of both soils was within the acceptable limits.

Both the Akim Oda and Winneba soils were sandy. The sandy nature of the soils may be due to the underlying rocks (granite) through which the soils are formed (Opeyemi et al., 2020). The higher percentage of sand suggests the soils have low water holding capacity. The bulk density of the two soil types was relatively lower and within the desirable range. This may be due to the appreciable amount of organic matter in the soils.

Amendments' effects on the soil quality

Soil pH and TOC

The application of biochar significantly increased soil pH after the incubation. The higher soil pH at a higher level of biochar application (BC50) may be attributed to the higher pH (9.04) of the biochar (Mensah and Frimpong, 2018; Shetty et al., 2020). Comparatively, the pH values of Winneba soil after the application of biochar, sawdust and treatments with fertiliser were higher than those of Akim Oda soil. This is probably because the initial pH of the Winneba soil (7.39) before the treatment application was higher than that of the Akim Oda soil (5.33) (Table 2). Zwieten et al. (2010) reported that the addition of biochar to soil can raise soil pH due to its liming effects. Thus, the addition of biochar could have provided basic cations which replaced the exchangeable Al at the soil exchange sites. Consequently, the basic cations may have buffered the soil pH, leading to deprotonation. The presence of base cations i.e., Ca, K, Mg, in the sawdust might have also accounted for the observed increase in the pH of the biochar after pyrolysis of sawdust (Novak et al., 2009). We can thus argue that these cations might have buffered the pH through their liming effects. The liming effects of biochar have been recounted in many past studies (DeLuca et al., 2015; Tian et al., 2017). The application of sawdust alone and biochar alone increased the soil's pH but the application of sawdust or biochar with fertiliser correspondingly decreased the soil pH. The reduced pH obtained by biochar with fertiliser or sawdust with fertiliser treatment may be attributed to the acidic nature of the nitrogen fertiliser (Adekiya et al., 2020). The addition of nitrogen fertiliser could acidify soil by oxidizing NH_4^+ to NO_3^- during the process of nitrification. This could produce H^+ and a low pH (Schroder et al., 2011). The TOC of the Akim Oda and Winneba soils generally increased with the treatment application rate. However, sawdust treatment resulted in a higher TOC of soils than biochar. This might be due to the higher organic carbon content of the sawdust (48.00%) and perhaps a higher rate of mineralisation than that of the biochar (44.00%) (Table 3). Also, treatments without fertilisers had higher TOC, probably because the presence of fertiliser enhanced the microbial breakdown of organic carbon. The addition of fertiliser provided more N to the soil. It could therefore be inferred that the microbes used the N to increase their biomass and increase the decomposition rate of organic carbon. The lignin found in sawdust is challenging to decomposition due to its chemical characteristics and may be responsible for the greater TOC in sawdust-amended soil. The ease of decomposition of an organic residue is governed by its carbon-to-nitrogen ratio (C/N). A carbon-to-nitrogen ratio below 20 indicates the availability of more N to be used by microbes for the decomposition of the organic residue. In this study, the C/N of the sawdust (114.28) and biochar (81.48) were both high (Table 3). It could therefore be inferred that the decomposition of the amendments by microbes was slow (Eiland et al., 2001). Also, the TOC of the Winneba soil (1.29 %) before the treatment application was higher than that of the Akim Oda Soil (1.22 %) (Table 2). This might probably be the reason for the higher TOC in the application treatments for the Winneba soils than the Akim Oda soils (Manzano et al., 2020). However, it should be emphasised that the biochar feedstock, pyrolysis conditions, application rates, and the soil type to which the biochar is applied all have a significant impact on the effect of biochar on soil's TOC (El-Naggar et al., 2018).

Total N and Available P

The nitrogen contents in the biochar-treated soils in Akim Oda and Winneba were relatively lower compared to the sawdust. We could infer that the biochar was recalcitrant to decomposition and thus resisted the possible mineralisation to release nitrogen into the soil. Conversely, the sawdust might have decomposed easily to release nitrogen into the soil. Abujabhah et al. (2018) reported that biochar has a large specific surface area and a rich pore structure that allows it to store and adsorb soil N, limiting its availability and aiding in sequestering it. This is in contrast with the case of a faster decomposition rate associated with organic sources such as compost and manure. This recalcitrant nature of biochar to decomposition favours its use as a climate mitigation option and a holder of nutrients for the next cropping seasons. In this regard, Duku et al. (2011) reported that biochar application in soils minimises ammonium loss through leaching and NH_3 volatilisation. De Gryze et al. (2010) also opined that biochar decreases the possibility of nutrient losses in soils and enhances nutrient recycling, resulting in positive impacts on crop yields. These reasons accounted for the lower total nitrogen contents in the biochar-treated samples and relatively higher TN contents in the sawdust-treated samples.

The available P increased when biochar with or without fertiliser was added to Akim Oda and Winneba soils, and this could be attributed to the presence of phosphorus in the biochar and the biochar's capacity to hold onto nutrients in the soil. A biochar application has a liming action to raise soil pH, which causes a decrease in soil P sorption to raise the amount of soil available P that is accessible (Naom et al., 2022). This rise in the soil available P may also be explained by the increased pH and CEC of the soil, which led to a decrease in H^+ and $Al.^{3+}$ Ameyu (2019) reported that aluminium, iron oxides, and hydroxides fix phosphorus in soil with low pH levels. The available P in the soil did not increase when sawdust was added to the Akim Oda soils with or without fertiliser, except with the SD5-F treatment. However, the specific role played by the sawdust in this observation is not clear. Apart from the SD5 treatment, all the sawdust treatments increased the available P of the Winneba soil. It thus appears higher level of available P in the initial soil used in the study might have contributed to this observation.

Effective Cation Exchange Capacity (ECEC)

Cation exchanges are due to negative charges on clay and humic substances in the soil. In this study, the clay content of the Akim Oda soil (4.2%) and that of the Winneba soil (4.1%) were low (Table 2). However, during the pyrolysis of sawdust to produce biochar, negatively charged functional groups were formed. These functional groups are thought to increase the biochar's ECEC (Tan et al. 2017; Tomczyk et al., 2020) compared with the sawdust. Nkoh, et al., (2022) also reported that the negative charge functional groups of the biochar increase its cation exchange capacity. According to Sun et al., (2022), a higher ECEC indicated a strong nitrogen fixation capacity required for plant growth. The higher ECEC of the biochar-treated soils may also be attributed to the higher exchangeable cations in the biochar than in the sawdust (Table 3). Also, the higher ECEC of the Winneba-treated soils may be due to the relatively higher exchangeable cations content of the initial Winneba soil used for the study (Table 2).

As soil acidity increases, Al^{3+} and H^+ occupy cation exchange sites on mineral surfaces (McKenzie et al. 2004). The greater ECEC of the biochar, and its capacity to bind Al^{3+} and Fe^{2+} with the soil exchange sites, may be responsible for the decrease in the exchangeable acidity in the amended soils (Mensah and Frimpong, 2018). According to Shetty and Prakash (2020), using biochar made from eucalyptus wood decreases soil's exchangeable acidity, which leads to an increased ECEC. The enhanced ECEC of the soils biochar may be related to the surface properties and functional groups of biochar (Medyńska-Juraszek, et al., 2021).

The decomposition of the slightly acidic sawdust (pH, 6.05) (Table, 3) might have produced H^+ to make the soil more acidic. In this study, adding sawdust at 0.25% with fertiliser and 2.5% with fertiliser to Akim Oda soil increased exchangeable acidity by 58.2% and 12.7%, respectively (Table 4). The acidic (pH=6.05) nature of the sawdust may be why the exchangeable acidity of the SD5-F and SD50F treatments was higher than that of the control. In acidic soils, ECEC is reduced, and then increasingly dominated by surfaces with a permanent negative charge. This is likely a reason for the lower ECEC in the sawdust-treated soils. Apart from adding sawdust at 0.25% with fertiliser to the Winneba soil, which increased the exchangeable acidity, the exchangeable acidity in all other treatments did not change compared with the non-amended soil. This might be due to the neutrality effects of the relatively more basic cations in the initial Winneba soil than those of the Akim Oda soil. The weakly alkaline pH (7.39) of the Winneba soil before amendment (Table 2) may also account for this observation. In neutral to slightly alkaline soils (pH 7–8), the ECEC is saturated with the base cations. If the soil pH drops, the base cations on variable charge sites are substituted by H^+, and the ECEC decreases accordingly.

Tiller number and plant height

Compared with the control, adding soil amendment with fertiliser to the Akim Oda and Winneba soil produced a higher tiller number. These soil amendments contain a small amount of essential nutrients (Mg, Ca, K, P, and N) for plant growth (Table 3). Mineralisation of the amendments releases these nutrients for plant use. The nutrients from the amendments and that provided by the addition of inorganic fertiliser could enhance soil fertility. Uzoma et al., (2011) reported that adding biochar improves plant development performance because it can release nutrients slowly that are naturally present in the biochar and those that have been absorbed from outside sources. The combined applications of inorganic fertiliser and biochar make nutrients available, which in turn improve crop development and production (Liu et al., 2021). The relatively higher amount of nutrients in the biochar than in the sawdust might have contributed to the higher tiller number in the BC5-F treatment. This outcome is consistent with that of Sang et al., (2019), who observed the highest tiller number in biochar application treatment of 5 t ha-1 with fertiliser. This suggests applying biochar at the rate of 5t ha^{-1} with fertiliser to soils can enhance growth in rice plants

The lower tiller number after adding sawdust without fertiliser may be attributed to a higher C/N ratio of the sawdust than biochar (Table 3). The C/N ratio of the amendments indicates how readily the organic matter mineralises to release nutrients. A C/N ratio greater than 25:1 indicates a low rate of decomposition. This implies that the amount of N is not enough for microbial decomposition. Consequently, N in the soil is immobilized by microbes, leading to temporal depression of nitrogen in the soil. In our study, the C/N ratio of the sawdust (114.28: 1) was higher than that of the biochar (81.48: 1) (Table 3). Thus, it can be inferred that the decomposition rate of sawdust was slow, leading to the immobilisation of soil N by microbes. The immobilised soil N might have prevented it from being released into the soil, and hence reduced plant growth in the sawdust-amended soil. AYang et al., (2002) have also observed decreases in plant growth immediately following sawdust application. They argued that this was due to the temporary depression of nitrates, but not the harmful or toxic effects on either plants or soil.

The overall findings demonstrated that the growth performance of rice produced on the Akim Oda soil was better than on the Winneba soil when biochar or sawdust was applied. This might be explained by the changes in soil pH between the two types after the amendments were applied. The ideal pH range for rice is (5.5-7.5), and this makes nutrients available for plants (Sys et al., 1993). However, following incubation, the pH levels of the Winneba soils, which were initially 7.39, exceeded the 7.5 threshold. This might have negatively impacted the availability of nutrients for plant growth. The fact that sawdust or biochar with fertiliser outperformed soil without fertiliser in terms of growth performance was not surprising. This can be a result of the applied amendments and inorganic fertiliser working together in harmony (Shamim et al., 2015). Khan et al., (2021) also reported that the combined application of biochar and nitrogen fertiliser significantly increased plant height and tiller number compared to the single application of either biochar or nitrogen fertiliser.

Grain and straw yield

The application of soil amendment is to enhance the soil quality and crop yield. In the Akim Oda soil, the highest grain yield was obtained from the application of sawdust at 2.5% with fertiliser (SD 50 -F). This may be attributed to the slightly improved soil pH of 5.6 of the soil after the application of the amendment, which might have improved nutrient availability for plant growth. The addition of sawdust to the Akim Oda soil increased the soil pH from 5.33 to 5.6, which falls within the optimum soil pH range (5.5 and 6.5) for upland rice in Ghana. Conversely, the BC50 treatment with the lowest grain yield had an alkaline pH of 8.6. The amount of nutrients available for plant growth may have been reduced by the high soil pH. During development, nitrogen is stored in plant biomass and redistributed from the leaves and stems for grain protein formation at the grain-filling stage (Abbruzzini et al., 2019; Ullah et al., 2021).

Comparatively, the grain yield of rice in Akim Oda soils was higher than that for the Winneba soil. This may be due to the fact that the pH of the soils varied, which had an impact on the availability of nutrients. However, rice yield on the Winneba soil was negatively impacted by the application of a greater amount of biochar. This might be explained by the strong binding forces present in soil with high biochar concentrations, which, as a result of their liming impact, reduced the availability of nutrients and increased salt content (Khan et al., 2021). The excessive use of biochar can increase the amount of highly volatile matter in the soil, which can negatively impact plant growth and yield (Deenik et al., 2010). The lower plant growth brought on by the heavy application of biochar in this study is consistent with research by Abideen et al. (2020).

The higher straw yield recorded for the BC5-F treatment in the Akim Oda soil may be due to nutrient additions from the biochar and increased nutrient retention through higher exchange capacity (Utomo et al., 2011; Yin et al., 2014). It is clear from our study that the addition of inorganic fertiliser impacted the straw yield. Nitrogen availability and uptake have a significant impact on a plant's straw yield by encouraging tillering before stem extension (Abbruzzini et al., 2019; Ullah et al., 2021). The application of sawdust without fertiliser (SD50) produced the lowest straw yield. This might be due to the higher C/N ratio of the sawdust, which might have immobilised N and prevented it from being available to plants.

Conclusion

Applying biochar increased soil pH more than sawdust but soil pH decreased with the application of amendments with fertiliser. Sawdust with and without fertiliser enhanced the total organic content more than the biochar. Mineralization of sawdust produced a higher total nitrogen and available phosphorous content than the biochar. The increased soil pH and carbon by biochar in Akim soil made nutrients available for plant growth. This resulted in an increased number of tillers, plant height, and straw yield of rice plants. Sawdust at 2.5% with fertiliser produced the highest grain yield in the Akim Oda soil. The decrease in soil pH by the addition of sawdust at 0.25% with fertiliser in the Winneba soil also produced the highest number of tillers, plant height, and straw yield. Similarly, the addition of sawdust at 2.5% with fertiliser produced the highest grain yield in the Winneba soil. The study demonstrated that applying biochar or sawdust with inorganic fertiliser to the soil has the potential to improve soil quality, growth, and yield of upland rice. We propose a large-scale field study using different crops on different soil types to better evaluate the impact on soil quality and crop yield.

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