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The role of biochar, poultry manure, and biochar-poultry manure in improving leaf nutrient concentrations, root storage minerals, growth, and yield of sweet potato (*Ipomoea batatas* L.)

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Abstract
Research information on the effects of biochar and poultry manure on the growth, yield, and concentrations of nutrients in edible portions of sweet potato is rare, as essential nutrient concentrations in crops can affect human health. The objective of this study was to examine the synergistic effects of biochar (B) and poultry manure (PM) on leaf nutrient concentrations, root storage minerals, sweet potato growth, and yield. The field experiments were conducted in the forest-savanna transition zone of southwest Nigeria at two degraded sites (Owo - site A and Obasooto - site B). The treatments each year consisted of four levels of biochar (B): 0, 10.0, 20.0 and 30.0 t ha^{-1} and three levels of poultry manure (PM): 0, 5.0, and 10.0 t ha^{-1}, which were combined in a 4 × 3 factorial layouts to form a total of twelve treatments. The twelve treatments were factorially arranged in a randomized complete block design with three replications. Data collected on sweet potato leaves, storage roots, growth, and yield were analyzed over two growing seasons (2019 and 2020). The results showed that the sole application of B and PM, as well as their combined application, improved the growth, yield, and nutritional quality parameters of sweet potatoes. As B and PM applications increased from 0 to 30.0 t ha^{-1} and 0 to 10.0 t ha^{-1}, respectively, leaf nutrient concentrations, root storage minerals, growth, and sweet potato yield increased. In both years, there were significant interactions of B and PM (B × PM) on all the sweet potato variables that were determined, indicating the potential of B in enhancing PM use efficiency. It was found that the highest application rate of 30.0 t ha^{-1} B and 10.0 t ha^{-1} PM gave the highest leaf nutrient concentrations, root storage minerals, growth, and yield of sweet potato at both sites. The study indicated that B in combination with PM has the potential to improve the growth, yield and nutrient content of the edible portions of sweet potato for human health in severely degraded soils.
Keywords: Biochar, Degraded sites, Leaf nutrient contents, Mineral composition, Poultry manure, sweet potato

Introduction

Low-fertile soil and poor soil fertility management practices are the major factors underlying poor agricultural productivity and its attendant low nutritional qualities of most crops in sub-Saharan Africa. Severely degraded land is a major challenge that threatens the productivity and sustainability of crops worldwide, due to continuous cultivation of the same land. According to Yousaf et al. (2017) and Asante et al. (2019), excessive chemical fertilizer application reduced the growth, yield, and nutritional quality of most crops. Root storage vegetables, especially sweet potato (*Ipomoea batatas* L.), are widely consumed in Nigeria and other parts of the world. Sweet potato is a healthy carbohydrate source, and the root crop is acknowledged with “antidiabetic” activity (Anbuselvi et al., 2012; Neela and Fanta, 2019). In vivo studies carried out by Mohanraj and Sivasankar (2014) found that carbohydrate from sweet potato stabilizes blood sugar levels and reduces insulin resistance. The leaves are eaten as vegetables in some Nigerian tribes and are commonly utilized as livestock fodder. The tuber contains anti-oxidants and carotenes, making it an inexpensive and excellent source of vitamin A for the impoverished. Sweet potato also has a significant amount of minerals like potassium, magnesium, and calcium, as well as vitamins (vitamin C and PVA), and different bioactive compounds (phenolic acids and anthocyanins for consumers (Hernández Suárez et al., 2016).

For human welfare and economic development, access to nutritionally adequate and safe food is essential (FAO, 2021). According to statistical data for 2017, the FAO (2019) reported that 820 million people around the world were severely malnourished. 'Hidden hunger,' a deficiency of micronutrients, vitamins, and minerals, is the most severe type of malnutrition, affecting as many as 3 billion people worldwide (FAO, 2013). The concentration of trace nutrients has been reported to be an important component of healthy food (Dimkpa and Bindraban, 2016; Rattanachaiwong and Singer, 2019). According to Dimkpa and Bindraban (2016) and Kihara et al. (2020), trace nutrient deficiency in food is a growing human health issue, with N, P, K, Ca, Mg, and S classified as essential macronutrients, while Cu, Fe, Mn, Mo, Ni, Zn, B, Cl, Se, Si and Na are regarded as micronutrients (Dimkpa and Bindraban, 2016).

The presence of low nutrient elements in the soil can have a negative impact on plant growth, yield, and nutritional value. Degraded soils have been remedied using methods such as the application of chemical fertilizers. Excessive use of these chemical fertilizers, on the other hand, causes soil physical degradation, acidification, increased eutrophication of water bodies, and increased greenhouse gas (GHG) emissions (Bisht and Chauhan, 2020; Piash et al., 2021). Most crops suffer from a reduction in yield and a loss of nutritional value as a result of these factors. As a result, natural and more environmentally friendly and sustainable soil remediation technologies, such as biochar, must be used in place of synthetic fertilizers.

Biochar is a pyrogenous, organic material synthesized through pyrolysis of different biomass (plant or animal waste) with little or no oxygen (Tomczyk et al., 2020). It has the ability to improve the physical, chemical, and biological characteristics of some soils (Lehmann and Joseph, 2015; Yan et al., 2020). It has attracted much interest in the last decade because of its numerous benefits in the fields of agriculture, climate change, wastewater treatment, and soil health (Yu et al., 2019). Biochar application has been shown to boost soil nutrient elements, improve agronomic benefits, and increase carbon residence time in soil (Lehmann and Joseph, 2015), improve soil aeration and water retention (Oh et al., 2014; Obia et al., 2018), and reduce nutrient leaching (Major et al., 2012; Gao and DeLuca, 2016). Nevertheless, due to its low nutrient concentrations and high resistance to biodegradation, biochar may be limited as a nutrient supply alone (Partey et al., 2014; Ndoung et al., 2021). Because of this negative impact, it has been advocated that biochar be used in conjunction with other amendments/organic manures such as poultry manure (Agegnehu et al., 2017; Blanco-Canqui, 2017; Adekiya et al., 2019; Ndoung et al., 2021). Poultry manure is rich in organic matter and supplies nutrients necessary for crop productivity. It has been observed that applying poultry manure to the soil, increases soil organic matter and other plant nutrients, improves soil physical and chemical qualities, and increases crop yields (Ewulo et al., 2008; Adeleye et al., 2010; Adeyemo et al., 2019; Hoover et al., 2019).

So far, research on the potential of biochars to sequester carbon, improve soil physical qualities, and eliminate pollutants has primarily concentrated on pot experiments in greenhouses or laboratories (Novak et al., 2019; Yuan et al., 2019). To the best of our knowledge, no prior field research has examined the interacting effect of biochar and poultry manure on leaf nutrient concentrations, mineral composition, growth, and yield of sweet potato grown in severely degraded tropical Alfisols of southwest Nigeria. Thus, bridging these knowledge gaps is critical for long-term advantages in understanding the variations in biochar, poultry manure, and biochar-poultry manure nutrients release mechanisms and residual nutrition value. The working hypothesis in this study was that amending soils with biochar and poultry manure would significantly improve the agronomic characteristics of sweet potato and concentrations of key inorganic minerals for human nutrition in the edible portions of the sweet potato crop when compared to the untreated control. Hence, the objective of this study was to assess how application of biochar and poultry manure, affected the leaf nutrient concentrations, mineral composition, growth and yield of sweet potato grown on severely degraded tropical agricultural soils in southwest Nigeria.

Materials and methods

Site description and treatments

Field experiments were carried out at the Teaching and Research Farm of Rufus Giwa Polytechnic (Site A - latitude 7°13'29.0"N - 7°13'30.9"N and longitude 5°32'52.3"E - 5°32'54.2"E, with elevation varying from 314 to 320 m above sea level) and Obasooto village (Site B - latitude 7°12'30.5"N - 7°12'31.8"N and longitude 5°32'53.3"E - 5°32'54.1"E, with elevation varying from 272 to 280 m above sea level) (Fig. 1), in Owo, Ondo State, Nigeria during the 2019 and 2020 cropping seasons. Obasooto is located in the west of the Owo region and is about 10 km from Owo. Both sites are located within the forest-savanna transition zone of southwest Nigeria. The soils at Owo and Obasooto have a basement complex texture belonging to the Alfisols, classified as Oxic Tropuldalf (Soil Survey Staff, 2014) or Luvisol (IUSS Working Group WRB, 2015) and locally classified as Okemesi Series (Smyth and Montgomery, 1962). The physical and chemical properties of the soils at site A and site B before the commencement of the experiment are presented in Table 1. The soil texture at site A was entirely sand, whereas the soil texture at site B was sandy loam (Table 1). Both sites' soils were high in bulk density and moderately acidic, with low levels of organic carbon (OC), total N, available P, exchangeable K, Ca, and Mg. This could be due to soil degradation caused by continuous cropping of the soils at the experimentation sites. The average annual rainfall is about 1400 mm, and the mean annual temperature is about 32°C. The sites had been followed for a year after arable cropping, and none of them had received fertilizer in the previous six years. The experiment consisted of 4 × 3 factorial combinations of biochar (B) (0, 10.0, 20.0 and 30.0 t ha^{-1}) and poultry manure (PM) (0, 5.0 and 10.0 t ha^{-1}). The twelve treatments were factorially arranged in a three-replication randomized complete block design. Each block comprised of 12 plots, each measuring 5 × 4 m. The blocks were 1 m apart and the plots were 0.5 m apart. Crop establishments were carried out in April each year. Throughout the two-year trial, the same location was used at each site.

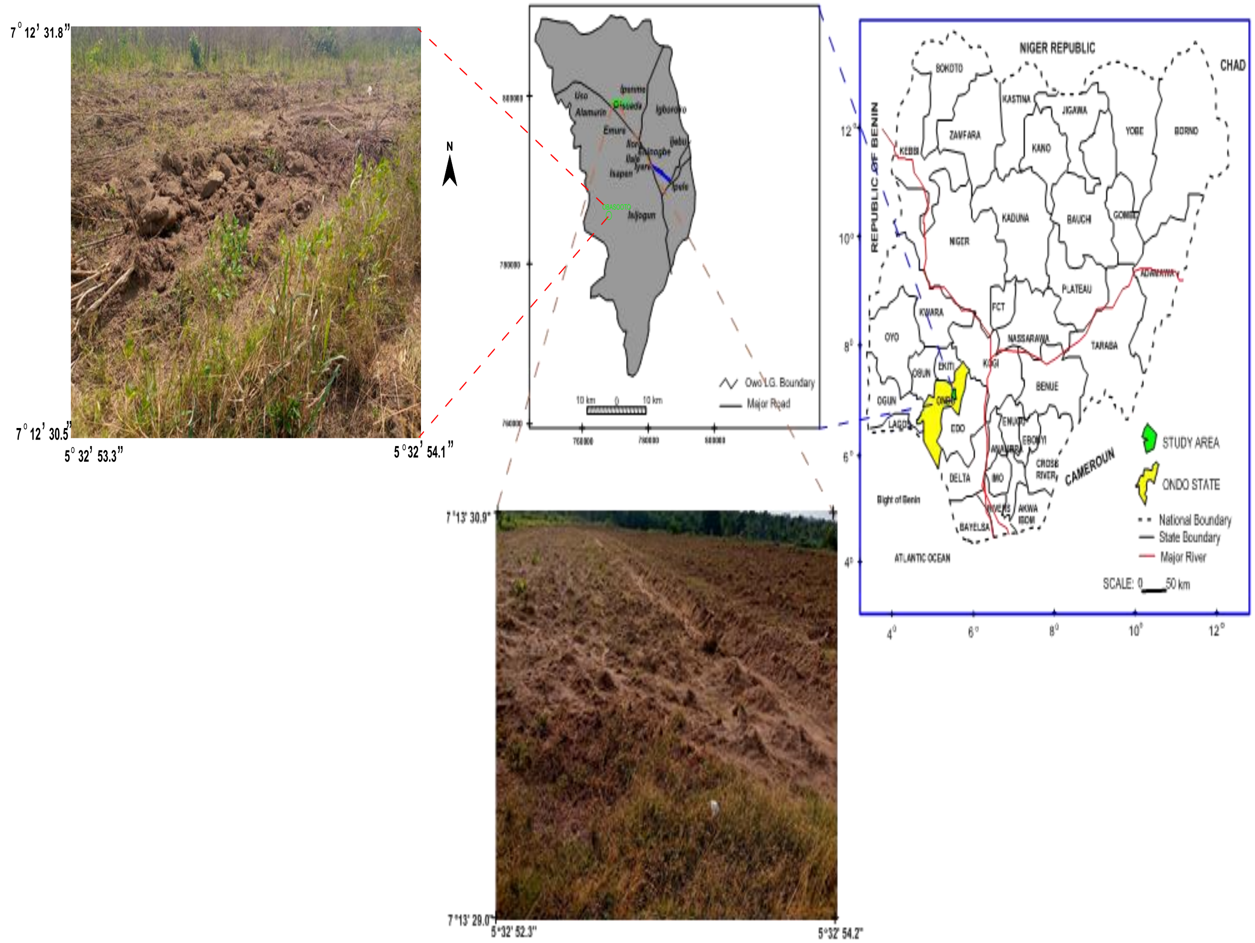

Figure 1. Location map of the study area

Table 1. Soil physical and chemical properties (0-15 cm depth) of site A and site B prior to experimentation in 2019 (mean ± standard deviation)

Property	Site A	Class	Site B	Class
Sand (%)	92 ± 5.8		76 ± 4.3	
Silt (%)	3 ± 0.1		13 ± 0.5	
Clay (%)	5 ± 0.2		11 ± 0.4	
Textural class	Sand		Sandy loam	
Bulk density (Mg m^{-3})	1.61 ± 0.04	High	1.58 ± 0.03	High
pH (water)	5.51 ± 0.2	Moderately acidic	5.52 ± 0.3	Moderately acidic
Organic carbon (%)	1.23 ± 0.02	Low	1.34 ± 0.02	Low
Total N (%)	0.12 ± 0.01	Low	0.14 ± 0.01	Low
Available P (mg kg^{-1})	6.75 ± 0.3	Low	8.12 ± 0.4	Low
Exchangeable K (cmol kg^{-1})	0.11 ± 0.01	Low	0.12 ± 0.01	Low
Exchangeable Ca (cmol kg^{-1})	1.35 ± 0.02	Low	1.51 ± 0.02	Low
Exchangeable Mg (cmol kg^{-1})	0.37 ± 0.01	Low	0.39 ± 0.01	Low

Biochar and poultry manure preparation

Biochar was procured from a neighboring industrial charcoal producer at Owo, Ondo State, Nigeria, who uses hardwood species such as *Parkis biglosa, Khaya senegalensis, Prosopis africana* and *Terminalia glaucescens* in traditional kilns to produce charcoal for home use. A thermocouple thermometer was used to monitor the temperature within the kiln, which had an average temperature of 580^{o}C for the 24 hour carbonization period. Before use, the biochar was crushed and sieved through a 2-mm sieve. The poultry manure (PM) was obtained from the poultry unit of Rufus Giwa Polytechnic's Teaching and Research Farm in Owo, Ondo State. Layer chickens, egg laying breed (Leghorn), were reared/kept in battery cages, and the poultry manure was collected from their droppings. From their first laying period, the egg-laying chickens were fed Top Feeds Layer Mash and kept for a year. To allow for mineralization, the poultry manure was composted for three weeks.

Land preparation, incorporation of biochar and poultry manure and planting of sweet potato vines

The experimental sites were prepared by slashing the vegetation with a cutlass followed by removing weeds. The trial sites were then laid out according to the 5 × 4 m plot size that had been clearly specified. The soils were then tilled to a depth of 20 cm with a hand-held hoe. The biochar (B) and poultry manure (PM) were weighed and evenly spread over the soil at the specified rates (B: 0, 10.0, 20.0 and 30.0 t ha^{-1}; PM; 0, 5.0 and 10.0 t ha^{-1}). In this study, biochar application rates were kept within the International Biochar Initiative's suggested ranges (5-50 t ha^{-1}) (Jirka and Tomlinson, 2015). The poultry manure rates (5-10 t ha^{-1}) used in this study was adapted from

Agbede (2010), and the treatment combination was based on the integrated plant nutrition system strategy (IPNS), which involved combining full sole application of biochar at various levels with half and full sole application of poultry manure at various levels. A hand held hoe was used to incorporate the amendments into the soil to the depth of approximately 10 cm. Two weeks before planting sweet potato vines, biochar and poultry manure were incorporated into the soil to allow for equilibration of the amendments in the soil and the commencement of mineralization. Hardwood biochar was used for the production of the biochar while chicken droppings from egg laying breed (Leghorn) was used for the preparation of poultry manure. The hardwood feedstock and poultry manure were selected based on their accessibility, availability and sustainability in the region.

After tilling the soil, sweet potato (*Ipomoea batatas* L. local variety) vines about 40 cm long were planted in April each year of the experiment. At a spacing of 1 m x 1 m, one sweet potato vine was planted per hole, giving sweet potato population of 10,000 plants ha^{-1}. The field plot was manually weeded twice at 3 and 8 weeks after planting (WAP). During the trial, there was no irrigation water applied.

Determination of initial soil physical and chemical properties

Before the start of the experiment in 2019, soil samples were collected from 0-15 cm depth at 10 different points selected randomly from the two experimental sites. The soil samples collected were bulked, air-dried and sieved using a 2-mm sieve for routine physical and chemical analysis, as described by Carter and Gregorich (2007). Particle-size analysis was done using the hydrometer method. Textural class was determined using a textural triangle. Soil bulk density was determined using the core method. Soil pH was determined in a soil/water (1:2) suspension using a digital electronic pH meter. Soil organic carbon content was determined by the Walkley and Black procedure using dichromate wet oxidation. Total N content was determined using micro-Kjeldahl digestion and distillation techniques. The content of available P was determined by Bray-1 extraction followed by molybdenum blue colorimetry. Exchangeable K, Ca and Mg were extracted with a 1 M ammonium acetate (NH_4OA_C), pH 7 solution. Thereafter, exchangeable K was analyzed with a flame photometer, and exchangeable Ca and Mg were determined with an atomic absorption spectrophotometer.

Analysis of biochar and poultry manure

Standard procedures were employed to determine the chemical properties/characteristics of the biochar and poultry manure used in the trials (Tel and Hagarty, 1984; International Biochar Initiative, 2011). The biochar was slightly alkaline, whereas poultry manure was slightly acidic. When compared to poultry manure, biochar had higher concentrations of OC, K, Ca, Mg, and a high C:N ratio, but poultry manure had higher concentrations of N and P, as well as micronutrients than biochar (Table 2).

Table 2. Chemical composition of biochar and poultry manure used in the experiment

Soil amendment	Biochar	Poultry manure	t-value	Sig. (2-tailed)
pH (water)	7.86	6.25	4.48*	0.011
Ash (%)	8.32	12.10	15.06**	0.000
Organic C (%)	55.70	22.30	50.74**	0.000
Nitrogen (%)	0.85	2.89	18.91**	0.000
C/N	65.50	7.72	228.16**	0.000
Phosphorus (%)	0.38	1.34	33.26**	0.000
Potassium (%)	1.92	1.57	14.29**	0.000
Calcium (%)	4.63	0.92	119.33**	0.000
Magnesium (%)	3.78	0.46	22.84**	0.000
Copper (%)	0.01	0.37	30.88**	0.000
Manganese (%)	0.07	0.21	12.24**	0.000
Sulphur (%)	0.10	0.33	17.82**	0.000
Zinc (%)	0.01	0.24	20.07**	0.000
Sodium (%)	0.21	0.27	3.67*	0.021

Note: **means significant at 1%; *means significant at 5%

Leaf analysis of sweet potato

In 2019 and 2020 cropping season, 2- to 3-week-old sweet potato leaves were collected at 90 days after planting from five plants per plot for chemical analysis. The leaf samples were oven dried at 80^{o}C for 48 h before grinding in a Willey-mill. Leaf N was determined by micro-Kjeldahl digestion method. Samples were dry ashed at 500^{o}C for 6 h in a furnace and extracted using nitric-perchloric-sulphuric acid mixture for the determination of P, K, Ca and Mg. Leaf phosphorus was determined colorimetrically by the vanadomolybdate method. Potassium was determined using a flame photometer, and Ca and Mg were determined by the EDTA (ethylene diamine tetra acetic acid) titration method (AOAC, 2019).

Analysis of mineral composition of sweet potato storage roots

At 5 months after planting, the 10 central plants from each plot were harvested at each experimental site. From all the storage roots of sweet potato harvested per plot, five of them of uniform sizes were selected randomly. Selected storage roots of the sweet potato were washed with clean water and peeled. Samples from each storage root were mixed together and chopped into small pieces. Resulting chips were properly mixed to obtain a uniform sample of root tissue from the five original storage roots. A 100 g sample was then taken and oven-dried at 60^0C for 24 h. Dried samples were then ground in a mill with a stainless steel grinding tool and stored in air-tight containers prior to chemical analysis. Mineral elements of sweet potato roots were subsequently determined or analyzed according to methods recommended by the Association of Official Analytical Chemists (AOAC, 2019). The samples were digested using 12 cm^{-3} of the mixture of HNO_3, H_2SO_4 and $HClO_4$ (7:2:1 v/v/v). Phosphorus was determined by the molybdenum blue colorimetric technique. Potassium, Ca, Mg, Fe and Zn contents were determined by the atomic absorption spectrophotometer.

Determination of crop growth and yield parameters

At 90 days after planting (DAP), when the sweet potato plant had reached its maximum development, ten plants were randomly selected per plot to determine vine length and leaf area. The length of the vines was estimated using the meter rule. The leaf area was calculated using a graphical method. The yield variables measured included the quantity of tubers, tuber weight (kg $plant^{-1}$), and tuber yield (t ha^{-1}). These were determined at 5 months after planting (MAP) by harvesting 10 sweet potato plants from each plot. The total number of tubers produced by each plant was physically counted and recorded as the number of tubers; the weights of the tubers were calculated and recorded as the tuber weight, and thereafter converted to tuber yield in tons per hectare.

Statistical analysis

The experiments were carried out in a randomized complete block design, with factorial arrangements so that the main effects of site (S), biochar (B) and poultry manure (PM) and the interactions of S × B, S × PM, B × PM and S × B × PM on leaf nutrient concentrations, root storage minerals, growth and yield of sweet potato could be tested. The data collected were analyzed using two-way analysis of variance (ANOVA) with the SAS (Statistical Analysis System) statistical software (SAS, 2013). The means of main factors and interactive effects were separated using Fisher's least significant difference (LSD) test at the 0.05 probability level. A t-test was conducted for the biochar and poultry manure data to determine if there is a significant difference between the means of the two amendments.

Results

Effect of site, biochar and poultry manure on leaf nutrient concentrations of sweet potato

The data on the effect of site, biochar and poultry manure on leaf nutrient concentrations of sweet potato in 2019 and 2020 are presented in Table 3. In both years (2019 and 2020), sites, biochar and poultry manure significantly influenced the leaf nutrient concentrations of the sweet potato. In both years (2019 and 2020), sole biochar or poultry manure application significantly increased leaf N, P, K, Ca and Mg concentrations, and concentrations increased with increasing rates of biochar and poultry manure application. Biochar application increased concentrations of N, P, K, Ca and Mg in the sweet potato leaves with rate of biochar from 0 to 30.0 t ha^{-1} in both years. Similarly, poultry manure application increased leaf N, P, K, Ca and Mg concentrations with rate of poultry manure from 0 to 10.0 t ha^{-1} in both years. In both years, the application of the sole biochar, sole poultry manure and their combined application at different rates significantly increased leaf N, P, K, Ca and Mg of sweet potato compared with the control (no application of biochar or poultry manure). The mixture or combined application of biochar and poultry manure at different levels increased leaf N, P, K, Ca and Mg of sweet potato than the sole biochar and sole poultry manure in both years. However, the highest application rates of both amendments (biochar applied at 30.0 t ha^{-1} in combination with poultry manure applied at 10.0 t ha^{-1}) (B_{30} + PM_{10}) gave the highest sweet potato leaf N, P, K, Ca and Mg concentrations compared with other treatments in both years. When studied as individual factor, site significantly ($p \leq 0.05$) influenced sweet potato leaf N, P, K, Ca and Mg concentrations in both years. When studied as individual factor, application of biochar significantly ($p \leq 0.05$) increased sweet potato leaf N, P, K, Ca and Mg concentrations in both years. Likewise, the application of poultry manure as individual factor, significantly ($p \leq 0.05$) increased leaf nutrient concentrations of sweet potato in both years. The interactive effect of S × B, S × PM, and B × PM were significant for leaf N, P, K, Ca and Mg concentrations of sweet potato in both years. When all three factors (S × B × PM) were considered together, interactions were significant in both years.

Table 3. Effect of site, biochar and poultry manure on leaf nutrient concentrations of sweet potato

Site	Biochar (t ha^{-1})	Poultry manure (t ha^{-1})	N (%)		P (%)		K (%)		Ca (%)		Mg (%)	
			2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Site A	0.0	0.0	2.15	2.05	0.06	0.06	1.45	1.36	0.10	0.08	0.05	0.04
	0.0	5.0	2.32	2.47	0.08	0.10	1.68	1.80	0.13	0.20	0.07	0.12
	0.0	10.0	2.61	2.76	0.10	0.12	1.98	2.11	0.31	0.38	0.09	0.14
	10.0	0.0	2.29	2.24	0.07	0.09	1.91	2.03	0.19	0.26	0.10	0.15
	10.0	5.0	2.54	2.69	0.14	0.16	2.17	2.29	0.43	0.50	0.12	0.17
	10.0	10.0	2.83	2.98	0.17	0.19	2.48	2.60	0.66	0.73	0.14	0.19
	20.0	0.0	2.31	2.46	0.08	0.10	2.35	2.47	0.46	0.53	0.13	0.18
	20.0	5.0	3.12	3.27	0.20	0.22	2.61	2.73	0.69	0.76	0.16	0.21
	20.0	10.0	3.41	3.56	0.23	0.25	2.83	2.95	0.80	0.87	0.18	0.23
	30.0	0.0	2.67	2.82	0.10	0.12	2.52	2.64	0.93	1.00	0.15	0.20
	30.0	5.0	3.44	3.59	0.26	0.28	2.93	3.05	0.98	1.05	0.17	0.22
	30.0	10.0	3.99	4.14	0.29	0.31	3.16	3.28	1.06	1.13	0.19	0.24
Site B	0.0	0.0	2.39	2.24	0.05	0.08	1.57	1.49	0.13	0.11	0.07	0.06
	0.0	5.0	2.53	2.63	0.09	0.12	1.81	1.94	0.19	0.28	0.14	0.20
	0.0	10.0	2.82	2.92	0.11	0.15	2.11	2.24	0.37	0.46	0.16	0.22
	10.0	0.0	2.40	2.40	0.08	0.12	2.04	2.17	0.26	0.34	0.17	0.23
	10.0	5.0	2.75	2.86	0.15	0.21	2.30	2.43	0.50	0.58	0.19	0.25
	10.0	10.0	3.04	3.17	0.18	0.25	2.61	2.74	0.72	0.81	0.21	0.27
	20.0	0.0	2.52	2.62	0.09	0.13	2.48	2.61	0.51	0.61	0.20	0.26
	20.0	5.0	3.33	3.45	0.21	0.25	2.74	2.87	0.76	0.84	0.23	0.29
	20.0	10.0	3.62	3.74	0.24	0.29	2.96	3.09	0.88	0.95	0.25	0.31
	30.0	0.0	2.88	2.98	0.11	0.15	2.65	2.78	0.99	1.08	0.22	0.28
	30.0	5.0	3.65	3.76	0.27	0.31	3.06	3.19	1.05	1.13	0.24	0.30
	30.0	10.0	4.20	4.32	0.30	0.35	3.29	3.41	1.14	1.20	0.26	0.33
		LSD (0.05)	0.11	0.13	0.003	0.004	0.10	0.12	0.004	0.006	0.003	0.005
Site (S)			*	*	*	*	*	*	*	*	*	*
Biochar (B)			*	*	*	*	*	*	*	*	*	*
Poultry manure (PM)			*	*	*	*	*	*	*	*	*	*
S × B			*	*	*	*	*	*	*	*	*	*
S × PM			*	*	*	*	*	*	*	*	*	*
B × PM			*	*	*	*	*	*	*	*	*	*
S × B × PM			*	*	*	*	*	*	*	*	*	*

*Significant difference at $p \leq 0.05$

Effect of site, biochar and poultry manure on mineral composition of sweet potato storage roots

The effect of site, biochar and poultry manure application on mineral composition of sweet potato storage roots in 2019 and 2020 are shown in Table 4. In both years (2019 and 2020), site, biochar and poultry manure application significantly affected concentrations of mineral nutrition in the storage roots of sweet potato. Generally, the sole application of biochar, sole application of poultry manure and their mixture at different levels significantly ($p \leq 0.05$) increased mineral concentrations of P, K, Ca, Mg, Fe, Zn and Na with rates of application compared with the control (no application of biochar or poultry manure) in both years. In both years, biochar application significantly ($p \leq 0.05$) increased mineral concentrations of P, K, Ca, Mg, Fe, Zn and Na with rates of application from 0 to 30.0 t ha^{-1}. Similarly, poultry manure application significantly ($p \leq 0.05$) increased mineral concentrations of P, K, Ca, Mg, Fe, Zn and Na with rates of application from 0 to 10.0 t ha^{-1} in both years. In both years, the combined application of biochar and poultry manure at different levels increased mineral concentrations of P, K, Ca, Mg, Fe, Zn and Na than the sole biochar and sole poultry manure. The highest values of P, K, Ca, Mg, Fe, Zn and Na was attained at the highest application rate of 30 t ha^{-1} biochar + 10.0 t ha^{-1} poultry manure (B_{30} + PM_{10}) compared with other treatments. The control had the least values of mineral nutrition in the storage roots of sweet potato in both years.

When studied as an individual factor, site influenced mineral concentrations of P, K, Ca, Mg, Fe, Zn and Na in the storage roots of sweet potato significantly in both years. Biochar and poultry manure, as individual factors, also affected mineral nutrition in sweet potato storage roots in both years. The interactive effect of S × B, S × PM and B × PM were significant for all mineral nutrition in the sweet potato storage roots in both years. When all three factors (S × B × PM) were considered together, interactions were significant in both years.

Table 4. Effect of site, biochar and poultry manure on mineral composition of sweet potato

Table 4. Effect of site, biochar, and poultry manure on the mineral composition of sweet potato

Site	Biochar (t ha^{-1})	Poultry manure (t ha^{-1})	P (mg 100 g^{-1})		K (mg 100 g^{-1})		Ca (mg 100 g^{-1})		Mg (mg 100 g^{-1})		Fe (mg 100 g^{-1})		Zn (mg 100 g^{-1})		Na (mg 100 g^{-1})	
			2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Site A	0.0	0.0	18.3	16.8	180.4	168.8	20.4	18.4	9.2	8.0	0.18	0.17	0.13	0.12	0.05	0.05
	0.0	5.0	21.6	23.9	200.6	218.0	24.6	28.1	11.4	13.8	0.20	0.22	0.17	0.20	0.07	0.09
	0.0	10.0	24.2	26.5	213.3	230.7	26.8	30.3	14.5	16.7	0.27	0.29	0.19	0.23	0.09	0.11
	10.0	0.0	20.7	22.9	205.9	223.3	24.2	27.7	11.2	13.5	0.23	0.25	0.15	0.17	0.06	0.07
	10.0	5.0	27.5	29.8	221.7	239.1	34.5	38.0	16.5	18.9	0.28	0.30	0.22	0.25	0.12	0.14
	10.0	10.0	31.2	33.5	236.8	254.2	39.8	43.3	21.7	23.8	0.40	0.42	0.25	0.28	0.15	0.17
	20.0	0.0	22.4	24.7	216.3	233.7	33.4	36.9	12.8	15.0	0.26	0.28	0.17	0.19	0.09	0.10
	20.0	5.0	34.6	36.9	248.6	266.1	44.6	48.1	23.6	25.8	0.48	0.51	0.29	0.33	0.19	0.21
	20.0	10.0	37.8	40.3	269.5	286.9	51.1	54.6	29.5	31.6	0.55	0.58	0.33	0.37	0.23	0.25
	30.0	0.0	24.9	27.4	228.4	245.8	47.3	50.8	14.6	17.2	0.30	0.32	0.20	0.22	0.10	0.12
	30.0	5.0	38.7	41.5	293.0	310.4	61.4	64.9	32.9	35.4	0.63	0.65	0.36	0.40	0.26	0.28
	30.0	10.0	41.6	44.8	305.6	323.0	62.7	66.2	34.5	36.9	0.67	0.69	0.41	0.44	0.29	0.31
Site B	0.0	0.0	19.9	18.1	187.8	175.9	25.3	23.5	10.3	9.1	0.20	0.19	0.15	0.14	0.08	0.07
	0.0	5.0	23.4	26.2	208.0	218.0	29.4	33.6	12.6	14.5	0.23	0.28	0.22	0.25	0.11	0.13
	0.0	10.0	26.5	29.3	220.7	230.7	31.5	35.7	15.6	17.5	0.30	0.35	0.25	0.28	0.13	0.15
	10.0	0.0	23.0	25.1	213.3	223.3	29.0	33.4	12.0	13.9	0.25	0.30	0.19	0.21	0.09	0.11
	10.0	5.0	30.4	33.4	229.1	239.1	39.4	43.6	17.7	19.6	0.31	0.36	0.27	0.30	0.16	0.18
	10.0	10.0	34.5	37.5	244.2	254.2	44.7	48.9	22.9	24.6	0.43	0.48	0.30	0.34	0.19	0.21
	20.0	0.0	25.3	28.1	223.7	233.7	38.1	42.3	13.9	15.8	0.29	0.34	0.21	0.24	0.12	0.14
	20.0	5.0	37.8	40.6	256.0	266.1	49.2	53.4	24.4	26.3	0.51	0.56	0.35	0.39	0.23	0.25
	20.0	10.0	41.2	44.0	276.9	286.9	55.9	60.1	30.8	32.6	0.58	0.63	0.39	0.43	0.27	0.29
	30.0	0.0	27.6	29.9	235.8	245.8	52.7	56.9	15.3	17.0	0.33	0.38	0.24	0.27	0.14	0.16
	30.0	5.0	44.3	47.1	300.4	310.4	66.1	70.2	33.6	35.5	0.66	0.71	0.42	0.46	0.30	0.32
	30.0	10.0	47.8	50.6	313.2	323.0	67.3	71.5	35.9	37.8	0.70	0.75	0.46	0.51	0.33	0.35
		LSD (0.05)	1.4	1.1	11.8	12.0	1.8	1.9	0.9	1.0	0.004	0.006	0.005	0.006	0.004	0.005
Site (S)			*	*	*	*	*	*	*	*	*	*	*	*	*	*
Biochar (B)			*	*	*	*	*	*	*	*	*	*	*	*	*	*
Poultry manure (PM)			*	*	*	*	*	*	*	*	*	*	*	*	*	*
S × B			*	*	*	*	*	*	*	*	*	*	*	*	*	*
S × PM			*	*	*	*	*	*	*	*	*	*	*	*	*	*
B × PM			*	*	*	*	*	*	*	*	*	*	*	*	*	*
S × B × PM			*	*	*	*	*	*	*	*	*	*	*	*	*	*

*Significant difference at $p \leq 0.05$

Effect of site, biochar and poultry manure on growth and root storage yield of sweet potato

The effect of site, biochar and poultry manure on the vine length, leaf area and root storage yield of sweet potato in 2019 and 2020 are shown in Table 5. In both years (2019 and 2020), site, biochar and poultry manure significantly influenced growth and root storage yield of sweet potato. In the first and second years, biochar significantly ($p \leq 0.05$) increased vine length, leaf area and root storage yield of sweet potato with the rate of application from 0 to 30.0 t ha^{-1}. Similarly, poultry manure significantly ($p \leq 0.05$) increased vine length, leaf area and root storage yield of sweet potato with the rate of application from 0 to 10.0 t ha^{-1}. In both years, the highest application rate of 30.0 t ha^{-1} biochar + 10.0 t ha^{-1} poultry manure gave the highest vine length, leaf area and root storage yield of sweet potato compared with all other treatments. The control gave the least values of vine length, leaf area and root storage yield of sweet potato in both years.

When studied as individual factor, site influenced vine length, leaf area and root storage yield of sweet potato significantly in both years. Biochar and poultry manure as individual factors also affected vine length, leaf area and root storage yield of sweet potato in both years. When biochar and poultry manure (B × PM) are considered, the interaction was significant for vine length, leaf area and root storage yield of sweet potato in both years. However, the interactive effect of S × B and S × PM for vine length, leaf area and root storage yield of sweet potato was not significant, nor was the S × B × PM interaction in both years.

Table 5. Effect of site, biochar and poultry manure on vine length and leaf area at 90 days after planting and root storage yield of sweet potato at 5 months after planting

Site	Biochar (t ha^{-1})	Poultry manure (t ha^{-1})	Vine length (cm)		Leaf area per plant (cm^2)		Root storage yield (t ha^{-1})	
			2019	2020	2019	2020	2019	2020
Site A	0.0	0.0	152	149	1.35	1.32	9.5	10.6
	0.0	5.0	213	228	2.28	2.44	14.6	15.3
	0.0	10.0	234	249	2.54	2.71	17.3	18.0
	10.0	0.0	210	225	2.25	2.40	10.4	11.1
	10.0	5.0	258	273	2.73	2.89	20.1	20.7
	10.0	10.0	274	289	2.89	3.05	22.9	23.5
	20.0	0.0	255	270	2.65	2.80	12.7	13.4
	20.0	5.0	286	301	2.98	3.16	25.6	26.2
	20.0	10.0	291	306	3.16	3.33	28.4	29.0
	30.0	0.0	282	297	2.86	3.01	15.3	16.1
	30.0	5.0	316	331	3.35	3.51	31.0	31.5
	30.0	10.0	324	346	3.52	3.65	33.7	34.2
Site B	0.0	0.0	167	158	1.47	1.39	12.8	11.7
	0.0	5.0	228	239	2.41	2.56	16.6	17.5
	0.0	10.0	249	263	2.67	2.82	19.7	20.6
	10.0	0.0	225	236	2.38	2.53	12.9	13.8
	10.0	5.0	273	288	2.86	3.02	21.3	22.2
	10.0	10.0	290	305	3.02	3.17	24.6	25.5
	20.0	0.0	269	280	2.77	2.90	15.4	16.3
	20.0	5.0	301	316	3.11	3.26	26.0	26.9
	20.0	10.0	310	327	3.29	3.44	29.5	30.4
	30.0	0.0	297	308	2.97	3.10	18.1	19.1
	30.0	5.0	331	347	3.48	3.63	33.9	34.8
	30.0	10.0	345	363	3.63	3.79	37.1	38.0

	LSD (0.05)	13	11	0.09	0.06	1.4	0.8
Site (S)		*	*	*	*	*	*
Biochar (B)		*	*	*	*	*	*
Poultry manure (PM)		*	*	*	*	*	*
S × B		ns	ns	ns	ns	ns	ns
S × PM		ns	ns	ns	ns	ns	ns
B × PM		*	*	*	*	*	*
S × B × PM		ns	ns	ns	ns	ns	ns

*Significant difference at $p \leq 0.05$; ns = Not significant difference at $p \leq 0.05$

Discussion

The high soil bulk densities before the start of the experiment was attributed to the low organic matter of the sites and sandy nature of the soils. The higher bulk density values obtained in this study may be due to compaction by animal traction as common in southwestern Nigeria or continuous tractorization. The low soil organic carbon (OC), total N (TN), available P, exchangeable K, Ca and Mg before the commencement of the experiment could be attributed to soil degradation caused by continuous cropping for several years without fertilization. Nutrient concentrations in the leaves of sweet potato plants in the control plots were below the critical levels of 4.0% N, 0.22% P, 2.6% K, 0.76% Ca and 0.12% Mg, as determined by O'Sullivan et al. (1997), thus the leaves of sweet potato plants exhibited symptoms of deficiencies in N (yellow colouration), P (purple colouration) and K (burnt leaf margin). Increased leaf N, P, K, Ca, and Mg concentrations, sweet potato plant growth, and yield with biochar and poultry manure application rates compared to the control could be attributed to increased macronutrient availability, which is an important factor in soil fertility (Sahin et al., 2014). There was increased nutrient availability in the soil as a result of biochar and poultry manure application, leading to increased uptake by sweet potato plants. The increase in leaf nutrient concentrations, mineral composition, sweet potato growth and yield with biochar and poultry manure application rates can be related to soil quality improvement, nutrient release into soil solution, increase in chemical properties and/or beneficial organisms, and balanced plant nutrition. These results agree with the findings of (Gunes et al., 2014) who found increases in mineral composition and growth of lettuce plants after applying biochar and poultry manure. The positive effect of biochar on sweet potato plant leaf N, P, K, Ca, and Mg concentrations, mineral composition, growth, and root storage yield could also be attributed to improvements in soil friability and water holding capacity (Basso et al., 2013; Guo et al., 2020; Yi et al., 2020), as well as reduced nutrient losses and leaching (Gao and DeLuca, 2016; Gwenzi et al., 2018; Banik et al., 2021). Application of biochar-based fertilizer in a subtropical environment has been shown to boost growth and yield, as well as P, K, Ca, Al, and Cu uptake by ginger plants (Farrar et al., 2019). Biochar and compost application was also found to increase plant growth and uptake of N, P, K and Ca (Cox et al., 2021). The addition of biochar to different soils has resulted in increased growth, availability and uptake of nutrients by plants (Joseph et al., 2015; Liao et al., 2020; Shi et al., 2020; Ndoung et al., 2021). Agbede (2010) also observed that applying poultry manure to soil increased sweet potato growth, yield, and leaf N, P, K, Ca, and Mg nutrient concentrations. Processed poultry manure and biochar application increased growth and N, P, K, Zn, Cu and Mn concentrations of both bean and maize plants (Inal et al., 2015).

The significant influence of biochar and poultry manure application on mineral composition of sweet potato storage roots, as well as growth and yield, indicated that biochar and poultry manure contain some macronutrients and micronutrients that are released into the soil during mineralization. The value of minerals P, K, Ca, Mg, Fe, Zn and Na increased at different levels of biochar and poultry manure application. The findings that sweet potato growth, yield and storage roots mineral composition increase with biochar and poultry manure rates might be attributable to improved soil fertility due to the favourable impacts of organic matter after biochar and poultry manure incorporation. This is consistent with the soil chemical properties of the biochar and poultry manure rates (Chaganti and Crohn, 2015; Agbede et al., 2017). These findings reveal that biochar promotes nutrient cycling by improving the physical, chemical, and biological properties of the soil, allowing for better utilization of the applied poultry manure, resulting in greater nutrient uptake and allocation to the sweet potato storage roots. According to Cockell (2011), minerals are the inorganic substances that must be ingested and absorbed in adequate amounts to satisfy a wide variety of essential metabolic and/or structural functions in the body. Consumption of optimum concentration of minerals are essentials for growth and good health (Cockell, 2011). The application of biochar and poultry manure as sources of macronutrients would have positive influence on growth, yield and P, K, Ca, Mg, Fe, Zn and Na concentrations of sweet potato storage roots. Much of the improvement in leaf nutrient concentrations, mineral composition, growth and yield of sweet potato could be attributed to the supply of these nutrients through biochar and poultry manure materials to soil, as well as synergistic effects due to improved N absorption. Biochar is acknowledged for its ability to improve fertilizer use efficiency (Liao et al., 2020; Puga et al., 2020; Shi et al., 2020).

Conclusions

Degraded sand soil and sandy loam soil amended with sole biochar, sole poultry manure and their mixture at various levels increased leaf nutrient concentrations, mineral composition, growth and root storage yield of sweet potato, which could be due to improvements in the physical, chemical and biological properties of the soils. There were significant interactions between biochar and poultry manure (B × PM) on leaf N, P, K, Ca and Mg concentrations, mineral concentrations, growth and root storage yield of sweet potato, showing that biochar has the ability to improve poultry manure use efficiency and nutrient utilization. The highest application rate of 30.0 t ha^{-1} biochar and 10.0 t ha^{-1} poultry manure gave the best growth, root storage yield and nutritional quality of sweet potato and is therefore recommended for soil fertility management, nutritional sustainability and good performance of sweet potato in the study areas (forest savanna transition zone of southwest Nigeria). The findings of this study indicate that soil enriching with biochar and poultry manure could improve sweet potato leaf nutrient concentrations, mineral composition, growth and root storage yield, depending on the quantity of biochar or poultry manure added to the soil. These findings, however, should be confirmed through experiments that cover a wide range of spatial heterogeneity, such as various soil types, crops, agroecological zones, and land-use. Long-term field studies focusing on the persistence of biochar impacts on soils and crops are suggested for further studies. Variable rates of biochar and poultry manure, as well as their combined application on soils and crops, should also be considered.

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