



Research article

Effects of wood biochar and potassium fertilizer on soil properties, growth and yield of sweet potato (*Ipomea batata*)Aruna Olasekan Adekiya^{a,*}, Ojo Vincent Adebisi^b, Ayibanoa Lekoo Ibaba^b, Charity Aremu^b, Razaq Ola Ajibade^b^a Agriculture Programme, College of Agriculture, Engineering and Science, Bowen University, Iwo, Osun State, Nigeria^b College of Agricultural Sciences, Landmark University, PMB 1001, Omu-Aran, Kwara State, Nigeria

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ABSTRACT

Studies on integrating biochar with potassium (K) fertilizer is not common. Hence, experiments were conducted in 2020 and 2021 to evaluate the sole and combined applications of biochar and K fertilizer on soil properties and performance of sweet potato. It was hypothesized that the effects of combined applications of biochar and K fertilizer on the growth, and yield of sweet potato will be more than their individual applications. The study each year consisted of a 3 × 3 factorial experiment with three levels (0, 10, and 20 t ha⁻¹) of wood biochar and three levels (0, 70, and 120 kg ha⁻¹) of K fertilizer (potassium chloride). The 9 treatment combinations have three replications and follow a randomized complete block design. Results revealed that biochar alone or in combination with K fertilizer improved soil physical and chemical properties, growth, and yield of sweet potato relative to the control and K fertilizer alone. The interaction of biochar and K (biochar × K fertilizer) fertilizer was significant for growth and yield parameters. The addition of K fertilizer to biochar improved the performance of sweet potato compared with sole applications of K fertilizer or biochar. 20 t ha⁻¹ biochar + 70 kg ha⁻¹ K fertilizer and 20 t ha⁻¹ biochar + 120 kg ha⁻¹ K fertilizer increased growth and yield relative to 10 t ha⁻¹ biochar + 70 kg ha⁻¹ K fertilizer and 10 t ha⁻¹ biochar + 120 kg ha⁻¹ K fertilizer. Since 20 t ha⁻¹ biochar + 120 kg ha⁻¹ K fertilizer and 20 t ha⁻¹ biochar + 70 kg ha⁻¹ K fertilizer were statistically similar, for this experiment, 20 t ha⁻¹ biochar + 70 kg ha⁻¹ K fertilizer would be recommended for sweet potato production. Therefore, the addition of 70 kg K fertilizer with biochar has reduced the cost of increasing the rate to 120 kg ha⁻¹ which would have been economical in view of the high price and lack of K fertilizer in Nigeria and other sub-Saharan African countries.

1. Introduction

Sweet potato (*Ipomea batata*) is an essential root and vegetable crop grown throughout sub-Saharan Africa. The root tuber can be roasted, sliced, and fried as chips. The tuber can also be used in the industry for the production of starch, sugar, and alcohol (Ukom et al., 2009; Kasali, 2011). The leaves can also be consumed as vegetables, sweet potato also serves as an important feed for farm animals. Sweet potato cultivation has many benefits over the production of other tuber or root crops like yam, cassava, and cocoyam: it has a shorter cultivation period of three to four months with higher yield, and the carbohydrates in sweet potato are more nutritious because they are high in fiber, low in calories, and contain vitamins and minerals which may lower a person's risk of diabetes and heart diseases (Anbuselvi et al., 2012).

In Nigeria, sweet potato is usually planted on marginal soils with the belief that it requires less nutrients. However, with adequate fertilization sweet potato would reach its expected yield potential. Among all nutrients required by sweet potato, potassium (K) is of the utmost importance, because its addition to the soil will improve the performance of sweet potato by forming big tubers (Uwah et al., 2013; Aboyeji et al., 2019). A sweet potato crop that will yield 20 t ha⁻¹ of tuber removed 123, 15.5, and 175 kg ha⁻¹ N, P, and K, respectively (Mohankumar et al., 2000). K is vital in the production and movement of carbohydrates from the source to sink (tubers), supports photosynthesis and protein synthesis, regulates opening of stomata, increases nitrogen usage, promotes the transportation of assimilates, improves plant's ability to withstand stress, water use efficiency and activation of plant enzyme (Byju and Nedunchezhiyan 2004; Pettigrew, 2008; Usherwood, 1995) and consequently increases crop yields. It is usually presumed that soils of the tropics have

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sufficient quantities of K for good growth of crops (Afari-Sefa et al., 2004), but, under continuous cropping and intense rain in the tropics, K might not be found to be adequate. However, over the years, Agricultural land in Nigeria had been repeatedly cultivated for crop production and therefore causes severe degradation, especially in the Nigerian savanna that is fragile leaving no option than the addition of external inputs.

Biochar is the end product of organic materials that have been thermochemically converted with a little quantity of oxygen (Adekiya et al., 2020). According to Sohi et al. (2010), adding biochar to soils lowers the rate of nutrient leaching while also improving soil pH, water content, organic matter, cation exchange capacity, and microbial content. Application of biochar to the soil could also enhance soil characteristics (Sadaf et al., 2017). Biochar contains both macro and micronutrients and making soil nutrients to be available, so enhancing soil productivity and crop yield. Biochar has been recommended as a likely ways of increasing soil potassium (Wang et al., 2018). This favourable effects could be ascribed to the inherent nutrients especially K within biochar (Angst and Sohi, 2013). Numerous kinds of research have been done to show the effects of biochar on crops in tropical soils (Aneseeye and Wolde, 2021; Adekiya et al., 2019, 2020; Agbede and Adekiya, 2020). However, work on the effects of Biochar on sweet potato is not common.

One of the most crucial farm inputs for boosting crop yield is fertilizer. There aren't many studies on how K fertilizer affects soil chemical characteristics and sweet potato productivity in Nigeria. Few studies are concentrated on the application of NPK fertilizer to sweet potato (Nmor and Okobia, 2017; Esan et al., 2021; Balogun et al., 2021). This could be added to the high cost and scarcity of K fertilizers.

Biochar plays a vital part in improving soil health and is also known to be substantially rich in cations including K (Adekiya et al., 2020). While K fertilizer is expensive and not easily accessed by local farmers, biochar can be locally made from many waste agricultural materials. Integrated management is necessary in order to determine whether biochar application can reduce or totally eliminate the need for K fertilizer. Previous studies reported that the addition of organic and inorganic fertilizers increased sweet potato yield compared to their sole forms (Yeng et al., 2012; Nedunchezhiyan and Reddy, 2002; Martí and Mills, 2002). Studies on integrating biochar with K fertilizer have not been conducted. Thus, the objective of this study was to assess the effects of sole and combined applications of biochar and K fertilizer on soil properties, growth, and yield of sweet potato on tropical derived savanna Alfisol. In this, we hypothesized that the effects of combined applications of biochar and K fertilizer on the growth, and yield of sweet potato will be more than their individual applications. Therefore experiments were conducted to verify these facts.

2. Materials and methods

2.1. Site description and experimental layout

Field experiments were conducted in the 2020 and 2021 cropping seasons at the Teaching and Research Farm, Landmark University, Omu-Aran, Kwara State, Nigeria. The studies were established to assess the effects of single and combined applications of biochar and K fertilizer on soil properties, growth, and yield of sweet potato. The study site (Landmark University) is within Latitudes 8° 7' 26.21388" and Longitudes 5° 5' 0.1788" with an elevation of 560 m. The rainfall in the area has its highest peaks in June and October every year. Yearly rainfall ranges between 1200 – 1300 mm with an average temperature of 32 °C. The soil of the site of the study (Landmark University) is an Alfisol classified as Oxic Haplustalf or Luvisol (Adegbite et al., 2019). The study site had been under continuous maize and cassava cultivation for two years and a rest of one year before experimentation. Major weeds on the site before the experiment are Mexican sunflower and Guinea grass.

The study each years 2020 and 2021 consisted of a 3 × 3 factorial experiment with three levels (0, 10, and 20 t ha⁻¹) of wood biochar and three levels (0, 70, and 120 kg ha⁻¹) of K fertilizer (potassium chloride -

muriate of potash). The 9 treatment combinations formed have three replications and follow a randomized complete block design. The size of a plot was 4 m × 4 m and there were 9 plots per block one block is separated from the other by a distance of 2 m and a plot is 1 m from the other plot. A similar design of experiment treatments/plot allocations as applied for the study in 2020 was repeated in 2021 but the 2021 experiment was conducted at a different site/location within the University Farm.

2.2. Addition of biochar to the soil, planting of sweet potato vines and application of muriate of potash fertilizer

Biochar used in the experiment was produced from hardwood (*Prosopis africana*) by using a metal drum container that was 70 cm in height and 46 cm in diameter. The hardwood (*Prosopis africana*) was kept in the drum as close as possible and was kindled by using natural gas. The temperature during the process of burning was checked with a thermocouple and it was 580 °C for 24 h of pyrolysis. The biochar produced was allowed to cool down, powdered, and later sieved with a 2 mm sieve prior field application.

Land preparation was by conventional method (ploughing, harrowing, and ridging), after which the study area was portioned out to the necessary plot size of 4 × 4 m. Four ridges were maintained per plot. Immediately after land preparation biochar treatments were applied as required at 10 and 20 t ha⁻¹ with the use of a traditional hoe and were applied about 10 cm deep into the soil. Each year (2020 and 2021), approximately 25–30 cm long sweet potato vines were planted using a spacing of 1 m × 1 m to produce a total of 10,000 plants of sweet potato per ha. Two weeks after planting, the application of potassium fertilizer (muriate of potash) was done at rates of 0, 70, and 120 kg ha⁻¹, banded at a distance of 10 cm from the planted sweet potato vines.

2.3. Determination of soil and biochar characteristics

Before the application of treatments each year (2020 and 2021), Soil samples were collected using a core sampler and were placed in an oven fixed at 105 °C for 24 h for determination of bulk density using the method of Campbell and Henshall (1991). Total porosity was calculated from the values of bulk density and particle density of 2.65 Mg m⁻³. Also, before the application of amendments, soil samples were taken from 10 places from the site each year. The soil samples were bulk together, air-dried, and sieved with a 2 mm sieve for chemical analysis. After the experiment each year, soil samples were also taken but this time on an individual plot basis (three samples collected from each plot and later bulked together) and similarly analyzed for soil chemical properties. The hydrometer method was used for the determination of particle size (Gee and Or, 2002). Soil organic carbon (OC) was determined by the procedure of Walkley and Black using the dichromate wet oxidation method (Nelson and Sommers, 1996). Total N was determined by the micro-Kjeldahl digestion method (Bremner, 1996). Available P was determined by Bray-1 extraction followed by molybdenum blue colorimetry (Frank et al., 1998). Exchangeable K, Ca, and Mg was extracted using 1 M ammonium acetate (Hendershot et al., 2008). Thereafter, the concentration of K was determined on a flame photometer, while Ca and Mg were read on an Atomic Absorption Spectrophotometer. Soil pH was determined using a soil-water medium at a ratio of 1:2 with a digital electronic pH meter.

Four weeks after the application of treatments, determination of bulk density, total porosity, and gravimetric water content in all plots started and was repeated at 4 weeks interval for each year. Bulk density and porosity were determined as described above. Soil moisture content was determined gravimetrically by oven drying at 105 °C for 24 h.

The bulk density of biochar used was determined by filling a container of a known weight and volume with biochar without compression or pressing down the biochar inside. The container with

Table 1. Properties of pre-plant soil in 2020 and 2021 before experimentation and chemical analysis of biochar used.

Property	2020	2021	Biochar
Sand (%)	68.8	68.8	NA
Silt (%)	15.8	15.9	NA
Clay (%)	15.4	15.3	NA
Textural class	Sandy loam	Sandy loam	NA
Bulk density (g cm ⁻³)	1.46	1.47	0.63
Porosity (%)	44.7	45.7	70.1
Organic carbon (%)	1.17	1.18	54
Total nitrogen (%)	0.18	0.19	0.77
C: N ratio	6.50	6.21	70.1
pH (H ₂ O)	5.62	5.68	7.48
Ash (%)	NA	NA	17
Available P (mg kg ⁻¹)	9.4	9.6	878
Exchangeable K (cmol kg ⁻¹)	0.11	0.12	1.78
Exchangeable Ca (cmol kg ⁻¹)	1.62	1.64	4.47
Exchangeable Mg (cmol kg ⁻¹)	1.44	1.49	8.01
Electrical conductivity (ds m ⁻¹)	0.11	0.10	0.65

biochar inside was later weighted. The bulk density of biochar (b_d) was calculated using Eq. (1) (Unal et al., 2008):

$$b_d = \frac{w_b}{v_b} \quad (1)$$

Where w_b = weight of biochar; v_b = volume of biochar.

The solid density of biochar was determined using the liquid displacement method (Unal et al., 2008), thereafter porosity of biochar was estimated using Eq. (2) (Keawpoolphol et al., 2017):

$$\text{Porosity (\%)} = 1 - \frac{b_d}{s_d} \times 100 \quad (2)$$

b_d = bulk density of biochar and s_d = solid density of biochar

2.4. Growth and yield of sweet potato

Sweet potato growth (Vine length, number of leaves) and yield (number of tubers and tuber weight) parameters were recorded when the potato is fully matured (about 22 weeks after planting). The length of the vine was estimated using the meter rule, and the number of leaves on each plant was counted. Utilizing a hoe, tubers were picked, and any remaining soil wiped off of them. Tubers were counted and weighed on a weighing scale.

Table 2. Effect of biochar and K fertilizer on soil chemical properties.

Treatment combinations		pH (H ₂ O)		Organic C (%)		N (%)		P (mg kg ⁻¹)		K (cmol kg ⁻¹)		Ca (cmol kg ⁻¹)		Mg (cmol kg ⁻¹)	
Biochar (t ha ⁻¹)	K fertilizer (kg ha ⁻¹)	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
0	0	5.54d	5.60d	1.17c	1.17c	0.17e	0.18g	9.1c	9.3c	0.10g	0.10i	1.71c	1.74c	1.40c	1.43d
	70	5.64cd	5.66cd	1.18c	1.18c	0.18d	0.19f	9.3c	9.4c	0.21ef	0.20h	1.74c	1.76c	1.42c	1.44c
	120	5.69cd	5.71cd	1.18c	1.18c	0.19c	0.20e	9.5c	9.4c	0.22e	0.22ef	1.70c	1.72c	1.38c	1.43c
10	0	5.88b	5.93b	1.60b	1.61b	0.19c	0.21de	10.8b	10.9b	0.21ef	0.20h	1.96b	1.96b	1.72b	1.74b
	70	5.91b	5.98b	1.61b	1.62b	0.21bc	0.21d	10.8b	10.9b	0.28d	0.27d	1.98b	1.98b	1.75b	1.76b
	120	5.93b	6.01b	1.61b	1.62b	0.23bc	0.22cd	10.9b	11.1b	0.31c	0.30c	1.99b	2.01b	1.77b	1.78b
20	0	6.31a	6.41a	1.86a	1.85a	0.21ab	0.23bc	12.6a	12.8a	0.22e	0.21gh	2.20a	2.21a	1.95a	1.96a
	70	6.38a	6.49a	1.86a	1.85a	0.25a	0.24ab	12.7a	13.0a	0.33ab	0.33ab	2.24a	2.25a	2.01a	2.01a
	120	6.41a	6.53a	1.86a	1.86a	0.27a	0.25a	12.7a	13.1a	0.35a	0.34a	2.26a	2.27a	2.05a	2.06a
Biochar (B)		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K fertilizer (K)		0.0604	0.086	0.100	0.037	0.000	0.008	0.914	0.914	0.000	0.000	0.000	0.000	0.000	0.000
B × K		0.762	0.013	0.465	0.763	0.007	0.008	0.999	1.000	0.008	0.009	0.000	0.000	0.000	0.000

Means followed by the same letters are not significantly different according to Turkey pairwise comparisons ($P < 0.05$).

2.5. Statistical analysis

Using IBM SPSS Statistics 21, the acquired data was treated to a two-way analysis of variance (ANOVA). Tukey pairwise comparisons were used to compare treatment means at the $p = 0.05$ probability level.

3. Results

The physical and chemical characteristics of the site of the study in 2020 and 2021 before the application of treatments and the chemical characteristics of the biochar used for the experiment are showed in Table 1. The soil before experimentation was sandy loam in texture, high in bulk density, moderately acidic, and low organic carbon (OC), N, P, K, and Ca but high in Mg. The biochar used for the study was alkaline (pH 7.48) and had a high OC, K, N, Ca Mg, C: N ratio, porosity, and low bulk density when compared to the pre-planting soils.

3.1. Biochar and K fertilizer effects on soil chemical properties

Data on the effects of biochar and K fertilizer on soil chemical properties are presented in Table 2. In 2020 and 2021, K fertilizer alone raised the soil's N and K concentrations in comparison to the control. K fertilizer was not significant for pH, organic C, Ca and Mg, and P. Biochar alone increased soil pH, organic C, N, P, K, Ca, and Mg concentration relative to the control. 20 t ha⁻¹ biochar increased these properties relative to 10 t ha⁻¹. Biochar alone increased soil nutrient concentration relative to K fertilizer alone. The combinations of biochar and K fertilizer increased pH, organic C, N, P, K, Ca, and Mg relative to their sole forms (that is biochar alone and K fertilizer alone). The interactive effect (B × K) was significant for N and K but not significant for pH, organic C, P, Ca, and Mg. 10 t ha⁻¹ biochar +70 kg ha⁻¹ K fertilizer and 10 t ha⁻¹ biochar +120 kg ha⁻¹ K fertilizer has similar values of pH, organic C, N, P, Ca and Mg. Similarly, 20 t ha⁻¹ biochar +70 kg ha⁻¹ K fertilizer and 20 t ha⁻¹ biochar +120 kg ha⁻¹ K fertilizer have similar values of pH, organic C, N, P, Ca and Mg. The concentration of nutrients by 20 t ha⁻¹ biochar +70 kg ha⁻¹ K fertilizer and 20 t ha⁻¹ biochar +120 kg ha⁻¹ K fertilizer was significantly different from that of 10 t ha⁻¹ biochar +70 kg ha⁻¹ K fertilizer and 10 t ha⁻¹ biochar +120 kg ha⁻¹ K fertilizer.

3.2. Biochar and K fertilizer effects on soil physical properties

Data on the effects of biochar and K fertilizer on soil physical properties are presented in Figure 1. The application of K fertilizer alone did not improve soil's physical properties relative to the control. Values of soil physical properties between 70 and 120 kg ha⁻¹ are not significantly different. As a single factor, biochar alone improved soil physical

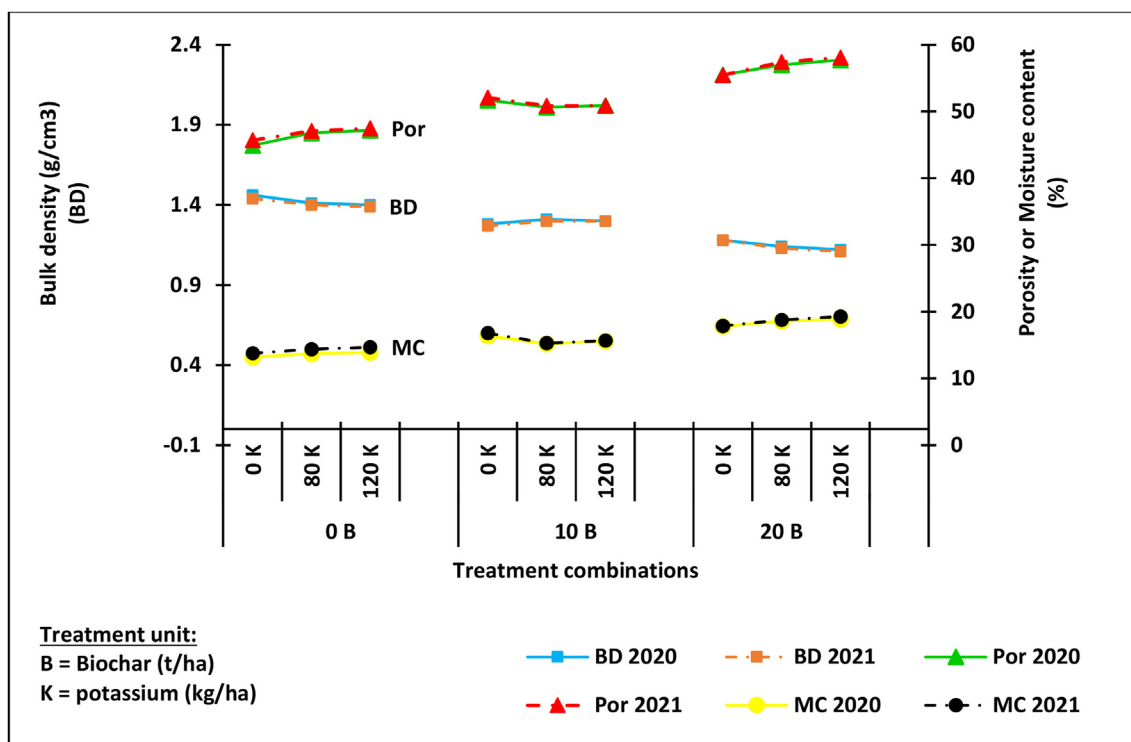


Figure 1. Effect of biochar and K fertilizer on soil physical properties.

properties relative to the control. 20 t ha⁻¹ biochar improved these properties relative to 10 t ha⁻¹ biochar. Biochar alone improved soil physical properties relative to K fertilizer alone. The interactive effect of biochar and K fertilizer (B × K) were significant for bulk density, porosity, and moisture content of the soil. The addition of biochar to K fertilizer improved soil physical properties relative to biochar or K fertilizer alone with 20 t ha⁻¹ biochar + K fertilizer having the best values. Relative to the control in 2020, 20 t ha⁻¹ biochar +120 kg ha⁻¹ K fertilizers reduced soil bulk density by 30.4 % and increase porosity and moisture content by 28.5 and 43.2 respectively. In 2021, bulk density was reduced by 29.7% and porosity, and moisture content increased by 27.1 and 39.9% respectively relative to the control by applying 20 t ha⁻¹ biochar +120 kg ha⁻¹ K fertilizers. The values of soil physical properties between 20 t ha⁻¹ biochar +70 kg ha⁻¹ K fertilizer and 20 t ha⁻¹ biochar +120 kg ha⁻¹ K fertilizer were not significantly different. Similarly, the values between 10 t ha⁻¹ biochar +70 kg ha⁻¹ K fertilizer and 10 t ha⁻¹ biochar +120 kg ha⁻¹ K fertilizer were also not significantly different.

3.3. Response of the performance of sweet potato to biochar and K fertilizer

Data on the response of the performance of sweet potato to biochar and K fertilizer are presented in Figures 2 and 3. K fertilizer alone as a single factor influenced the growth (vine length and number of leaves) and yield (number of tubers and tuber weight) characteristics of sweet potato significantly relative to the control. 120 kg K ha⁻¹ also increases the growth and yield of sweet potato significantly relative to 70 kg K ha⁻¹. Biochar alone as a single factor also influenced the growth and yield of sweet potato significantly relative to the control and K fertilizer alone. 20 t ha⁻¹ increased growth and yield relative to 10 t ha⁻¹. The interactive effect of biochar and K fertilizer (B × K) were significant for vine length, number of leaves, fruit number, and fruit weight. The addition of K fertilizer to biochar increased the performance of sweet potato compared with sole applications of K fertilizer or biochar. In 2020, 20 t ha⁻¹ biochar +120 kg ha⁻¹ K fertilizer raised the yield of sweet potato by 56.9, 46.8, 40.0, 33.8 and 21.3%, respectively relative to

control, 70 kg ha⁻¹ K fertilizer, 120 kg ha⁻¹ K fertilizer, 10 t ha⁻¹ biochar and 20 t ha⁻¹ biochar. In the same vein in 2021, 20 t ha⁻¹ biochar +120 kg ha⁻¹ K fertilizer increased the yield of sweet potato by 68.9, 52.4, 43.3, 39.1 and 26.3%, respectively relative to control, 70 kg ha⁻¹ K fertilizer, 120 kg ha⁻¹ K fertilizer, 10 t ha⁻¹ biochar and 20 t ha⁻¹ biochar. 20 t ha⁻¹ biochar +70 kg ha⁻¹ K fertilizer and 20 t ha⁻¹ biochar +120 kg ha⁻¹ K fertilizer increased growth and yield relative to 10 t ha⁻¹ biochar +70 kg ha⁻¹ K fertilizer and 10 t ha⁻¹ biochar +120 kg K fertilizer. However, the values between 20 t ha⁻¹ biochar +70 kg ha⁻¹ K fertilizer and 20 t ha⁻¹ biochar +120 kg ha⁻¹ K fertilizer were not significantly different. Average over two years, 20 t ha⁻¹ biochar +120 kg ha⁻¹ K fertilizer improved the root tuber of sweet potato only by 2.2% compared with 20 t ha⁻¹ biochar +70 kg ha⁻¹ K fertilizer.

4. Discussion

There was a rise in N and K and a slight reduction in Ca and Mg with K fertilizer application. The increase in N due to K application could be as a result of increase in the amount of K⁺ in soil solution which could have induced displacement of fixed NH₄⁺ making them available due to similarity in ionic radii (Natarajan, 1980 cited by Surendran (2005)). The increase in the amount of K in the soil was due to K fertilizer application. There were however reductions of Ca and Mg in the soil at a higher rate of 120 kg ha⁻¹. When there is a high quantity of K in the soil due to a high rate of application, magnesium and calcium deficiencies may occur as a result of the suppression of the uptake of these nutrients caused by nutrient imbalance (Spear et al., 1978 as cited by Byju and George, 2005). To avert this problem, Landon (1991) reported that, magnesium and calcium could be applied alongside potassium, to keep a favourable balance.

The result that sole biochar increased soil pH, OC, N, P, K, Ca, and Mg concentration compared with the control may be due to the chemical composition of biochar used (Table 1). The pH of biochar applied soil was higher than the control soil because of the biochar's liming ability (pH 7.48) and is also enriched with basic cations especially Ca which is necessary to raise soil pH. Biochar applied soil has higher OC relative to

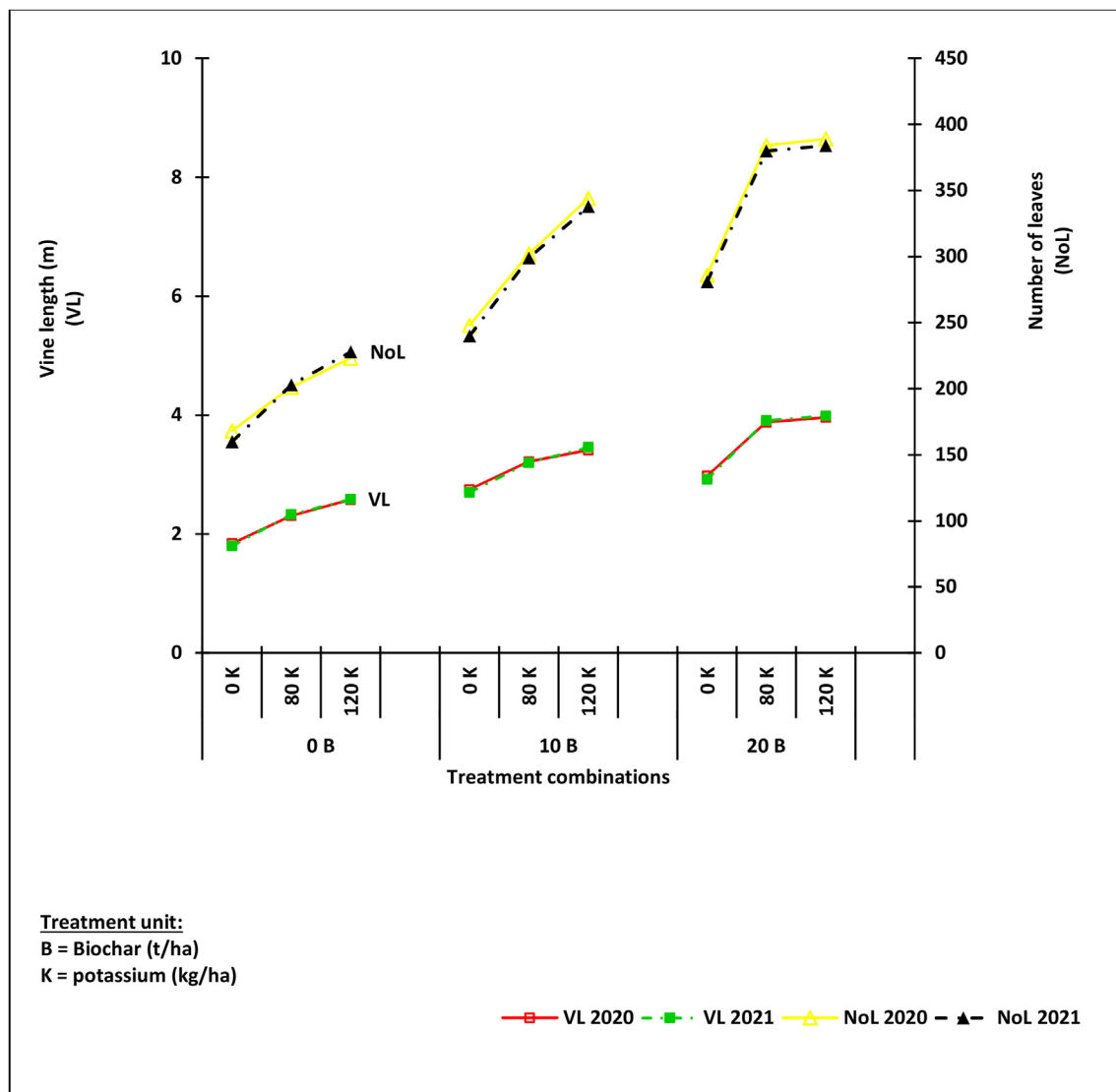


Figure 2. Effect of biochar and K fertilizer on growth parameters of sweet potato.

the control, this is so because wood feedstock is known to contain high carbon content. Gwenzi et al. (2015) stated that about 2.2 M t year⁻¹ of organic carbon can be added using biochar. In this experiment, biochar treatments have increased soil N relative to the control due to greater availability of soil N (applied through the basal application) as a result of retention in the biochar treatments compared with the control (where N might be prone to losses by leaching). Because biochar adsorbed cations and anions, therefore leaching of applied and regular soil nutrients is minimized (Major et al., 2009). The high retention capacity ascribed to biochar was as a result of the carboxylate groups existing in it (Glaser et al., 2021). Nigussie et al. (2012) and Abdeen (2020) likewise stated that there is significant increase in N by applying biochar using biomass and wood sawdust biochar respectively as their feedstock. Biochar application to soil also has the propensity to reduce the leaching of P and therefore keep a reasonable level of P in the soil (Miller et al., 2012), thus biochar amended soil has significantly higher P content relative to no biochar treatments in this experiment. The significant increase in K, Ca, and Mg soil concentrations as a result of biochar application was added to the existence of cation exchange sites on the surface of biochar. Biochar particles are colloidal in nature with large specific surface area and negative surface charges from deprotonated functional groups. Consequently, nutrients dissolved in the soil solution are attracted to the colloidal surfaces. Also, because biochars adsorbed cations and anions,

leaching of applied and regular soil nutrients are reduced (Major et al., 2009). This result is in consonance with that of Njoku et al. (2015) where rice husk and sawdust biochars were used and the highest rate of biochar (10 t ha⁻¹) has the highest values of pH, N, K, OC, Mg, Na, and CEC. Also, Adekiya et al. (2020) also found that the chemical properties were improved with application of biochar and that the improvement in these properties increased with rates of biochar applied. Biochar alone increased soil nutrient concentration relative to K fertilizer alone. This could be added to the dissimilarities in the chemical nature of biochar relative to K fertilizer and differences in their effects on the soil ecosystem. K fertilizer contains only K, whereas biochar contains both macro and micronutrients, ash and increased pH. One can therefore say that the type of nutrient elements present in an amendment will determine the amount and quality of nutrients available in the soil and consequently absorbed by the plant. K fertilizer alone did not increase OC relative to biochar alone, because K fertilizer is not an organic material and so cannot increase soil organic carbon.

Addition of biochar with K fertilizer increased pH, OC, N, P, K, Ca, and Mg relative to their sole forms. This was so because of the complementary effect of biochar and K fertilizer.

The decrease in soil bulk density and increase in porosity due to the addition of biochar alone or when combined with K fertilizer relative to K fertilizer alone and the control was due to the fairly lower bulk density

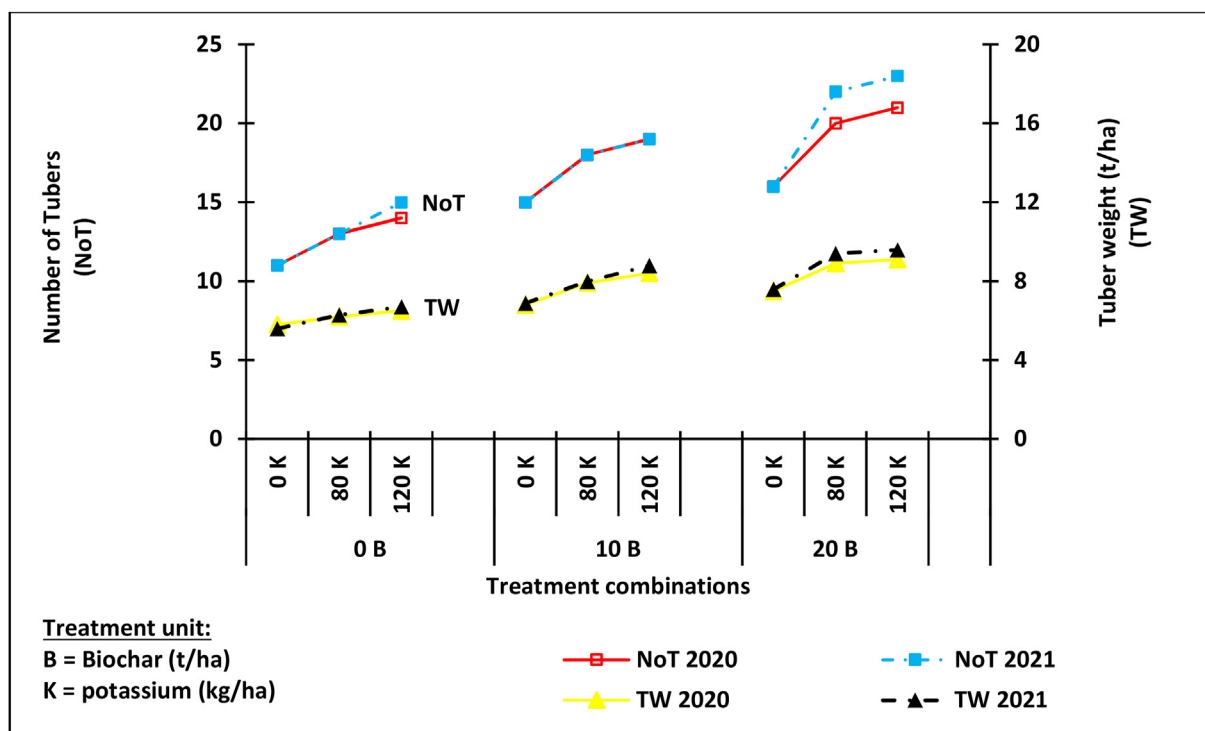


Figure 3. Effect of biochar and K fertilizer on yield parameters of sweet potato.

(0.63 g cm^{-3}) and high porosity (70.1%) of biochar compared with the bulk density of the soil which is approximately 1.46 g cm^{-3} with porosity of 45.3% (Table 1). Consequently, the addition of biochar possibly decreases the density of the bulk soil by the mixing or dilution effect (Blanco-Canqui, 2017). The bulk density of soil added with biochar had been found to significantly decrease by 12%–25% compared with the control (Hseu et al., 2014). In a two-year study on Alfisol of southwest Nigeria, it was found that the bulk density reduced from 1.54 to 1.16 g cm^{-3} and 1.55 to 1.04 g cm^{-3} in 2018 and 2019, respectively due to the application of 30 t ha^{-1} wood biochar (Agbede and Adekiya, 2020). The increase in porosity of soil added with biochar could be as a result of: decreasing soil bulk density, improving soil aggregation, interacting with mineral soil particles, and decreasing soil packing (Hseu et al., 2014). The improved moisture content of biochar applied soils could be partly indirectly by improving soil structure through good aggregation and also as a result of biochar's ability to retain water because of its huge surface area and a large number of micropores can alter the normal surface area and the pore size distribution of the soil and consequently its water retention ability (Chintala et al., 2014). The water content of a sandy loam the soil was found to increase by 55.8% as a result of the addition of 30 t ha^{-1} biochar (Agbede and Adekiya, 2020).

K fertilizer alone influenced the vine length, number of leaves and tuber/plant, and tuber weight in t ha^{-1} of sweet potato compared with the control. This result was as a result of an increase in K present within the soil, therefore improved the amount taken up by the crop. K fertilizer increase the yield of sweet potato relative to the control due to the combination of the fact that K fertilizer brings a rise to the rate of photosynthesis in the leaves, CO_2 absorption and also aids carbon movement (Sangakkara et al., 2000), and enhances nitrogen uptake by the plant. The yield might also be due to the function of K in cell division, production, and movement of sugars within the plant, the catalyst of numerous enzymatic processes, in the transformation of carbohydrates to organic acids in tubers crops (Agbede, 2009). Potassium is known to increase the growth and expansion of tubers in roots and tuber crops (Aboyeji et al., 2019).

Biochar alone influenced vine length, number of leaves and tuber/plant, and tuber weight in t ha^{-1} of sweet potato relative to the control

and K fertilizer alone. The improved yield of sweet potato under biochar relative to the control was due to better soil physical characteristics (reduction in soil density and improved porosity and moisture content) of biochar relative to the control. Bulk density is essential to tuberization, soil water movement, root spreading and function and therefore water and nutrient uptake and plant growth. Agbede and Adekiya (2011) had earlier reported that sweet potato responds to high bulk density. Also, the improvement of yield under biochar relative to the control can as well be due to changes brought to the soil by biochar such as nutrient addition, increased soil pH, nutrient availability, provision of chemically active surfaces which might have affected the dynamics of soil nutrients (Hossain et al., 2010; Jeffery et al., 2011; Lehmann et al., 2003; Sohi et al., 2009; Sukartono et al., 2011). The increase in cations due to biochar addition resulted in an improvement in the fertility and retention of soil nutrients (Cheng et al., 2006), particularly K which is essential for tuber expansion in sweet potato (Aboyeji et al., 2019). The improved yield of sweet potato in this experiment is in line with Jeffery et al. (2017) who stated that the use of biochar could particularly be important to crop production in poor fertile and acidic soils in the tropics. An increase of 8–45% in storage root of sweet potato had been reported by Indawan et al. (2017) with the addition of 5 t ha^{-1} tobacco biochar. The improved growth and yield of sweet potato under biochar alone relative to K fertilizer alone is in consonance with the improved soil chemical and physical characteristics of the biochar relative to K fertilizer in this experiment (Table 2 and Figures 2 and 3).

The interactive effect $B \times K$ was significant for the performance of sweet potato. The result supports the fact that biochar can increase the efficiency of use of K fertilizer. The addition of biochar with K fertilizer (in addition to improving soil physical properties) would have possibly reduced the leaching of K in soil and improved the K holding ability of the soil and therefore improve sweet potato yield. The good effects of biochar addition on crop performance that has to do with the retention of nutrients worked best when added with organic manures or chemical fertilizers, particularly on tropical soils (Alburquerque et al., 2013; Glaser et al., 2002; Hossain et al., 2010; Ogawa et al., 2006; Schulz and Glaser, 2012; Van Zwieten et al., 2010). Oladele et al. (2019) found that addition of biochar produced from rice husk residues with N fertilizer increased

Table 3. Correlation coefficient between soil physical and chemical properties and sweet potato performance.

		pH	OC	N	P	K	Ca	Mg	BD	POR	MC
Vine length	2020	0.78*	0.72*	0.95**	0.74*	0.96**	0.76*	0.77*	-0.78*	0.78*	0.74*
	2021	0.78*	0.72*	0.87**	0.75*	0.97**	0.76*	0.78*	-0.78*	0.78*	0.74*
Number of leaves	2020	0.83**	0.79*	0.96**	0.80**	0.96**	0.81**	0.83*	-0.82*	0.82**	0.78*
	2021	0.83**	0.80**	0.91**	0.81**	0.97**	0.82**	0.83**	-0.82**	0.82**	0.76*
Number of tubers	2020	0.80**	0.71*	0.96**	0.76*	0.933**	0.77*	0.78*	-0.80**	0.80**	0.78*
	2021	0.81**	0.73*	0.88**	0.77*	0.95**	0.78*	0.79*	-0.81**	0.80**	0.77*
Tuber weight	2020	0.73*	0.69*	0.94**	0.70*	0.93**	0.73*	0.75*	-0.72*	0.72*	0.68*
	2021	0.72*	0.68*	0.81**	0.69*	0.95**	0.72*	0.73*	-0.71*	0.71*	0.69*

*Significant difference at $p = 0.05$; **significant difference at $p = 0.01$; BD = bulk density, POR = porosity, MC = moisture content.

the yield of rain-fed upland rice (*Oryza sativa*). Also, doubled maize grain yield was realized when biochar and NPK fertilizer were applied together relative to NPK fertilizer alone (Steiner et al., 2007).

20 t ha⁻¹ biochar +70 kg ha⁻¹ K fertilizer and 20 t ha⁻¹ biochar +120 kg ha⁻¹ K fertilizer increased growth and yield relative to 10 t ha⁻¹ biochar +70 kg ha⁻¹ K fertilizer and 10 t ha⁻¹ biochar +120 ha⁻¹ kg K fertilizer. This was as a result of the better soil physical condition and best values of soil nutrients with these treatments.

The values between 20 t ha⁻¹ biochar +70 kg ha⁻¹ K fertilizer and 20 t ha⁻¹ biochar +120 kg ha⁻¹ K fertilizer were not significantly different. The similar values between the two may be adduced to excessive K availability leading to an imbalance of nutrients in the sweet potato plants. Any further increase in K fertilizer may result in a decrease in yield. This may result in over utilization of K fertilizer because sweet potato yield has reached its maximum use of K, any further application will only increase the cost of production without any significant increase in yield over time. Therefore, 20 t ha⁻¹ biochar +70 kg ha⁻¹ K fertilizer would be optimum for sweet potato production. Therefore, the addition of 70 kg K fertilizer with biochar has reduced the cost of increasing the rate to 120 kg ha⁻¹ which would have been economical, given the high cost and shortage of potassium fertilizer in Nigeria and other sub-Saharan African countries.

Therefore, sweet potato performance in this experiment was related to the soil's physical and chemical characteristics. The positive and significant correlation among growth and yield characteristics and pH, OC, N, P, K, Ca, Mg, moisture content, porosity, and negative and significant correlation between these characteristics and bulk density (Table 3) showed that these soil properties both influenced the growth and yield of sweet potato in this experiment. Agbede and Adekiya (2011) and Aboyeji et al. (2019) earlier reported that sweet potato react to increased soil nutrients and are also sensitive to bulk density and porosity which may influence tuberization, root penetration, and nutrient absorption.

5. Conclusion

This research showed that sole application of biochar or in addition with K fertilizer improved soil physical (reduced bulk density and increased porosity and moisture content) and chemical (pH, OC, N, P, K, Ca and Mg) properties, growth (vine length and number of leaves) and yield (number of tubers and tuber weight) of sweet potato relative to the control and K fertilizer alone. This was due to a straight change in the soil chemistry and physics of the soil by biochar due to its intrinsic properties. Additionally, the growth and yield of sweet potato were improved with K fertilizer + Biochar compared with sole applications of K fertilizer or biochar. 20 t ha⁻¹ biochar +70 kg ha⁻¹ K fertilizer and 20 t ha⁻¹ biochar +120 kg ha⁻¹ K fertilizer increased growth and yield relative to 10 t ha⁻¹ biochar +70 kg ha⁻¹ K fertilizer and 10 t ha⁻¹ biochar +120 ha⁻¹ kg K fertilizer. This was as a result of better soil physical conditions and best availability of soil nutrients in these treatments. The values between 20 t ha⁻¹ biochar +70 kg ha⁻¹ K fertilizer and 20 t ha⁻¹ biochar +120 kg ha⁻¹ K fertilizer were not significantly different. Consequently, 20 t ha⁻¹

biochar +70 kg ha⁻¹ K fertilizer would be optimum for sweet potato production. Therefore, the addition of 70 kg K fertilizer with biochar has reduced the cost of increasing the rate to 120 kg ha⁻¹ which would have been economical given the high cost and shortage of potassium fertilizer in Nigeria and other sub-Saharan African countries.

Declarations

Author contribution statement

Aruna Olasekan Adekiya: Conceived and designed the experiments; Wrote the paper.

Charity Aremu: Contributed reagents, materials, analysis tools or data.

Ojo Vincent Adebiyi; Razaq Ola Ajibade: Analyzed and interpreted the data.

Ayibanoa Lekoo Ibaba: Performed the experiments.

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The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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