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The Effect of Biochar on Sulfate Desorption Kinetics by Selected Soil in Sudan Savanna, Nigeria

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ABSTRACT

Biochar is regarded as a promising soil amendment that maximizes soil productivity to boost food security. Limited data is available on the influence of biochar on sulfate desorption behavior in soil. To fill the knowledge gap, this research attempts to investigate sulfate sorption and desorption kinetics with soil parent materials mixed with biochar. Understanding the effects is of great importance in selecting a fit diagnosis and fertilization of S to ensure sustainable crop production and environmental protection. Maize stalk biochar was prepared and used for the study. The variation between soil desorption data (with and without biochar) was examined using a two-way analysis of variance (ANOVA) with fully randomized designs (CRD). The results obtained showed that the studied Biochar (BC) had no significant (P = 0.05) impact on the release of adsorbing S, independent of time and soil constituents. The findings led to the conclusion that the rate of desorption of adsorbed sulfate desorption by the studied soil parent material is not primarily controlled by biochar. Therefore, it is recommended to test the compatibility of BC to release the adsorbed sulfur, before applying it as an amendment to the soil. Linking the practice of on-farm sulfur management to OM management is also recommended.

INTRODUCTION

Sulphur (S) has been recognized as an essential element for plant growth and development since the time of Justus von-Liebig (Tabatabai, 2005a), although receiving little attention in comparison to nitrogen, phosphorus, and potassium (NPK). Sulphate (SO_4^{2-}) in soil solution is normally taken up by plants via roots; thus, adsorption-desorption processes are critical for enhancing S bioavailability (Sumner, 2000; Aliyu *et al*., 2022a).

Farmers have switched from sulfur-rich fertilizers to high-analysis fertilizers with less sulfur over the previous two decades, masking several latent or incipient sulfur deficits in Nigeria's cultivated land (Raji, 2008). However, there is currently a lack of understanding of how to maximize the amount and time of S fertilization. Additionally, a significant factor in most tropical soils that prevents S from being bioavailable to plants is variable charges. This is true of the heavily weathered soils of Nigeria.

The investigation of biochar-spiked soils in the Amazon showing significant improvements in soil quality and beneficial influence on farm crop output has sparked a lot of interest in biochar (BC) (Lehmann *et al*., 2003). Technically, biochar is produced during a process known as pyrolysis from the thermal conversion of biomass at a constrained supply of oxygen under a comparatively low temperature (<700^{0}C) (Lehmann and Joseph, 2009). According to Grantstein *et al*. (2009), quick pyrolysis at higher temperatures yields mostly biooil with a negligible quantity of biochar, whereas slow pyrolysis at lower temperatures normally favors BC synthesis. Several researchers (Lehmann *et al.,* 2009) indicated that biochar exhibits a great potential to effectively address soil nutrient deficiencies and exhibits favorable soil surface properties (Tan *et al.,* 2015). This may render biochar one of the greater factors in the adsorption and desorption of several elements in soils. However, Sokolova and Alekseeva (2008) studies reported that the presence of BC decreased S sorption and could increase the desirability of adsorbed S. Given interpretation, all emphasized that this augmenting was likely a result of the significant pH raise caused by BC supplementation. Limited information is available, however, on the significant impact of BC on sulfate adsorption and desorption phenomena in soils, particularly Nigeria savanna soils.

There are no well-documented studies on the influence of biochar on S bioavailability in Nigerian Savanna soils. Therefore, the examination of biochar on S desorption and its sorption is important in predicting the bioavailability and management of S to augment farm output. Although BC is a far, more effective source of soil amendments than compost and manure since it is a more stable nutrient source (Lehmann *et al.,* 2009). This may be attributed to the longevity of carbon in soils. Therefore, the paper intended to examine the effect of the BC amendment on sulfate desorption in soils.

METHODS

Field location

Geologically, the research was conducted in some parts of the Sudan savannah of the state of Bauchi, Nigeria. The soils in the research area are derived from three (3) rocks as follows; the Kerri-Kerri Formation (KKF), Chad Formations (CF), and the Basement Complex Rock (BCR), the first two being sedimentary rocks (Mustapha and Fagam, 2005).

The trees typically grow alone or in groups, with areas inside being occupied by non-woody species that can reach heights of 3 m. The natural vegetation comprises grasses (*Hyparrhenia, Ripania spp,* and *Andropogon)* and scattered *Tamarindus indica*, *Pankia clapertania,* and *Khaya senegallensis* as the dominant trees. The most widely cultivated crops on the research sites are rice (*Oryza sativa*), tomato (*Lycopersicon lycopersicum*), maize (*Zea mays*), and pepper (*Capsicum annum*). Typically, the research sites have fallen under tropical climates with distinct wet and dry seasons. The wet season often begins in June or July and lasts until November whereas November through April constitutes the dry season. The average rainfall of roughly 280 mm per year, is characteristic of the rainy season. The temperature ranges from 16 to 35 degrees Celsius (Hassan *et al*., 2016).

Soil sampling and analysis

After a field survey, three sites were selected from each of the Base Complex Rock, Chad Formation, and Kerri-Kerri Formation soil source materials. Twenty (20) auger samples (0-15 and 15-30 cm respectively) were taken at random and processed into a composite sample. This technique was repeated twice at each site as described above. A total of 36 composite soil samples were air-dried in a well-ventilated laboratory location for one week before being crushed and sieved through a 2mm sieve.

Particle size analysis was determined by the Bouyoucos hydrometer method, and the sample pH was determined in 1:1 soil/water (Gee and Bauder, 1986). Sulfate in soil was extracted with 500 mg P/l monocalcium phosphate (Ca $(H_2PO_4)_2$) (Fox *et al*., 1964) and all filtrates were used to determine inorganic sulfate by the turbidimetric method of Tabatabai (1982).

Kinetic analysis

1.81 g of potassium sulfate was used to make a stock solution that had a concentration of 1000 mg/L after dissolving it in a small amount of distilled water and then adding it to a total volume of 1 liter. The stock solution was diluted sufficiently to provide the additional concentrations needed.

Sorption and Desorption kinetics of S

Put 2.5 grams of sieved soil sample in measuring tubes and then add 500 mg S/g potassium sulfate using the prepared stock S solution of 1000 mg S m/l (in a 0.01 M NaCl solution). Cap the measuring tubes and shake them in the electric shaker for 24 hours to reach equilibration time. Shaken samples were then centrifuged and the filtrates were analyzed for measuring S according to the method described by Tabatabai (1982). The amount of adsorbed S was computed by subtracting the amount of S in the equilibrium solution from the amount of added S.

Adsorbed S in the soil sample was used to determine the desorbing S. Add 15 ml monocalcium phosphate mixed with 500 mg P/l and shake for 30, 60, 150, 180, or 240 minutes. The supernatant was filtered and then used for the determination of inorganic S using the method described by Tabatabai (1982). The amount of desorbed sulfate was calculated from the difference between recovered sulfate (µ/g) and measured sulfate in solution (µ/g). Percent desorbed sulfate was estimated as desorbed sulfate (µ/g) divided by adsorbed sulfate (µ/g) multiplied by 100.

Soil mixed biochar analysis

The biochar used in this research was produced under a 500^{0}C pyrolysis temperature (Fig. 1), according to the technique of Lehmann (2007). Biochar was crushed and sieved through a 2 mm sieve. In the test tube, 0.06 grams of dry BC were thoroughly mixed with 2.5 grams of the soil before adding potassium sulfate (15 ml of 0.01M $CaCl_2$ solution containing 500 mg S g-1 as K_2SO_4). Initially, the soils were brought to field capacity by adding distilled water. The soil samples also underwent a 7-day incubation period. After, the analysis, the desorption of adsorbed sulfate was done in the same pattern described above.

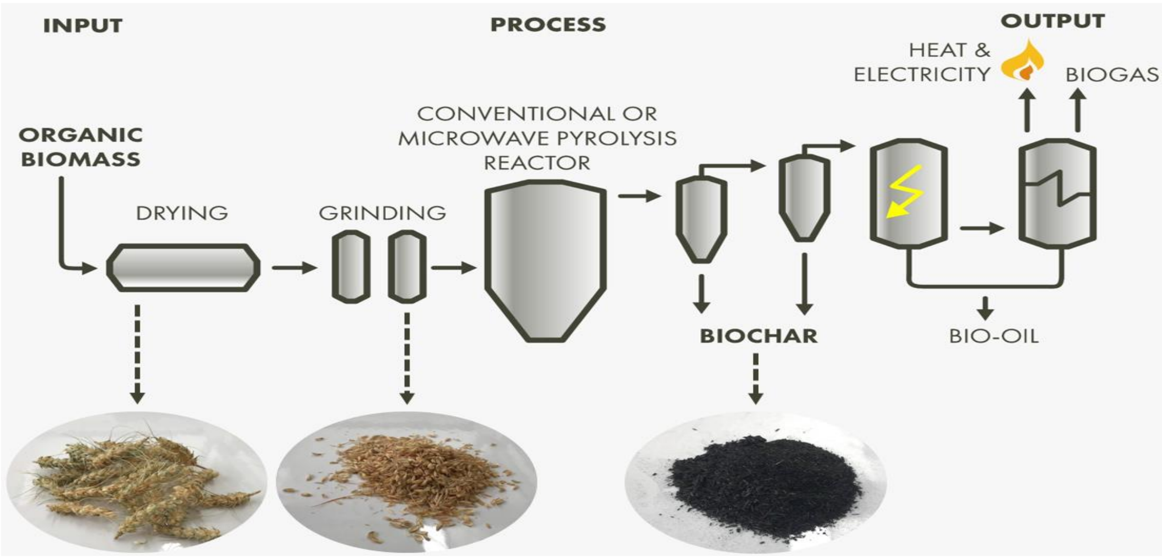

Figure 1. Biochar processes

Data analysis

The variation among parent materials and between the soil's desorption data (with biochar and without biochar) was analyzed using a two-way analysis of variance (ANOVA) and completely randomized designs (CRD). The three parent materials, locations, depths, and soils (with and without biochar) were treated as the treatments, whilst replicate samples and shaking times were regarded as the replication or random, respectively. According to statistics, significant means were divided by the least significant difference (LSD). A 95 percent level of confidence was used for all statistical analyses (SAS 9.2, 2011).

RESULTS AND DISCUSSION

Physical and chemical characteristics of the soils

Sand content was dominant in all three soil parent materials (table 1), with higher values in surface soils and their corresponding sub-surface soils. This result was consistent with those found by Maniyunda *et al*. (2014) and Hassan *et al*. (2016) for various Nigerian savanna soils.

Table 1. Physical and chemical characteristics of the soil across soil parent materials

Parameters	CF	BCR	KKF
Sand (%)	77.8	74.0	73.5
Silt (%)	12.9	14.4	14.1
Clay (%)	9.9	11.6	12.4
pH in water	6.5^a	6.2^b	5.9^c
Inorganic S (mg/kg)	46.8	30.2	41.1

CF: Chad Formation, BCR: Basement Complex Rock, and KKF: Kerri-Kerri Formation. Means in the same horizontal column with the different superscript characters do not differ significantly within 5% of one another.

The average sand, silt, and clay divisions of the three parent materials did not differ significantly from each other (p = 0.05) (Table 1). The fact that tropical soils are often quite old and weathered may account for the lack of difference.

Soil pH in water ranged from 5.9 to 6.5 and was classified as acidic in all the studied parent materials (table 1) as having a pH less than 7.0 (Sparks, 2002), which is within the range of values reported by Abdu (2006) for similar Nigerian savanna soils. Similarly, Raji and Muhammad (2000) reported similar values for Nigerian savanna soils. Mean soil pH values in water were significantly (p=0.05) different among the three (3) parent materials (table 1). These variations should be expected given that the soils developed from various parent materials. This finding supports those made by Jaiyeoba (2006) regarding soils formed in Nigeria over various parent materials.

Inorganic Sulphur values varied from 30.2 to 46.8 mg/kg in all soils of the three parent materials, but they are broadly low, and comparable observations were made by Kang *et al*. (1981) and Raji (2008) for Nigerian savanna soils, while Buri *et al*. (2000) for West African lowland soils. Sulfur deficiency is caused by poor organic matter levels and the sandy character of West African soils. The mean levels of inorganic sulfur were not significantly different (p = 0.05) (table 1). The aged and heavily weathered condition of the soils may be responsible for the failure of the difference.

The effect of Biochar on Kinetics Desorption of Sulphate

Comparative studies of soils without biochar and soils with biochar from various parent materials were conducted to investigate the influence of biochar on the desorption of sulfate at different time intervals.

Table 2. Biochar effect on the sulfate desorption kinetics at various time intervals

Time	Soil mixed with biochar	Soil sample	LSD
	← mg/kg →		
30 min.	31.5	31.3	NS
60 min.	31.0	30.8	NS
150 min.	27.4	27.5	NS
180 min.	27.2	27.0	NS
240 min.	23.2	23.1	NS
Total	28.1	27.9	NS

Not significant (NS).

The mean sulfate concentration desorbed from soils without biochar and soils with biochar at different periods was not statistically different (P=0.05) (Table 2). This suggests that this particular form of biochar had no impact on any of the three parent materials analyzed soils. A little increase in the desorption of adsorbed sulfate was seen as a result of applying biochar, though (Table 2 & 3). Comparable findings were also reported by Uchimiya *et al*. (2010a) and Borchard *et al.* (2012). According to Sokolova and Alekseeva (2008), an increase in the amount of sulfate desorbed may be the result of the sharp increase in pH caused by the application of biochar. This situation might also be true for the increased amount of sulfate desorbed in all the soils in the current study. Biochar's competitive advantage can help boost sulfate desorption. (Sokolova and Alekseeva, 2008; Borchard *et al*., 2012).

Table 3. Percent of sulfate desorbed from biochar-mixed soils at various periods

Location	Depth (cm)	Adsorption % 24 hours	Desorption % of the various time (minutes)				
			30	60	150	180	240
BASEMENT COMPLEX ROCK (BCR)							
Tawayla	0-15	83.5	76.1	75.0	69.0	68.5	58.9
Tawayla	15-30	85.3	71.1	69.3	62.8	62.4	53.7
Jaberi	0-15	84.7	73.2	71.5	64.7	64.4	53.1

Jaberi	15-30	86.0	70.6	69.8	59.9	58.5	50.2
Zenabari	0-15	84.2	76.5	76.1	69.0	68.5	55.8
Zenabari	15-30	86.0	70.1	68.7	62.1	61.9	48.4
KERRI – KERRI FORMATION (KKF)							
Kauyan Jalo	0-15	82.7	74.1	73.1	61.4	60.9	54.9
Kauyan Jalo	15-30	81.4	74.6	73.9	60.8	59.7	56.2
Doguwa	0-15	82.5	78.0	77.6	63.0	62.8	54.3
Doguwa	15-30	82.3	74.0	73.3	61.0	59.6	50.4
Kwari	0-15	82.6	77.7	77.6	64.5	63.3	50.2
Kwari	15-30	86.1	67.8	67.6	54.7	55.3	44.8
CHAD FORMATION (CF)							
Digiza	0-15	82.9	78.8	77.2	72.1	71.7	61.2
Digiza	15-30	80.9	80.3	78.7	72.6	71.3	60.2
Gongo	0-15	83.3	75.3	74.0	70.6	70.0	59.9
Gongo	15-30	83.7	72.5	71.4	64.6	64.1	56.0
Guda	0-15	77.8	90.4	88.7	81.2	80.8	74.2
Guda	15-30	80.5	83.8	81.9	75.3	74.6	66.1

It was observed that the percentage of sulfate adsorbed and desorbed with the presence of this type of biochar was irregularly distributed along with the locations in all studied soils (Table 3). This reflects the fact that studied soils were derived from different parent materials. In the past decade, Yao *et al*. (2012) reported that many processes might also be responsible for increased or decreased plant nutrient sorption in soils. Application of BC in soils might raise soil pH which may be another reason for a slightly decreased adsorbed S (Borchard *et al*., 2012). For this study, the application of biochar into the soil could not justify its cost of production. Under the current situation, farmers will rarely adopt biochar incorporation into soils due to its small effects and difficulty in sourcing materials that is large enough for farm application.

CONCLUSION

The BC utilized in this investigation had no significant influence on the release of adsorbing S, according to the findings. However, this type of BC tested in this study had very little S sorption and desorption affinity. Several studies found that biochar had little or no effect on sulfate adsorption and desorption processes in soil. The influential effect of this type of biochar on S desorption at different time intervals in this paper was negligible in all studied soils. Therefore, it is suggested that BC's propensity to release plant nutrients be assessed before its use as an amendment to the soil. It is also recommended to conduct plant growth studies to see whether this type of BC has a significant effect on crop performance or not.

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