Charcoal production and soil fertility status in savannah derivative ecological zone of Nigeria

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Abstract: Charcoal burning is one of the common practices in most of the rural areas of Nigeria. This study considers feedback effect of charcoal burning on physical and chemical soil properties with a view to examining status of soil nutrient in Saki, Oyo State, Nigeria. Ten composite soil samples were collected from each demarcated quadrats (5 m × 5 m) of charcoal production site (CPS) and adjacent field site (AFS) at 0 cm–15 cm (topsoil) and 15 cm–30 cm (subsoil) and subjected to laboratory analysis. Mean, standard deviation and coefficient of variation (CV) examined the variation within the set of variables. The study revealed that soils exhibit homogeneity in all the examined parameters of the charcoal production site except silt and phosphorous. This is to show that surface burning is a factor for nutrient distribution and availability in soil. It was generally observed that clay is resistant to heat having being insulated from surface heating.

Keywords: charcoal production; soil fertility; savanna zone; soil; fire; Nigeria.

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1 Introduction

Charcoal production is one of the major sources of energy in most of rural areas of Nigeria. The production of charcoal has a significant impact on all natural resources in the process especially the vegetation and soil. The heat effect of charcoal burning has reactionary feedback on soil nutrient and it is capable of altering both physical and chemical soil properties, such as soil sand, clay, silt, water holding capacity, pH, total nitrogen, available phosphorus, organic matter, among others. The extent at which fire can affect these soil properties depends on fire intensity, fire severity and fire frequency. However, low intensity fires may not cause enough soil heating to produce significant changes to soil properties.

It has been recently observed that charcoal production is multiplying in most of the rural areas of Nigeria, while the area considered in this study termed as prominent production field. The reason is because production of charcoal is more of commercial activities than home use and most rural farmers have made the production a supplement to their agricultural occupation. This is more that charcoal production returns rapid incomes to the producers.

Apart from possible loss of soil structure, intensive charcoal production is also capable of leading to deforestation. The problem of environmental degradation and widespread deforestation according to Kohlhemp (1995) has been traced to increased production in charcoal in the prominent production fields. Most plants that are in good production status are susceptible to daily use by charcoal producers. This scenario was further observed that 400 plants are being cut and processed for charcoal production daily in most communities in Nigeria.

In general, Fontodji et al. (2009) identified reduced organic matter, soil carbon sequestration and thus facilitating global warming. Also, regular removal of plants and surface burning has tremendous impact on soil and general degradation of environment. It should be equally noted that charcoal production has direct impact on soil through regular loss of soil quality in terms of nutrient and fertility reduction.

Charcoal export started in Nigeria in 1904. In 2000, 67,767,000 cubic metres (2.4 billion cubic feet) of round wood were produced, 85% for fuel. In the same year, Nigeria's consumption of fuel wood and charcoal was the third highest in Africa (Olori, 2009). Of the country's population of over 144 million, about 70% live in rural areas and are directly or indirectly dependent on forest resources – especially wood – to meet both domestic and economic energy needs. This activity is leading to destruction of forest cover, a situation aggravated by illegal commercial logging (Olori, 2009). FAO (2005) indicates that between 1990 and 2005, Nigeria lost 35.7% of its forest cover and only 12.2% of the country's land is currently forested while 350,000 hectares of land in the country are lost to desertification annually. Problems posed by the production of charcoal are numerous. Adeniyi (1995) noted that the problems in Nigeria include environmental pollution from smoke, deforestation which causes erosion hazard and exposes the soil to direct sunshine, thereby reducing the fertility of the soil and the health problems to the producers and the entire community as a whole. Charcoal production is associated with felling of both mature and nearly-mature trees in the study area.

In Ghana, charcoal is produced by using earth as a shield against oxygen and to insulate the carbonising wood against excessive loss of heat (FAO, 1983). Thermal decomposition of the wood starts when the wood is raised to a temperature of about 300°C. This pyrolysis process, once started, continues by itself and gives off considerable heat with a maximum temperature of approx. 500°C for high efficiency and product quality (FAO, 1983). However, higher temperatures may occur due to inefficiency. The amount of heat released during pyrolysis is similar to that from bushfires or shifting-cultivation (slash and burn) fires, depending on period and wood load in the piles. Charcoal production has both heating and amelioration effects on soils (Glaser et al., 2002; Oguntunde et al., 2004) and hence influences soil properties.

Charcoal amendments may affect soil water retention and aggregate stability, leading to enhanced crop water availability and reduced erosion (Piccolo and Mbagwu, 1989). Tryon (1948) studied the effect of CC additions on the available moisture in soils with different textures. A positive effect of 18% increase in soil water retention was observed upon addition of 45% (by volume) charcoal to a sandy soil while a decrease of approx. 20% was noted for a clay soil, whereas no change was recorded for a loamy soil, given the same charcoal treatment. Therefore, improvements of soil water retention by charcoal ameliorations may only be expected in coarse-textured soils or soils with large amounts of macropores (Glaser et al., 2002). Evidently, well-documented studies have been carried out on the different fire effects and the ameliorating effects of charcoal. However, field-testing of the combined effects is still lacking. The aims of this study were to determine the impact of charcoal-making fires and charred residue on soil physical properties in Ghana where charcoal production, in addition to bush-fires, is widespread and is a major driver of land-cover change (Braimoh and Vlek, 2004).

Soil, being a poor conductor of heat may react to fire differently and based on fire intensity, soil parent materials and structure. For example, fire tends to increase the amount and biodegradation rate of readily decomposable soil organic matter (SOM) while simultaneously increasing the resistance of the stable portion of SOM. Charcoal burns may have serious effects on soil properties by destroying SOM. Since SOM holds sand, silt, and clay particles into aggregates, a loss of SOM will result in a loss of soil structure. The implications of severe fire on soil structure are that there may be increase soil bulk density resulting in reduction of soil porosity, mostly through the loss of macrospores.

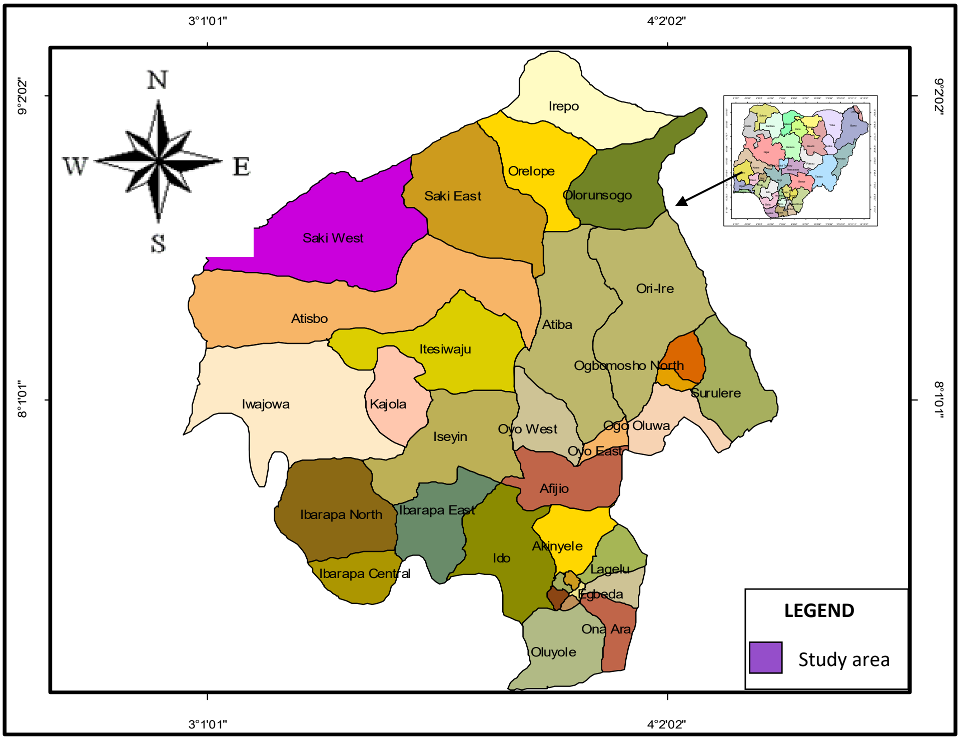
Thus, this paper examines the effects of charcoal production on the status of soil fertility in a selected savanna derivative ecological zone in Nigeria.

2 Materials and methods

2.1 Materials

This study was carried out in Saki West, Oyo State in the Southwestern Nigeria. The location lies between latitudes 7°31 and 9°21 north of the equator and longitudes 2°471 and 4°231 east of the meridian (Figure 1).

Figure 1 Map of Oyo State showing study area (see online version for colours)



Note: Inset: Nigeria.

Source: Oyo State Ministry of Lands and Housing (2016)

The area under consideration has an open woodland vegetation of two deferent seasons, the very wet and short dry seasons. The rainfall ranges between 1,000 mm and 1,500 mm and the temperature between 68°F and 86°F (Alex, 2000). In the rainy season, there are broad, green leaves trees characterised by fire resistant, thick bark and deep tap root. Such trees include *Viteloria paracloxum* (Emin) trees, *Khaya ivorensis* (Ogano), *Triplochiton scleroxylon* (Arere), *Anogeissus leiocarpus* (Ayin), *Burkea africana* (Asapa), *Distemonanthus benthamianus* (Ayan), *Perkia bigolobosa* (Igba), *Terminalia avicenniocles* (Idi), *Gmelina arborea* (Igi Isana), *Milicia excelsa* (Iroko), *Tectona grandis* (Gedu) and so on. Harmattan, which is a cool dry wind from the Sahara, occurs between November and February. The temperature ranges from 20°C to 36°C and the average relative humidity is 10% but can be up to 85% in the night and low as 59% in the afternoon. It has an annual rainfall of 102 mm (Udo, 1987).

The zone is cozy by ferruginous tropical soil with high sandy surface horizon (Agboola, 1979). The soil is considerably, naturally fertile because of the presence of trees and favourable climatic condition. However, the old method of the use of fire to clear vegetation and thorough cultivation of land for agriculture has led to the degradation of lands in general. Also, the degradation due to traditional management practices was pronounced as reported by Agboola (1979).

2.2 Methods

Primary data for the study was the laboratory soil test results. Ten soil samples each were collected from demarcated quadrats (5 m × 5 m) of charcoal production site (CPS) and adjacent field site (AFS), which formed the basis for comparison between the two soil characteristics of the various sampled quadrats. A systematic random sampling was adopted and a total of 20 soil samples were collected (at every other quadrat) at 0–15 cm (topsoil) and 15–30 cm (subsoil) in order to have a better representation of the sampling. Zakeeya et al. (2009) and Abdullahi et al. (2010) in their previous works adopted 0–15 cm and 15–30 cm depth in soil sample collection to identify spatial variation of soil fertility for cropping in Sri Lanka, and the examination of fertility status of fadama soils in Nigeria. The composite soil samples collected into well-labelled polythene bags were subjected to various laboratory analyses. The soil samples were air-dried and carefully sieved with 2 mm diameter mesh in order to separate the soil from stones. However, as noted by Ogundele et al. (2012), soil samples excluded the ash released by the burnt biomass. One-way frequency tables and two ways cross-tabulation frequency tables show the distribution values of the variables while coefficient of variation (CV) examined the variation within the set of variables. Variation only exists when CV is greater than 33% (Olubusoye and Olaomi, 2002). The particle size distribution was analysed, using the hydrometer method (Bouyoucos, 1926). Soil pH was measured by using glass electrode pH meter in soil: K Cl (suspension) of ratio 1:2. The Kjeldahl analytical procedure was used to determine the total amount of nitrogen in the sampled soils. Also, Walkley and Black (1934) method, modified by Juo (1981) was used to determine organic matter content of sampled soils. To obtain available phosphorous, extracts of the soil samples were leached with Bray P-I extracting solution (0.025N HCL + 0.03N NH_4F) (Bray and Kurtz, 1945). The concentration was determined calorimetrically with spectrophotometer. Available phosphorous was expressed in milligram per kilogram (mg/Kg).

Reliability test

$$\mathrm{RT} = \frac{n\sum xy - \left(\sum x\right)\left(\sum y\right)}{\sqrt{\left[\sum n\left(\sum x^2 - (x)^2\right)\right]\left[n\left(\sum y^2 - \left(\sum y\right)^2\right)\right]}}$$

$$\mathrm{RT} = \frac{10[216.16] - [50.76][41]}{\sqrt{10(285.2] - [2576.5776][10(179][1681]}}$$

$$\mathrm{RT} = \frac{2161.6 - 2081.16}{\sqrt{[275.4224][109]}} = \frac{80.44}{\sqrt{30021.0416}}$$

$$\mathrm{RT} = \frac{80.44}{173.27} = 0.465 \simeq 0.5$$

The reliability test (RT) indicates that sand sample has reliability regression coefficient of 13.65 and silt content has 0.5. The result for the soil RT was considered adequate at 0.5 level of significance.

3 Results

3.1 Soil physical properties

This study examined the particle size distribution of soil. The proportion of sand, silt and clay are referred to as particle size of the soil. They are important features of soil that determine the textural composition of soil. In this study, sand content in soil of the CPSs ranged between 81.52% and 88.72% (Table 1), while the mean for the topsoil and subsoil stand at equal value of 83.92% (Table 1). The contents of the clay ranged between 12.48% and 14.48% with the mean values ranged between 11.68% and 11.88%. The recorded values for the silt content was between 8% and 6%, while the mean values for the topsoil and subsoil ranged between 4.40% and 4%.

Table 1 Sand and silt contents in soil

Sand content (%)					*Silt content (%)*				
Sites	*Topsoil*		*Subsoil*		*Sites*	*Topsoil*		*Subsoil*	
	CPS	*AFS*	*CPS*	*AFS*		*CPS*	*AFS*	*CPS*	*AFS*
1	83.52	83.52	85.52	88.52	1	6.00	8.00	4.0	5.0
2	81.52	83.56	83.52	87.52	2	8.00	7.96	4.0	6.0
3	83.52	89.52	83.52	89.52	3	4.00	4.00	4.0	4.0
4	83.52	89.52	83.52	89.52	4	4.00	4.00	6.0	4.0
5	83.52	89.52	84.52	85.52	5	4.00	4.00	3.0	4.0
6	85.52	89.52	83.52	84.52	6	4.00	4.00	4.0	5.0
7	83.52	87.52	83.52	84.52	7	4.00	6.00	6.0	2.0
8	84.52	86.52	84.52	89.52	8	3.00	5.00	1.0	4.0
9	84.52	86.52	83.52	89.52	9	3.00	5.00	4.0	4.0
10	85.52	88.72	85.52	90.52	10	4.00	2.80	4.0	3.0
Mean	83.92	87.44	83.92	88.42	Mean	4.4	5.08	4.0	4.1
SD	1.17	2.38	0.69	1.97	SD	1.51	1.75	1.41	1.10

Source: Authors' computation, 2019

The values for the mean in this study imply that impacts of burning on sand content are homogenous in both soil layers.

Considering the general values for the topsoil, 81.52% and 88.72%, it should be generally noted that the heat impact generated from the charcoal burning tends to reduce the sand content of soil with depth. However, the clay and silt contents are more resistant to heat from charcoal burning. This is because the values of clay as recorded in this study, 12.48% and 14.48%, with the mean values (11.68% and 11.88%) for both topsoil and subsoil indicate increased contents with depth. More reasons for the resistance of clay is that the soil property often concentrated in subsurface layers where it is insulated from surface heating.

The calculated values for the CV in Table 3 established that silt (34.09*, 35.25*, 34.32*) varied significantly among the three physical properties of soil (sand, silt and clay). The content of silt varies in both topsoil and subsoil of the charcoal and adjacent sites, while only shown homogeneous distribution at the subsoil of the adjacent site. This observation is not unconnected from the influence of the parent materials that produce the soil. More so, the silt content in soil reacts differently to heat effect from the burning of charcoal. The fact that CPS reflects heterogeneous distribution of silt for both topsoil and subsoil is a reflection that burning is a factor for nutrient distribution and availability.

Table 2 Clay contents in soil (%)

Sites	*Topsoil*		*Subsoil*	
	CPS	*AFS*	*CPS*	*AFS*
1	10.48	8.48	10.48	6.48
2	10.48	8.48	12.48	6.48
3	12.48	6.48	12.48	6.48
4	12.48	6.48	10.48	6.48
5	12.48	6.48	12.48	10.48
6	10.48	6.48	12.48	10.48
7	12.48	6.48	10.48	8.48
8	12.48	8.48	14.48	6.48
9	12.48	8.48	12.48	6.48
10	10.48	8.48	10.48	6.48
Mean	11.68	7.48	11.88	7.48
SD	1.03	1.05	1.35	1.69

Source: Authors' computation, 2019

3.2 Soil chemical properties

The soil pH is a chemical property of soil that measured the degree of acidity and alkalinity in the soil. The values of this soil property ranged between 6.2 and 7 for the topsoil; 5 and 6 for the subsoil. This pH level, according to Sandor et al. (1992), indicates that the soil of this area falls within acidic and slightly acidic to neutral (Table 4).

The mean values for topsoil (6.5) and subsoil (5.52) in Table 4 suggest that pH declines with increasing depth of the soil profile. This shows that the topsoils are more acidic than the subsoils. The values of CV show that the pH of the soils is homogenous in the study area (Table 3). However, CPS generally indicates mean value of 6.5 for pH and 5.8 for adjacent site. This simply connotes that soils at the charcoal site are slightly acidic to neutral, while adjacent site is acidic.

Maars et al. (1983) established that nitrogen is most likely to limit tree growth in forests and other woodland ecosystems, particularly if nitrogen replenishment mechanisms are not provided for during post fire management. Understanding the behaviour of soil total nitrogen, according to Hossain et al. (2005), is essential for maximising crop productivity and environmental stability. The content of this soil parameter is higher in the topsoil of the adjacent site (2.23) than the charcoal site (2.08). As noted by DeBano et al. (1979), although large amounts of total nitrogen are lost during the combustion of plants and litter, available NH_4-N is usually higher in the underlying soil following a fire because of the transfer mechanism.

Table 3 Computation of CV for the soil properties

Soil properties	*Charcoal production site (CPS)*						*Adjacent field site (AFS)*					
	Topsoil			*Subsoil*			*Topsoil*			*Subsoil*		
	M	*SD*	*CV*	*M*	*SD*	*CV*	*M*	*SD*	*CV*	*M*	*SD*	*CV*
Sand (%)	83.92	1.17	1.39	83.92	0.69	0.82	87.44	2.38	2.72	88.42	1.97	2.22
Silt (%)	4.40	1.50	34.09*	4.0	1.41	35.25*	5.07	1.74	34.32*	4.10	1.10	26.83
Clay (%)	11.68	1.03	8.82	11.88	1.35	11.36	7.48	1.05	14.03	7.48	1.69	22.59
pH	6.5	0.27	4.15	5.52	0.29	5.25	5.8	0.48	8.28	6.03	0.40	6.63
Total N	2.08	0.39	18.75	1.56	0.18	11.54	2.23	1.50	67.26*	1.16	0.48	41.38*
SOM	6.45	0.59	9.15	5.36	0.89	16.60	2.96	0.52	17.57	3.00	0.72	24.0
AP	5.34	1.27	23.78	1.44	0.59	40.97*	1.15	0.32	27.82	0.74	0.24	32.43
CEC	7.54	0.93	12.33	5.04	0.61	12.10	5.20	0.45	8.65	3.50	0.78	22.29

Note: *means CV values are significantly varied.

Table 4 pH and nitrogen contents in soil

	pH (%)					*Nitrogen (%)*			
Sites	*Topsoil*		*Subsoil*		*Sites*	*Topsoil*		*Subsoil*	
	CPS	*AFS*	*CPS*	*AFS*		*CPS*	*AFS*	*CPS*	*AFS*
1	6.7	6.1	6.0	6.4	1	2.1	1.68	1.8	1.9
2	6.2	6.4	5.5	5.5	2	2.1	3.5	1.4	1.05
3	6.5	6.5	5.3	6.2	3	1.75	1.40	1.75	1.75
4	6.8	5.8	5.7	6.5	4	2.52	1.26	1.4	0.7
5	7.0	5.5	5.7	6.0	5	2.66	1.26	1.75	0.84
6	6.2	5.0	5.0	6.4	6	2.45	1.75	1.4	1.75
7	6.2	5.9	5.5	6.4	7	1.96	1.40	1.75	1.26
8	6.5	5.4	5.8	5.7	8	1.75	2.50	1.4	0.77
9	6.5	5.4	5.4	5.7	9	2.1	1.54	1.54	0.7
10	6.4	6.4	5.3	5.5	10	1.4	1.6	1.4	0.84
Mean	6.5	5.8	5.52	6.03	Mean	2.08	2.23	1.56	1.16
SD	0.27	0.48	0.29	0.40	SD	0.39	1.49	0.18	0.48

Source: Authors' computation, 2019

Table 5 SOM and available phosphorus

	Soil organic matter (%)					*Available phosphorus (mg/kg)*			
Sites	*Topsoil*		*Subsoil*		*Sites*	*Topsoil*		*Subsoil*	
	CPS	*AFS*	*CPS*	*AFS*		*CPS*	*AFS*	*CPS*	*AFS*
1	6.87	3.09	4.12	2.5	1	7.26	1.09	2.27	0.58
2	5.24	3.09	4.16	1.37	2	5.58	1.73	1.77	1.13
3	6.88	2.76	4.47	2.76	3	6.15	1.32	1.5	0.81
4	6.88	1.72	5.29	3.44	4	6.64	1.19	1.28	0.66
5	5.91	3.09	5.49	3.78	5	5.55	0.79	0.8	0.56
6	6.88	3.78	4.47	3.78	6	5.06	0.62	0.71	0.50
7	6.88	3.09	6.53	3.44	7	4.36	1.15	0.58	0.61
8	6.88	2.76	6.19	2.76	8	2.85	1.06	1.59	0.56
9	6.19	3.09	6.19	3.09	9	4.34	1.51	2.19	1.17
10	5.19	3.09	6.19	3.09	10	5.58	1.07	1.75	0.84
Mean	6.45	2.96	5.36	3.00	Mean	5.34	1.15	1.44	0.74
SD	0.59	0.52	0.89	0.72	SD	1.27	0.32	0.59	0.24

Source: Authors' computation, 2019

SOM content is a crucial element of soil. As identified by Steila and Pond (1989), it includes both living and dead matters within and upon the soil. Generally, the content of SOM in the charcoal site ranged between 4.12% and 6.88% within the topsoil and subsoil respectively. The values of the adjacent site indicate 1.37% and 3.78% in the topsoil and subsoil, respectively. However, the mean values of this soil property in Table 5 depict higher concentration of SOM at the topsoil (6.45%) than subsoil (5.36%) for the charcoal site, while the adjacent site reflected relatively homogenous distribution of SOM content in both top and subsoil. It is worthy to note that most of the organic materials available in the soils are mostly retained within the top layer of soil due to low activities of leaching.

The concentration of SOM at the topsoil was also influenced by the adoption of increased water availability of biomass production, biological activity and plant residues, and roots that provide organic matter. Similarly, the SOM content of the soils is relatively homogenous in the soils of both charcoal adjacent sites (Table 3). The observed pattern of the distribution of organic matter in this study followed the observation of Foth (1984) that most of the soil organisms are usually concentrated in the top layer of soil. However, during a fire the nutrients stored in fuels and SOM are subjected to severe heating, and as a result, undergo various irreversible transformations during combustion. Hence, improving the level of SOM content in soils, according to Katyal et al. (2001) is a prerequisite to ensuring soil quality, future agricultural productivity and sustainability.

The mean values of the available phosphorus in Table 4 indicate that its content in topsoil (5.34 mg/kg) is higher than subsoil (1.44 mg/kg) on charcoal burn site. The CV value of 40.97* for the subsoil shows that this soil element has heterogeneous distribution below the soil surface region. The reason for this pattern is because phosphorus does not appear to be translocated downward in the soil profile as readily as N compounds. As a result, AP increases mainly in the ash and on, or near, the soil surface (DeBano and Klopatek, 1988). It should also be noted that AP is moderately sensitive to surface heating, having threshold temperatures of 774°C (Raison et al., 1985).

The cation exchange capacity (CEC) measured the ability of the soil to retain cations, which are part of soil nutrients. The mean values of the CEC on charcoal site are 7.54 and 5.04 for the top and subsoil respectively (Table 6). This result indicates that this soil element decreases with depth. However, results from the calculated CV (12.33% and 12.10%) established homogenous distribution of CEC in the entire soil.

Table 6 Cation exchange capacity

Sites	*Topsoil*		*Subsoil*	
	CPS	*AFS*	*CPS*	*AFS*
1	6.94	5.02	4.14	3.18
2	7.34	4.66	4.64	2.68
3	6.28	4.86	5.34	2.98
4	6.98	6.02	5.58	2.92
5	7.32	5.22	6.18	2.68
6	8.16	5.78	5.18	3.98
7	9.54	5.52	4.51	3.82
8	8.34	5.22	4.94	5.08
9	7.64	4.86	5.34	3.42
10	6.84	4.82	4.54	4.22
Mean	7.54	5.19	5.04	3.49
SD	0.94	0.45	0.61	0.78

Source: Authors' computation, 2019

The observed characteristics of CEC in charcoal soil was equally observed on the adjacent site as an indicative of similar case about the organic matter where the soil nutrients are concentrated at the top layer of the soil. Molloy (2007) observed that this CEC level serves as an important property of soil fertility with nutrient retention capacity and the capacity to protect groundwater from cation contamination.

4 Conclusions

The results of the study revealed the textural similarity in the charcoal and the fallow sites. The soil is primarily loam sand with high proportion of sand in the fallow site. The soils exhibit homogeneity in all the examined parameters of the CPS except silt and phosphorous. A similar trend was seen in the fallow site but total nitrogen is varied in this site. The similarity exhibited can be ascribed to pedogenetic resemblance (Ogundele et al., 2012). Nevertheless, there are considerable increase in the soil contents of soil pH, organic matter, total nitrogen, CEC and phosphorous in the CPSs as described in similar studies by Fontodji et al. (2009). No major differences between the soils of CPSs and adjacent fallow land with reverence to nitrogen, acidity and base saturation. All other soil parameters shown significant differences which can be accredited to the effect of charcoal production. This is to show that surface burning is a factor for nutrient distribution and availability in soil. It was generally observed that clay is resistant to heat having being insulated from surface heating.

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