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Original Research Article

Impact of Soil Excavation and Fuel Wood-Based Brick Burning on Soil Organic Matter and Soil Acidity at Burnt Brick Sites in Benue State, Nigeria

[1]Agera, S.I.N, [2]Ayuba S.A. and [1]Agbidye, F.S.

1. Department of Forest Production and Products, University of Agriculture, Makurdi, P.M.B. 2373, Makurdi, Benue State, Nigeria
2. Department of Soil Science, University of Agriculture, Makurdi, P.M.B. 2373, Makurdi, Benue State, Nigeria

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There is a dearth of baseline data on the physical, chemical and biological impact of burnt brick production processes on soil properties in fuel wood-based burnt brick-producing areas of Benue State, Nigeria. Eight (8) out of 23 Local Government Areas (LGAs) were purposively sampled to assess the impact of soil excavation and brick firing on soil pH and soil organic matter content (SOM). A total of 96 composite soil samples was randomly taken from 32 soil pits at pre-determined depth ranges of 10-15cm, 60-65cm and 90-95cm. Also, another batch of 48 composite soil samples was taken at 0-5cm depth from both 32points of brick firing and 16 unburnt areas (control) at 16 brick sites evenly distributed in the study area. The sum of 144 soil samples was analysed using guidelines outlined by the Soil and Plant Analysis Council (SPAC). Data was analysed using descriptive statistics (percentages, Student T-test and analysis of variance). Results indicated that increased depth of soil excavation from 10-15 cm depth range to 60-65cm and 90-95cm depths range significantly decreased SOM. Conversely soil pH increased with a corresponding increase in depth of soil excavation within the depth ranges of 10-15cm, 60-65cm and 90-95cm. In all sampled LGAs, burning significantly increased soil pH, while SOM significantly declined at points of brick firing. Afforestation of brick sites with fast-growing tree species capable of tolerating more acidic soils low in SOM can eventually reverse increased acidity and low SOM (through litter fall) when the canopy of the trees is re-established.

Keywords impact, soil excavation, brick burning, soil pH/organic matter and Benue State.

INTRODUCTION

Brick is defined as a small, rectangular block of fire clay used in the construction of foundations, walls, piers, buttresses and arches of buildings and other structures and in the construction of ducts, flues, lining and chimneys of furnaces (Encyclopaedia Britannica, 1998). Fuel wood tree species like *Prosopis africana, Khaya senegakensis* are used in firing bricks in the study area. Fire exerts influence on a variety of physical and chemical properties of soil, including the loss or reduction of structure and soil organic matter, reduced porosity, and increased pH (Certini, 2005). DeBano (2000) posited that fire also increases water repellency (hydrophobicity) in soil, resulting into infiltration and soil erosion. Fires may also affect soil colour and bulk density. Change in soil properties after fire incidences produce varying responses in the water-vegetation dynamics, and fauna of ecosystems. These effects emanate from pre-burn variability in these resources, fire behaviour characteristics, season of burning, and pre-fire and post-fire environmental conditions like timing, amount, and duration of rainfall (Clark, 2001). The effects of fire on soils directly depend on fire intensity and the duration of combustion, the volume and arrangement of fuel wood. Depending on the fire severity, these changes in soil properties may be beneficial or detrimental to the entire ecosystem (Neary, 1999).

Soil organic matter (SOM) represents the third largest terrestrial carbon pool, with a global estimated total of 1526 pgC (Lal, 2004). The most intuitive change soils experience

Corresponding Author: Agera, S.I.N *, Department of Forest Production and Products, University of Agriculture, Makurdi, P.M.B. 2373, Makurdi, Benue State, Nigeria., Department of Soil Science, University of Agriculture, Makurdi, P.M.B. 2373, Makurdi, Benue State, Nigeria
Phone: 2348058484045 *Email:* stephenagera@gmail.com

during burning is loss of organic matter (Certini, 2005). The organic horizon is a critical component of ecosystem sustainability since it provides a protective soil cover that mitigates erosion, aids in regulating soil temperature, provides habitat and substrates for soil biota and can be the main source of readily mineralizable nutrients (Neary *et. al*., 1999). It plays an important role in soil cation exchange capacity (CEC) and retention of ions (Crasswell and Lefroy, 2001).

Disturbances such as soil excavation or land levelling would alter the soil profile by destroying vegetation, root channels, and the soil horizons. Such activities expose the soils to increased wind and water erosion (NRCS, 2005). The most common human-induced factors that cause accelerated erosion include deforestation, inappropriate agricultural practices such as over cultivation and overgrazing, and inappropriate institutional and policy applications, such as land tenure, input supply and forest regulation policies. Poorly designed and constructed roads, defective conservation measures, cattle tracks and footpaths are also some of the human induced factors causing visible degradation. The objectives of this paper are to:

(i) Assess the impact of depth of soil excavation and wood based brick firing on the organic matter content of soils at brick production sites.
(i) Investigate the impact of depth of soil excavation and wood based brick firing on the hydrogen ion concentration of soils at brick production sites in the study area.

METHODOLOGY

The Study Area (Benue State)

The study was carried out in Benue State, located along Longitude 6º35' and 10ºE and Latitude 6º30' and 8º10'N. The state has a total land mass of 30,955km2. Benue State was created by the Murtala Mohammed Military Administration from the.defunct Benue-Plateau State in 1976, with Makurdi as the state capital. The State has a population of 4. 219, 244 (NPC, 2007). The population has been extrapolated to 5, 505,157 in 2015 given an annual population growth rate of 3% for Benue State. The State is made up of 23 local governments (Figure 1) Benue State is bounded to the north by Nassarawa State, Taraba State to the East, Ebonyi, Cross River and the Republic of Cameroon to the south as well as Kogi and Enugu States to the West.

Sampling Procedure

Eight out of twenty-three Local Government Areas (LGAs) were purposively selected for the study. A total of 32 soil pits each measuring 1m x 1m x 1m were dug in the eight (8) randomly selected local government areas (LGAs). For each selected LGAs (Buruku, Gboko, Gwer West, Konshisha, Kwande, Makurdi, Ushongo and Vandeikya) composite soil samples were collected from four (4) soil pits distributed in two randomly selected brick sites (i.e. two pits per brick site) at pre-determined depths of 10-15cm, 60-65cm, and 90-95cm. Thus 96 composite soil samples were taken from the 32 pits at varying depths in the eight selected LGAs. A second batch of 36 composite soil samples was taken from 16 brick sites evenly distributed in the study area (that is 2 composite soil samples were taken from burnt areas of each brick sites; and one (1) composite soil sample was taken at an unburnt area of each brick site as a control).

Altogether 144 composite soil samples were used for the study. A representative soil samples were obtained taking into cognisance the spatial and temporal variability over brick sites. Soil pits of 1m x 1m x 1m ideally warranted detailed observation of soil structure, texture, colour, stratification and depth of strata (Rowell, 1994). Each soil sample was placed in a separate polythene bag and much of the air expelled before tying the neck (Rowell, 1994). Using indelible ink, each soil sample was labeled with a number, sampling depth, pit number, location as well as the date on which the sample was collected.

Each of the labels was placed into a second polythene bag into which each soil sample was separately placed. The second polythene bag was also labelled before transportation to the laboratory. Data Analyses of the 144 composite soil samples at the University of Agriculture, Makurdi. Soil Science Laboratory, Benue State, Nigeria, complied with guidelines outlined by SPAC (1999). The student T-text, percentages and analysis of variance were used to analyze data.

RESULTS

The mean pH of soil samples was taken in water and potassium chloride. pH values were also taken at varying depths of excavation, viz: 10-15cm, 60-65cm and 90-95 cm as well as at burnt and unburnt areas of burnt brick sires (Tables 1and 2). The organic matter (CM) content of soil samples was also assessed at 10-15cm, 60-65cm and 90-95cm as well as at burnt and unburnt areas of burnt brick sires (Tables 1and 2). The following is the report of results obtained: Organic Matter (OM)

The mean range of organic matter (OM) in the study area was 0.93±0.10% to 2.67±0.21%, corresponding to mean OM content of soils for Makurdi and Gwer West Local Government Areas, respectively (Table 1). Makurdi Local Government Area had the least mean value of OM (0.93±0.10%). Buruku Local Government Area had a mean soil organic matter content of 1.38±0.17%, which varied significantly with that of Makurdi Local Government Area. Konshisha and Vandeikya Local Government Areas had mean soil OM contents of 1.70±0.29% and 1.79±0.16% respectively. These values were significantly different from mean OM content for soils in Makurdi and Buruku.

Gboko Local government Area had a mean OM content of 1.95±0.25%, which was also significantly different from the means for Makurdi, Buruku as well as Konshisha and Vandeikya Local Government Areas. Gwer-West and Kwande Local Government Areas had mean soil OM contents of 1.67±0.21% and 2.21±0.17%, respectively. These values varied significantly with means for the other groups of Local Governments earlier discussed. The mean coefficient of variation and Fisher's LSD values for the studied Local Government |Areas were 0.347 and 0.6322 respectively. Soil excavation depth ranges of 10-15cm, 60-65cm and 90-95cm recorded mean soil OM contents of 2,41±0.15%, 1.65±0.11% and 1.28±0.11% respectively (Table 1). These mean OM values differed significantly between the three ranges of soil excavation depths. The mean coefficient of variation and Fisher's LSD values was 0.341 and 0.3832 respectively.

The organic matter (OM) content of soil samples taken at points of brick burning ranged from 0.60±0.10% to 1.54±0.11%, representing OM content for Ushongo and Buruku LGAs respectively (Table 2).

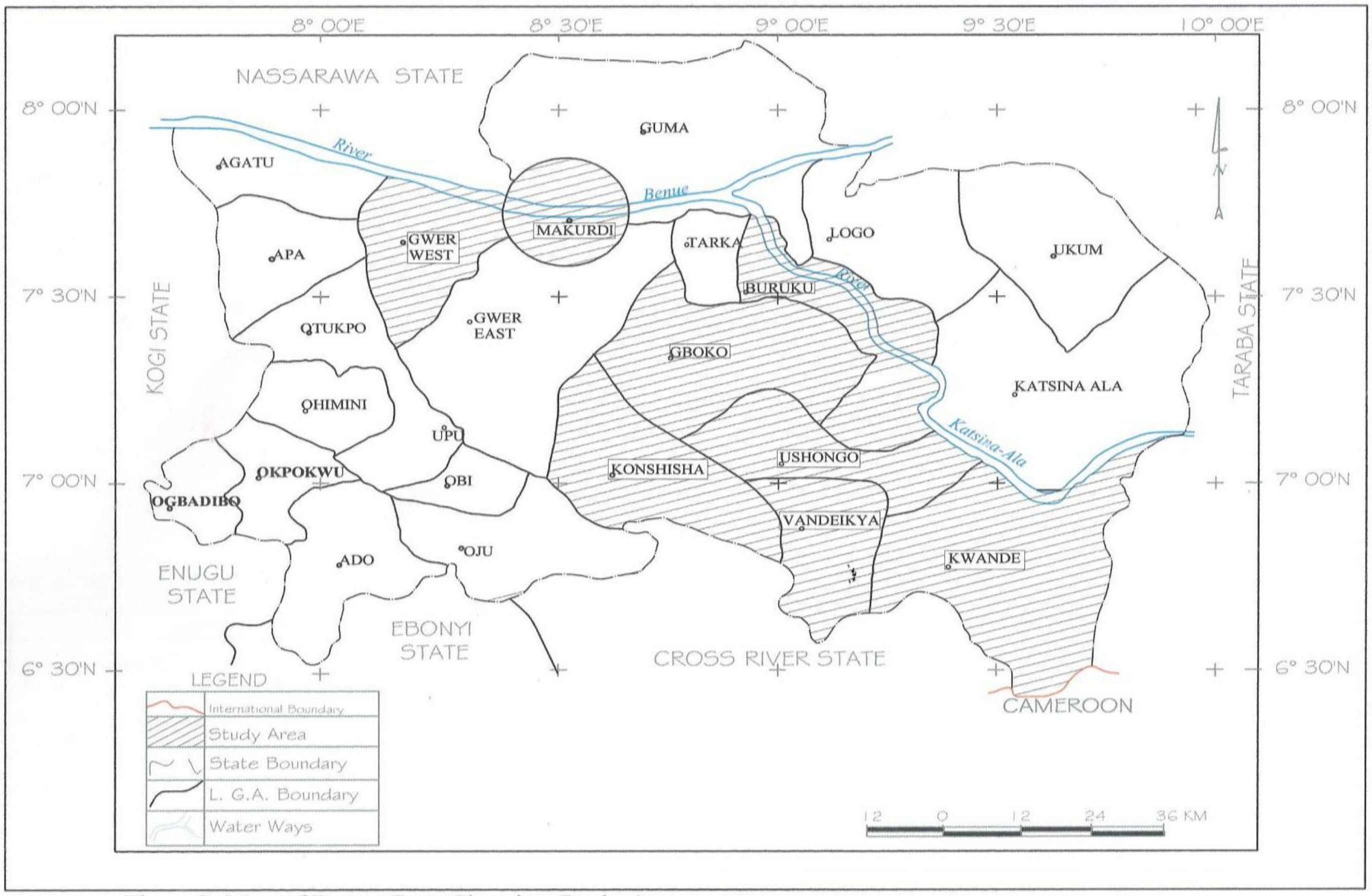

Figure2: Map of Benue State Showing Study Area.
Source: Ministry of Lands and Survey Makurdi, 2013

Table 1: Mean Hydrogen Ion Concentration and Organic Mattter Content of Soil Samples by Local Government Area and Depth of soil Excavation

LGA	**pH**		**Organic Matter (%)**
	H_2o	KCl	
Buruku	4.67 ± 0.20^{a}	4.58 ± 0.27^{b}	1.38 ± 0.17^{ab}
Gboko	4.81 ± 0.03^{ab}	4.29 ± 0.06^{ab}	1.95 ± 0.25^{bc}
Gwer/west	5.21 ± 0.08^{c}	4.77 ± 0.11^{b}	2.67 ± 0.21^{c}
Konshisha	4.59 ± 0.04^{a}	4.24 ± 0.05^{a}	1.70 ± 0.29^{b}
Kwande	4.97 ± 0.13^{b}	4.55 ± 0.12^{b}	2.21 ± 0.17^{c}
Makurdi	4.61 ± 0.04^{a}	4.18 ± 0.04^{a}	0.93 ± 0.10^{a}
Ushongo	5.23 ± 0.11^{c}	4.67 ± 0.07^{b}	1.58 ± 0.34^{b}
Vandeikya	4.87 ± 0.05^{b}	4.54 ± 0.05^{b}	1.79 ± 0.16^{b}
CV	*0.258*	*0.141*	*0.347*
LSD	*0.2855*	*0.3354*	*0.6322*
10-15	5.02 ± 0.08^{b}	4.58 ± 0.09^{b}	2.41 ± 0.18^{c}
60-65	4.87 ± 0.07^{a}	4.44 ± 0.08^{ab}	1.65 ± 0.11^{b}
90-95	4.72 ± 0.06^{a}	4.31 ± 0.05^{a}	1.28 ± 0.11^{a}
CV	*0.351*	*0.214*	*0.341*
LSD	*0.1984*	*0.2106*	*0.3832*

Means on the same column with the same superscript are not statistically different ($p<0.05$)

Table 2: Values of Hydrogen Ion Concentration and Organic Matter Content of Soil Samples at Burnt and Unburnt Areas of Brick Sites in Benue State

Soil Property	Treatments	Local Government Area Mean + SEM								General Mean
		Buruku	Gboko	Gwer/west	Konshisha	Kwande	Makurdi	Ushongo	Vandeikya	
pH	H2O									
	Burnt	4.78±0.27	5.43±0.29	4.95±0.05	5.54±0.04	5.59±0.42	4.99±0.19	5.29±0.16	5.79±0.79	5.30±0.20
	Unburnt	4.34±0.14	5.22±0.32	4.83±0.06	4.26±0.09	5.35±0.07	4.50±0.17	4.68±0.26	4.95±0.39	4.77±0.14
	P-Value	0.561	0.741	0.230	0.417	0.358	0.056	0.048*	0.046*	0.042*
	KCl									
	Burnt	5.86±1.22	6.34±0.27	6.27±0.55	5.68±0.30	7.22±0.78	6.13±0.49	6.87±0.41	6.54±0.47	6.11±0.19
	Unburnt	5.74±1.32	6.23±0.20	6.05±0.63	5.59±0.26	6.64±0.43	5.81±0.77	6.44±0.62	6.42±0.52	6.03±0.13
	P-Value	0.521	0.085	0.341	0.214	0.847	0.214	0.068	0.074	0.301
SOM (%)	Burnt	1.54±0.11	1.15±0.11	1.44±0.19	1.01±0.09	1.23±0.08	0.79±0.28	0.60±0.10	1.09±0.24	1.11±0.09
	Unburnt	1.97±0.13	2.39±0.89	2.71±0.81	2.83±1.48	2.79±0.93	2.19±1.09	1.69±0.48	2.29±0.71	2.36±0.25
	P-Value	0.056	0.240	0.034*	0.057	0.049*	0.048*	0.043*	0.051	0.034*

* Indicates statistical difference at $p < 0.05$ SOM = Soil organic matter; pH = Hydrogen ion concentration; SEM = Standard error of the mean

The mean organic matter content of soil samples taken from unburnt areas of brick sites ranged from 1.69±0.48% to 2.83±1.48%, representing OM content of soil samples taken from unburnt areas of brick sites from Ushongo and Konshisha LGAs respectively. There were significant differences in the OM content of soil samples taken from unburnt areas of brick sites and those taken at points of brick burning. Generally, samples from unburnt areas of brick sites had higher organic matter content than soil samples taken from burnt areas.

Soil pH in Water and Potassium Chloride (KCl)
Soil pH in Water (pHw)

Soil samples from Buruku, Konshisha and Makurdi recorded mean pH values in water (pHW) as 4.67±0.20, 4.59±0.04 and 4.61±0.64 respectively (Table 1). These pH values did not vary significantly from each other. A mean pHW value of 4.81±0.03 was recorded for soils Gboko Local Government Area. Kwande Local Government Area had a soil pH value of 4.81±0.03 which differed significantly from pH values recorded for Buruku, Konshisha and Makurdi Local Government Areas. pH values of soils taken in water for Kwande and Vandeikya Local Government Areas were 4.97±0.13 and 4.87±0.05 respectively. These values differed significantly with that of Gboko as well as those of Buruku, Konshisha and Makurdi Local Government Areas.

Soil pHw values, for Gwer West and Ushongo Local Government Areas were 5.21±0.08 and 5.23 respectively; even though these values did not vary significantly between these Local Government Areas, they varied significantly with those of Buruku, Konshisha, and Makurdi as well as that of Gboko and those of Kwande and Vandeikya LGAs. Values of pHw in the soil depth range of 10-15cm varied significantly with those of 60-65cm and 90-95cm ranges (Table 1). The soil depth ranges of 60-65cm and 90-95cm did not vary significantly from each other and had pHw values of 4.87±0.07 and 4.72±0.06 respectively.

The coefficient of variation and Fisher's LSD values for all depth ranges was 0.351 and 0.1984 respectively. Values of soil pH in Kcl (pHKcl) were generally lower (Table 1) than soil pHw even though these values did not show any significant variation among themselves. Values of pHKCl for Konshisha and Makurdi were 4.24±0.05 and 4.18±0.04 respectively (Table 4); these values did not vary significantly. Soil (pHKCl) for Gboko varied significantly with those of Konshisha and Makurdi. Soil pHkcl values for Buruku, Gwer West, Kwande, Ushongo and Vandeikya were 4.58±0.27, 4.77±0.11, 4.55±0.12, 4.67±0.07 and 4.54±0.05 respectively, these values did not vary significantly between this group of Local government Areas, however the values varied significantly with those of Konshisha and Makurdi.

The values also varied significantly with that of Gboko as well as those of Buruku, Gwer West, Kwande as well as Ushongo. Coefficient of variation and Fisher's LSD values was 0.141 and 0.3354 respectively. Soil pHKCl values at excavation depths of 10-15cm, 60-65 and 90-95cm were 4.58±0.09, 4.44±0.08 and 4.31±0.05. These values varied significantly among the ranges of excavation depths. Coefficient of variation and Fisher's LSD values were 0.214 and 0.2196 respectively Points of brick burning had soil pH in water (pHW) values which ranged from 4.78±0.27 to 5.79±0.79, representing soil pHW values for Buruku and Vandeikya Local Government Areas respectively (Table 2).

Generally, soil pHW values at points of brick burning were higher than pHW values of soil samples from unburnt areas of brick sites. Soil pHW values at poins of brick burning were significantly different from pHW values for unburnt areas for Makurdi, Ushongo and Vandeikya Local Government Areas; however, there were no significant differences between burnt and unburnt areas of brick sites for Buruku, Gboko, Gwer West, Konshisha and Kwande Local Areas. Soil pH in potassium chloride (pHKCl) values for burnt and unburnt areas of brick sites were generally higher than soil pHW values (Tables 1and 2). Soil pHKCl values for samples at points of burning ranged from 5.68±0.30 to 7.32±0.78, representing values for Konshisha and Kwande Local Government than that from burnt areas and ranged from 5.59±0.26 to 6.64±0.43, representing soil pHKCl values for Konshissha and Kwande Local Government Areas respectively. Soil pHKCl values at points of brick burning and at unburnt areas of brick sites did not exhibit any significant variation from each other.

DISCUSSION OF RESULTS

Increases in pH at burnt areas of brick sites were significantly high, compared to unburnt areas (Table 2). This increase in pH at burnt areas of brick sites implies that the firing of bricks leads to significantly higher increases in soil pH. Also the pH of soils generally increased with increasing depth of soil excavation at brick sites. This implies that the pH of soil samples taken at soil excavation depth range of 90-95cm was higher than pH of the soil samples taken at the excavation depth range of 10-15cm. Soil pH is generally increased after the firing of soils, particularly firing with fuel wood (Aref et al., 2011; Boerner et al., 2009).

However, significant increases occurred only at higher temperatures [450-5000 ºC] (Certini, 2005). The presence of wood ash may increase soil pH due to high pH of ash (Molina et al., 2007; Schafer and Mack, 2010). The surface layers of the soil generally witness an increase in pH after burning; the increase is closely related to the aboveground biomass burned (Nwoboshi, 2000). Soils with little clay or organic matter will show marked changes in pH immediately following a fire, but as cations such as calcium, magnesium and potassium are lost from the soil, the pH may decrease (Afolayan, 1977).

Conversely, where a soil has a large cation exchange capacity, it is likely to be buffered against such shifts in soil pH. Burning of bricks decreased SOM in all soils sampled in the selected local government areas, but decreases were more significant in Ushongo and Vandeikya Local government Areas. Correspondingly, the SOM content of unburnt soil samples was much higher, indicating that observed differences in SOM were mainly as a result of fire effect. This result is in consonance with finding of Certini, (2005), and Gonza´lez-Pe´rez et al. (2004). SOM represents the third largest terrestrial carbon pool, with a global estimated total of 1526 pgC (Lal, 2004).

The most intuitive change soils undergo during burning is loss of organic matter (Certini, 2005). The organic horizon of soils is the critical component of ecosystem sustainability since it provides a protective soil cover that mitigates erosion, aids in regulating soil temperature, provides habitat and substrates for soil biota and can be a major source of readily mineralizable nutrients (Neary et al., 1999). It is vital in soil cation exchange capacity (CEC) and retention of ions (Crasswell and Lefroy, 2001). The effect of fire on SOM is highly variable from total destruction of SOM to partial scorching depending on fire severity, dryness of the surface OM and fire type (Gonza´lez-Pe´rez et al., 2004).

The effect of fire on SOM is highly dependent on the type and intensity of the fire, among other factors, soil moisture, soil type, and nature of the burned materials (firewood). Therefore, the effect on soil processes and their intensity influenced by fire are highly variable and no generalized tendencies can be suggested for most of the fire-induced changes in humus composition (Gonza´lez-Pe´rez et al., 2004). Low-intensity prescribed fire usually results in little change in soil carbon, but intense prescribed fire or wildfire, and firing of burnt bricks can result in a huge loss of soil carbon (Johnson, 1992). Charcoal is formed when woody biomass is used in firing bricks. Charcoal can promote rapid loss of soil humus and belowground carbon during the first decade after its formation, because the charred plant material causes accelerated breakdown of simple carbohydrates (Wardle et al., 2008). Fernandez et al., (1997) suggested that in a low intensity fire, lipids are the least affected group, whereas 90% of water-soluble cellulose, hemicelluloses and lignin are destroyed

Usually, trace amounts of all surface organic matter in the upper mineral soil may be lost to fire (Pritchett, 1979). Phosphorus becomes available as well as Ca and K. Nutrient losses result from fire through volatilisation of elements like carbon, nitrogen and sulphur in the vegetation and litter component of the ecosystem and through removal of solid ash in the smoke (Nwoboshi, 2000). Prescribed burning does not significantly decrease total organic matter (Pritchett, 1979), however, organic matter is redistributed in the different soil horizons by fire. The ash accumulated on the soil surface can either be blown away by the wind, carried away from the site in overland erosion, or leached through the soil by rains.

CONCLUSION

The excavation of soil for production of bricks results in increased soil pH. Thus the pH values of soil samples assessed in both water and Potassium chloride were significantly higher for samples taken at the soil excavation depth range of 80-95 cm than those samples taken at the soil excavation depth range of 10-15. Similarly, the organic matter content of soils sampled decreased with an increase in depth of soil excavation; thus the organic matter content of soil samples taken at the soil excavation depth range of 10-15 cm were higher than those taken at the soil depth range of 90-95cm. Generally the pH of soil samples taken at burnt areas of brick sites was higher than that of soil samples taken at unburnt areas of brick sites. This implies that the burning of bricks with fuel wood increases soil pH.

REFERENCES

Afolayan, T.A. and Amubode, F.O. (1985): Stock Assessment of Large mammals in Nigerian Wooded Savannah and its Management Implications. Forest Ecology and Management 13; 257-263. Agroecosystem, 61: 7-18

Aref IM, Atta HA, Ghamade AR. 2011. effect of forest fires on tree diversity and some soil properties. International Journal of Agriculture and Biology, 13: 659-664

Certini G. 2005. Effect of fire on properties of soil - A review. Oecologia, 143: 1-10

Clark B. 2001. Soils, water, and watersheds. In: Fire Effects Guide. National Interagency Fire Center, USA

Craswell ET, Lefroy RDB. 2001. The role and function of organic matter in tropical soils. Nutrient Cycling in Agroecosystem, 61: 7-18

DeBano LF. 2000. The role of fire and soil heating on water repellency in wildland environments: a review. Journal of Hydrology, 231-232: 195-206.

Encyclopedia Britannica (1998): The New Encyclopedia Britanica, Vol. 2., 15th Edition, USA

Fernandez I, Cabaneiro A, Carballas T. 1997. Organic matter changes immediately after a wildfire in an atlantic forest soil and comparison with laboratory soil heating. Soil Biology and Biochemistry, 29(1): 1-11

Gonza´lez-Pe´rez JA, Gonza´lez-Vila FJ, Almendros G, et al. 2004. The effect of fire on soil organic matter—a review. Environment International, 30: 855– 870

Johnson DW. 1992. Effects of forest management on soil carbon storage. Water, Air, and Soil Pollution, 64: 83-120

Lal R. 2004. Soil carbon sequestration to mitigate climate change. Geoderma, 123: 1-22

Molina M, Fuentes R, Calderón R, et al. 2007. Impact of forest fire ash on surface charge characteristics of Andisols. Soil Science, 172 (10): 820-834

National Population Commission (NPC) (2007) Facts Sheet, issued on 3st April, 2007, p. 82

Neary DG, Klopatek CC, DeBano LF, et al. 1999. Fire effects on belowground sustainability: a review and synthesis. Forest Ecology and Management, 122: 51-71

Nwoboshi, L.C. (2000): The Nutrient Factor in Sustainable Forestry. Ibadan University Press, Nigeria.
Pritchett, W.L. (1979): Properties and Management of Forest Soils. John Wiley and Sons Inc., N.Y. pp. 1 – 110.
Rowell, D.L. (1994): Soil Science: Methods and Applications. Addison Wesley Longman, England.
Schafer JL, Mack MC. 2010. Short-term effects of fire on soil and plant nutrients. Plant Soil, 334: 433-447
Soil and Plant Analysis Council (1999)
Verma, S., and Jayakumar, S (2012): Impact of forest fire on physical, chemical and biological properties of soil: A review. Proceedings of the International Academy of Ecology and Environmental Sciences, 2012, 2(3):168-176
Wardle DA, Nilsson MC, Zackrisson O. 2008. Fire-derived charcoal causes loss of forest humus. Science, 320:629