Soil Properties Dynamics induced by the Passage of the Fire during Agricultural Burning

Edem, I. Dennis[*1], Alphonsus D. Usoroh[1] & Christiana J. Ijah[2]

1. Department of Soil Science & Land Resources Management, Faculty of Agriculture, University o f Uyo, P.M. B.1017, Uyo, Akwa Ibom State, Nigeria.

2. Department of Soil Science, Akwa Ibom State University

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ABSTRACT

Aims: Effects of fire on soil properties was performed in experimental plots, whose fuel amount was altered in order to obtain different heating intensities with the aim of assessing changes in soil physical conditions at varying fire temperature and also the fire temperatures within which soil quality attributes are depleted.

Study design: The experiment consisted of two treatments (burned and un-burned plots) arranged in a RCBD with three replicates. Data were statistically analyzed for variance (ANOVA). A post Hoc Duncan multiple comparisons test was performed to compare the severity of fire temperature on soil properties. Paired t-test was used to compare means of the unburnt and burnt plots. For all tests, a threshold of P = 0.05 was used to define statistical significance. All statistical analyses were performed using SigmaStat (3.5 Edition) and validated using SPSS 17.0. Pearson correlation coefficients were used to assess the degree of relationships among variables

Place and Duration of Study: The research was conducted in a continuous cropped arable experimental plots located at the University of Uyo Teaching and Research Farm (UUTRF), Use-Offot, Uyo, Nigeria for four growing seasons, between March, 2010 to October, 2011.

Methodology: The severity of burning in each site was measured qualitatively from the degree of litter consumption of the applied biomass. Immediately after burning, soil temperatures were read from the installed temperature sensors at the surface and subsurface of the respective plots. To ensure representative sampling, bulk soil samples, which were analyzed for soil physico-chemical properties, were composite of five random samples taken at 0–15 and 15-30 cm depths within replicated plots. Particle-size distribution was determined in the soil samples using hydrometer method. Bulk density was estimated by dividing the oven-dry mass of the soil by the volume of the soil. In addition, core samples were also used to determine saturated hydraulic conductivity (Ks) in the laboratory using a constant head permeameter. pH was determined with the use of glass electrode pH meter to read the suspension of 10g soil sample with 20 ml 0.01 N $CaCl_2$. Available phosphorus was determined using bicarbonate extraction, with acid reductant. Meanwhile, the exchangeable cations (calcium, Ca; magnesium, Mg; potassium, K; and sodium, Na) in the soil were determined by first extracting the soil sediment with 1M NH4 OAc (ammonium acetate) solution. The amounts of exchangeable Na and K in the extract were determined by flame photometry while Ca and Mg were determined by atomic absorption spectrometry.

Results: Temperature differences significantly (P < 0.05) affected sand, total nitrogen,

* Tel.: +234-8027031426

*Corresponding author's E-mail address: inidennis117@yahoo.com or dennis.edem@gmail.com

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organic carbon and pH contents of the soils positively (r = 0.518* 0.478*, 0.582*, 0.595** respectively), whereas a reduction in the soil temperature increased the concentrations of clay, 1mm, 0.05mm and 0.25 mm stable soil aggregates in the soil (r = -0.619**, -0.578*, -0.780, -0.526* respectively) after burning. Exchange acidity increased to 5.12 $cmolkg^{-1}$ at 40^0C from 0.80 $cmolkg^{-1}$ at initial temperature of 25^0C at the surface soil.

Conclusion: Though aggregates formation was significantly higher (P = 0.05) after burning than the control soil locations, both organic matter and ECEC increased at increasing fire temperature. Potassium content remained surprisingly constant as the fire temperature increased. However, despite the merits of quick release of occluded nutrients, heating temperatures of slash-and-burn method of land clearing altered soil quality attributes, this soil will easily be distressed with the least application of force.

Keywords: Slash-and-burn; traditional farming; soil quality; modification;

1. INTRODUCTION

Slash and burn method of land clearing is an integral part of the traditional farming system (bush fallow rotation) widely used as a means of land clearing to pave way to tillage in southern Nigeria. Depending on management practices being used, human activities like bush burning, fossil fuel uses and deforestation have alter the atmosphere's composition and earth balance. The invention of fire ignition and its control by man started the anthropogenic modification of biosphere (Neff et al., 2005). Fire has long been recognized as a disturbance that maintains grasslands and savannas and prevents invasion of woody species (Archer et al., 1988; Blair, 1997; Ruddiman, 2003). Therefore, prescribed fire is often employed as a land management tool to suppress the encroachment of woody plants into grass-dominated ecosystems. In humid tropics, fire frequencies and interactions between fire and other disturbance factor (such as tillage equipment and tillage methods) determined to a large extent the balance between trees and grasses, stand structure and dynamics, and shrub cover abundance (Edem et al., 2012; Neary et al., 1999; Rice & Owensby, 2000; Ruddiman, 2003). Above and below ground productivity often increase following fire as a result of microclimatic modification due to removal of litter and standing crop and changes in nutrient availability and distributions (Creighton & Sutherland; National Wildfire Coordinating Group, 2001; Peterson & Reich, 2001).

According to Edem *et al* (2012), most land that is left unused in a cropping year is often set on fire by farmers. This is common with the livestock farmers so that their animals could browse on young plants that grow after burning. Before the plants come up to cover the ground surface, the soil is exposed to rainfall. Subsequently, soil aggregates are dispersed: pores are clogged with particles which further result in higher rates of surface

* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or dennis.edem@gmail.com

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runoff (Mallik et al., 1984). The level of alteration may even be enormous if quantity of trash is large and the residence time of burning is long, or a thin dry litter is completely incinerated (Ruddiman, 2005). More severe burns may alter soil fundamental characteristics such as texture, mineralogy and cation-exchange capacity (Johnson & Matchett, 2001).

So far, most research assesses change in organic carbon due to bush burning and few efforts were made to assess the effect on other soil properties. Moreover, no studies are known to that assesses the spatial variability of soil properties at different heating temperature in humid tropics. Hence, tropical conditions are often under represented. These researches aimed at developing regional-specific approaches and improve estimates on soil quality factor modifications at varying temperatures.

Therefore, the objectives of this study were to assess; (i) changes in soil physical conditions at varying fire temperature and (ii) the fire temperature within which soil quality attributes are depleted.

2. MATERIAL AND METHODS

2.1 Study area

The research was conducted in a continuous cropped arable experimental plots located at the University of Uyo Teaching and Research Farm (UUTRF), Use-Offot, Uyo, Nigeria. Uyo is located between latitudes 4^0 $30^{'}$ and 5^0 $3^{'}$N and longitudes 7^0 $31^{'}$ and 8^0 $20^{'}$ E and altitude 65 m from the sea level. The area is divided into two distinct seasons, the wet and dry seasons. The wet or rainy season begins from April and lasts till October. It is characterized by heavy rainfall of about 2500-4000 mm per annum. The rainfall intensity is very high and there is evidence of high leaching and erosion associated with slope and rainfall factors in the area (Edem et al., 2012). In the area measuring 774.4 m^2 on a slope of 7 %, were prepared 10 sub plots; each 24 x 3 m^2, separated from each other by fireproof tracts (20 cm). In preparing the plots, dry biomass treatments of 50, 100, and 150 kg/m^2 were applied on the cleared plots in order to produce three levels of fire intensities, and progressively fire was set into 9 out of the 10 plots.

2.2 Pre-and-post burnt soil samplings

Profile pits (50 cm depth) were dug at the centre of each plot to ease installation of temperature sensor in the subsoil. Bulk soil, core and aggregate samples were collected at two depths of 15 cm interval before and after passage of fire before mineralization of the $CaCO_3$ in the ash content. The core samples were obtained for saturated hydraulic conductivity and bulk density determinations. The soil samples were secured in a core, and one end of the core was covered with a piece of cheese cloth fastened with a rubber band and properly labeled while the bulk samples collected were secured in properly labeled polythene bags before taken to the University of Uyo Soil Science laboratory for physical, chemical and structural parameters determinations using standard methods and procedures (Danielson & Sutherland, 1986).

* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or dennis.edem@gmail.com

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2.3 Experimental measurements and statistical analyses

The severity of burning in each site was measured qualitatively from the degree of litter consumption of the applied biomass. Immediately after burning, soil temperatures were read from the installed temperature sensors at the surface and subsurface of the respective plots for the four growing seasons the experiment lasted. To ensure representative sampling, bulk soil samples, which were analyzed for soil physico-chemical properties, were composite of five random samples taken at 0–15 and 15-30 cm depths within replicated plots.

Particle-size distribution was determined in the soil samples using hydrometer method. Bulk density was estimated by dividing the oven-dry mass of the soil by the volume of the soil. In addition, core samples were also used to determine saturated hydraulic conductivity (Ks) in the laboratory using a constant head permeameter. Undisturbed soil samples were taken for the determination of water-Stable aggregates (WSA) and mean weight diameter (MWD) using a modified Kemper and Rosenau wet sieving method. Soil organic carbon (SOC) was determined by loss-on-ignition and the standard Van Bemmelen factor (1.724) was used for conversion of SOC into organic matter content. Total nitrogen was determined by dry combustion using Leco CHN Analyzer (Laboratory Equipment Corporation, St Joseph, MO, USA; Bremner and Mulvaney 1982) .

pH was determined with the use of glass electrode pH meter to read the suspension of 10g soil sample with 20 ml 0.01 N $CaCl_2$. Available phosphorus was determined using bicarbonate extraction, with acid reductant. Meanwhile, the exchangeable cations (calcium, Ca; magnesium, Mg; potassium, K; and sodium, Na) in the soil were determined by first extracting the soil sediment with 1M NH4 OAc (ammonium acetate) solution. The amounts of exchangeable Na and K in the extract were determined by flame photometry while Ca and Mg were determined by atomic absorption spectrometry.

Effective cation exchange capacity (ECEC) was obtained by addition of the values of exchangeable bases and exchangeable acidity. Base saturation was expressed as the fraction of the negative binding sites occupied by exchangeable cations .It was calculated by summing together the levels of Ca, Mg, K ,and Na found in the soil, then expressing this sum as a percentage of the ECEC value as follows:

$$BS = \frac{100\,(Ca + Mg + K + Na}{ECEC}$$

Where, BS represents base saturation (%).

The experiment consisted of two treatments (burned and un-burned plots) arranged in a RCBD with three replicates. Data were statistically analyzed for variance (ANOVA), and significant means were compared using Duncan multiple range test. Paired t-test was used to compare means of the unburnt and burnt plots. For all tests, a threshold of P =0.05 was used to define statistical significance. All statistical analyses were performed using SigmaStat (3.5 Edition) and validated using SPSS 17.0. Pearson correlation coefficients were used to assess the degree of relationships among variables.

3. RESULTS AND DISCUSSION

Regardless of varying fire temperatures, some physical and chemical characteristics of soil Before and after experimental fire, clearly and strongly differed between burnt and unburnt Soils in this study area as shown in Table 1.

* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or dennis.edem@gmail.com

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3.1 Particle size distribution and soil texture

The results show that total sand fraction with mean value of 838.50 gkg^{-1} in the burnt plot was significantly (*P*= .05) greater than the unburnt plot with the mean value of 772.60 gkg^{-1}. The silt fraction was higher in the unburnt plot with the mean value of 78.86 gkg^{-1} than the burnt plot with the mean of 47.58 gkg^{-1}. Although Hubbert *et al*., (2006) reported increase in silt fraction after burning, but this result in line with the report Kettering *et al*., (2000), that burning has effect on soil particle distribution. Clay fraction was greater in the unburnt plot with the mean of 148.53 gkg^{-1} than the burnt plot with the mean of 114.02 gkg^{-1} but was not significant. The result showed that the burnt and unburnt plots were loamy sand texture. Therefore, the textural class was not affected by burning even though there were significant changes in the distribution of particle sizes. This result conformed to the earlier report of Edem *et al*., (2012) that soil texture is a fundamental attribute of the soil and cannot easily alter by management practices. Intense heating temperature (>400^{0}C) may permanently alter soil texture by aggregating clay particles into stable sand-sized particle making the soil texture more coarse and erodible (Chandler et al., 1983)

3.2 Bulk density (BD) and Total porosity (P)

Bulk density responded to burning with increase in the mean value of 1.67 g/cm^3 compared to 1.59 g/cm^3 before burning but was not statistically significant. This result confirmed the earlier report of Klemmedson et al., (1952) that bulk density increased after slash and burn. They ascribed this change to the disruption of soil aggregation and loss of organic matter. Also, there was 10 % decrease in Total porosity after burning. This observation is in consonance with Mallik et al., (1984) and Neary et al., (1999) who reported reduction in larger pores and total porosity following burning and ascribed it to the ash deposits in the larger pores. The reduction in total porosity can also be ascribed to increase in bulk density. Although, reduction in total porosity has been reported by Mallik et al., (1984), but Oguntunde et al., (2008) and Ajaji et al.,(2009), reported reduction in bulk density due to burning of soils. It therefore appears that the reduction in total pore volumes was perhaps due to ash deposits in larger pores.

* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or dennis.edem@gmail.com

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Table 1: Mean and standard deviation of some soils' physical and chemical properties before and after experimental fire

Soil parameters	Pre-burnt plot	Burnt plot
Sand, gkg^{-1}	772.60 ± 59.01^{b}	838.50 ± 41.85^{a}
Silt, gkg^{-1}	78.86 ± 33.60^{a}	47.58 ± 14.40^{b}
Clay, gkg^{-1}	148.53 ± 52.24^{a}	114.02 ± 37.03^{a}
Texture	Loamy sand	Loamy sand
Ks, cm/hr	3.30 ± 3.82^{b}	7.32 ±9.25^{a}
BD, g/cm^{3}	1.59 ± 0.13^{a}	1.67 ± 11.96^{a}
P, $cm^{3}cm^{-3}$	39.88 ± 4.98^{a}	35.98 ± 13.58^{a}
Θv, cm^{3}/cm^{3}	2.55 ±0.40^{a}	7.93 ± 14.52^{a}
pH	5.9 ± 0.15^{a}	5.4 ± 0.19^{b}
EC, dsm^{-1}	0.04 ±0.31^{a}	0.02 ± 0.09^{b}
TN, gkg^{-1}	0.36 ± 0.13^{b}	0.67 ± 0.12^{a}
AVP, $mgkg^{-1}$	27.77 ± 4.12^{a}	26.56± 2.75^{a}
Ca, $cmolkg^{-1}$	3.12 ± 0.93^{b}	4.98 ± 2.39^{a}
Mg, $cmolkg^{-1}$	1.86 ± 0.46^{b}	3.92 ± 2.22^{a}
K, $cmolkg^{-1}$	0.05 ± 0.03^{a}	0.05 ± 0.01^{a}
Na, $cmolkg^{-1}$	0.05 ± 0.01^{a}	0.04 ± 0.10^{b}

* Means followed by different letters along the rows are significantly different (*P* = .05)
Ks = saturated hydraulic conductivity; BD = bulk density; Θv= volumetric moisture content; P = total porosity; EC = electrical conductivity; TN = total N; AV. P =available phosphorus.

3.3 Volumetric moisture content (ϴV) and Saturated hydraulic conductivity (K_s)

A significant (*P* = .05) increase in saturated hydraulic conductivity in the burnt plot was observed with the mean of 7.23 cm/hr compared to the unburnt plot having a mean of 3.30 cm/hr . This observation is contrary to the report of Pyne & Goldammer (1997). They found that K_s of soil decreased approximately 50% in the burnt plots relative to adjacent unburned plots. But Ruddiman (2005), paid attention to the textural characteristics, organic matter content, and structure which appeared to have been responsible for high K_s values. Volumetric moisture content increased after burning with the mean of 7.93 cm^3/cm^3 compared to 2.55 cm^3/cm^3 in the un-burnt plot. This is in consonance with Edem et *al*., (2012) who reported an increase in water retained after burning. The increased in volumetric

* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or dennis.edem@gmail.com

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moisture content in this study however contradict with Mallik et al., (1984) who reported reduction in moisture content from 0.13 to 0.03 $m^{-3}m^{-3}$ at a depth of 0-0.5m in a steep chaparral watershed, southern California, following burning.

Table 2: Variation induced by experimental fires on some soils' physical properties and erodibility.

Heating temp. ^0C	Sand (gkg^{-1})	Silt (gkg^{-1})	Clay (gkg^{-1})	K_s cm/hr	BD gcm^{-3}	P cm^{3}cm^{-3}	MC cm^3 cm^{-3}	PSS t/ha/yr	**K factor** (t□ha/MJ□m m
				Surface soil layer					
24(control)	802.44f	76.48a	121.08b	5.78e	1.50b	43.00b	2.59b	7.79d	0.41c
35	821.00e	47.20d	131.80b	1.80g	1.75a	34.00c	3.14b	9.88b	0.53ab
40	821.00e	47.20d	131.80b	8.40d	1.65a	38.00c	3.47b	11.02a	0.58a
48	841.00c	47.20d	111.80c	19.80b	1.50b	57.00a	3.15b	10.07a	0.57a
49	831.00d	57.20c	151.80a	11.70c	1.53b	42.00b	3.07b	9.69b	0.58a
50	851.00b	50.70c	111.80c	20.70a	1.45c	45.00b	2.77b	8.55c	0.51b
58	861.00a	67.20b	71.80d	3.60f	1.76a	32.00c	2.95b	8.17c	0.55ab
60	821.00e	47.20d	111.80c	5.40e	1.40c	37.51c	7.37a	8.55c	0.53ab
CV(%)	**5.16**	**30.26**	**25.71**	**12.27**	**20.70**	**37.75**	**18.31**	**12.07**	**10.47**
				Sub-surface soil layer					
24(control)	741.88c	85.53a	172.97b	0.80c	1.67b	36.00b	2.46b	7.96c	0.43c
25	761.00a	27.20c	171.80b	2.40b	1.64b	36.00b	2.95b	7.60c	0.45c
30	721.0b	40.53c	138.46c	3.60a	1.60b	39.00a	3.03b	10.07b	0.50b
33	761.00a	47.20c	191.80a	1.80b	1.75a	38.00a	2.97b	10.45b	0.42c
35	721.0b	47.20c	171.80b	1.80b	1.65b	39.00a	3.14b	11.35a	0.53b
36	761.00a	67.20b	171.80b	3.00a	1.50c	36.00b	2.79b	10.00b	0.45c
37	781.00a	37.20c	181.80ab	3.30a	1.62b	34.00c	8.49a	9.56b	0.55a
CV (%)	**7.63**	**42.60**	**35.17**	**11.57**	**8.17**	**12.48**	**15.68**	**14.05**	**10.71**

Means followed by different letter along the column within the soil layer are significantly (*P* =.05) different

BD = Bulk density; P = total porosity; PSS = potential soil loss; MC = moisture content ;
K_s = Saturated hydraulic conductivity

* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or dennis.edem@gmail.com

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3.4 Changes in soil chemical properties following burning.

3.4.1 Soil pH and Electrical conductivity (EC)

The pH of the soil significantly decreased after burning with the mean value at 5.4 compared to 5.9 in the unburnt plot (P =.05). Electrical conductivity of the soil significantly decreased after burning with the mean of 0.02 dSm^{-1} compared to 0.04dSm^{-1} in unburnt plot (P =.05). But according Austin & Baisinger, (1955) as reported by Hernandez *et al*., (1997), EC values of burnt plots were higher than that of the unburned plots. The reduction of pH and EC in this research after burning could be ascribed to lack of mineralization of $CaCO_3$ in the ash content due to immediate soil sampling after burning.

3.4.2 Total nitrogen, Organic carbon and Available phosphorus

Total nitrogen responded to burning with a significant increase in the mean value of 0.67gkg^{-1} after burning and 0.36gkg^{-1} in the unburned plot. This observation agreed with the earlier work of Neary et al., (1999) who reported increase in availability of total nitrogen after burning. Surprisingly, organic carbon significantly (P=.05) increased after burning with mean of 15.97 gkg^{-1} compared to 9.29 gkg^{-1} in the unburnt plot. But Pyne & Goldammer (1997) reported that loss of organic carbon in soil occurs as a result of fire depleting the litter on the surface. Although, they did not assess heat intensity at varying temperatures and depth. Available phosphorus decreased after burning with the mean of 26.56 $mgkg^{-1}$ compared to 27.77 $mgkg^{-1}$ in the unburnt plot but was not significant. This is against the report of Neff et al., (2005) and Schevner et al., (2004) who reported that the ash deposits after burning, helps to fertilize the soil by immediate release of available P and other mineral nutrients-Mg and Ca. However, in this study, the ash was not allowed to mineralize, as samples were collected immediately after burning in order to assess sudden modifications induced to soil properties at varying heating temperature.

3.4.3 Exchangeable bases (Ca, Mg, K & Na) and Exchange acidity

Calcium (Ca) and magnesium (Mg) significantly (P= 0.05) increased after burning with the mean of 4.98 and 3.92 cmol/kg respectively compared to 3.12 and 1.86 cmol/kg respectively in the unburnt plot. P content remains 0.05 cmol/kg. Sodium (Na) significantly (P = 0.05) decreased after burning with the mean of 0.04 $cmolkg^{-1}$ compared to 0.05 cmol/kg before burning. The result of Ca and Mg were similar to Opera-Nadi *et al*., (2010) who reported that burned surface soils tend to have higher concentrations of non combustible elements such as Ca, K, Mg and Na compared with unburned soil but the result of K is on the contrary. The significant increase (P =.05) in Ca and Mg in the burnt plots is important because they cause flocculation of soil particles there by encourages aggregation of particles. Decrease in Na is

* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or dennis.edem@gmail.com

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significant because high content of Na^+ can destroy soil structure through dispersion of the particles which in turn heads to high erosion but in this case reduction in Na content after burning signified less susceptibility of this soil erosion. Exchange acidity significantly (P = 0.05) decreased after burning with the mean of 1.17 cmol/kg compared to 3.42 cmol/kg in the unburnt plot.

Table 3: Variations induced by experimental fire on soil chemical properties

Temp ^0C	pH	EC dSm^{-1}	TN (gkg^{-1})	OC (gkg^{-1})	C:N	AV. P $mgkg^{-1}$	EA (cmolkg^{-1})	Ca (cmolkg^{-1})	Mg (cmolkg^{-1})	K (cmolkg^{-1})	Na (cmolkg^{-1})	ECEC (cmolkg^{-1})	BS %
						Surface soil							
(control 24	5.9a	0.03a	0.40c	10.67c	24.07a	27.42a	2.68b	2.96d	1.90d	0.05bc	0.54a	8.13c	63.27c
35	5.3c	0.02b	0.60b	14.05d	23.6ab	28.97a	0.80d	6.72b	5.04b	0.06b	0.04b	12.66b	92.76b
40	5.9a	0.03a	0.80a	18.80a	23.5ab	25.64b	5.12a	6.72b	5.28b	0.08a	0.05b	17.25a	70.32c
48	5.5b	0.02b	0.80a	19.20a	24.00a	25.97b	1.12c	2.88d	2.40c	0.06b	0.06b	6.52	82.85bc
49	5.6b	0.03a	0.70ab	17.05b	24.35a	29.8a	0.88d	5.76c	4.80b	0.06b	0.04b	11.54b	92.13b
50	5.5b	0.03a	0.80a	19.05a	23.8ab	23.31c	0.56d	2.88d	1.92d	0.06b	0.04b	5.46d	87.37b
58	5.6b	0.02b	0.80a	17.80b	22.25b	25.64b	0.80d	3.36d	2.40c	0.04c	0.04b	6.64d	87.99b
60	5.6b	0.01c	0.70ab	17.20b	24.57a	25.64b	0.80d	9.12a	7.68a	0.05bc	0.05b	17.7a	95.48a
Cv(%)	**2.6**	**75**	**36.11**	**36.38**	**14.7**	**14.87**	**54.09**	**29.8**	**24.73**	**5.17**	**9.43**	**45.14**	**16.66**
						Subsurface soil							
(control) 24	5.9a	0.05a	0.31d	8.10c	23.5a	28.14a	3.42a	3.14cd	1.86cd	0.05ns	0.54a	9.01b	62.47c
25	5.5b	0.02b	0.60ab	13.2ab	22.0c	25.97c	1.6b	2.40d	1.14d	0.06	0.04b	5.24c	71.12bc
30	5.2c	0.02b	0.70a	15.26a	23.13b	25.86bc	0.96c	4.32b	3.52b	0.05	0.04b	8.89b	86.16a
33	5.3bc	0.02b	0.50bc	12.20b	24.4a	26.31b	1.12b	3.80c	2.88c	0.07	0.05b	7.92bc	86.71a
35	5.2c	0.02b	0.40cd	9.20c	23.0bc	26.97b	0.80c	4.32b	2.4b	0.05	0.05b	7.62bc	90.12a
36	5.3bc	0.01b	0.50b	11.0bc	22.0c	25.97c	0.96c	8.64a	7.2a	0.06	0.03b	16.89a	94.32a
37	5.3bc	0.01b	0.60ab	14.4a	24.0a	27.64a	1.12b	4.56b	3.60b	0.06	0.06b	9.40b	84.25a
CV (%)	**3.48**	**40**	**17.91**	**17.74**	**3.87**	**10.35**	**87.17**	**47.99**	**56.63**	**1.69**	**25**	**39.11**	**9.25**

Means followed by different letter along the column within the soil layer are significantly (P =.05) different.
ns = not significantly different; CV= coefficient of variation; EC = electrical conductivity, TN = total nitrogen, AV.P available phosphorus, EA = exchange acidity, BS = base saturation, ECEC = effective cation exchange capacity

3.4.4 Effective cation exchange capacity (ECEC) and percentage base saturation (BS)

The ECEC of the soil increased after burning with the mean of 10.37 cmolkg^{-1} compared to 8.40 cmolkg^{-1} in the unburnt plot. This increase however was not significant (P=.05). This could be ascribed to the vegetation burning despite the fact that ash in the burnt biomass

* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or dennis.edem@gmail.com

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was not added or incorporated into the soil before sampling. The percentage base saturation significantly increased with the mean of 86.68% after burning and 61.67% before burning.

3.5 Paired Samples test for physical and chemical properties of pre and post-burn soils

The results of this study (Table 3) indicate a clear distinction of pair differences between soil properties of burnt and unburnt soils. Sand content was 8.52% higher in post-burnt plot than pre-burnt plot (37.28 g/kg). For silt, it was 65.75% (31.27 g/kg) higher in pre-burnt plot then post burnt plot while clay was 30.26% (4.51 g/kg) higher in pre-burnt plot than post burnt plot and saturated hydraulic conductivity had a percent mean difference of 121% (3.93 cm/hr) in post-burnt plot than pre-burnt plot. The major determining factor s for saturated hydraulic conductivity is the degree of disturbance to the surface of the soil by fire, which is usually organic debris that protects the underlying mineral soil (Valzano et al., (1997). But for bulk density, a percent change was only 5.03% (0.02 g/cm^3) higher in post-burnt soils than pre-burnt soil and total porosity had a percent mean difference of 10.83% (3.90 cm^3/cm^3) higher in pre-burnt soil than post-burnt soil while that of moisture content was 210 % (5.38 cm^3/cm^3) in post-burnt soil than pre-burnt soil. According to National Wildfire Coordinating Group (2001), fire can either reduce or increase soil moisture content. It all depends on the distribution of pore sizes higher after the imposed treatment.

Soil pH was 9.25% (0.51) higher in pre-burnt soil than post-burnt soil but electrical conductivity had 100% change from pre-burnt plots (0.02 dSm^{-1}) while total nitrogen had a percent mean difference of 86% (0.31 g/kg) higher in post-burnt soil that pre-burnt soil. For available phosphorus, it was 4.55% (1.20 cmolkg^{-1}) higher in pre-burnt soil than post-burnt soil and calcium was 59% (1.86 cmolkg^{-1}) higher in post-burnt soil than pre-burnt soil. Magnesium was 110% (2.05 cmolkg^{-1}) higher in post-burnt soil than in pre-burnt soil. Potassium content did not change after passage of fire (0.001 cmolkg^{-1}). But for sodium, percent change was only 25% (0.007 cmolkg^{-1}) higher in pre-burnt plot than post-burnt plot. Paired difference for exchange acidity was 192% (2.24 cmolkg^{-1}) higher in pre-burnt plot than post-burnt plot. While effective cation exchange capacity was 14.69% (1.97 cmolkg^{-1}) higher in post-burnt plot than pre-burnt plot. But for organic carbon, percent change was 69% (6.50 g/kg) higher in post-burnt plot than pre-burnt plot and base saturation had a percent mean difference of 40.55% (25.00%) higher in post-burnt soil than pre-burnt soil. Fire significantly increased the concentration of non combustible elements (such as Ca^{++}, Mg^{++}, K^{++}) , hence increased the fertility status of the soil.

* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or dennis.edem@gmail.com

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3.6 Thermal effect on soil physical properties

As shown in Table 2, fire increased the soil temperature from 24^0C (control) to 60^0C in both surface and sub-surface soil layer. Sand content in the soil surface layer increased to 861 gkg^{-1} at temperature of 58^0C from 821.00 gkg^{-1} when the initial temperature rise was 35^0C. Whereas in the sub-surface layer, sand content increased to 781.00 gkg^{-1} at 37^0C from 761 gkg^{-1} when the initial temperature rise was 25^0C. At the initial temperature rise of 35^0C, the silt content was 47.20 gkg^{-1} and increased to 67.20 gkg^{-1} at 58^0C in the surface soil. In the sub-surface soil, silt content equally increased to 67.20 gkg^{-1} at 36^0C from 27.20 gkg^{-1} when the initial temperature rise was 25^oC. The increased temperature caused marked variations of the soil physical parameters. Particle-size-distribution showed a continuous increase of sand fraction with the increasing temperature, corresponding to a significant decrease of clay fraction at temperature above 49^oC However, the silt content in surface layer was irregularly distributed but significantly reduced at sub-surface soil as the temperature increased. Thus the soil would continue to be classified as loamy sand up to 60^oC.

K_s increased in the surface layer to 20.70 $cmhr^{-1}$ at 50^0C from 1.80 $cmhr^{-1}$ when the initial temperature rise was 35^0C. Where as in the sub-surface, saturated hydraulic conductivity increased to 3.60 cm/hr at temperature of 30^0C from 2.40 cm/hr when the initial temperature rise was 25^0C. At the initial temperature rise of 35^0C, bulk density was 1.75 gcm^{-3} but increased to 1.76 gcm^{-3} at 58^0C in the soil surface whereas, in the sub-surface soil, bulk density increased to 1.75 gcm^{-3} at 33^0C from 1.64 gcm^3 when the initial temperature rise was 25^0C. At the initial temperature rise of 35^0C, total porosity was 34.00 cm^3 cm^{-3} but increased to 57.00 cm^3 cm^{-3} at 30^0C and 35^0C from 36.00 cm^3 cm^{-3} when the initial temperature was 25^0C. The average density values reported in literature (Hillel, 1980) for organic and mineral soils (average) are 1.3 g/cm3 and 2.65 g/cm3 respectively. Therefore, increases in bulk density after fire is considered attributable to an increased contribution, weighted according to their volume fraction of minerals characterized by higher density.

At temperature of 60^0C, moisture content increase to 7.37 cm^3 cm^{-3} from 3. 14 cm^3 cm^{-3} when the initial temperature rise was 35^0C in the surface soil. In the sub-surface soil, moisture content increased to 8.49 cm^3 cm^{-3} at 37^0C from 2.95 cm^3 cm^{-3} when the initial temperature rise was 25^0C. Heat transfer in the soil occurs mainly by thermal conduction, and the conductivity increases with the moisture content (Edem et al., 2012). Thus, heating dry soil should cause a greater rise in surface temperature, but less heat penetration

* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or dennis.edem@gmail.com

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compared with moist soil. If we consider the percentage decrease of the moisture content, we note that at lower temperature, from 48^{o}C up to 58^{o}C, the decrease ranges between 31.5 and 29. 5 %, whereas at higher temperature, 60^{o}C, it reaches the value of 73.7 %.   In the surface soils, highest content of sand, silt, clay and saturated hydraulic conductivity change was noticed at 58^{0}C and 49^{0}C whereas the least change in bulk density, total porosity and moisture content was observed at 60^{0}C, 58^{0}C and 50^{0}C respectively. In the sub-surface soil, highest content of sand, clay and saturated hydraulic conductivity changes was noticed at 30^{0}C, 25^{0}C, and 33^{0}C whereas the least change in silt, bulk density, total porosity, and moisture content was observed at 25^{0}C, 36^{0}C and 37^{0}C. Overall, the most varied physical property at the soil surface was total porosity (CV = 37.74%) and the least varied was sand (CV = 5.16%). In the sub-surface layer, the must varied physical property was silt (CV = 42. 17%) while the least varied was sand (CV = 7.63%).

3.7 Thermal effects on soil chemical properties

The thermal effect on soil chemical properties of both surface and sub-surface soil are presented in Table 3. Following burning, different temperatures were measured at surface and sub-surface soil layers. In the surface layer, the temperatures were 35^{0}C, 40^{0}C, 49^{0}C, 50^{0}C, 58^{0}C and 60^{0}C while the temperatures for sub-surface soil were 25^{0}C, 30^{0}C, 33^{0}C and 37^{0}C.

Soil pH (Table 3) decreased with increasing temperature up to 60^{o}C. this was probably due to the lowering he buffer action associated with denaturing of the colloids and the combustion of organic matter. The successive increase between 35^{o}C and 40^{o}C is probably attributable to the loss of OH groups resulting from the denaturing of clay mineral (Giovannini et al., 1990). At 24^{0}C electrical conductivity was 0.03 dSm^{-1}, however, electrical conductivity was irregularly distributed as temperature increased in the surface soil. But in the sub-surface layer, electrical conductivity decreased to 0.01 dSm^{-1} at heating temperature of 36^{0}C, and 37^{0}C from 0.0 2 dSm^{-1} when the initial temperature rise was 25^{0}C.

Relative highest value of total nitrogen (0.80gkg^{1}) was noticed at 35^{0}C, 40^{0}C, 48^{0}C, 50^{0}C and 58^{0}C in the surface soil whereas in the sub-soil, high value of total nitrogen (0.70 gkg^{-1}) was noticed only at 30^{0}C. Was it a matter of compensation between the decrease caused by volatilization in the sub-surface layer or is the soil N not affected by increase heating? At this time we are unable to account for the balance between the outputs and inputs of N.

* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or dennis.edem@gmail.com

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At the initial temperature of 35^{0}C, the content of available phosphorus was 30.97 mgkg^{-1} but decreased to 29.80 mgkg^{-1} at 49^{0}C. At the sub-surface soil, available phosphorus increased to 27.64 mgkg^{-1} at 30^{0}C from 25.97 mgkg^{-1} when the initial temperature rise was 25^{0}C. Increased in available P with temperature increase at subsurface layer, confirming the report of Giovannini et al., (1990) that the available phosphorus is the outcome of the mineralization process of organic phosphorus.

At the surface soil, highest calcium content (9.12 cmolkg^{-1}) was observed at 35^{0}C and 60^{0}C. whereas at the sub-surface soil, calcium increase to 8.64 cmolkg^{-1} at 36^{0}C from 2.40 cmolkg^{-1} at initial temperature of 25^{0}C . At the sub-face soil calcium increase to 8. 64 cmolkg^{-1} at 36^{0}C from 2.40 cmolkg^{-1} at initial temperature of 25^{0}C. At the soil surface, highest magnesium content (7.68 cmolkg^{-1}) was observed at 35^{0}C and 60^{0}C whereas at the sub-surface soil Mg increased to 7.20 cmolkg^{-1} at 36^{0}C from 1.14 cmolkg^{-1} at initial temperature of 25^{0}C. Potassium increased to 0.08 cmolkg^{-1} at 35^{0}C and 0.05 cmolkg^{-1} at 40^{0}C at the surface soil, whereas at the sub-surface soil, K increased to 0.07 cmolkg^{-1} at 33^{0}C from 0.06 cmolkg^{-1} at initial temperature rise of 25^{0}C. Sodium decreased in the surface layer to 0.06 cmolkg^{-1} at 48^{0}C from 0.04 cmolkg^{-1} when the initial temperature rise was 35^{o}C whereas at the sub-surface soil, Na increased to 0.06 cmolkg^{-1} at 37^{0}C from 0.04 cmolkg^{-1} from the initial temperature rise of 25^{0}C.

Exchange acidity increased to 5.12 cmolkg^{-1} at 40^{0}C from 0.80 cmolkg^{-1} at initial temperature of 25^{0}C at the surface soil but at the sub-surface, exchange acidity decreased to 1.12 cmolkg^{-1} at 33^{0}C and 36^{0}C, from 1.60 cmolkg^{-1} when the initial temperature rise was 25^{0}C. Effective cation exchange capacity increased to 17.71 cmolkg^{-1} at 60^{0}C from 17.70 cmolkg^{-1} when the initial temperature rise was 35^{0}C at the surface soil. At the sub-surface soil, effective cation exchange capacity increased to 16.89 cmolkg^{-1} at 36^{0}C from 5.54 cmolkg^{-1} when the initial temperature rise was 25^{0}C.

At the surface soil, organic carbon increased to 19.20 gkg^{-1} at 48^{0}C from 18.90 gkg^{-1} at the initial temperature of 35^{0}C whereas, at the sub-surface soil, organic carbon increased to 15.26 gkg^{-1} at 30^{0}C from 13.20 gkg^{-1} at initial temperature of 25^{0}C. Whereas, base saturation increased to 95.48% at 35^{0}C from 95.40% when the initial temperature rise was 35^{0}C whereas at the sub-surface, base saturation increase to 94.32% at 36^{0}C from 71.12% at the initial temperature of 25^{0}C. C:N ratio increased to 24.57 at 60^{0}C from 23.63 when the initial temperature rise was 35^{0}C at the surface layer. At the sub-surface soil layer, C:N ratio increased to 24.40 at 33^{0}C from 22.00 when initial temperature rise was 25^{0}C. Despite pronounced variability in soil chemical properties at different heat intensity , the most varied

* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or dennis.edem@gmail.com

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chemical property of the soil at the surface was electrical conductivity (CV = 75.00%) while the least varied was pH (CV =2.63%). In the sub-surface soil, the most varied chemical property was exchange acidity (CV = 87.17%) while the least varied was potassium (CV = 1.69%).

3.8 Correlation of heating temperatures, and depth with soil properties

As summarized in Table 4, the correlation of heating temperatures and depths with soil properties in the pre-burnt and burnt plots of arable field revealed that, clay, 1mm, 0.5 mm stable aggregate and organic carbon relates positively and highly significant (*P*=0.05) with depth in the burnt plots (r = 0.648 **, 0.718**, 0.712**, 0.840* respectively). This implies that these parameters increase with corresponding increase in depth. But total nitrogen stock, sand, saturated hydraulic conductivity, total nitrogen, soil carbon stock, pH and electrical conductivity correlated negatively and highly significant with soil depth (r = -0.617**. -0.656**. -0.478*, -0.753**, -0.697**, -0.835**, -0.544* respectively). Therefore, increase in soil depth decreased the concentration of these soil parameters (acidity increases) under burnt condition. While significant, the high coefficient of determination indicates that most of the variability noticed in the burnt plots could be explained by the measured parameters.

Temperature differences affect sand, total nitrogen, organic carbon and pH contents of the soils positively (r = 0.518* 0.478*, 0.582*, 0.595** respectively), whereas a reduction in the soil temperature increased the concentrations of clay, 1mm, 0.05mm and 0.25 mm stable soil aggregates in the soil (r = -0.619**, -0.578*, -0.780, -0.526* respectively) after burning. Thus, based on the correlation results, soil management in burnt plot based on soil aggregates of 1 mm, 0.05mm 0.25 m and Total N, organic C, and pH fertility would lead to better management decisions.

Under pre-burnt condition, depth correlates positively and significantly with clay, bulk density, 1 mm and 0.5mm stable soil aggregates to water (r = 0.481*, 0.636**, 0.773* and 0.820** respectively). This means that as the soil depth increase, clay, bulk density, 1 mm and 0.5mm water stable aggregate also increases. As expected, sand, saturated hydraulic conductivity and total porosity decreased with an increase in depth (r = -0.542*, 0.673**,and -0.643** respectively) in the un-burnt plots. This shows that increase in soil depth decrease sand fraction, K_s and total porosity. The negative relationships is attributable to tortuosity pore configuration down the profile.

* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or dennis.edem@gmail.com

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Table 4: Significantly Related Soil Properties with Depth and Temperature in the Burnt and Pre-burnt soils .

Treatments	Depth	Temperature
Post-Burnt	TN (r = -0.617**)	Sand (r = 0.518*)
	WSA 0.5 (r = 0.820**)	Clay (r = -0.619**)
	Clay (r = 0.648**)	WSA 1 (r = -0.578*)
	Ks(r = -0.478*)	WSA0.5 (r = -0.780**)
	WSA1mm (r = 0.718**)	WSA0.25 (r = -0.526*)
	WSA0.5mm (r = 0.712**)	TN (r = 0.478*)
	TNS (r = - 0.753**)	OC (r = 0.582*)
	OC (r = 0.840**)	pH (r = 0. 595 **)
	SCS (r = -0.697**)	
	pH (r= - 0.835**)	
	EC (r = -0.544*)	
Pre burnt	Clay (r= 0.481*)	
	Ks(r= -0.673**)	
	BD (r= 0.636 **)	
	P (r= -0.643 **)	
	WSA1 (r= 0.773**)	

** Correlation is significant at the 0.01 level.
*Correlation is significant at the 0.05 level.

4. CONCLUSION

Burning results in changes in soil temperature, soil moisture and nutrient availability. Fire significantly affects soil properties due to rapidly combusted organic matter on the soil surface. The Organic matter acts as the primary reservoir for several nutrients, stable aggregates and infiltration. Also, this may reduce the resistance of the soil to erosion due to tensile cracks and excess pore-water associated with burning during the first down pour. However, this research has shown that there is immediate increase in plant nutrients due to the release of occluded minerals after burning, but sure consequences of repeated vegetation burning might be detrimental to soil health.

* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or dennis.edem@gmail.com

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5. RECOMMENDATIONS FOR FUTURE RESEARCH

The results of this study indicate the need for a review of the method of land clearing for sustainable agricultural production. Therefore, sequential soil samplings should be carried out after slash-and-burn land clearing say, monthly for six growing seasons, to assess further changes in the soil quality attributes.

ACKNOWLEDGMENTS

We thank Miss. Ndifreke Etim, an undergraduate student working on Agricultural burning project based at University of Uyo. We thank Mr. Idongesit Ambrose, a staff of Akwa Ibom State Ministry of Environment and BGI-resources LTD. Laboratory staff Port Harcourt, for access to facilities to complete soil sample analyses. We acknowledge support from the Department of Soil Science, University of Uyo for providing the experimental site for this study and the anonymous reviewers for their useful contributions.

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* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or dennis.edem@gmail.com

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* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or
dennis.edem@gmail.com

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* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or dennis.edem@gmail.com

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* Tel.: *+234-8027031426*
*Corresponding author's E-mail address: *inidennis117@yahoo.com* or dennis.edem@gmail.com

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