***Original research paper**

Soil Properties Dynamics at Varying Heating Temperatures during Agricultural burning

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Abstract

Characteristics of an ecosystem are altered both as sudden modifications induced by the passage of the fire and the delayed changes derived from the simultaneous modifications of various soil physical and chemical parameters. 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 determining changes in the soil physico-chemical parameters at varying heating temperatures. Core and bulk samples from the burned and adjacent unburned plots (control) were collected for physico-chemical analysis. These induced temperatures were highly variable on the soil surface. Though aggregates formation was significantly higher after burning than the control soil locations, this soil will easily be distressed with the least application of force. The pH decreased to 5.4 at higher temperatures following burning before ashes mineralized. However, both organic matter and ECEC increased at increasing soil temperature. Potassium content remained surprisingly constant as the soil temperature increased. Despite the merits of quick release of occluded nutrients, heating temperatures of slash-and-burn method of land clearing altered soil quality attributes.

Key words: Slash-and- burn; traditional farming; soil quality; modification; temperature

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, the balance between trees and grasses, stand structure and dynamics, and shrub cover and abundance is determined to a large extent by fire frequencies and interactions between fire and other disturbance factor such as tillage equipment and tillage methods (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 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). Most research assesses change in on organic carbon due to bush burning. So far, 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 are to assess (i) changes in soil physical conditions at varying fire temperature and (ii) thefire temperature within which soil quality attributes are depleted.

Materials and methods

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 40^0 $30^'$ 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 [5]. In the area measuring 720 m^2 on a slope of 7 %, we prepared 10 sub plots; each 24 x 3 m^2 , separated from each other by fireproof tracts

In preparing the plots, we imposed 50, 100, and 150 kg/m^2 of the dry biomass on the cleared plots inorder to produce three levels of fire intensities, and progressively fire was set into 9 out of the 10 plots.

Pre-and-post burnt soil samplings

Profile pits (50 cm depth) were dug at the centre of each plot. 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)

Experimental measurement and statistical analyses

Immediately after the fire, infrared thermometer and temperature sensor were used to measure soil temperature at the surface and subsurface soil respectively. The experiment consisted of two treatments (burned and un-burned plots) arranged in a RCBD with three replicates. The data obtained were statistically analyzed for variance (ANOVA), and significant means were compared using Fisher's least significant difference ($LSD_{0.05}$). 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.

Results and Discussion

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.

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 greater than the unburnt plot with the mean value of 772.60 gkg^{-1} but was not statistically significant ($p > 0.05$) .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 ($p > 0.05$). 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 (>400^0C) may permanently alter soil texture by aggregating clay particles into stable san-sized particle making the soil texture more coarse and erodible (Chandler et al., 1983)

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 ($p>0.05$). This observation agreed with the earlier report at Indonesia, an increase in bulk density after slash and burn and ascribed it to the disruption of soil aggregation and loss of organic matter (Klemmedson et al., 1952). 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. 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.

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

A significant increase with the mean of 7.23 cm/hr for K_s in the burnt plot was observed compared to the unburnt plot having a mean of 3.30 cm/hr (p> 0.05). 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 (Ruddiman, 2005). The textural characteristics, organic matter content, structure 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 Mallik et al., (1984) who reported an increase in water retained after burning. The increased in volumetric moisture content in this study however contradict with Edem et *al*., (2012) 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.

Changes in soil chemical properties following burning.

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<0.05). 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<0.05). 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.

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 ($P<0.05$) 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 ($P > 0.05$). 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.

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 ($p<0.05$) 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 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.

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 ($P<0.05$). This could be ascribed to the vegetation burning despite the fact that ash in the burnt biomass 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.

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) higher 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 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.

Thermal effect on soil physical properties

As shown in Table 2, fire increased the soil temperature from 24^{0}C (control) to 60^{0}C in both surface and sub-surface soil layer. Sand content in the soil surface layer increased to 861 gkg^{-1} at temperature of 58^{0}C from 821.00 gkg^{-1} when the initial temperature rise was 35^{0}C. Whereas in the sub-surface layer, sand content increased to 781.00 gkg^{-1} at 37^{0}C from 761 gkg^{-1} when the initial temperature rise was 25^{0}C. At the initial temperature rise of 35^{0}C, the silt content was 47.20 gkg^{-1} and increased to 67.20 gkg^{-1} at 58^{0}C in the surface soil. In the sub-surface soil, silt content equally increased to 67.20 gkg^{-1} at 36^{0}C from 27.20 gkg^{-1} when the initial temperature rise was 25^{o}C. However, the silt content in both surface and sub-surface layer was irregularly distributed as the temperature increased.

At temperature of 49^{0}C the clay content increased to 151.80 gkg^{-1} from 131.80 gkg^{-1} when the initial temperature rise was 35^{0}C in the surface soil where as in the sub-surface, clay content increased to 191.80 gkg^{-1} at 33^{0}C from 171.80 gkg^{-1} when the initial temperature rise was 25^{0}C. K_s increased in the surface layer to 20.70 cmhr^{-1} at 50^{0}C from 1.80 cmhr^{-1} when the initial temperature rise was 35^{0}C. Where as in the sub-surface, saturated hydraulic conductivity increased to 3.60 cm/hr at temperature of 30^{0}C from 2.40 cm/hr when the initial temperature rise was 25^{0}C. At the initial temperature rise of 35^{0}C, bulk density was 1.75 gcm^{-3} but increased to 1.76 gcm^{-3} at 58^{0}C in the soil surface whereas, in the sub-surface soil, bulk density increased to 1.75 gcm^{-3} at 33^{0}C from 1.64 gcm^3 when the initial temperature rise was 25^{0}C. At the initial temperature rise of 35^{0}C, total porosity was 34.00 cm^3 cm^{-3} but increased to 57.00 cm^3 cm^{-3} at 30^{0}C and 35^{0}C from 36.00 cm^3 cm^{-3} when the initial temperature was 25^{0}C. At temperature of 60^{0}C, moisture content increase to 7.37 cm^3 cm^{-3} from 3. 14 cm^3 cm^{-3} when the initial temperature rise was 35^{0}C in the surface soil. In the sub-surface soil, moisture content increased to 8.49 cm^3 cm^{-3} at 37^{0}C from 2.95 cm^3 cm^{-3} when the initial temperature rise was 25^{0}C. 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 30^0C, 25^0C, and 33^0C whereas the least change in silt, bulk density, total porosity, and moisture content was observed at 25^0C, 36^0C and 37^0C. 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%).

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 35^0C, 40^0C, 49^0C, 50^0C, 58^0C and 60^0C while the temperatures for sub-surface soil were 25^0C, 30^0C, 33^0C and 37^0C.

At 24^0C 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 36^0C, and 37^0C from 0.0 2 dSm^{-1} when the initial temperature rise was 25^0C. Relative highest value of total nitrogen (0.80gkg^{1}) was noticed at 35^0C, 40^0C, 48^0C, 50^0C and 58^0C in the surface soil whereas in the sub-soil, high value of total nitrogen (0.70 gkg^{-1}) was noticed at 30^0C

At the initial temperature of 35^0C, the content of available phosphorus was 30.97 mgkg^{-1} but decreased to 29.80 mgkg^{-1} at 49^0C. At the sub-surface soil, available phosphorus increased to 27.64 mgkg^{-1} at 30^0C from 25.97 mgkg^{-1} when the initial temperature rise was 25^0C. At the surface soil, highest calcium content (9.12 cmolkg^{-1}) was observed at 35^0C and 60^0C. whereas at the sub-surface soil, calcium increase to 8.64 cmolkg^{-1} at 36^0C from 2.40 cmolkg^{-1} at initial temperature of 25^0C

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

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.

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.

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.

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.

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 four growing seasons, to assess further changes in the soil quality attributes.

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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^3cm^{-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 the same letter along the rows are not significantly different ($p > 0.05$)

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

Heating temp. ^{0}C	Sand	Silt (gkg^{-1})	Clay	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□ mm
				Surface soil layer					
24(control)	802.44	76.48	121.07	5.78	1.50	43.00	2.59	7.79	0.41
35	821.00	47.20	131.80	1.80	1.75	34.00	3.14	9.88	0.53
40	821.00	47.20	131.80	8.40	1.65	38.00	3.47	11.02	0.58
48	841.00	47.20	111.80	19.80	1.50	57.00	3.15	10.07	0.57
49	831.00	57.20	151.80	11.70	1.53	42.00	3.07	9.69	0.58
50	851.00	50.70	111.80	20.70	1.45	45.00	2.77	8.55	0.51
58	861.00	67.20	71.80	3.60	1.76	32.00	2.95	8.17	0.55
60	821.00	47.20	111.80	5.40	1.40	37.51	7.37	8.55	0.53
CV(%)	**5.16**	**30.26**	**25.71**	**12.27**	**20.70**	**37.75**	**18.31**	**-**	**-**
				Sub-surface soil layer					
24(control)	741.88	85.53	172.97	0.80	1.67	36.00	2.46	7.96	0.43
25	761.00	27.20	171.80	2.40	1.64	36.00	2.95	7.60	0.45
30	721.00	40.53	138.46	3.60	1.60	39.00	3.03	10.07	0.50
33	761.00	47.20	191.80	1.80	1.75	38.00	2.97	10.45	0.42
35	721.00	47.20	171.80	1.80	1.65	39.00	3.14	11.35	0.53
36	761.00	67.20	171.80	3.00	1.50	36.00	2.79	10.0	0.45
37	781.00	37.20	181.80	3.30	1.62	34.00	8.49	9.56	0.55
CV (%)	**7.63**	**42.60**	**35.17**	**11.57**	**8.17**	**12.48**	**15.68**	**-**	**-**

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

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

Temp ^{0}C	pH	EC dSm^{-1}	TN	OC	C:N	AV. P	EA	Ca	Mg	K	Na	ECEC	BS %
			gkg^{-1}			$mgkg^{-1}$		$cmolkg^{-1}$					
						Surface soil							
(control 24	5.9	0.03	0.40	10.67	24.07	27.42	2.68	2.96	1.9	0.05	0.54	7.26	63.27
35	5.3	0.02	0.60	14.05	23.63	28.97	0.80	6.72	5.04	0.06	0.04	14.09	92.76
40	5.9	0.03	0.80	18.80	23.50	25.64	5.12	6.72	5.28	0.08	0.05	17.25	70.32
48	5.5	0.02	0.80	19.20	24.00	25.97	1.12	2.88	2.4	0.06	0.06	6.53	82.85
49	5.6	0.03	0.70	17.05	24.35	29.8	0.88	5.76	4.8	0.06	0.04	11.55	92.13
50	5.5	0.03	0.80	19.05	23.81	23.31	0.56	2.88	1.92	0.06	0.04	5.63	87.37
58	5.6	0.02	0.80	17.80	22.25	25.64	0.80	3.36	2.4	0.04	0.04	6.66	87/99
60	5.6	0.01	0.70	17.20	24.57	25.64	0.80	9.12	7.68	0.05	0.05	17.71	95.48
Cv(%)	**2.6**	**75**	**36.11**	**36.38**	**14.7**	**14.87**	**54.09**	**29.8**	**24.73**	**5.17**	**9.43**	**26.66**	**16.66**
						Subsurface soil							
(control)24	5.9	0.05	0.31	8.1	23.5	28.14	3.42	3.14	1.86	0.05	0.54	8.71	62.47
25	5.5	0.02	0.6	13.2	22	25.97	1.6	2.4	1.14	0.06	0.04	5.54	71.12
30	5.2	0.02	0.7	15.26	23.13	25.86	0.96	4.32	3.52	0.05	0.04	9.11	86.16
33	5.3	0.02	0.5	12.2	24.4	26.31	1.12	3.8	2.88	0.07	0.05	8.43	86.71
35	5.2	0.02	0.4	9.2	23	26.97	0.8	4.32	2.4	0.05	0.05	10.49	90.12
36	5.3	0.01	0.5	11	22	25.97	0.96	8.64	7.2	0.06	0.03	16.89	94.32
37	5.3	0.01	0.6	14.4	24	27.64	1.12	4.56	3.6	0.06	0.06	8.19	84.25
Cv(%)	**3.48**	**40**	**17.91**	**17.74**	**3.87**	**10.35**	**87.17**	**47.99**	**56.63**	**1.69**	**25**	**46.38**	**9.25**

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.