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Effects of biomass burning on soil properties and air quality under slash-and-burn agriculture

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ABSTRACT

Changes in soil properties, soil organic C (SOC) and total nitrogen (TN) stocks associated with different heating temperatures from 50, 100, and 150 kg/m^2 dry biomass that provided for different heat intensities were compared with natural soil temperature of arable land adjacent to the burnt plots. Soil samples were collected in three replicates from control and burnt plots and soil temperatures were measured with soil thermometer placed at surface and sub-surface layers, while gas emissions were measured with sensitive gas dictators. The induced temperatures were highly variable at the soil surface whereas below 15cm depth, the temperature rise was not more than 37^{0}C. Modifications of various soil physico-chemical parameters caused by fire were related to increasing temperatures. The passage of fire promoted SOC and TN stocks, mean weight diameter, the aggregation of 2 mm stable structures which become even more resistant to disrupting action of water. 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. Air quality measurement revealed that NO_2, SO_2 H_2S and CO_2 were above the limits indicating air pollution through these activities. Despite the merits of quick release of occluded nutrients, heating temperatures of slash-and-burn method of land clearing altered soil and air quality.

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 and deforestation have alter the atmosphere's composition and earth balance. The invention of deliberate fire ignition and its control by man started the anthropogenic modification of biosphere [14]. Fire has long been recognized as a disturbance that maintains grasslands and savannas and prevents invasion of woody species [1,2, 23]. 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 [5, 13, 19, 20]. 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 [3, 7, 12, 15, 16],.

Most land that is left unused in a cropping year is often set on fire by farmers. This is common with the livestock farmers, for the animals to browse on young plants that grow after burning. Before the plants come up to cover the ground surface, the soil is exposed to climatic element of rainfall. Subsequently, soil aggregates are dispersed; pores are clogged with particles and further result in much higher rates of surface runoff [11]. 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 [21]. More severe burns may alter such fundamental characteristics as texture, mineralogy and cation-exchange capacity [8].

Atmospheric concentration of several green house gases (GHGs) has changed drastically since the industrial revolution because of biomass burning and other factors like bush burning and fossil fuel combustion. The concentration of CO_2 responsible for 62% of the total radiative forcing by earth has increased by 35% from 280% around 1750 to 377% in 2006[24]. The concentration of methane (CH_4), responsible for 20% of the radiative forcing of the earth, has also increased by 155% from about 700 ppb around 1750 to 1785 ppb in 2004. the atmospheric concentration of nitrous oxide (N_2O), responsible for about 6% of the radiative forcing of the earth has increased by 18% from about 270 ppb around 1750 to 318.6 ppb in 2004 [23]. According to Ruddiman [20,21], soil cultivation is not as obvious a source of atmospheric CO_2 as are fossil fuel combustion, deforestation, and biomass burning. Yet world soils have been a dominant source of CO_2 ever since the dawn of settled agriculture[7].

Despite these challenges, a number of countries have successfully implemented soil emission inventories and several others including Nigeria are in the process of joining the crusade

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of climate change with little or no computational data base tailored to this global circumstance. To facilitate this, a default approach with the advantages of having a reliable simple structure as well as providing default emission measure was develop in continuous arable land of humid tropics of Uyo to detect gas emission bush burning. This work aimed at assessing the effects of this method on air quality and soil properties. However with simplification there are tradeoffs in the form of increase uncertainty, particularly with the application of digital gas dictator. Inherent, globally averaged emission factors will be subjected to error when applied to a particular country having conditions different from the global mean[7]. In addition, global defaults for soil processes are likely biased in that most of the data in their derivation are from temperate regions, where the preponderance of the field research has been done. Hence, tropical conditions are often under represented. This research will help to develop country-specific approaches and improve estimates of soil derived emissions

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 or rainy 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 evidenced of high leaching and erosion associated with slope and rainfall factors in the area [5]. The experiment was established in 2009 with the initial goals of analyzing effect of heating temperatures on soil properties and determining changes in soil characteristics and crop growth that could be associated with yield differences. Later in 2010 effort was made to measure the emission of some gases during burning exercise. A plot of land measuring 720 m^2 on a slope of 7 % was selected and cleared for the study.

A total of six plots each measuring 40 x 3 m^2 were cleared, pegged, and the trash was left on the ground for two weeks to dry. 50, 100, and 150 kg/m^2 of the dry biomass was measured using measuring scale and was imposed on the respective replicated plots to produce three levels of fire intensities, and progressively fire was set into three out of the six plots.

Pre-and-post burnt soil samplings

Nine mini-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[4].

Performance of experimental fires, thermal results and detection of emitted gases

The experimental fire with measured dry biomass was performed at the end of August 2010. Winds were calm and air temperature was ± 24^0C and relative humidity 80%. The maximum temperatures reached during the fires were recorded by means of soil thermometer, while the gas fluxes were measure with portable sensitive gas dictators.

Experimental design and statistical analysis

The experiment consist 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 and validated using SPSS 17.0. Pearson correlation coefficients were used to assess the degree of relationships among variables. Regression equations were used to assess the temporal changes in SOC & TNS pools for each soil depth[15], and temperature differences considering the un-burnt plots as base line or reference point. The rates of SOC stock were calculated by determining the slope of the regression line (dy/dx) for each depth for the 50, 100 and 150 kg/m^2 (treatments). Statistical significance was computed at $P \leq 0.05$ and $P \leq 0.01$ respectively.

Results and Discussion

Some physical 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}. 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 and others that soil texture is a fundamental attribute of the soil and cannot easily alter by management practices[5].

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[9]. Total porosity decreased after burning with the mean of 35.98% compared to 39.88% before burning but was not statistically different ($p > 0.05$). This observation is in consonance with [11], [17] 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.

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 1997. The authors found that K_s of soil decreased approximately 50% in the burnt plots relative to adjacent unburned plots[21]. 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 [11] who reported an increase in water retained after burning. The increased in volumetric moisture content in this study however contradict with [6] 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 are presented in Table 2.

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 ($p<0.05$). The observation is contrary to the finding at Chile, an increased in pH following burning in Chile[4]. 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 ($P<0.05$). The reduction of pH and EC after burning can be ascribed to lack of mineralization of Ca CO_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 [10,11,12]; 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 [15] 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 [14, 22] 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 $cmolkg^{-1}$ respectively compared to 3.12 and 1.86 $cmolkg^{-1}$ respectively in the unburnt plot. P content remains 0.05 $cmolkg^{-1}$. Sodium (Na) significantly ($p < 0.05$) decreased after burning with the mean of 0.04 $cmolkg^{-1}$ compared to 0.05 $cmolkg^{-1}$ before burning. The result of Ca and Mg were similar to [15] 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 [15]. 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 $cmolkg^{-1}$ compared to 3.42 $cmolkg^{-1}$ 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.

Changes in soil structural parameter following burning are presented in Table 3 .

Mean weight diameter (MWD) significantly ($P <0.05$) increased after burning with the mean of 0.46mm compared to 0.42mm in the unburnt plot. Percent water stable aggregate (WSA) for 1mm, 0.5mm and 0.25mm sizes decrease but not significant ($p>0.05$) after burning with the mean of 1.58%, 1.42% and 1.86% respectively compare to 7.63%, and 2.15% respectively before burning. However, WSA of 2 mm size increase after burning with the mean of 1.53% compared to 1.48%.The soil physical disruption in aggregate following burning was reflected in reduced aggregate size and concentration of WSA in the soils. The observation in this study agreed with that the findings of many researchers, who found a reduction in aggregate stability following burning [6, 7, 11, 12, 13]. However, it was observed in this study that lower value of WSA for 1mm, 0.5mm, 0.25mm sizes of soil aggregate after burning were primary due to considerable lower percentage of aggregate present in 1mm, 0.5mm and 0.25mm diameter size classes. The reduction in clay fraction likely accounted for the reduction in soil WSA, due to the cohesive influence of clays that reduced after burning.

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

The results of this study 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. 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. 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.

Thermal effect on soil physical properties

As shown in Table 4, soil temperature varied 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^{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 must 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%).

Soil erodibility and potential erosion hazard after burning

Values of erodibility determined by Wischmeier and Smith (1978) equation are presented in Table 4. Ironically, the erodibility values of these erosion-prone soils were generally low. This might be attributed to the low silt and very fine sand content observed in these soils. Variation of erodibility values among heating temperature is likely to be associated with differences in the intensity and heating duration, profile permeability, soil structure and percent silt and very fine sand content. Generally, erodibility increased when the soil was heated up.

The product of erodibility K and the average annual EI_{30} erosivity (data not shown) values gives the potential soil loss for a given heating temperature. The amount of soil that would lose annually when the soils are burnt, exposed to raindrop impact and the runoff after bush burning reveals that, soil loss increased with depth covering 5.2 % area immediately the top soil is removed. Generally on the average, these potential soil losses are very high on the soil surface with more or less supports widespread soil to erosion in the study site. Since the natural susceptibility of soils in the site (erodibility) is low, the high potential soil losses are directly related to high erosivity values used to multiply the erodibility values. Therefore, one is justified to conclude that widespread soil erosion in Uyo must be blame on accidental and manmade bush burning and high rainfall erosivity. This is particularly so when the area is characterized by long steep slope as is the case in some of the locations.

Thermal effects on soil chemical properties

The thermal effect on soil chemical properties of both surface and sub-surface soil are presented in Table 5. 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.

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 at 30^{0}C

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. 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.

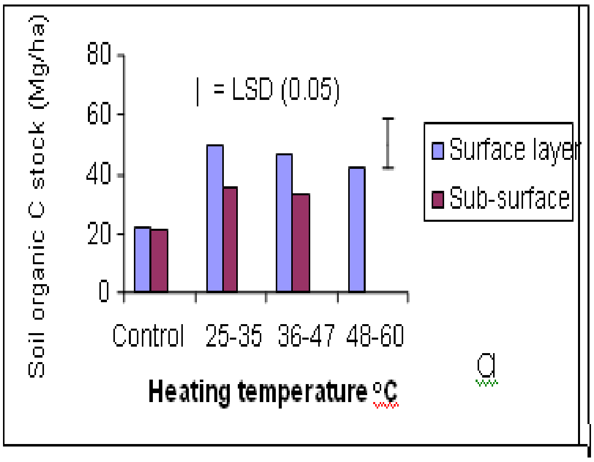
Whereas, base saturation increased to 95.48% at 35^{0}C from 95.40% when the initial temperature rise was 35^{0}C whereas at the sub-surface, base saturation increase to 94.32% at 36^{0}C from 71.12% at the initial temperature of 25^{0}C. C:N ratio increased to 24.57 at 60^{0}C from 23.63 when the initial 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 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%)

Thermal effect on soil organic carbon stock (SOCS) and total nitrogen stock (TNS).

As shown in Figure 1 (a), no significant ($p > 0.05$) change in soil organic carbon stock between the surface and sub-surface layers, but soil organic carbon stock was significantly ($p<0.05$) higher at heating temperature between 25-47^{0}C in surface layer than sub-surface soil. Soil organic carbon stock was completely removed from the sub-surface when the soil heating temperature increased up to 48-60^{0}C.

Figure 1(b) showed varied total nitrogen stocks (TNS) at different temperature. Control plot showed no significant ($p>0.05$) different between total nitrogen stocks in the surface and sub-surface layers. More total nitrogen content was observed on heating the soil, and the surface soil recorded significant high ($P<0.05$) total nitrogen stocks than the sub-surface soil, but none was found in the sub-surface layer when the temperature increased beyond 47^{0}C.



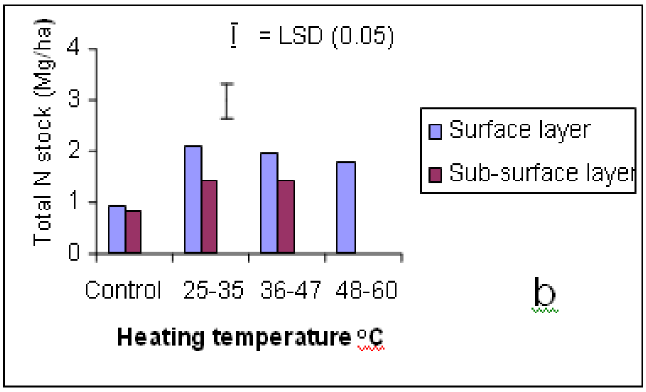


Figure 1: Soil organic C (a) and total N (b) stocks in the surface and sub-surface layers at different heating temperature

Relationships between soil properties and soil carbon stock

Step wise elimination techniques of pedotranfer function (PTF) were performed to determine the soil properties that are capable of predicting ($P<0.05$) soil carbon storage in the soil under the two treatments. The model results (Table 6) showed that all properties of the soil in the un-burnt plots were removed except total nitrogen storage (TNS), carbon/nitrogen ratio (C:N), electrical conductively (EC) and exchange acidity (EA), that were retained in the model ($P < 0.05$). The result indicated a positive relationship between soil carbon stock with TNS, C to N ratio, EC, and EA (R = 0.951, 0.985, 0.994 and 0.996 respectively). The result in the burnt plots showed that, of all the soil properties, total nitrogen (TN), saturated hydraulic conductivity (K_s), Organic carbon (OC) and clay were the only properties that significantly ($P < 0.05$) affected SOCS. The excluded soil parameters in the PTF reduced their significance ($p>0.05$) in determining soil carbon storage after burning. As TN, K_s and OC increase, soil carbon storage also increases with the following significant coefficient of determination (R = 0.892, 0.414 and 0.769 respectively), but clay had a negative relationship with SCS (R = - 0.141). That is, soil carbon stock will increase at a reduce clay content. Thus the parameters capable of predicting soil carbon storage before burning is different from those that predicts soil carbon storage after burning.

Relationship of total nitrogen stock with soil properties

In order to determine soil properties capable of affecting the storage of total nitrogen in the soil, The PTF result (Table 7) revealed that total nitrogen storage can increase by increasing soil organic carbon storage, carbon : nitrogen ratio, electrical conductivity and exchange acidity with determinant coefficients of 0.943, 0.981.0.992 and 0.996 respectively. The result further showed that all soil parameters in the burnt plats were removed except total nitrogen and saturated hydraulic conductivity (K_s), where a positive significant ($p<0.050$) relationship was observed with total nitrogen (R = 0.896) whereas, a reduction in K_s significantly ($P <0.05$) increase the concentration of total nitrogen stock in the soil (R= -0.466). Therefore, the role of total nitrogen is very important in the concentration of soil organic carbon and total nitrogen stock in arable farm land.

Correlation of heating temperatures, depth, SOC and TN stocks with soil properties

As summarized in Table 8, 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.

In the burnt plots, soil carbon stocks gave the significant positive correlations with pH, total nitrogen (TN), organic carbon (OC), total nitrogen stock (TNS) and sand (r = 0.581*, 0.892**, 0.882** 0.976**, and 0.697** respectively). This means that increase in these soil parameters increased soil carbon storage. But the reverse relationship was true for clay and 1mm water stable aggregate (r = -0.680**, and -0.722** respectively).

Some emitted gases during the passage of fire at different heating intensities

As indicated in (Table 9), the measurable gases emitted during experimental fire were NO_2, SO_2 CO, H_2S, Cl_2, NH_3 and HCN. The fluxes of NO_2 and SO_2 were the same at different heat concentration but other gasses varied. At 50 kg of biomass per square meter, the respective volume of gases emitted was 0.2, 0.2, and 23.7, 0.3, 0.5, 2.3, 0.7 mg/m^2 ground space. But for 100 kg of biomass, 0.2, 0.2, 26.7, 0.4, 0.5, 3.0 and 1.0 mg/m^2 were emitted. While for 150 kg of biomass per square meter, the volume of gases emitted was 0.3, 0.2 28.0, 0.4, 0.6, 3.3 and 1.0 mg/m^2 for NO_2, SO_2, CO, H_2S, Cl_2 NH_3 and HCN respectively. The value for these gases was above the permissive limits, indicating air pollution through these activities. Therefore despite the merits of quick release of occluded nutrients during burning, heating temperatures of slash-and-burn method of land clearing altered soil properties and air quality, and these alterations have bearing on the of sustainability of nutrients in the soil, also when the emitted gases (SO_2 and H_2S) reacts with water vapour it results in acid rain formation that increased soil acidity.

Generally, regardless of the quantity of biomass per square meter soil, CO was the most emitted gas while SO_2 was the least emitted during burning exercise. Soils in Uyo, Southern Nigeria exhibit marked differences in physical characteristics under slash and burn land use. These significant changes in soil properties in the upper 15 cm layer in the burnt plot compared with the sub-soil of the burnt plots and both layers of pre-burnt soil could be attributed to heating temperature and soil disturbances. Results of this study support the following conclusions: the release of SO_2 is not related to the quantity of biomass imposed. CO and NH_3 positively correlated with soil temperature ($p<0.05$). The contribution of the quantity of biomass burnt to emission of gases in the burnt plots evident the contribution of slash-and-burn method of land clearing to the depletion of ozone layer. Potential soil losses, the product of erodibility and erosivity were generally high after clearing and burning. Based on the foregoing conclusions, one is justified to attribute the problem of erosion in the site to burning and rainfall erosivity. Presently, soil erodibility values range from 0.85 (easily eroded) to 0.13 (less erosive).

Soil high in silt and very fine sand are easily eroded than other soils. Organic matter, larger structural aggregates, and rapid soil permeability all lessen the soil K factor. 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 failure may be attributed to tensile cracks and excess pore-water associated with burning during the first down pour, thereby reducing its resistance to the applied forces. The assessment of the land potential for general agricultural suitability revealed that, the land is suitable for common arable and tree crops under both conditions and the environment will be able to support other land uses with inferior land qualities.

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 two growing seasons, to assess further changes in the soil quality

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Table 1: Mean and standard deviation of some soil physical properties before and after experimental fire

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

* Means followed by the same letter along the rows are not significantly different ($p > 0.05$)

Table 2. Means and standard error of chemical properties of soil before and after experimental fire

Parameters	pre-burnt plot	burnt plot
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
EA, cmolkg^{-1}	3.42 ±1.85^a	1.17 ± 1.02^b
ECEC,cmolkg^{-1}	8.40 ± 2.24^a	10.37 ± 4.81^a
OC, gkg^{-1}	9.29 ± 2.98^b	15.79 ± 3.38^a
BS, %	61.67± 10.28^b	86.68± 8.02^a

- Mean followed by the same letter along the rows not significantly different ($p > 0.05$)

Table 3. Mean and standard deviation of structural parameters of pre-burnt and post -burnt plots

Parameters	Aggregate sizes (mm)	pre-burnt plots	burnt plots
WSA, %	2	1.48 ± 0.43^a	1.53 ± 0.51^a
	1	7.63 ± 3.09^a	1.58 ± 4.86^a
	0.5	1.53 ± 0.47^a	1.42 ± 0.37^a
	0.25	2.15 ±2.15^a	1.86 ±1.13^a
MWD, mm		0.42 ± 22.67^b	0.46 ± 0.12^a

* Mean followed by the same letter along the rows not significantly different ($p > 0.05$)

Table 4. Variation induced by experimental fires on some soils' physical properties

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 lager									
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

Table 5. Variation induced by experimental fires on some soils' chemical properties

Temp ^{0}C	pH	EC dSm^{-1}	TN (gkg^{-1})	OC	C:N	AV. P (mgkg^{-1})	EA	Ca (cmolkg^{-1})	Mg	k	Na	ECEC	BS %
						Surface soil							
(control) 24	5.9	0.03	0.4	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	0.6	14.05	23.63	28.97	0.8	6.72	5.04	0.06	0.04	14.09	92.76
40	5.9	0.03	0.8	18.8	23.5	25.64	5.12	6.72	5.28	0.08	0.05	17.25	70.32
48	5.5	0.02	0.8	19.2	24	25.97	1.12	2.88	2.4	0.06	0.06	6.53	82.85
49	5.6	0.03	0.7	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	0.8	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	0.8	17.8	22.25	25.64	0.8	3.36	2.4	0.04	0.04	6.66	87/99
60	5.6	0.01	0.7	17.2	24.57	25.64	0.8	9.12	7.68	0.05	0.05	17.71	95.48
Cv(%)	2.63	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 6. Relationship between soil carbon storage (SCS) and soil parameters in pre-burnt and post-burnt conditions

Treatment	Parameters	R	P (p < 0.05)
Pre-burnt	TNS	0.951	0.000
	CN	0.985	0.000
	EC	0. 994	0.001
	EA	0.996	0.024
Post- burnt			
	TN	0.892	0.000
	KS	0.414	0.000
	OC	0.769	0.003
	Clay	- 0.141	0.039

Dependent variable: Soil carbon stock (SCS)

Table 7. Relationship between total nitrogen storage (TNS) and soil parameters in post-burnt and pre-burnt

Treatment	Parameters	R	P < 0.05
Post- burnt	SCS	0.943	0.000
	CN	0.981	0.000
	EC	0. 992	0.000
	EA	0.996	0.024
Pre-burnt			
	TN	0.896	0.000
	KS	-0.466	0.000

Dependent variable: Total nitrogen stock (TNS).

Table 8. Significantly Related Soil Properties with Depth, Temperature, TNS and SCS in the Burnt and Pre-burnt soils .

Treatments	Depth	Temperature	SCS	TNS
Post-Burnt	TN (r = -0.617**)	Sand (r = 0.518*)	pH (r = 0.581*)	pH (r = 0.539*)
	WSA 0.5 (r = 0.820**)	Clay (r = -0.619**)	TN (r = 0.892**)	TN (r = 0.886**)
	Clay (r = 0.648**)	WSA 1 (r = -0.578*)	OC (r = 0.882**)	OC (r = 0.831**)
	Ks(r = -0.478*)	WSA0.5 (r = -0.780**)	TNS (r = 0.976**)	SCS (r = 0.976**)
	WSA1mm (r = 0.718**)	WSA0.25 (r = -0.526*)	Sand (r = 0.697**)	Sand (r = 0.665**)
	WSA0.5mm (r = 0.712**)	TN (r = 0.478*)	Clay (r = -0.680**)	Clay (r = -0.680**)
	TNS (r = - 0.753**)	OC (r = 0.582*)	WSA1(r = -0.722**)	WSA 1 (r = -0.718**)
	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*)		TN (r = 0.765**)	TN (r = 0.879**)
	Ks(r= -0.673**)		OC (r = 0.738**)	OC (r = 0.794**)
	BD (r= 0.636 **)		TNS (r = 0.943**)	SCS (r = 0.943**)
	P (r= -0.643 **)		Clay (r = -0.547*)	Clay (r = -0.525*)
	WSA1 (r= 0.773**)		MC (r = - 0.714*)	MC (r = - 0.655*)

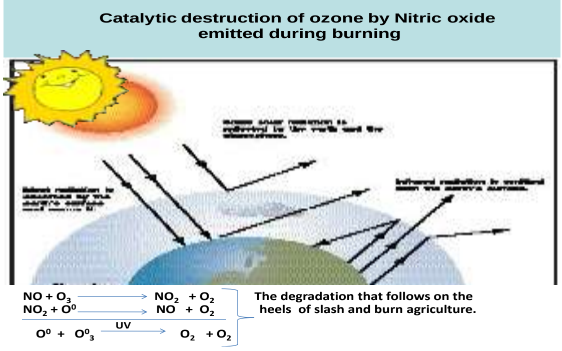
** Correlation is significant at the 0.01 level.
*Correlation is significant at the 0.05 level.

Table 9. Gas emission (mg/kg) during the experimental burning at different Dry biomass content (kg/m^2)

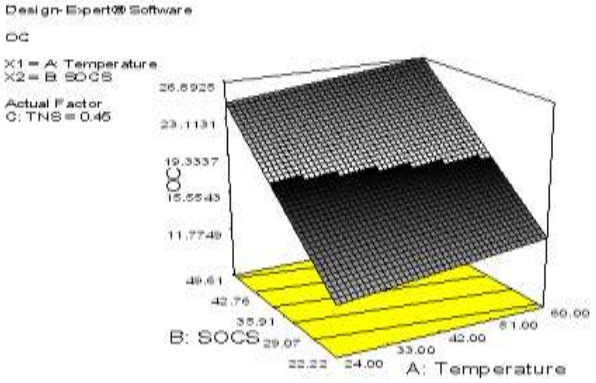
	Gases emitted						
Biomass	**NO_2**	**SO_2**	**CO**	**H_2S**	**Cl_2**	**NH_3**	**HCN**
50 kg/m^2	0.2	0.2	23.7	0.3	0.5	2.3	0.7
100 kg/m^2	0.2	0.2	26.7	0.4	0.5	3.0	1.0
150 kg/m^2	0.3	0.2	28.0	0.4	0.6	3.3	1.0

Toc Graphics

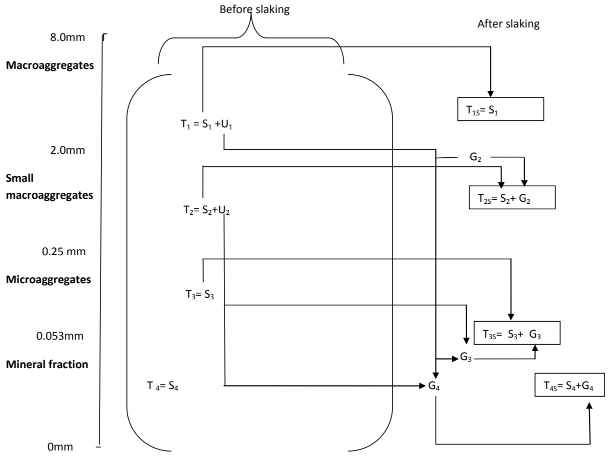
Graphic 1: Emission of gases during experimental fire passage on arable land



Graphic 2. Ecosystem destruction in photochemically decomposed two-step process of nitrous oxide emitted from burnt soil



Graphic 3. Organic carbon sequestration at varying heating temperature



S = stable aggregates; U = unstable aggregates;
G = gain in aggregates from other fractions;
T1 = total amount of aggregates in fraction;
1 and T_{1s} = total amount of aggregates in fraction 1' after slaking

Graphic 4: Thermal deformation of secondary particles during burning increased vulnerability of soil to erosion

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