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Impact of Prescribed Burning on Soil Physico-Chemical Properties in Semi-Arid Environment, Sokoto State, Nigeria

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Abstract: *The effects of prescribed burning on physico-chemical properties at Dabagi Forest Reserve in Dange/Shuni Local Government Area of Sokoto state Nigeria was investigated. The experimental plot was measured 30mx30m and separated from other fuel loads by fire track of 3mx3m wide to prevent uncontrolled burning. In each of the plots, three sub-plots (A, B and C) were designed each measuring 9mx9m and separated by 1.5mx1.5m between each sub-plot as fire track. Soil sample was collected in each of the sub-plots. Soil samples were collected from the experimental site before and after burning at (0-15cm depth). The plot was sketched out and leveled; A, B and C. Plot A was subjected to prescribed burning in the early dry season (November), Plot B (December) and Plot C (January). The experimental design was Randomized Complete Block Design (RCBD) at three (3) replications. The physical properties of the soils indicated high percentage (80.9%) of sand and the soil was therefore sandy in textural class. Soil physico-chemical properties were significantly ($p<0.05$) influenced by different burning regimes. It is indicated in this study that prescribed burning had positive impact on pH, phosphorous, calcium, magnesium, potassium and cation exchange capacity on the post-fire determination, it is recommended that prescribed burning had positive impact on physico-chemical properties of the soil, which therefore needed to be adopted.*

Keywords: *Prescribed Burning, Organic Carbon, Organic Matter, Soil pH and Physicochemical Properties.*

INTRODUCTION

Physical impacts of fire on soil include breakdown in soil structure, reduced moisture retention and capacity, and development of water repellency, all of which increase susceptibility to erosion. Fire also affects soil bulk density, erosion, hydrophobicity and moisture. Burning above

300°C increases bulk density, clay and silt content and decreases organic matter and sand content (Stool, 2010). During burning, plant cover and litter layers are consumed, and the mineral soil is heated, resulting in changes to soil bulk density, porosity, texture, color, moisture content and permeability. However, several studies by Allen (2006) reported either an increase or no change in bulk density following fire. Negative effects of fire on soil are caused primarily by high temperatures that affect surface as well as deeper soils (Korb *et al.,* 2004). The extent of fire effects on soil physical properties varies considerably depending on fire intensity, fire severity, and fire frequency. The weather, topography, and available fuel will determine the temperature and intensity of the prescribed burn, and this along with the timing of the treatment; largely determine how the burn impacts the vegetation and the abundance of particular species. In general, most fires do not cause enough soil heating to produce significant changes to soil physical properties (Hungerford *et al.,* 1990).

A prescribed or controlled burn, also known as hazard reduction burning, is a wildfire set intentionally for the purposes of forest management, farming, prairie restoration or greenhouse gas abatement. A controlled burn may also refer to the intentional burning of slash and fuels through burn piles. Fire is a natural part of both forest and grassland ecology and controlled fire can be a tool for foresters. Hazard reduction or controlled burning is conducted during the cooler months to reduce fuel buildup and decrease the likelihood of serious hotter fires. Controlled burning stimulates the germination of some desirable forest trees, and reveals soil mineral layers which increase seedling vitality, thus renewing the forest. Some cones, such as those of lodgepole pine and sequoia, are serotinous, as well as many chaparral shrubs, meaning they require heat from fire to open cones to disperse seeds. In industrialized countries, controlled burning is usually overseen by fire control authorities for regulations and permits (Gaze, 2016).

Low-intensity prescribed fire usually results in little change in soil carbon, but intense prescribed fire or wildfire can result in a huge loss of soil carbon (Johnson, 1992). Whereas increasing the fire frequency results in an increase in carbon in the fine fractions of the soil, and an increase in the δ13C value of SOC in all size fractions, while soil texture, on the other hand, controls the magnitude of the increases in both the abundance and δ13C value of SOC in all size fractions (Bird *et al.,* 2000). The soil chemical characteristics most commonly affected by fire are organic matter (OM), carbon (C), nitrogen (N), phosphorus (P), sulfur (S), cations, cation exchange capacity, pH and buffering capacity. Some purely chemical reactions occur in soils; these include the exchange of cations adsorbed on the surface of mineral soil particles and humus with their surrounding solutions (Knoepp *et al.,* 2005). The chemical changes in soils brought about by burning are similar regardless of the type of burning; it is only the degree that may differ coupled with the type and intensity of burning. Fire may maintain greater soil carbon stocks than long unburnt stands but depends on frequency and intensity (Oseni *et al.,* 2009).

There are basic confusions and uncertainties in the interpretation of the effects of burning on West African savanna brought about by lack of knowledge on the precise time of burning, frequency and duration of burning (Isah, 2007). People lack adequate knowledge on when and how often an area is burned, as well as the intensities, size and patchiness of fires (Fisher, 2000). Fire regimes can have different impacts on fuels, fodder and biodiversity by changing the composition of plant species and altering habitats. Furthermore, different fire regimes may be needed for different land management goals, and also no single regime is best for all land management purposes (Fisher, 2000). Therefore it is necessary to define fire regime for a particular ecosystem and for particular land management objectives. Fire affects the environment indirectly by removing or reducing plant and litter cover, thereby modifying both the post-fire microclimate and the activity of the soil biota. The most common hazard in forests is forest fire. They pose a threat not only to the forest wealth but also to the entire regime to fauna and flora seriously disturbing the bio-diversity and the ecology of the Nigerian environment (Trollope, 1984).

However, this research was conducted to enlighten the Foresters, Farmers, Hunters and Rangers on the use of prescribed burning for the wildfires control, soil fertility improvement in the farming systems, which will ensure food production, food security, increase the yield of crops and better quality of forage for feeding animals. The main aim of this study was to determine the effects of prescribed burning on physical and chemical properties of the soil in Dabagi Forest Reserve, Sokoto, Nigeria.

MATERIALS AND METHODS

Study Area

This research was conducted at Dabagi Forest Reserve, located in Dange/Shuni Local Government Area of Sokoto State. Dange/Shuni is located between latitudes $12^0$39'00"$13^0$00'0"N and Longitudes $5^0$10'00"-$5^0$40'02"E (MBEPS, 2012).The climate of the area is Tropical Continental dominated by two opposing air masses; the dry Tropical Continental blowing from the Sahara desert and a moist Tropical Maritime air mass from the Atlantic Ocean. While the former blows from a north-easterly direction. The latter comes from a south westerly direction. The interaction of the two major Air masses results into two major seasons, the wet and dry seasons. While rainy season commences from mid April and lasts to the end of September, the dry season extends from early October to May. In between these two major categories, there are four other sub-types: *Rani, Bazara, Kaka and Hunturu* (Hamattan). The hamattan is a dry, cold and dusty wind experienced in the state from November to February. During this period, the weather is usually cold at night and in the morning with temperatures less than 20^{o}C in some cases. Temperatures are highest from late March to May, ranging from 35^{o}C to 45^{o}C. Mean annual rainfall is about 600mm with most of it falling in July and August. Over the last fifty years, the rainy season has been characterized by late arrivals of rains, long spells of aridity of up to 21 days and early cessations (MBEPS, 2012).

The vegetation of the state is mostly the Sudan savanna type, characterized by mixed woodland and short grasses. Trees are short and have developed a series of drought adaptation mechanisms, such as long root systems, leaf shedding during the dry season, needlelike- thin leaves and hard barks. The shrubs are mainly of the Acacia species and are thorny. Along the river courses, plant density is however higher.

Sandy soils and clayey materials predominate except along the flood plain of the river valleys (*fadama*) where alluvial soils are found. In the northern parts of the state, especially along the Niger-Nigeria border, the plains are covered by Aeolian deposits from the Sahara desert and the Sahel-which give rise to light sandy soil. This by extension has led to the problems of desert encroachment and land degradation that are environmental challenges in the state (MBEPS, 2012).

Experiment

The burning procedure was conducted for the experiment to study the influence of fire on physico-chemical properties.

Experimental Design

The experiment was set up in a Randomized Complete Block Design (RCBD) at three (3) replications.

Experimental Plot (Field layout)

The experimental plot was selected within the area of the experiment, measuring 30mx30m and separated from other fuel loads by fire track of 3mx3m wide to prevent un-prescribed burning. In each of the plots, three sub-plots (A, B and C) were designed each measuring 9mx9m and separated by 1.5mx1.5m between each sub-plot. The Plot was sketched out and leveled; **A, B** and **C.** Plot **A** was subjected to prescribed burning in the early dry season (November), Plot **B** (December) and Plot **C** (January).

Procedure for Soil Sampling

Soil sample was collected in each of the sub-plots. Soil samples were collected from the experimental site (0-15cm depth) using soil auger and mix to make a composite sample. Thus, soil samples were taken from the plots before and after burning in the early dry season. The soil samples were taken to the laboratory for preparation and analysis. In the laboratory, the dried soils was crushed and passed through a 2mm sieve to remove debris and coarse fragments. The sample was also be oven dried at 70^0C (Bhisma *et al.,* 2010). The physicochemical properties analyses of the soils were then carried out.

Laboratory Analyses Experiment 1: Effects of prescribed burning on Soil physicochemical properties

Soil pH determination

Procedure: 10g of soil using weighing balance and plastic beaker, 10ml distilled water using measuring cylinder and washed the bottles stirring using stirring rod and leave for 30minutes to settle, washed the electron using distilled water and took pH reading using pH meter.

Organic carbon determination

Procedure: 1g of soil and put inside conical flask added 10ml of potassium dichromate, 10ml of concentrated sulphuric acid swirled and leave for 30minutes to gel and put 100ml of distilled water, 5ml orthtophosphoric acid, 3 drops barium diphynalamic acid then titrated against 0.5molar ferroux sulphate to dark green colour end point and recorded the burette reading as titer value and calculated percentage organic carbon using the formula below (Nelson and Sommer 1982).

$$\% \text{ O.C } \frac{(K_2Cr_207\text{-}FeSO_4)x0.003x1.33x100}{\text{Weight of soil}}$$

Cation Exchange Capacity (CEC) determination

Procedure: 5g of soil was put into conical flask, added 20ml of ammonium acetic solution and swirled and covered the mouth of the flask and kept it over night, the following day the filter paper was used to filter the solution and added 30ml of ammonium acetic solution to washed the sand particles into the filter paper after filtering, the filtrate solution was used to determine the exchangeable base of K, Ca, Mg, Na then the soil in the filter paper was used to determine the CEC using Kjeldhl apparatus and recorded the data (Anderson and Ingram, 1998).

Sand, Silt and Clay determination

Procedure: 5g of soil and was put 1000ml measuring cylinder and added 500ml of water and was mixed with 50ml of 5% calgon solution which break the different soil particles, mixer was used to stir the solution after stirring, water was added to 950ml and shake the cylinder again using stirrer and put soil hygrometer and leave for 40seconds to take the first and second temperature reading respectively (Gee and Bauder, 1986).

Total Phosphorus

Procedure: Seven milliliters of P extractant was added to 1g of soil into a centrifuge tube with a stopper. The mixture was shaken on a mechanical shaker for 1 minute and the suspension centrifuged at 2000rpm for 15 minutes. Two milliliters of supernatant was pipetted into a 20ml test tube. About 5ml of distilled water and 4ml of ascorbic acid was added and make up to the mark with distilled water. It was allowed to stand for 15 minutes for the colour to develop. The colour development was measured at 660nm on Corning 29 Colorimeter 253 and the absorbance read. The standards were also measured in the same way (Bray and Kurtz 1945).

Nitrogen determination

Procedure: 2g of soil was put into the Kjeldhal flask and added tablet of catalyst, added 10ml of concentrated sulphuric acid H_2S0_4 and mounted it on Kjeldhal, after the sample digested and was allowed it to cool and diluted it with distilled water using measuring cylinder to make it 50ml volume then take 10ml of the solution into microKjeldhal flask and used the distilled water to rinse the measuring cylinder with distilled water and put 20ml of 40% of sodium hydroxide and mount the flask then 20ml of buric acid indicator into 25ml conical flask and placed under the condenser to commence the distillation and collect 40ml of the distillate and stop the distillation, titrate the distillate again 0.01molar H_2S0_4 from green to pink colour end point and the recorded the data value or calculated the percentage of nitrogen using formula below (Soil Survey Staff 1984).

$$\% N = \frac{TV x 0.01 x 0.014 x 50 x 100}{2 x 10}$$

Sodium and potassium determination

Procedure: the exchangeable base of potassium and sodium using flame photometer was determined, distilled water was used to calibrate the photometer, the 10ppm K part per million was used and calibrated the machine to 100% emission and 10pp Na was also used and calibrated the machine to 100% emission and took the reading of intermediate standard solution and aspirated the sample solution and recorded the reading, the linear graph was used to calculate the sodium and potassium.

Calcium and magnesium determination

Procedure: determination of Ca and Mg using (Ethylenediame Tetra Acetic Acid) EDTA method.

Calcium determination:- 1m of the extract into titration flask was pipette and added 19ml of distilled water to make the volume 20ml and 10ml of sodium hydroxide and a tip of Murexid indicator and titrated against 0.01molar EDTA from the pink to purple colour end point and the data value was recorded from the burette reading.

Magnesium determination: - 1ml of the extract into titration flask was pipette and added 19ml of distilled water to make volume 20ml add 5ml of buffer solution and added 3 drops of eriochrome black T indicator and titrated against 0.01molar EDTA from purple to blue colour end point and the data value was recorded from burette reading.

Statistical Analyses

The data collected on soil physico-chemical properties was analyzed using analysis of variance (ANOVA) based on randomized complete block design (RCBD) and means were separated using Least Significant Different (LSD) where significant difference exist between the means.

RESULTS AND DISCUSSION Physico-Chemical properties

The physico-chemical and microbial properties of the soils in the study area is presented. The result indicated high percentage (80.9%) of sand and was therefore sandy in textural class. The soil was slightly acidic, low in organic carbon, organic matter, total nitrogen, available phosphorus and calcium, medium in exchangeable magnesium, CEC was however high in exchangeable potassium and sodium (Esu, 1991).

Table 1: Soil Properties (before burning) at Dabagi Forest Reserve, Sokoto, Nigeria

Soil Property	Value
Physico-Chemical Properties pH	
	5.47
Organic carbon (%)	0.24
Organic matter (%)	0.42
Total Nitrogen (%)	0.11
Phosphorous Cmol/kg^{-1}	0.70
Calcium Cmol/kg^{-1}	0.56
Magnesium mg kg^{-1}	0.49
Potassium Cmol/kg^{-1}	0.45
Sodium Cmol/kg^{-1}	0.38
CEC Cmol/kg^{-1}	13.6
EC µs/cm	72.2
Sand (%)	80.9
Silt (%)	8.85
Clay (%)	10.25

Source: field survey, 2021

Similar result was reported by Ogungbile *et al*., (1998), the main soil types found in (Sudan Savanna zones) is classified as Entisols, Inceptisols and Alfisols. They are young immature welldrained soils formed from parent materials rich in quartz and crystalline rocks of basement complex and sedimentary deposits (Enewezor *et al*., 1990). A common feature of these soils is their low organic matter content, cation exchange capacity and other nutrient content, especially nitrogen and phosphorus.

Table 2: Effects of burning on soil chemical properties as influenced by prescribed burning in the study area

Soil property	Burning regime				
	Control	Early	Mid	Late	S. E
pH	5.47[c]	5.70[a]	5.41[c]	5.57[b]	0.04
Organic carbon (%)	0.24[a]	0.07[d]	0.19[b]	0.17[c]	0.02
Organic matter (%)	0.42[a]	0.15[d]	0.33[b]	0.28[c]	0.03
Total Nitrogen (%)	0.11[a]	0.10[a]	0.11[a]	0.11[a]	0.00
Phosphorous Cmol/kg^{-1}	0.70[b]	0.61[b]	0.62[b]	0.88[a]	0.03
Calcium Cmol/kg^{-1}	0.56[a]	0.50ab	0.57[a]	0.42[b]	0.02
Magnesium mg/kg^{-1}	0.49[b]	0.38[d]	0.62[a]	0.42[c]	0.03
Potassium Cmol/kg^{-1}	0.45[d]	0.53[b]	0.51[c]	0.75[a]	0.03
Sodium Cmol/kg^{-1}	0.38[b]	0.19[d]	0.22[c]	0.67[a]	0.06
CEC Cmol/kg^{-1}	13.60[b]	12.80[c]	14.60[a]	10.40[d]	0.47
EC µs/cm	72.20[b]	81.10[a]	23.00[d]	61.70[c]	6.68
Sand (%)	80.90[a]	74.03[d]	77.93[c]	80.60[b]	0.83
Silt (%)	8.85[c]	13.77[a]	11.83[b]	11.80[b]	0.53
Clay (%)	10.25[b]	12.20[a]	10.23[b]	7.60[c]	0.49

Means in a row denoted by the same letter are not significantly different ($p>0.05$)

Soil pH was significantly ($p<0.05$) influenced by different burning regimes, early and late burning regime recorded the highest (5.70 and 5.57) respectively, and were statistically the same, while the least value was observed under the control and middle burning regimes and was also not statistically different. However, numerical values indicated higher pH during early season burning which may be due to the presence of available fuel load that will give more ash in turn increased base forming cation that react quickly in the soil as a result of soil residual moisture (Certini, 2005).

Organic carbon pool was significantly affected ($p>0.005$) under post burnt, there was inconsistent decreased in organic carbon as compared to the control plot. The reduction in organic pool may be related to the combustion due to burning and destruction of organic residues (Gonza´lez-Pe´rez *et al.*, 2004, Verma *et al.,* 2014).

Organic matter was significantly affected ($p>0.005$) by burning under different burnt plots as compared to the control plot (0.42), the decrease in organic matter was observed in mid burnt plot (0.33) and late burnt plot (0.28) but recorded the lowest value during early burnt plot. This may likely be due to the nature of plant residues presence and moisture content in the early burnt plot that caused low fire intensity during burning (Johnson, 1992).

The phosphorous reduction was observed in the early burnt plot (0.61) and mid burnt plot (0.62) as compared to the control plot (0.70). However, highest value (0.88Cmol/kg) of phosphorous was also recorded during the late burnt plot than control plot. This may be possible because of dry nature of fuel materials, ash deposition following fire and different fire intensity after burning (DeBano, 1989).

Calcium was significantly ($p<0.05$) influenced by burning regime. It was observed that late burnt plot recorded the lowest values (0.42) than early burnt plot (0.50), mid burnt plot (0.57) and control plot (0.56). This may be attributed to the high intensity of fire due to the dryness of fuel materials in the late burnt as well as the moisture content in early burnt plot, mid burnt plots and control plot (Khanna and Raison 1986; Certini, 2005).

Magnesium was observed to be high in mid burnt plot (0.62) but lowest in the early burnt plot. This indicated that the changes in magnesium content may be related to the different plant materials presence and also the different time of burning (regimes) (Khanna and Raison 1986; Certini, 2005).

Potassium was significantly affected ($p>0.05$) by post burnt from early burnt plot (0.53), mid burnt plot (0.51) and late burnt plot as compared to the control plot (0.45). It was observed that there was constant increase in potassium under the post fire condition. This may be related to the addition of ash deposition from the already burned fuel materials (Khanna and Raison 1986; Certini, 2005).

Sodium and CEC were higher after burning and fluctuating with the inconsistent decrease or increase under different burnt plots as indicated from the results of the study. The texture of the soil was not significantly different ($p>0.05$) affected by the burning. It is documented that prescribed burning has little or no effect on the soil textural properties (Knops and Tilman, 2000).

Soil pH is inexorably increased in non calcareous soil by the soil heating as a result of organic acids denaturation. Less intensive burning often increase soil pH, stimulates nitrification, and improves soils chemically (Certini, 2005). Increases in soil pH following fire have been widely reported (Kutiel *et al*., 1990). Increases in pH have been attributed to the release of basic cations during combustion and their deposition on the soil surface; this increase in pH increases the availability of phosphorus, calcium, magnesium, and potassium (Smith *et al*., 2008). The response depends on the amount of ash and buffering capacity of the soil and is considered negligible in grasslands (Smith *et al*., 2008). Soil pH is generally increased after forest fire (Boerner *et al.,* 2009). The presence of ash may increase soil pH due to high pH of ash (Molina et al., 2007).

The effect of fire on soil organic matter (SOM) is highly variable from total destruction of SOM to partially scorching depending on fire severity, dryness of the surface organic matter (OM) and fire type (Neary *et al.,* 1999; Gonza´lez-Pe´rez *et al.,* 2004). The effect of fire on soil organic matter (SOM) is highly dependent on the type and intensity of the fire, among other factors, soil moisture, soil type, and nature of the burned materials. Therefore, the effect on soil processes and their intensity influenced by fire are highly variable and no generalized tendencies can be suggested for most of the fire-induced changes in humus composition (Gonza´lez-Pe´rez et al., 2004, Verma *et al.,* 2014). Low-intensity prescribed fire usually results in little change in soil carbon, but intense prescribed fire or wildfire can result in a huge loss of soil carbon (Johnson, 1992).

Sanford (1982) had reported that in Nigerian savanna, mild fires at the beginning of the dry period resulted in increase in cation exchange capacity, available phosphorus, exchangeable calcium, magnesium and potassium and percentage base saturation. However, hot fires coming late in the dry season were found to reduce the cation exchange capacity and exchangeable calcium and potassium, while phosphorus and cation exchange capacity remained unchanged and the percentage base saturation only slightly increased. Reports by Christensen (1976), Raison (1979) indicated that, availability of potassium (K), calcium (Ca), and magnesium (Mg) may increase after fire. Concentrations of cations, such as Ca2+, Mg2+, and K+, and the anion SO4 2- increase considerably in the soil solution immediately following burning (Khanna and Raison 1986; Certini, 2005).

Prescribed burning may improve physical condition of some soils, especially clays, rendering them more friable, easier to work on and better able to accept infiltration of water (Knops and Tilman, 2000). Depending on the intensity during burning, plant cover and litter layers are consumed, and the mineral soil is heated, resulting in changes in soil bulk density, porosity, texture, color, moisture content and permeability (Hubbert *et al.,* 2005; DeBano *et al,* 2005).

Other soil physical properties, such as clay content, are not readily affected, except on the immediate soil surface during a very intense fire.

CONCLUSION

It is indicated in this study that prescribed burning had positive impact on pH, phosphorous, calcium, magnesium, potassium and cation exchange capacity on the post-fire determination, these soil parameters got incorporated into the soil and increased the fertility of the soil through prescribed fire which in turn improved rangeland management in the semi-arid environment. However, based on the finding of this study, prescribed burning had positive impact on physicochemical properties of the soil, which therefore needed to be adopted.

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