EFFECT OF BURNING ON SOIL PHYSICAL PROPERTIES IN THE DRY SUB-HUMID SAVANNA ZONE OF NIGERIA

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Abstract: A study was carried out to assess the effects of burning on the physical properties of soil on soils obtained from within the dry sub-humid savanna agro-ecological zone of northern Nigeria. Surface (0-15cm) composite soil samples were collected from selected locations comprising Bauchi, Gombe and Kano states from un-burnt, lightly burnt and intensely burnt sites in farmers' farms during land preparation of the 2007/2008 cropping season. The samples were obtained from both upland and lowland areas and analysed in the laboratory to assess the effect of burning on the soil's physical properties. The collected data were analysed using the SAS statistical software to test for significant differences at 5% level of significance. Where significant differences were found, the means were separated using the Least Significant Difference (LSD). Results of the laboratory analysis revealed that the soils within the study area are sandy loam in texture, and burning has no significant effect on the particle size distribution. Bulk density and water holding capacity were seen to be significantly affected as a result of burning. Bulk density increased from a mean value of 1.35gcm^{-1} to 1.53gcm^{-1} as a result of zero-burning and intense burning respectively within the lowland areas and from 1.4135gcm^{-1} to 1.5635gcm^{-1} for the same treatments within the upland areas. The water holding capacity was observed to reduce from a mean value of 37.47% to 35.90% within the lowland areas while within the upland areas the reduction was from a mean value of 35.44% to 28.85% also for similar treatments. [Report and Opinion 2010;2(8):64-70]. (ISSN: 1553-9873).

Keywords: burning; soil; agro-ecological zone; Nigeria

Introduction

Burning as a means of land clearance and field preparation prior to planting is a common practice in the West Africa Savannah ecological zone. It is regarded as the easiest and most convenient method of removing plant residues from previous cropping and other debris from the farm (Iwuafor *et al*., 2000). Fire is recognized as a potent ecological factor in woody and bushy environments (Assunta *et al*., 2004).

The vast majority of area burnt and cleared annually for cropping, to drive game for hunters, to improve grazing condition for livestock and for migration and land settlement lies within the savanna ecological zone (Isah and Adegeye, 2002). This practice invariably results in heating and drying of the soil. The soil temperature reached during such burnings ranged from 93^{o} to 1004^{o}C as a result of burning different types of materials and the time of exposure to heating (Roberts, 1965; Landelout, 1964; Isaac and Hopkins, 1937).

All fires, regardless of whether they are natural or human-caused, alter the cycling of nutrients and the biotic, physical, moisture, and temperature characteristics of soil (Isaac and Hopkins, 1937). In many cases however, these impacts are either negligible or short-lived and thus have little, if any, impact on the overall ecosystem. In some cases however, the impact of fire on soil conditions can be moderate to severe. The overall degree and longevity of this impact is determined by numerous factors including fire severity, temperature, fire frequency, soil type and moisture, vegetation type and amount, topography, season of burning, and pre- and post-fire weather conditions. Studies by Smith (1968) and Kershaw and Rouse (1976) pointed out that relatively large-scale loss of nutrients and an alteration of soil physical conditions occur after a fire.

Past researchers have identified many fire-related impacts on soil conditions. They have divided them into the following categories: Physical and Chemical Properties, Nutrient Properties, Soil Temperature, Soil Moisture, and Soil Biota. In general, when compared to the impacts felt by other ecosystem components, fire effects on soil are typically minor, are often short-lived and can be either positive or negative, with degree of impact increasing with increased fire severity (Haase *et al*. 1988).

Fire can impact a variety of soil physical properties including the loss or reduction of structure and soil organic matter and reduced porosity. These changes can also result in various indirect impacts including increased hydrophobicity (water repellency) which results in decreased infiltration and increased run-off which often results in increased erosion. Most of these changes to the soil, including a loss or reduction of structure and reduced porosity, are caused by an alteration in soil chemistry resulting from complex interactions among geomorphic processes, climate, vegetation, and landforms. Organic matter is also consumed or lost during a fire. This is dependant on the soil moisture content of the organic layer of the soil profile, fire severity and the subsequent precipitation (Northern Prairie Wildlife Research Centre, 2005). This paper presents the results of a study on the effect of burning on the physical properties of soil within the dry sub-humid savanna agro-ecological zone of Nigeria.

Materials and Methods

Location

Three locations were selected within the dry sub-humid savanna agro-ecological zone of Nigeria (latitudes 8°52'-14 °23'N and longitudes 4 °12' - 12°37') (FAO/NSPFS, 2005) representing both the high and low plains. Soil samples were collected from the dry sub-humid Kauran Namoda-Kano-Bauchi high plain and the dry sub-humid Azare-Gombe-Yola plain. The area were the samples were collected is bordered by the dry sub-humid Gumel-Nguru-Maiduguri plain at the northeast, the dry sub-humid Chibok-Biu-Mubi-Song high plain at the east, the dry sub-humid Ilela-Sokoto-Yelwa plain at the west, the sub-humid Jalingo-Donga-Ganye high plain at the southeast, the sub-humid central Niger-Benue trought and the sub-humid Minna-Kaduna-Kafanchan high plain both to the south (FAO/NSPFS, 2005). The altitude of the entire area exceeds 500m above sea level (Kowal and Knabe, 1972).

Climate

The study area has a tropical climate which is characterised by two distinct seasons, that is the wet and dry seasons. The wet season start from April to October while the dry season commence from November and ends in March, with the rains starting from the southern part and the dry season starting from the northern part. The average rainfall ranged from 600mm per annum in the northern part of the zone to as high as1200mm per annum in the southern part of the zone. Mean annual temperature range from 26°C - 32°C, while the diurnal temperature ranges from an average daily maximum of 31.6 °C to an average daily minimum of 13.1°C and relative humidity of 17%-90% (BSADP,1982; KNARDA, 2001; Kowal and Knabe, 1972). The soil temperature regime is iso-hyperthermic which suggests less than 5°C difference between mean summer and mean winter soil temperature (Soil Suvey Staff, 1999; Mustapha, 2003). The soil moisture regime is dominantly Ustic in the uplands and Aquic in the lowlands (fadama). The arable lands are mostly uplands with some few scattered fadama. The soil orders are mostly Ultisol, Alfisol, Inceptisol and Entisol which have developed mainly from basement complex rock parent material.

Reconnaissance Survey

A reconnaissance survey was carried out in June, 2007 to select appropriate sites for the study. Information collected during the survey includes farm sizes, land tenure system, cropping type and history, and method of land clearance.

Selection of Sampling Sites and Sample Collection

Following the survey, some farms were selected at different locations within the study area. Six locations were selected based on history of method of land clearance. Soil samples were collected from two sites each of Kano, Bauchi and Gombe states. The sites for sample collection were randomly selected from among the lowland and upland areas in the chosen states. The selected locations were; Bauchi 1 (Fadama), Bauchi 2 (Upland), Gombe 1 (Fadama), Gombe 2 (Upland), Kano 1 (Fadama), Kano 2 (Upland).

Treatments and Experimental Design

The treatments consisted of soil samples which had been subjected to three different burning regimes by the local farmers as part of their land preparation for farming. They consisted of soil samples from un-burnt areas as well as soil samples which had been subjected to Light-burning and Intense-burning from the three aforementioned geographical locations; Kano, Bauchi and Gombe states with two bulk soil samples from two of each location i.e. lowland and upland areas. The experimental design was hierarchical (nested) design in which the burning intensities were nested in the locations and the locations nested within the sites.

Sample Preparation

Sub-samples from the bulk soil samples were collected air-dried in the laboratory for several days. The sub-samples were gently crushed with porcelain pestle and mortar and passed through a 2mm sieve to remove debris and coarse fragments. The fine earth separates (<2mm soil portion) were labeled and stored in polythene bags for laboratory analyses. Weighing of the soil samples for laboratory analyses was done using an electric weighing balance, Model ADP 3100L.

Particle Size Distribution

Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986). Organic matter was removed from the soil samples by the addition of hydrogen peroxide and the soil samples were dispersed using 5% calgon (sodium hexametaphosphate) solution. The dispersed samples were then shaken on a reciprocating shaker after which particle size distribution was determined with the aid of Bouyoucous hydrometer at progressive time intervals. The textural classes were determined with the aid of a USDA textural triangle.

Bulk Density

Core samples were taken from the top soil with the aid of core samplers for bulk density determination by drying to a constant weight in an oven at 105°C and expressed as mass of dry soil per unit volume of moist soil (Campbell and Henshall, 1991).

$$\text{Bulk Density } (\rho b) = \frac{\text{Mass of oven-dry soil}}{\text{Volume of bulk soil sample}}$$

Percent Water Holding Capacity

The percent water holding capacity of the soil samples were determined with the use of tin cans opened at one end with holes at the bottom. Each can is fitted with a filter paper and then filled with soil sample with gentle packing to prevent loss of soil and placed in a Petri-dish. Water is then poured by the sides of the Petri-dish until the top of the soil sample is wet and left overnight with about 6mm of water in the Petri-dish. The weight of the absorbed water is determined by drying to a constant weight in an oven 105°C and the percent water holding capacity calculated by using the relation:

$$\%\text{Water Holding Capacity (WHC)} = \frac{\text{Weight of absorbed water}}{\text{Oven-dry soil}} \times 100$$

Data Analysis

The data collected was analyzed using Analysis of Variance (ANOVA) for using SAS Computer Statistical Software to test for significance (F* Test). Where the tests show there are Significant Differences, the Means were compared using Least Significant Difference (LSD).

RESULTS

Bulk Density

Bulk density was shown to be significantly increased as a result of burning in both lowland and upland areas. Intense burning resulted in a significantly higher a mean bulk density value of 1.53gcm^{-3} which is statistically similar to the effect produced as a result of light burning but different ($P \leq 0.05$) from the bulk density of un-burnt areas which gave a mean value of 1.35gcm^{-3} within lowland areas . A similar trend was observed as within the upland areas in which intense burning resulted in a significantly higher mean bulk density 1.53gcm^{-3} as against a mean bulk density value of 1.41gcm^{-3} recorded in un-burnt areas (Table 1). However, no significant difference was observed between burning effects on bulk density between the lowland and upland areas in the study area (Table 2). This increase in the bulk density of the soil may be attributed to the combustion of organic matter. The results are in agreement with the findings of Wahlenberg *et al.* (1939), Choromanska and DeLuca (2002) and Northern Prairie Wildlife Research Centre (2005) who found out lower organic matter in soils that were repeatedly burnt leading to denser soils. DeByle (1981) also reported that as a result of the loss of organic matter in heated soils, soil structure was destroyed which lead to increase in the bulk density of the soil. This effect is the same within both the lowland and upland areas which is also supported by the findings of Campbell *et al.* (1995) who stated temperature increase is the main cause of change rather than the location of the burning.

Water holding capacity

Water holding capacity of the soil under study was shown to be significantly ($P \leq 0.05$) reduced as a result of intense burning in which there was a reduction in the bulk density of the soil from a mean value of 37.47% to 35.90% within the lowland areas and a non-significant reduction in the bulk density of the soil from a mean value of 35.44% to 28.85% within the upland the upland areas (Table 1), while there was no significant difference as regards the effect of burning on water holding capacity between the lowland and upland areas (Table 2). The reduction may be ascribed to the reduction in the total organic matter of the soil which is burnt off during burning. This may be attributed to the fact that organic matter improves water retention (Brady and Weil, 1999) and that most organic matter within the soil contain 50-90% water (Urio *et al.,* 1979; Assunta *et al.* 2004).

Particle Size Distribution

The textural class of all the soils within the study area was found to be sandy loam (Table 1) with the sand fraction being the dominant particle size in all locations, and burning was found not to have any significant effect on the particle size distribution except when the effect of light burning within lowland areas was compared to light burning within the upland areas (Table 2) in which the mean silt content was found to be statistically ($P \leq 0.05$) different; that is from a mean value of 25.44% within the lowland areas to a mean value of 20.05% within the upland areas. This is in accordance with the report of Esu (1998) who stated that Nigerian savanna soils tend to be generally coarse in texture. The result show that burning has no effect on the particle size distribution which is supported by the findings of Heyward (1938) who stated that burning do not cause dramatic changes to soil texture and that single low-intensity prescribed burns in the southern United States typically do not cause dramatic changes to soil structure and texture and elevated soil temperatures during these fires are usually brief. Packham, (1969) also stated that the extent of fire effects on soil physical properties varies considerably depending on fire intensity, fire severity and fire frequency but in general, most fires do not cause enough soil heating to produce significant changes to soil physical properties. This is particularly true for low intensity prescribed fires, and even where fires do cause direct changes to soil physical properties, their indirect effects on soil hydrology and erosion will vary greatly depending on the condition of the soil, forest floor, topography and climate. A study by García-Corona *et al*. (2004) revealed that heating of two north-western Spanish soils at 170°C and 220°C caused no significant changes in aggregate size distribution. This finding is in contrast to that of Chandler *et al*. (1983) who stated that intense fires (> 400^{o} C) may permanently alter soil texture by aggregating clay particles into stable sand-sized particles thereby making the soil texture more coarse and erodible.

Conclusion

The results of the laboratory analysis revealed that burning has no significant effect on the particle size distribution. Bulk density was seen to be increased while the water holding capacity was seen to decrease as a result of burning. At the end of the experiment it will be recommended that although the burning intensities used by the farmers may not be high enough to cause serious alteration in the physical properties of the soil, farmers should still be cautious of the use of fire in land clearance and preparation as there might be cumulative effect as a result of burning.

Table 1: Effect of burning on some physical properties of soils in lowland and upland areas within the dry sub- humid savanna agro-ecological zone of northern Nigeria.

Location	BD	WHC	Sand	Silt	Clay	Textural Class
				Particle Size Distribution		
		(gcm^{-3})			%	
Lowland						
Zero-burning	1.35	37.47	64.11	26.00	9.89	Sandy Loam
Light-burning	1.41	37.09	65.63	25.44	8.93	Sandy Loam
Intense-burning	1.53	35.90	62.11	27.33	10.56	Sandy Loam
LSD (0.05)	0.17	0.61	NS	NS	NS	
Upland						
Zero-burning	1.41	35.44	74.77	16.00	9.23	Sandy Loam
Light-burning	1.51	33.40	72.53	20.05	7.41	Sandy Loam
Intense-burning	1.56	28.85	72.96	18.77	8.27	Sandy Loam
LSD (0.05)	0.07	NS	NS	NS	NS	

Table 2: Effect of burning-intensity on some physical properties of soils between lowland and upland areas in the dry sub- humid savanna agro-ecological zone of northern Nigeria.

Site	BD	WHC	Sand	Silt	Clay	Textural Class
				Particle Size Distribution		
		(gcm^{-3})		%		
Zero-burning						
Lowland area	1.35	37.47	64.11	26.00	9.89	Sandy Loam
Upland area	1.41	35.44	74.77	16.00	9.22	Sandy Loam
LSD (0.05)	NS	NS	NS	NS	NS	
Light-burning						
Lowland area	1.41	37.09	65.62b	25.44	8.93	Sandy Loam
Upland area	1.51	33.40	72.53a	20.05	7.41	Sandy Loam
LSD (0.05)	NS	NS	NS	2.99	NS	
Intense-burning						
Lowland area	1.53	35.90	72.96	27.33	10.56	Sandy Loam
Upland area	1.56	28.85	62.11	18.77	8.27	Sandy Loam
LSD (0.05)	NS	NS	NS	NS	NS	

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