CLIMATE CHANGE, FOOD SECURITY, NATIONAL SECURITY and ENVIRONMENTAL RESOURCES

GLOBAL ISSUES & LOCAL PERSPECTIVES

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TABLE OF CONTENTS

SAEREM BOOK CHAPTERS2023: First published 2024: ISBN 978-978-60709-9-5

Part three: NATIONAL SECURITY

Part four: ENVIRONMENTAL RESOURCES

Preface

This book adopts an exegetical approach as well as a pedagogic model, making it attractive agriculture and environmental economics teachers, professional practitioners and scholars. It is eschews pedantry and lays bars the issues in such clarity that conduces to learning. The book elaborates on contemporaneous climate change, food security, national security and environmental resources issues of global significance and at the same time, is mindful of local or national perspectives making it appealing both to international and national interests. The book explores the ways in which climate change, food security, national security and environmental resources issues are and should be presented to increase the public's stock of knowledge, increase awareness about burning issues and empower the scholars and public to engage in the participatory dialogue climate change, food security, national security and environmental resources necessary in policy making process that will stimulate increase in food production and environmental sustainability.

Climate Change, Food Security, National Security and Environmental resources: Global issues and Local Perspectives is organized in four parts. Part One deals with Climate Change with Six Chapters, Part Two is concerned with Food Security with Nine chapters, Part Three deals with National Security with Five Chapters, while Part Four pertains Environmental Resources, has Five Chapters.

Ahmed Makarfi / Eteyen Nyong

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CHAPTER 14

A Review of the Impact of Bush Burning on the Environment: Potential Effects on Soil Physical Attributes

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Abstract

Bush burning, during land clearing is a common practice among the smallholder farmers in most developing countries including Nigeria. The practice impacts not only the appearance of the landscape, but the quality of the soil as well. Controlled and uncontrolled bush fires impact the soil in a variety of ways with the magnitude of the disturbance largely dependent upon the fire intensity, duration and recurrence, fuel load, and soil characteristics. The impact on soil properties is intricate, yielding different results based on these factors. Whereas burning off the vegetation during land clearing for cultivation is a common farming practice among farmers in many parts of the tropics, yet little is known about the effects of this practice on the soil. This paper reviews research investigating the effects of wildfire and prescribed fire on the physical attributes of cultivated and forest soils and summarizes the current knowledge pertaining its effects on soil physical properties particularly the ones that largely determine the soil's water and air supplying capacity to plants.

Introduction

Increased human activities resulting from expanding population remains one of the biggest challenges to the quality of the environment (Ezihe *et al.*, 2020). Bush burning is the removal of the surface vegetation cover that protects the soil surface through the use of fire (Plate 1). The practice of bush burning has been an age long practice in many parts of the world including northern parts of Nigeria and this practice has been generally recognized as an integral part of the traditional farming system. Key drivers of soil degradation in forest and savannah ecosystems are deforestation, fires, erosion, and soil contamination (Ghazoul et al. 2015; Silvério et al. 2019).

Loss of plant biodiversity is the major footprint of bush burning. The preservation of vegetation cover is key to maintenance of the ecosystem balance and favourable climatic conditions. The practice of bush burning exposes the land surface to the adverse effect of wind, water erosion, ultraviolet radiation etc. Bush burning has detrimental effect to the environment, health and the economy. Bush burning, whether as a result of a wildfire or a controlled burning, affects not only the appearance of the landscape, but also the quality of the soil. The degradation of the biological, chemical, and physical properties of through bush fire reduces the capacity of the soil to function fully, with such effects being either temporary or permanent (Agbeshie *et al.*, 2022). Whereas the landscape may quickly recover after a fire, with fresh new growth and emerging seedlings, its negative effects on soil conditions is so enormous that it often takes much longer time for the soil to recover. Fires, either wild or naturally occurring have been shown to affect the biological and physico-chemical quality of soils and diminish the nutrient pool through various mechanisms, including volatilization, oxidation, ash transfer, and erosion (Pellegrini *et al.* 2018). Several researchers have documented the severity of wildfires on soil properties in both forest and grassland vegetations (Liu *et al.* 2018; Ibáñez *et al.* 2021; Jhariya and Singh 2021). Therefore, increased risk of fire risk not only affect forest flora, but also the soil physical, chemical, and biological properties (Romeo *et al.* 2020). However, the extent of soil disturbance by fire is largely dependent on such factors as fire intensity, duration and recurrence, fuel load, and soil characteristics (Agbeshie *et al.*, 2022).

According to a review by Certini (2005), an intense fire moving at a slow pace resulted in more severe damage to the soil than a fast-moving fire. Temperatures of $\geq$ 850 °C may be attained on soil surfaces with dry, heavy fuel loads, and may have destructive effects on soil properties (DeBano, 2000). Consequently, information on the changes to soil properties following fire is key to finding sustainable and adaptable management practices of soils and forests (Zhang and Biswas, 2017). With current global warming, higher temperatures and extreme drought conditions significantly increase the risk of forest fires (Zhang and Biswas 2017). There have been several recent predictions on the possible increase in fire duration, intensity, and frequency in forested regions, especially in the tropics as a result of higher temperatures (Zhang and Biswas 2017; Auclerc *et al.* 2019; Addo-Fordjour *et al.* 2020). Studies conducted in the African savanna ecological zone shows that large areas of open woodlands and wet savannahs with high populations of game and tall grasses recorded high mean fire counts (Anderson *et al.* 2003; Bagamsah and Vlek, 2005; Kugbe *et al.* 2014) with the high fire incidence attributed to hunting to flush out rodents and small animals as well as farming and charcoal burning (Day *et al.* 2014). Recurrent bush fires in northern parts of Nigeria is gradually becoming a norm, hence the need for proper enlightenment on the dangers of bush burning to the environment as well as the need to bring the practice to an end. Statistics has it that more than half of bush burning throughout Nigeria is deliberately lit, costing millions of naira damages annually. The negative impact of bush burning need not be overemphasized especially during the hot season in northern Nigeria especially when viewed against the backdrop of environmental pollution and health hazards (Otitoju *et al.* 2019; Ezihe *et al.* 2020). This is particularly so because the short and long-term impacts of uncontrolled bush fire exacerbates soil quality decline leading to soil degradation which may ultimately lead to complete loss of land values (Tadesse, 2016). The objective of this paper is therefore to review the current state of knowledge on the type and extent of soil modifications following wild and controlled fire disturbances.

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Plate 1: Photo of uncontrolled fire in a forested landscape

Impact of Fire on Physical Properties of Soil: The physical properties of soils are among the most important attributes that determining their potential uses, sustainability and productivity (Chartres, 1982). The benefits of bush burning in improving the soil through immediate release of occluded mineral nutrients for crop use seem to be short- lived due to its degenerative effects on soil physical properties (Tucker, 2003; Edem *et al.,* 2012). Many physical properties of soil can be affected by fire. Soil physical properties in the context of this paper are those characteristics, processes, or reactions of a soil that are caused by physical forces that can be described by, or expressed in, physical terms or equations (SSSA, 2001). In the light of the above, this paper will focus on those important physical characteristics that are affected by soil heating and these include: Soil colour, texture, structure, aggregation, bulk density, and water storage capacity.

Potential effects on soil colour

The colour of a given soil is generally determined by the amount and state of iron and/or organic matter it contains (Singh *et al.*, 2004). The hue of the soil colour depends on the presence of iron oxides that are significantly affected at different levels of temperatures reached during heating (Terefe *et al.*, 2008). Ash colour on the other hand can also be used as an indicator of fire severity, and depending on the removal of the organic matter, can range from black to white ash (complete ashing) (Neary *et al.*, 1999; Bodi *et al.*, 2011). Studies have shown that changes induced in the colour properties by fire are more or less permanent (Terefe *et al.,* 2005; Tadesse *et al.* 2016). At higher temperature (600^{0}C) reddening of soil matrix occurs. The redder hue that appears following severe heating of soils is apparently because of Fe-oxides transformation and complete removal of organic matter. The study by Certini, (2005) revealed that in low to moderate fire, the ground surface is covered by a layer of black or grey ash. The long term study (ranged from 22 d to 3 yr) by Uleri and Graham, (1993) revealed that soil color and texture were most noticeably altered in the severely burned soil under concentrated fuel (1–2% of the land surface), compared with nearby slightly or moderately burned areas. Furthermore, after severe burning, a 1- to 8-cm-thick reddened layer formed at all of the sites, which was redder in hue and had higher chromas and values than the unburned soils. Underlying this layer was a blackened layer with a thickness of 1 to 15 cm and lower Munsell values. The authors attributed the redder hues in the burned soils to the result of Fe oxide transformations while the blackened underlying layer was attributed to the loss of organic carbon resulting from charring of the organic matter that remained. In a similar study, a slashed burnt field of 12- to 15-yr-old secondary forest caused munsell values and chromas to decrease and hues to become yellower with increasing heat severity, especially in the top 5 cm of the soil (Ketterings and Bigham, 2000). The study also revealed that, at peak surface temperatures >600°C, the soil matrix was reddened following substantial loss of the soil organic carbon. However, these and other similar studies showed that color changes were highly dependent on temperature, heating time, organic content, iron oxide composition, and available oxygen during burning (Berna *et al.*, 2007; Canti and Linford, 2000; Ketterings and Bigham, 2000). Some literature on soil heating also shows that while some sediments redden dramatically at temperatures commonly found under the experimental fires, others fail to redden even at significantly higher temperatures (Canti and Llnford, 2000). These 'anomalies' according to the authors was attributed to either organic matter content or chemical variations affecting the progress- of the iron oxide transformations that lead to soil reddening.

Potential effects on soil texture: Soil texture and soil colour are the two most noticeable altered attributes in severely burned soil under concentrated fuel compared to nearby slightly or moderately burned soil (Ulery and Graham, 1993). In a severely_burnt Nigerian soil, Oguntunde *et al.* (2004) reported an alteration of the soils particle size distribution leading to a significant increase in the sand content relative to the contents of silt and clay. This was in agreement with the findings of previous studies (Praise and Cannon, 2012; Salim *et al.* (2020). According to Praise and Cannon, (2012), at temperatures exceeding 170^{o}C, the contents of the clay and silt fraction fractions deceases. The study by Salim *et al.* (2020) also showed that relative to the preserved site, the contents of the sand size fraction substantially increased compared to the clay size fraction in the burnt site when compared with the preserved site following only one year of fire disturbance (Table 1). Contrary to these findings, Garcia-Corona *et al.*, (2004) and Ibitoye *et al.*, (2019) did not find did not significant change the particle size distribution of the soil following fire incidence. However, these discrepancies however, stem from the fact that the impact of fires on soil quality

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indicators is largely dependent on their severity and frequency (Johnston and Barati, 2013; Pellegrini *et al.* 2018; Pérez-Izquierdo *et al.* 2021).

Table1: Soil physical analysis in the study site

Parameter	Preserved site	Burned site	Disturbed site
Clay (%)	3.83	3.61	3.60
Silt (%)	14.88	13.39	12.70
Sand (%)	81.29	82.50	83.70
Density (g/cm^3)	1.10	1.08	1.02

Source: Salim *et al.*, (2020).

Most literatures shows that amongst the soil separates, clay is the most sensitive textural fraction, which begins changing at soil temperatures of about 400^0C when clay hydration and clay lattice structure begins to collapse. The clay size fractions undergo several structural and compositional changes when exposed to increasing temperatures (Ramaswami and Kamalakkanan, 1995). Up to 200^oC the adsorbed water films around the finer fractions evaporates but when the temperatures increased to 450 to 600^oC, dehydroxylation and the loss of structurally bound water occurs with kaolinite. This change takes place rather abruptly in kaolinite but with other clay types such as smectide and illite, structural water loss is more gradual (Berna *et al.*, 2007). Studies revealed that at temperatures of 700 to 800^oC the complete destruction of internal clay structure can occur (Neary *et al.*, 2008). Another study revealed that at temperatures approaching up to 950^oC, crystallization of new phases such Aluminosilicate spinel ($Si_8Al_{16}O_{32}$) occurs while porosity rapidly diminishes and the initiation of the glassy phase [(amorphous free silica (SiO_2)] of the ceramic start (Rice, 1987; Carty and Senapati, 1998). According to Ulery and Graham (1993), burning result in the production of a finer texture due to an increase in the silt fraction resulting from the decomposition of kaolinized sand grains. These workers further revealed that after fire disturbance, the top reddened soil layers had significantly less clay content than that of the unburned soils. The blackened layers and sand-sized aggregates formed in the surface soils during burning led to a change in the particle-size distribution resulting in development of coarser textures as a result of the increase in the relative proportion of sand size fractions. Contrary to the above findings, Garcia-Corona *et al.* (2004) and Ibitoye *et al.* (2019) did not observe any significant change in particle size distribution following fire disturbance. This trend is not unexpected because the components of soil texture (i.e. sand, silt, and clay) have high temperature thresholds and as such are not usually affected by fire unless they are subjected to higher temperatures at the mineral soil surface (A-horizon) (Verma and Jayakumar, 2012). As previously reported, the most sensitive soil separate is the clay fraction, which begins changing at soil temperatures of about 400^{o}C when clay hydration and clay lattice structure begin to collapse.

Potential effects on soil water storage: Bush burning depending largely on the intensity of the fire and duration of exposure can cause the soil to lose its ability to absorb and retain water. After a fire, the top layer of soil often becomes water repellent thereby causing the rain water to drain off the soil without absorbing into the ground (Tibbits, 2017). Water repellency is as a result of the presence of organic compound with hydrophobic properties on soil particle surface (Doerr *et al.*, 2009). Water repellency is known to influence seedling survival and subsequent stand establishment (Reeder and Jurgensen, 1979). High surface temperatures 'burn' off organic materials and create vapours that move downward in response to a temperature gradient before finally condensing on the surfaces of soil particles causing them to become water repellent (Letey, 2001). Whereas most of the volatilized organic matter are lost through upward movement in the smoke, but a small proportion moves downward along steep temperature gradients in the upper 5 cm of the soil and condenses to form a water-repellent layer that impedes infiltration (Fig. 1 A, B, C). The degree of water repellency formed depends on such factors as the steepness of temperature gradients near the soil surface, antecedent soil water content, and soil physical properties. For example, relative to fine-textured soils such as clay, coarse-textured soils are more susceptible to heat induced water repellency (DeBano, 1990). According to this author, the formation of water-repellent layer after fire incidence, along with the loss of protective plant cover, increases surface runoff and erosion during the first rains following burning. A reduction in infiltration by a water-repellent layer can lead to increase in rill erosion on burned watersheds (Wells, 1981). Several studies have reported highly variable water repellent soil conditions following forest fires (Robichaud and Hungerford, 2000; DeBano, 2000; MacDonald and Huffman, 2004; Verma and Jayakumar, 2012). The impact is always strongest at the soil surface in areas burned at high and moderate severity, and declined in strength with decreasing burn severity and increasing depth (MacDonald and Huffman, 2004). Soil water repellency often prevents water from wetting or infiltrating the dry soils (Doerr *et al.*, 2009).

Studies have shown that soil burning decrease soil water retention capacity both at the field capacity and permanent wilting point leading to a final reduction in soil available water holding capacity (Tadesse, 2016). This was attributed to the resultant increase in sand size fractions and decrease in clay content following burning of the top soil layer. Another plausible reason for the reduction of soil water holding capacity is the reduction in the total organic matter content of the soil following soil burning (Ibitoye *et al.*, 2019). 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 contains 50-90% water (Assunta *et al.*, 2004). A confirmation of the above assertion can be found in the findings by Emerson (1995) who concluded that the increase in clay content following fire incident increases water holding capacity at both the field capacity and the permanent wilting point.

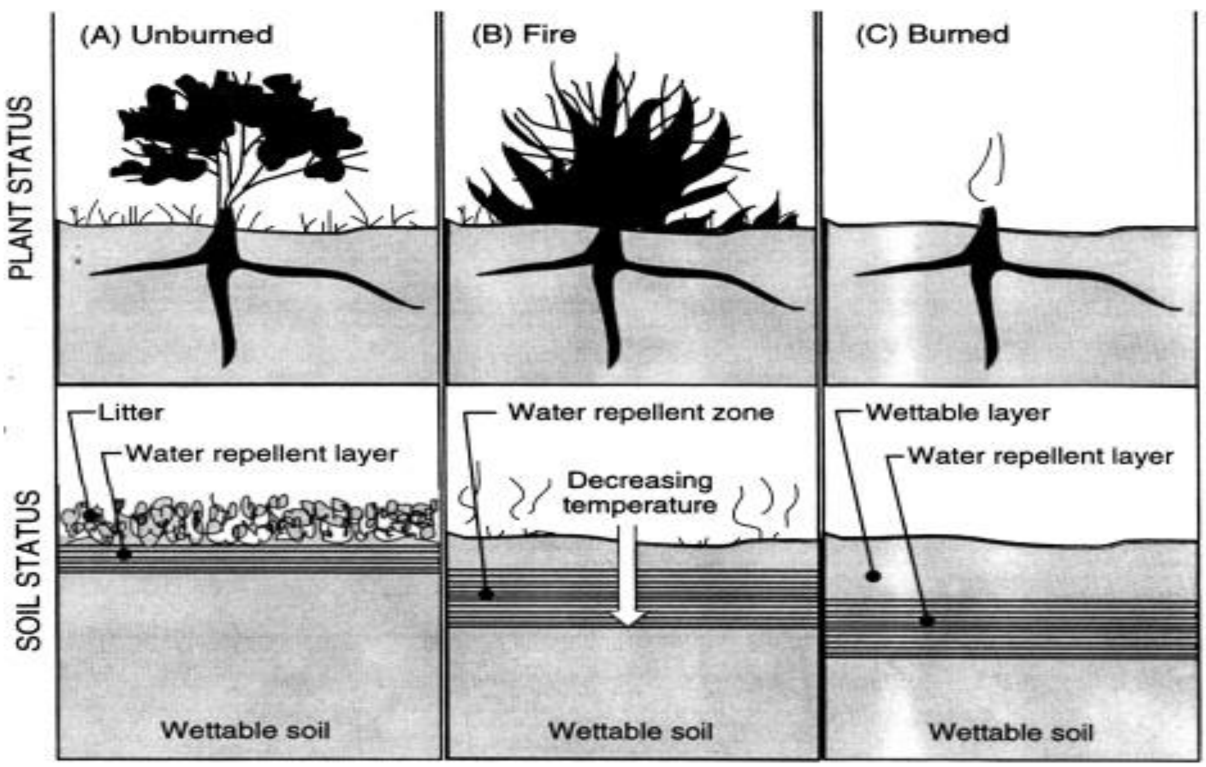

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Figure 1-Soil-water repellency as altered by fire: (A) before fire, hydrophobic substances accumulate in the litter layer and mineral soil immediately beneath; (B) fire burns the vegetation and litter layer, causing hydrophobic substances to move downward along temperature gradients; (C) after fire, a water-repellent layer is present below and parallel to the soil surface on the burned area (DeBano, 1981).

Potential effects on aggregate stability: Soil physical properties that are dependent on organic matter such as soil structure, pore space, aggregation are all affected by heating during a fire (DeBano, 1990). During the fire, heat transfer from burning biomass on the surface and within the soil is directly responsible for the changes that occur (O'Brien *et al*. 2018). The impacts fire on soil properties are a function of intensity, duration, and frequency, which constitute fire severity (Alcañiz *et al.* 2018; Lucas-Borja *et al.* 2020; FernándezGarcía *et al.* 2021). Obitoye *et al.,* (2019) reported a decrease in micro aggregate stability of a burned soil leading to a marked change of soil structure as previously suggested by Krol *et al*, (2013). These workers also posited that the decrease in micro aggregate stability of the burned soil was exacerbated by intensive cultivation of the soil. Inbar *et al.* (2014) also reported a gradual breakdown in soil aggregates and subsequent increase in soil loss following low to moderate wildfire. They concluded that the breakdown in soil aggregates resulted in an increase in water repellency and subsequent increase in runoff.

Bulk density, which is closely related to soil aggregate stability, has also been shown to increase significantly as a result of forest fire (Boerner, *et al.,* 2009; Certini, 2005). Heydari *et al.* (2017) also reported increase in soil bulk density following a wildfire in an oak forest in Ilam, Iran. Similarly, Granged *et al.* (2011) and Jordán *et al.* (2011) found significantly higher soil bulk densities in burnt soil following prescribed and wildfire in Australia and Mexico, respectively. In a similar study, Verma *et al.* (2019) also observed higher soil bulk densities in tropical dry deciduous forests of the Western Ghats, India, following the incidence of 12-year wildfires. The increase in soil bulk density following fire incident has been attributed to collapse in soil aggregates leading to destruction of soil organic matter (Alcañiz *et al.* 2018). This assertion was confirmed by the findings of Heydari *et al.* (2017) who concluded that the destruction of soil structure and structural pores, coupled with the decline in organic matter increased soil bulk density. Earlier investigators also attributed increases in bulk density following fire incidence to the collapse of aggregates and clogging of voids by the ash and dispersed clay minerals; as a consequence, both soil porosity and permeability decreases (Certini, 2005). Soil bulk density is inversely proportional to soil porosity, thus an increase in bulk density results in decreased porosity, with further ramifications on hydrological properties (Wieting *et al.* 2017; Lucas-Borja *et al.* 2020). Contrary to these findings, Downing *et al.* (2017) reported a lower soil bulk density after a high-intensity wildfire on Mount Kenya in Kenya. They attributed the decrease in bulk density to the addition of partially decomposed organic matter, coupled with soil vapour expansion.

Summary and conclusions: The literature reviewed suggest that the impact of burning on soil physical properties depends largely on factors such as temperature, heating time, organic content, iron oxide composition, and available oxygen during burning. For example, at peak surface temperatures greater than 600°C, soil organic carbon was mostly depleted and the soil matrix was reddened whereas in low to moderate fire, the ground surface is covered by a layer of black or grey ash. However, literature on the impacts of fire on soil texture is highly variable with some reports suggesting that burning significantly affects the texture of the soil, while others did not show any significant change in particle size distribution of the soil owing to fire disturbance. This discrepancy could be attributed to the fact that the components of soil texture (i.e. sand, silt, and clay) have high temperature thresholds and as such are not usually affected by fire unless they are subjected to very exceedingly high temperatures. Bush burning depending largely on the intensity of the fire and how long it burns has been shown to limit the ability of the soil to absorb and retain water. This is caused by downward movement of vaporized organic matter along steep temperature gradients and their subsequent condensation to form a water-repellent layer in the upper most few centimeter layers of the soil. The degree of water repellency formed depends on factors such as the steepness of temperature gradients near the soil surface, antecedent soil water content, and soil physical properties. There are reports in literature that shows low to moderate burning cause a breakdown in soil aggregates and the subsequent increase in soil loss thereby resulting in increased water repellency and the resultant increase in runoff. Increase in soil bulk density following fire disturbance has been attributed to collapse in soil aggregates owing to the depletion of soil organic matter. It can be concluded based on the present review that almost all the soil physical properties that are dependent on soil organic matter are negatively affected by burning with the magnitude of the effect largely depending on such factors as temperature, heating time, organic content, iron oxide composition, and available oxygen during burning. Hence it is imperative to find an alternative to the traditional practices of soil burning as a means of land clearing by farmers to safeguard the soil against progressive decline in quality.

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