

Full Length Research Paper

The influences of forest fire on the vegetation and some soil properties of a savanna ecosystem in Nigeria

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The effect of forest fire on natural forest in Southern Guinea Savanna in Nigeria was investigated. The study was carried out in Oro forest reserve in Kwara State, Nigeria. The study site was located in the north-eastern and south-western portions of the reserve. In each location in the forest, one hectare (100 m × 100 m) was divided into 100 plots of 10 m × 10 m. Twenty plots were randomly selected for determining the frequency of burned trees, re-sprouted trees and the numbers of seedling/ha. Soil samples were also collected at three depths: 0 - 5, 6 - 10, 11 - 15 and 16 - 20 cm. Soil samples were taken before burning and one year after burning. The effect of fire on tree species recovery showed that regeneration of *Byrsicarpus coccineus*, *Grewia mollis* and *Butyrospermum Paradoxium* were very encouraging in the burned area. In contrast, *Adenodolichos peniculatus*, *Fadogia pobegunii* and *Terminalia avicenioides* were very sensitive to fire as they failed to regenerate or poorly reproduced in the burned area. Fire had no effect on soil texture except 0 - 5 cm. Soil pH significantly increased available phosphorus increased significantly, whereas, soil organic matter, available acidity and total nitrogen significantly decreased in the burned area. Also, metallic cations (Ca, Mg, K) and cation exchange capacity increased in the burned area. These changes were related primarily to oxidation of the organic matter layer during fire and concurrent changes in the soil environment following fire (e.g. a reduction in organic matter content of the soil, and increased soil pH).

Key words: Guinea Savanna, soil properties, forest fire, Regeneration, *Byrsicarpus cocineus*, *Adenodolichos peniculatus*.

INTRODUCTION

Fire is an important natural disturbance in most forest ecosystems and can lead to rapid changes in soil and biogeochemical cycling, which, in turn can have important implications for long-term ecosystem dynamics (Schmoltdt et al., 1999). Fire resulted in disturbance of many forest lands depending on its severity and forest composition

also; severity and extent of forest fires had a significant effect on seeds regeneration (Lecomte et al., 2005). On the other hand, fire modifies the ecosystem for short, long term and some biota may be adapted to these changes in the ecosystem (Rydgren et al., 2004). In many instances, fire may used for forest management purposes e.g.

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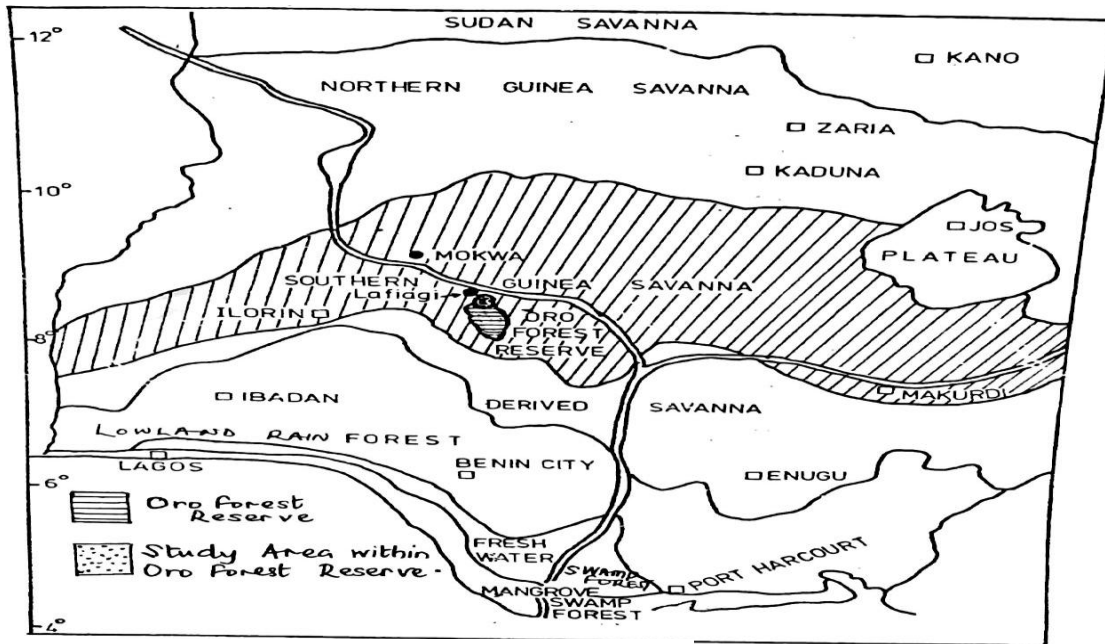


Figure 1. The location of Oro Forest Reserve within the Southern Guinea Savana of Nigeria.

prescribed burning (Bergeron et al., 2002). Basically, there are two types of forest fires, prescribed (controlled) fires and wildfires. Prescribed burning of naturally accumulated forest floor or slash following tree harvest is a standard practiced to reduce fuel levels with the intention of minimizing the extent and severity of wildfire or facilitating germination and growth of desired forest species. They are carried out when soil is moderately moist and thereby show a low level of severity (Wasterd et al., 1990).

It has been stated that logging after fire might have a considerable long term effect on vegetation and diversity in natural forest (Fraser et al., 2004). Spatial fire distribution has been widely used to categorize fire regime (Cui and Perera, 2008). Savanna ecosystems are characterized by the co-existence of carbon rich woody and carbon poor herbaceous plants dominated by grasses. Savannas occur in over 20 countries mostly in the seasonal tropics Nigerian inclusive with a limited distribution in temperate regions (Hutley and Setterfield, 2007).

Frequent and severe fires commonly result in degradation of soil (Anderson et al., 1981) forest fires threatened wild endangered species in Indonesia (Whitehouse and Mulyana, 2004). Fire is capable of exerting serious effects on soil properties (Giacomo, 2005). However, scarcity information is available on the influences of savanna burning on the vegetation and soil properties of southern Guinea savanna zone in Nigeria.

The objective of this study was to investigate the impact of forest fire on tree diversity and its effects on some soil physicochemical properties in the southern

Guinea savanna vegetation of Oro forest reserve located in the southern Guinea savanna zone of Nigeria.

MATERIALS AND METHODS

The field studies were carried out in 2010 at Oro Forest Reserve in Kwara State Nigeria at longitude $08^{\circ}53'E$ and latitude $05^{\circ}22'N$. The reserve is a wood land Savanna of about 5413 ha. The study site was located in the north-eastern and south-western portion of the reserve (Figure 1).

Plot description and samples collection

In each location in the forest, one hectare ($100\text{ m} \times 100\text{ m}$) was divided into 100 plots of $10\text{ m} \times 10\text{ m}$. Twenty plots were chosen for determining the frequency of burned trees, re-sprouted trees and the numbers of seedling/ha. The frequency and numbers of trees before and after were determined in each sample plot using quadrant. Soil samples were also collected at three depths: 0-5, 6-10 and 11-15 and 16-20 cm. Soil samples were taking before burning and one year after burning by wild fire.

A Dutch auger was used to collect soil sample which were carefully kept in well labeled plastic bags and sent immediately to Laboratory for analysis.

Particle size analysis

This was done by hydrometer method (Gee and Bauder, 1986) using sodium hexametaphosphate (calgon) as dispensing agent.

Chemical analysis

The soil samples were dried for few days sieved to pass through 2 mm mesh and chemically analysed. The pH (in water) was

Table 1. Site plant community in the study area.

Species	Density/ha	Rank	Relative density (%)
<i>Acadia nigrescan</i>	17.25	13	1.5
<i>Annona Senegalensis</i>	5.75	19	0.5
<i>Bridelia scleroneura</i>	17.25	13	1.5
<i>Bridelia stenocarpa</i>	46.01	8	4.00
<i>Butyrospermum paradoxum</i>	143.77	3	12.50
<i>Combretum collinumfresen</i>	80.51	4	7.00
<i>Daniellia oliveri</i>	11.50	16	1.00
<i>Detarium microcarpum</i>	230.03	1	20.00
<i>Ficus ingnens</i>	5.75	19	0.50
<i>Grewia mollis</i>	184.03	2	16.00
<i>Lannea kerstingii</i>	5.75	19	0.5
<i>Maytenus senegalensis</i>	11.50	16	1.00
<i>Prosopis africana</i>	5.75	19	0.50

Table 2. Population dynamics of selected species of regenerating plants in permanent quadrant.

Species	Population sizes												
	J	F	M	A	M	J	J	A	S	O	N	D	J
<i>Adenodolichos Paniculatus</i>	25	26	35	30	30	28	26	26	22	20	16	10	0
<i>B. paradoxum</i>	89	97	109	105	75	75	75	24	72	72	70	68	4
<i>Byrscarpus coccineus</i>	115	123	122	101	166	154	142	35	25	15	12	7	0
<i>D. microcapum</i>	40	39	42	33	39	33	33	36	23	20	15	10	5
<i>Fadogia pobeguini</i>	15	18	20	20	22	18	18	18	14	14	14	6	4
<i>G. mollis</i>	80	82	79	57	68	60	56	58	56	50	40	38	5
<i>M. seregalansis</i>	54	58	56	41	55	44	42	45	30	25	22	10	2
<i>Terminalia aricenioides</i>	48	51	57	44	60	54	52	51	52	42	40	28	2
<i>Piliostigma thonningii</i>	48	46	48	43	42	40	35	33	32	25	22	20	4
Total species	514	540	568	474	556	512	474	362	323	278	251	177	26

determined in a 1:2.5 solution (soil: distilled water) and was measured with a standard glass electrode. The organic carbon content of the soil was determined according to Walkley and Black (1965) dichromate oxidation method. The percentage organic matter content in the samples was calculated by multiplying the values of organic carbon by the conventional Van Bammeller factor of 1.724. Total soil nitrogen was determined by Macro kjeldahl methods (Bremner, 1965). Available phosphorus was extracted using Bray II method (Bray and Kurtz, 1965) and determined by spectrophotometer.

Exchangeable Na, K, Ca and Mg were extracted with BaCl₂ 0.1 M (Hendershot, et al., 1993) and analysed by atomic absorption. Exchangeable acidity was determined from 0.1 NaCl extracts and titrated with 1.0 N HCl.

Cation exchangeable capacity (CEC) was determined by summing up total exchangeable bases (TEBS) and total exchangeable acidity (TEA), which the base saturation = TEBS/CEC × 100, where TEBS = Total exchangeable bases, and CEC = Cations Exchangeable capacity.

Statistical analysis

The data were analyzed using two way analysis of variance (ANOVA) and means were separated by Duncan New Multiple

Range Test and student t- test was used to test the level of significance of some properties in the pre and post burn periods at 5% level.

RESULTS

Burning and regeneration

In the study area, *Detarium microcarpum* had the highest density/ha of 230.03 and relative density of 20.00, while *Annona selegalensis*, *Ficus ingnens*, *Lannea kerstingii* and *Prosopis africana* had the least density/ha with relative density of 0.5 (Table 1).

It is apparent that *Adenodolichos paniculatus* and *Byrscarpus coccinets* were most susceptible to forest fire. This is evident in the number of re-spouting of trees which were reduced to 0.0% (Table 2). However, fire also triggered-off regeneration more in *Brysicarpus coccineus*, followed by *Butyrospermum paradoxum* than any other species in the in the study area (Table 2).

The forest fire annually occurs between November and

Table 3. Effect of fire on soil texture.

Vegetation	Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)
Southern guinea savanna	0 -5	82.30 ^a	9.36 ^a	8.35 ^a
	6 - 10	84.90 ^a	7.30 ^a	7.80 ^{ab}
Before burning	11 -15	82.75 ^a	9.73 ^b	7.53 ^{ab}
	16 - 20	85.43 ^a	7.40 ^a	7.53 ^{ab}
After burning	0 - 5	83.31 ^b	10.37 ^{ab}	6.26 ^{bc}
	6 - 10	84.90 ^a	8.37 ^{ab}	6.73 ^{bc}
	11 - 15	82.75 ^a	9.73 ^b	7.53 ^{ab}
	16 - 20	85.43 ^a	7.80 ^a	7.53 ^{ab}

Means followed by the same letter in a column in a forest are not significantly different at $P \leq 0.05$.

January. The most resistant tree species are *Detarium microcarpum* and *Fodogia probeguinic* which reduced from 10 to 5 and 6 to 4 respectively. It is also noted that fire did not affect them in term of regeneration.

Soil texture

Fire did not affect soil texture at the level below 5 cm. However, effect of fire was found in the top layer (0-5 cm). This was indicated by the fact that sand, silt and clay (%) were not different when compared together at the sampling level below 5-10, 10-15 and 15–20 cm in unburned and burned sites (Table 3)

Soil pH, soil organic matter and soil N

Soil pH increased significantly ($p \leq 0.05$) from 5.0 to 6.3 at 0 - 10 cm depth and 5.7 to 6.2 to 6.3 at 11 - 20 cm depth for both pre-burn and post – burned plots, soil pH was lower at 10 - 20 cm depth. The values were statistically different at both sampling depths (Table 5). The soil nitrogen was lower in the post-burned plots with the values decreased from 0.09 to 0.05% at 0 - 10 cm depths. While the values decreased from 0.07 to 0.04% at 10 - 20 cm sampling depths ($P \leq 0.05$). It was also noted that, the values of soil nitrogen was lower at 10 – 20 cm depth.

Available phosphorus

Available phosphorus was higher in post-burned plots at all sampling depths and increased from 12.01 to 22.50 mg/kg at 0 - 10 cm depth. At 10 - 20 cm depth, it increased from 11.4 to 21.5 mg/kg, (Tables 4 and 5).

Exchanged cations, aluminum and cation exchange capacity

Exchangeable calcium was significantly ($P < 0.05$) higher

in the post-burned plots at all sampling depths and increased from 3.90 cmol/ kg of soil to 4.20 cmol/kg of soil at 0 - 10 cm depth, the values increased from 1.41 cmol/kg of soil to 2.42 cmol/kg of soil at 10 - 20 cm depths and was statistically different (Tables 4 and 5). Exchangeable magnesium was also higher in the post burned plots in all sampling depths and not significantly different and increased from 1.20 cmol/kg of soil to 2.95 cmol/kg of soil at 0-10 cm depth. While at 10-20 cm depth, it increased from 1.0 cmol/kg of soil to 1.80 cmol/kg of soil. Exchangeable potassium values did not show any significant different in all the sampling depths and but higher in the post-burned plots. Exchangeable aluminum decreased from 2.5 cmol/kg of soil to 1.5 cmol/kg of soil at 0 - 10 cm depth and decreased from 0.30 cmol/kg of soil to 0.15 cmol/kg of soil at 10 - 20 cm depth and did not statistically different (Table 5).

The cation exchangeable capacity increased from 11.10 cmol/kg of soil to 12.65 cmol/kg of soil after fire at 0 - 10 cm depth as well as, increased from 3.16 cmol/kg of soil to 4.97 cmol/kg of soil after fire at 10 - 20 cm depth.

DISCUSSION

Very sketchy studies have investigated factors that affect tropical savanna forest (Sukumar et al., 2005). Climate change, animals and fire are some factors that affected vegetation dynamics in those ecosystems (Silori and Mishra, 2001). As forest fire could be useful or destructive to the forest, while tree species vary in their responses to forest fires. Prescribed fire may play an important role in sustainable management of forest subjected to wild fires (Matthias et al., 2009). *B. coccineus* benefited from fire, as was indicated by the substantial increase of regeneration and the fact that considerable number of *B. coccineus*, *Grawia mollis* as well as *B. paradoxium* responded after fire (Table 2). Hein et al. (2010) mentioned that in mixed forests, the probability is low for succession after fire. In hard seeded legume, heat from fire may break the hard seed coat and

Table 4. Comparison of the pre and post burning soil chemical properties at 0-10cm depth by student's t-test.

Properties	Pre-burning	Post-burning	t-test values
pH	5.9	6.3	2.94*
OC	0.8	0.58	2.34*
OM	1.38	0.8	2.36*
N	0.09	0.05	2.44*
C/N	0.6	0.69	2.31*
Ex. Ca	3.9	4.2	2.80*
Ex. Mg	1.20	2.95	1.02 ^{ns}
Ex. K	3.5	4.00	1.20 ^{ns}
Ex.A1	2.5	1.5	0.67 ^{ns}
CEC	11.10	12.65	0.91 ^{ns}
Av. P	12.01	22.5	2.12*

*Significant at ($p \leq 0.05$), ns = not significant at ($p \leq 0.05$), OC = organic carbon, OM = organic matter, Ex. Ca = exchange calcium, Ex. Mg = exchange magnesium, Ex. K = Exchange potassium and CEC = cation exchange capacity.

Table 5. Comparison of the pre and post burning soil chemical properties at 0-20 cm depth by student's t-test.

Properties	Pre-burning	Post-burning	t-test values
pH	5.2	6.2	2.55*
OC	0.7	0.4	2.4*
OM	1.21	0.69	2.28*
N	0.07	0.04	2.24*
C/N	6.2	5.5	2.15*
Ex. Ca	1.41	2.42	2.11*
Ex. Mg	1.0	1.8	1.15 ^{ns}
Ex. K	0.45	0.60	0.91 ^{ns}
Ex.A1	0.30	0.15	1.11 ^{ns}
CEC	3.16	4.97	1.04 ^{ns}
Av. p	11.4	21.5	2.24*

*Significant at ($p \leq 0.05$), ns = not significant at ($p \leq 0.05$), OC = organic carbon, OM = organic matter, Ex. Ca = exchange calcium, Ex. Mg = exchange magnesium, Ex. K = Exchange potassium and CEC = cation exchange capacity.

allow water absorption by the seeds and hence dormancy is broken (Mballo and Witkowski, 1997). Removal of stem tips and young leaves by fires, for instance, may allow dormant buds to develop into new shoots. It appears that the presence of *B. coccineus*, *G. mollis*, *B. paradixium* and *Maytenus senegalensis* in fire prone ecosystem, as the case in the present study, facilitated its adaptation to fire in various ways including thickening of bark, ability to respond and dispersing of seeds. Hare (1965) mentioned that some trees have thick insulating bark, which protected them from the scorching heat of surface fires. In contrast, *Adenodolichos peniculatus*, *Fadogia pobeguunii* and *Terminalia avicenioides* in the present study, were very sensitive to forest fire since they failed to regenerate or poorly recovered in the burnt soils, *Detarium microcaupum* and *Piliostigma thonningii* were

more or less negatively sensitive to fire in terms of regeneration and recovery after forest fire. Species diversity was considerably affected by forest fires, although this effect dependent on the severity of fire (Kodandapani et al., 2008).

Fire has no significant effect on soil texture in the studied locations. However sand content increased in the post-burned plots at the 0-5cm depth which might be due to destruction of soil organic matter. Soil pH increased significantly after fire in all locations studied. This finding is in line with the earlier studies (Creighton and Santelies, 2003; Ekinci, 2006). Giacomo (2005) reported that soil pH in non-calcareous soils increased after fire because of the release of the alkaline cations (Ca, Mg, K and Na) bound to the organic matter sites and a decreased in organic acids produced during the biological oxidation

of organic matter (Wells, 1971). One pertinent implication of increased pH in the burned soils is the possibility of increasing nitrogen fixation under environmental conditions favouring both symbiotic and free-living nitrogen fixers.

The loss of soil organic matter represent one of the more obvious alteration to soil physical properties after a fire, significant reductions in soil organic matter were recorded in all locations studied during post-burned. The effect of fire on organic matter comprises volatilization, charring or oxidation (Giovannini et al., 1988). Fire causes burning and or total removal of organic matter (Simard et al., 2001). The decreased levels of soil organic matter observed in the burned plots in this study suggest important ramifications for other soil biological, chemical and physical properties. However, it is not likely that litter fall rates in post-burned forests will approximate those on pre-burned sites for sometimes and thus, soil organic matter content in post-burned plots will more than likely remain low for sometimes period. There was a significant reduction in total soil nitrogen after fire at all sampling depths in the study locations, which is in agreement with Neff et al. (2005). Forest floor layers are a major reservoir of soil N and their removal during forest fires can cause significant reductions in it (Driscoll et al., 1999). A likely explanation for decreased soil nitrogen in the post burning plots is through increased leaching of NO_2 during the rainy season that is characteristic of this area. Consumption of the litter layer during fire likely leads to increased infiltration rates for burned soils in rainy season, than in turn could lead to increased leaching of nitrogen in the form of NO_2 .

Significant increase in phosphorus might be attributed to the fact that burning converts some of the organic pool of soil P to orthophosphate (Cade-Menun et al., 2000). Also, at a large portion of the nutrient reserve in most forest ecosystems is contained in the organic material on the forest floor and that distributed throughout the profile (Wagner and Wolf, 1998). Nutrients contained in these organic materials are slowly released into the soil through biological oxidation is decomposition (Fuhrmann, 1998).

Exchangeable cation such as Ca, Mg and K were higher after fire, which is in agreement with Adams and Boyle (1980) who reported increase in alkaline cations after fire. Exchangeable aluminum was lower in the post-burned soil due to the conversion of aluminum into complex oxides, thereby reduces soil acidity after fire.

Conclusion

The present study revealed that fire encourages fire tolerant tree species and discouraged fire sensitive species as reported by Ivanauskas et al. (2003). *D. microcarpum* and *F. pobeguinic* have relatively thick and fissured barks and this might explain their resistance to fire relatively to *A. peniculatus* and *B. caccineus* which have relatively thin barks, probably the reason for their

susceptible to fire. Effects of wild fire on soil properties in this highly fragmented ecosystem are not well conceived. Data from this study suggest soil properties vary in their response to fire; soil pH and available phosphorus were higher following fire. In the same vein, exchangeable cations such as Ca, Mg and K were more at post fire while the exchangeable acidity became low during post-fire period, changes in soil properties were more than likely a result of the oxidation of the litter layer during the fire and concurrent changes in the soil environment following the fire. Nitrogen content decrease was due to leaching of NO_3 while phosphorus increase might be due to changing of organic phosphorus to the available form. Organic matter content of the soils was lower in post-fire plots due to the destruction of organic layer in the forest. The savanna burning in Nigeria southern Guinea savanna is annual one, which is used as a cheaper means of land clearing for planting seasons. However, we found that fire can significantly affect some soil chemical and physical properties as well as plant species composition (Litton and Santelices, 2002), in these native forests. In light of these discoveries, we recommend that more emphasis should be placed on preventing and fighting human caused fires in native vegetation, aggressive public awareness on the effect of forest fire and fire breaks should be established around native forest to prevent further degradation of this ecosystem. In addition, further research is needed on long term effects of fire on Guinea savanna in Nigeria.

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