SHORT-TERM EFFECTS OF EARLY-SEASON FIRE ON HERBACEOUS COMPOSITION, DRY MATTER PRODUCTION AND SOIL FERTILITY IN GUINEA SAVANNA, NIGERIA

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Abstract: The ecological impact of fire regimes on plant diversity and soil fertility has become a subject of intense discussion, especially in savannas where recurring incidences are common. This study assessed the short-term effects of early-season fire on herbaceous composition, dry matter yield and soil fertility in the Guinea savanna belt of Nigeria. Data on ground cover, dry matter yield (DMY) in plants and concentrations of C, N, P, K, Ca and Mg in soil were collected from 10 delineated subplots in the burned and unburned zones of four sites after annual wildfire had occurred. Ground cover was significantly higher in the burned zones, increasing progressively from January to April (dry season). Eleven herbaceous species in addition to 2 tree seedlings occurred and represented families of Asteraceae, Cyperaceae, Fabaceae and Poaceae. *Digitaria nuda*, *Brachiaria lata*, *Daniellia oliveri* and *Aeschynomene indica* were limited to the burnt zones while *Cyperus tuberosus*, *Mariscus alternifolius* and *Rottboellia cochinchinensis* were restricted to the unburned zones. DMY ranged from 0.32 g m^{-2} (*Desmodium tortuosum*) to 52.96 g m^{-2} (*Megathyrsus maximus*). Average biomass in the burned and unburned sites was 35.86 g m-2 and 28.42 g m-2, respectively. Soil C, N and P concentrations decreased (positive deterioration index - DI), while those of K, Ca and Mg improved (negative DI) in the burned sites. Burning altered the growth (ground cover) and composition of plant species in the short term, and could significantly influence soil nutrient dynamics in the long term, especially with recurring fire events.

Key words: dry matter yield; fire; herbaceous composition; savanna; soil nutrients

INTRODUCTION

Africa is often referred to as a 'fire continent' (Trollope and Trollope, 1996) because of widespread anthropogenic fires that annually burn the savanna vegetation (Sheuyange et al., 2005). Fire is believed to be an important determinant in the development and structure of savanna vegetation (Getzin, 2002), as species composition, net primary production and soil nutrient dynamics are influenced by the process (Pivello et al., 2010). The importance of fire in determining the composition, structure and function of these ecosystems (Bond and Van Wilgen, 1996) is probably the oldest issue in savanna ecology that remains contentious (Scholes and Walker, 1993). Other fire-associated effects, such as changes in soil temperatures and moisture, organic matter consumption and soil modifications, including changes in water holding capacity, infiltration and intensified erosion processes, have been reported (National Wildlife Coordinating Group, 2001; Neary et al., 2005).

The consequences of fire-induced structures are not a straightforward issue but quite complicated and often disputable (Getzin, 2002) as some plant species in fire-affected environments require fire to

germinate, establish or reproduce (obligate seeders), while others die from the heat of fire (DeBano and Conrad, 1978). Several studies predicted a shift in savanna structure due to frequent fires (Scholes and Archer, 1997) or absence of periodic fires (Trollope, 1982; Knoop and Walker, 1985; Oba et al., 2000). Huston (1994) argued to the contrary, that fires of high frequency often do not work as a disturbance at all, as plant species richness changes little due to the underground root systems and storage organs of species to survive the fire with only the loss of aboveground biomass. Silva et al. (1991) also reported that many plants are dependent on fire, to the degree that they become locally extinct in areas protected from fire. Fire is believed to favor some soil nutrients via ash deposition (Coutinho, 1990; Neary et al., 2005) while reducing the levels of others via a variety of mechanisms, including oxidation, volatilization, increase erosion and leaching (Harvey et al., 1987).

As anthropogenic burning has become predominant (DeBano and Conrad, 1978), the ecological impact of such fire regimes has become the subject of intense discussions (Purcell and Stephens, 2005; Bird et al., 2008; Smit et al., 2010), especially in Nigeria's savanna where such fires (early season) are set by herdsmen to improve pastures for their cattle (Adegbola and Onayinka, 1976). With millions of hectares being burnt annually, questions as to the obvious benefits in terms of herbage composition and production, as well soil fertility effects need to be asked in order to change or maintain the fire regime. In this light, the present study examines the short-term effects of early-season fire on herbaceous species composition, dry matter production and soil fertility in the Guinea savanna belt of Nigeria.

MATERIALS AND METHODS

Description of study area

The study sites fall within the University of Ilorin campus, Ilorin, north-central Nigeria. The area lies between 8.50º N and 4.55º E and elevation ranges of 273 m to 364 m a.s.l. The region falls into a southern Guinea savanna zone classified as woodland savanna

vegetation of *Daniellia oliveri*, *Vitellaria paradoxa*, *Prosopis africana*, *Parkia biglobosa*, with the understory dominated by annual grasses (Keay, 1953; Jaiyeoba and Essoka, 2006). The geology of the area is characterized by an underlying of the Nigerian Basement Complex of groups of igneous and metamorphic rocks of Precambrian age (Alao, 1982). The soils are lateritic consisting of three layers (Alao, 1982) classified as Luvisols according to the FAO/UNESCO (FAO, 2013) and Alfisols according to the USDA soil order (Soil Survey Staff, 1975). The soil is composed of sandy loam and sandy clay loam textures. The annual rainfall ranges from 300-1200 mm, while the average temperature of the area, according to Ajadi et al. (2011), varies between 33°C and 34°C during the year with distinct rainy and dry seasons. Burning in the area is uncontrolled and takes place at any time from late November (onset of the dry season) to early April (beginning of rainy season) (Adegbola and Onayinka, 1976). Site selection for the study was done after the annual wildfire that occurred with moderate intensity on December 18, 2012.

Site delineation, data collection and chemical analysis

Four sites (A, B, C and D) each with burned and unburned zones selected for the study were georeferenced using a Garmin eTrex Legend HCx device (Table 1). The choice of the sites was informed by the availability of herbaceous plant communities with a fire exclusion zone measuring ≥25 m² that were opposite or adjacent to the burned zones. Each site was systematically delineated into 10 subplots (1-m² quadrat) within the burned and unburned zones in order to monitor monthly ground coverage (expressed in %) of the plant species in each subplot using a 1-m² wooden quadrat with 9 × 9 regular grids. The plant materials in the

Table 1. Geoposition of four sites selected for study after wildfire of December, 2012 within the University of Ilorin campus, Nigeria.

Site	Latitude	Longitude	Elevation (above sea level)
A	8°28'42.48" N	4°40'40.28" E	345 m
B	8°28'42.32" N	4°40'42.98" E	340 m
C	8°28'55.65" N	4°40'42.21" E	344 m
D	8°28'55.61" N	4°40'46.74" E	351 m

unburned plots and the lightly burned plants within the burned zones were clipped to rid the surface of any plant matter after a site had been demarcated. Data collection on the ground cover (on monthly basis) started in January 2013 and ended in April 2013, prior to the start of the rainy season in Ilorin. Prior to determination of biomass in April, all plant species within the subplots were identified to species level to determine the floristic composition within the study sites. The aboveground plant materials within the subplots were then clipped, sorted into component species, and oven-dried at 80°C to constant weight to obtain the dry matter yield and biomass. DMY was determined by weighing the oven-dried samples of individual plant species separately. The dried plant materials from a subplot were combined to determine the biomass.

One soil sample was collected in each subplot (at 0-15 cm depth) in the burned and unburned zones using a stainless soil auger at the end of the study in April, 2013. A total of 10 subsamples were collected in each of the zones (burned and unburned) so that 40 samples were collected altogether from all the burned and unburned sites. The soil samples were air-dried, and sieved through a 2-mm mesh prior to chemical analysis of total organic carbon, total nitrogen, available phosphorus, potassium, calcium and magnesium.

Soil organic carbon (%) was calculated from soil organic matter (SOM) after wet combustion (Walkley and Black, 1934). SOM (%) was determined by weighing 1 g of soil into a 500-mL volumetric flask, then 10 mL 1 N $K_2Cr_2O_7$ was added and swirled gently to disperse the soil in the solution. Twenty mL of concentrated H_2SO_4 was added, swirled to mix and heated to 135°C for 30 s. The solution was cooled for 20-30 min in a fume cupboard and made up to 200 mL with deionized water. Four (4) drops of Ferroin indicator solution were added to the resulting solution and then titrated with $FeSO_4$. A blank solution (without soil) and quality control standard were prepared in a similar way to standardize the dichromate. The endpoint was marked by a reddish-brown solution.

Total nitrogen was determined by macro Kjeldahl method of digestion, distillation and back titration as adopted by Bremmer (1965). One g of soil was weighed in a Kjeldahl tube with 10g $CuSO_4$-Na_2SO_4 mixture and 2-3 anti-bumping granules (fused alumina) were added. Twenty-five mL of concentrated H_2SO_4 was also added. The mixture was stirred thoroughly and then heated for 30 min until a blue-green solution was visible. The digest was left to cool to 40°C, after which it was transferred to a 100-mL conical flask and filled to volume with distilled water. Five mL of the digest was pipetted into the distillation unit and 5 mL of NaOH solution was added. Five mL of 2% H_3BO_3 was measured into a 100-mL conical flask to receive the distillate. Ten mL of the distillate (green in color) was collected in the receiving conical flask and titrated with 0.01M HCl until the color changed from green to purple. Blank determinations were carried out for all samples.

The Bray and Kurtz (1945) method was used to analyze the available phosphorus in the samples. Thirty-five mL of Bray-P1 solution (0.025N HCl+0.03N NH_4F) was added to 5 g of sieved soil in a conical flask and shaken mechanically for 1 h and then filtered. Five mL of the filtrate was pipetted into a conical flask; 4 mL of solution prepared by dissolving 1.056 g of ascorbic acid in 200 ml of molybdate-tartrate solution was then added to the pipetted filtrate. The resulting solution was made up to 30 mL with distilled water and allowed to stand for 30 min for color development prior to absorbance determination at 400 nm. Exchangeable K, Ca and Mg were extracted by weighing 2 g of the sieved dried soil into an extraction flask and adding 20 mL of 1 N neutral ammonium acetate (NH_4OAc, pH 7.0). The solution was then shaken vigorously for 5 min and filtered. The filtrate was analyzed for K using a flame photometer at 767 nm. Ca and Mg were determined using an atomic absorption spectrometer at 422 nm and 371 nm, respectively.

Statistical analysis and model

The normality test of the variables revealed the data were normally distributed, and the mean parameters of burned and unburned zones were compared using Student's t-test with the inferences drawn at α=0.05 level. Data on percentage ground cover were presented using

a boxplot in SPSS ver. 17 for Windows, while those of average biomass, percentage soil nutrient composition and deterioration index were presented with bar charts in Microsoft Office Excel 2013. The deterioration index (DI) of Ekanade (1991) as adopted by Awotoye et al. (2011) was used to assess the rate of deterioration/ improvement of soil nutrients due to fire incidence.

$$Deterioration\ index, DI = \frac{X - X_i}{X} \times 100$$

where X = mean value of soil parameter in control/ Unburned site (reference site); Xi = mean value of soil parameter in compared site. Note: a positive value indicates deterioration and a negative value indicates improvement.
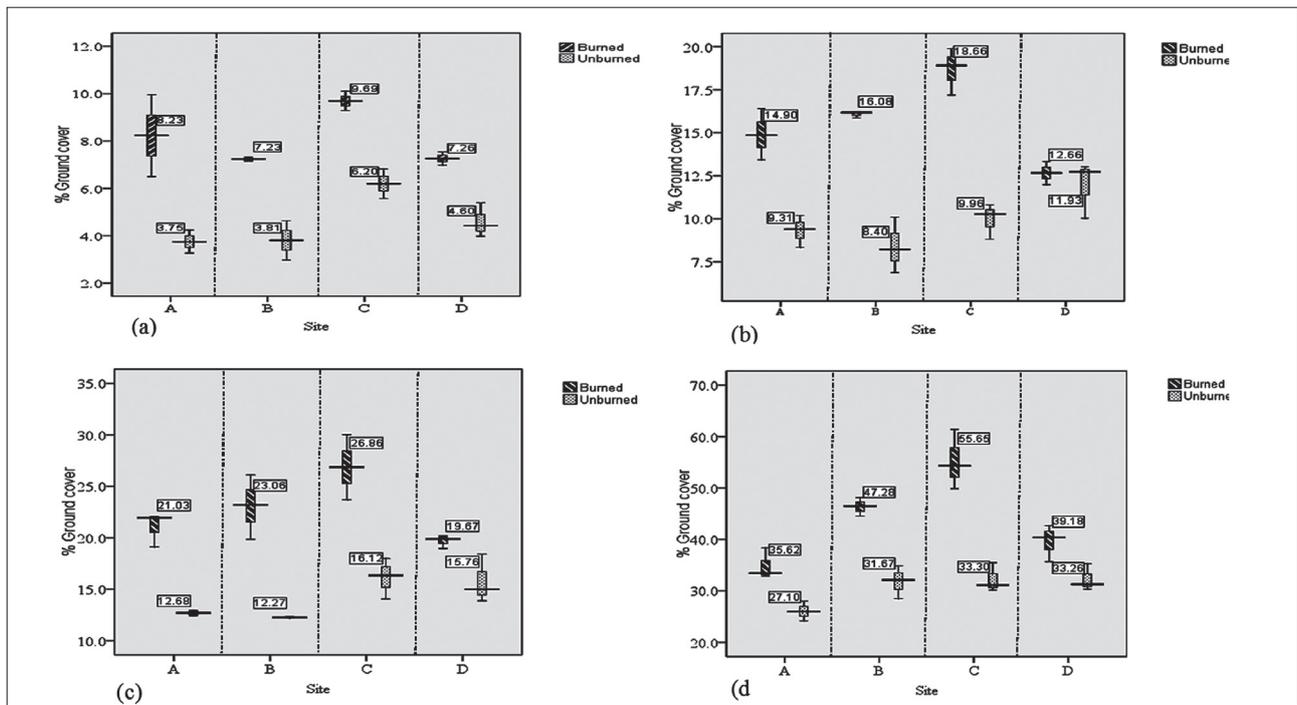
RESULTS AND DISCUSSION

Effect on ground cover

The ground cover of plants was significantly higher (p<0.05) in the burned zones than in the unburned zones in all the sites in January, with the high-

est ground coverage in the burned zone of Site C (9.69%) and the lowest in the unburned zone of Site A (3.75%) (Fig. 1a). Ground coverage of plants in February, March and April was also higher in the burned zones, except for Site D in February and April, where no significant difference was noted (Figs. 1b-d). The burned zone of Site C had the highest ground coverage in February (18.66%), March (26.86%) and April (55.65%) (Figs. 1b-d).

Fire constitutes a disturbance in any ecosystem (Jacobs and Schloeder, 2002; Anguyi, 2010), but the effect depends on species composition, season and severity of burning. Apart from survival as seeds, annuals in frequently burned vegetation grow rapidly to complete their reproduction before the next fire (Russell-Smith et al. 1998). The higher ground cover in the burned zones in this study corroborates that of Nepolo and Mapaure (2012). Fire is reported to stimulate tillering in tropical grasses (Edroma 1984), and accounts for the periodic dry season fires by herdsmen in a bid to stimulate forage production (Adegbola and Onayinka 1976). Boyd and Bidwell (2002) also reported that an-

Fig 1. Ground cover of plants (%) in burned and unburned zones of the four selected sites in (a) January (b) February (c) March and (d) April. Note: the values in boxes are the mean (n=10).

nual fires increase canopy cover of rhizomatous perennial grasses as well as those of annual and perennial forbs, regardless of the period of event.

It is possible the effects of fire stimulated the sprouting and luxuriance of some plant species in the burned zones, thereby explaining the higher ground cover compared to that of the unburned zones in this study. Apart from fire stimulating the growth of vegetative/reproductive buds in resprouting species, it activates dormant seeds in the soil and influences species composition and ground cover. The resprouting of grass tillers following fire is very possible and dependent upon the availability of growing point location (reproductive buds or bud primordia), the subsurface distribution and fire severity (Bruhgell and Tegart, 2014; DeBano and Conrad, 1978). These morphological characteristics, combined with fire severity, typically determine the number of bud primordia that survive fire (Bruhgell and Tegart, 2014; Vogl, 1974). Most bud primordia of the resprouters survived, possibly because the heat of the fire was less intense (Neary et al., 1999). Grassland fires are generally less intense due to the low

growth, rolling topography and the presence of winds, preventing heat build-up by the flames (Certini, 2005; Vogl, 1974), and thus reducing the damage on the belowground growth and soil seedbank. Fire disturbance has been reported to favor species that have traits allowing them to establish and grow rapidly, as there is also the possibility of fire removing a higher proportion of invasive biomass that could restrict growth in unburned sites (Hoffmann et al., 2009).

Effect on species composition and dry matter production

A total of 13 plant species, consisting of 11 herbaceous species in addition to 2 tree seedlings were encountered. The species were distributed among the plant families of Asteraceae, Cyperaceae, Fabaceae and Poaceae. Four species, *Albizia zygia, Brachiaria alata, Daniellia oliveri* and *Mimosa pigra*, were restricted to the burned zones. The unburned zones also had three species (*Cyperus tuberosus, Mariscus alternifolius* and *Rottboellia cochinchinensis*) not observed in the burned zones (Table 2). These species were probably damaged

Table 2. Species composition and dry matter yield (g m⁻²) of plant species in burned and unburned zones across four sites.

				Dry matter yield (g m⁻²)							
		Life	Family	Site A		Site B		Site C		Site D	
S/No.	Species	Form		B	U	B	U	B	U	B	U
1	*Aeschynomene indica* L.	H	Fabaceae	-	-	2.01	1.50	11.31	-	4.24	1.67
2	*Albizia zygia* (DC.) J.F. Macbr.	TS	Fabaceae	-	-	2.50	-	-	-	-	-
3	*Daniellia oliveri* (Rolfe) Hutch. & Dalz.	TS	Fabaceae	-	-	-	-	1.90	-	-	-
4	*Desmodium salicifolium* (Poir.) DC.	H	Fabaceae	-	1.34	12.07	5.75	-	-	1.45	-
5	*Desmodium tortuosum* (Sw.) DC.	H	Fabaceae	12.55	5.15	2.89	2.38	0.32	0.44	-	-
6	*Mimosa pigra* L.	H	Fabaceae	-	-	1.87	-	-	-	-	-
7	*Chromolaena odorata* (L.) King & H.E. Robins.	H	Asteraceae	-	-	-	-	3.23	7.98	-	-
8	*Cyperus tuberosus* Rottb.	H	Cyperaceae	-	-	-	-	-	-	-	5.75
9	*Mariscus alternifolius* Vahl	H	Cyperaceae	-	-	-	-	-	-	-	1.67
10	*Rottboellia cochinchinensis* (Lour.) Clayton	H	Poaceae	-	-	-	2.00	-	-	-	10.19
11	*Brachiaria lata* (Schumach.) C.E. Hubb.	H	Poaceae	-	-	-	-	1.46		0.66	
12	*Digitaria nuda* Schumach.	H	Poaceae	3.47	3.06	4.44	7.48	1.11	-	5.25	8.05
13	*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs	H	Poaceae	52.96	39.70	30.09	24.00	20.29	21.41	40.09	28.56

Keys: B – Burned zone; U – Unburned zone; H – Herb; TS – Tree seedling.

by the heat of the fire in the burned zones. Four plant species were found in Site A with *Desmodium tortuosum*, *Digitaria nuda* and *Megathyrsus maximus* common to both burned and unburned zones, while the unburned zone also had *Desmodium salicifolium* (Table 2). Of all plant species in Site A, *Megathyrsus maximus* had the highest DMY with 39.70 g m^{-2} and 52.96 g m^{-2}, respectively, in the unburned and burned zones (Table 2). Five of the 8 species encountered in Site B were common to both the burned and unburned zones (Table 2). *Albizia zygia* and *Mimosa pigra* occurred in only the burned zone, while *Rottboellia cochinchinensis* occurred in the unburned zone. *Megathyrsus maximus* had the highest DMY in both burned (30.09 g m^{-2}) and unburned zones (24.00 g m^{-2}) of Site B. *Mimosa pigra* (1.87 g m^{-2}) and *Aeschynomene indica* (1.50 g m^{-2}) had the least DMY in burned and unburned zones, respectively. Of the 7 species encountered in Site C, *Chromolaena odorata*, *Desmodium tortuosum* and *Megathyrsus maximus* were common to both burned and unburned zones. *Digitaria nuda*, *Brachiaria lata*, *Daniellia oliveri* and *Aeschynomene indica* that occurred only in the burned zone had DMYs of 1.11, 1.46, 1.90 and 11.31 g m^{-2}, respectively (Table 2). *Megathyrsus maximus* in the unburned zone of Site C had the highest DMY (21.41 g m^{-2}) while *Desmodium tortuosum* in the burned zone had the least DMY (0.32 g m^{-2}). Eight plant species occurred in Site D, with *Aeschynomene indica*, *Digitaria nuda* and *Megathyrsus maximus* common to both the burned and unburned zones. *Brachiaria lata* (0.66 g m^{-2}) and *Desmodium salicifolium* (1.45 g m^{-2}) were seen in the burned zone only while *Cyperus tuberosus* (5.75 g m^{-2}), *Mariscus alternifolius* (1.67 g m^{-2}) and *Rottboellia cochinchinensis* (10.19 g m^{-2}) were found in only the unburned zone of Site D. The average biomass in the burned and unburned zones was 35.86 g m^{-2} and 28.42 g m^{-2}, respectively (Fig.2). These values were, however, lower than the 63.65 g m^{-2} (burned area) and 29.18 g m^{-2} (unburned area) reported by Nepolo and Mapaure (2012) for the savanna grassland of Namibia due to variations in environmental factors and differences in the inherent growth rate of the plant species.

The occurrence of seedlings of tree species such as *Daniellia oliveri* and *Albizia zygia* seems unquestionable, as tree-grass co-existence forms an important
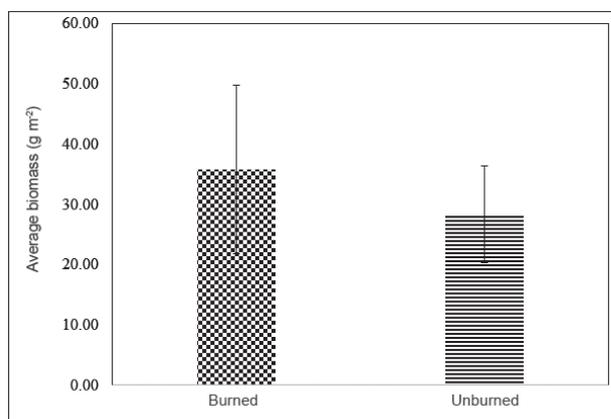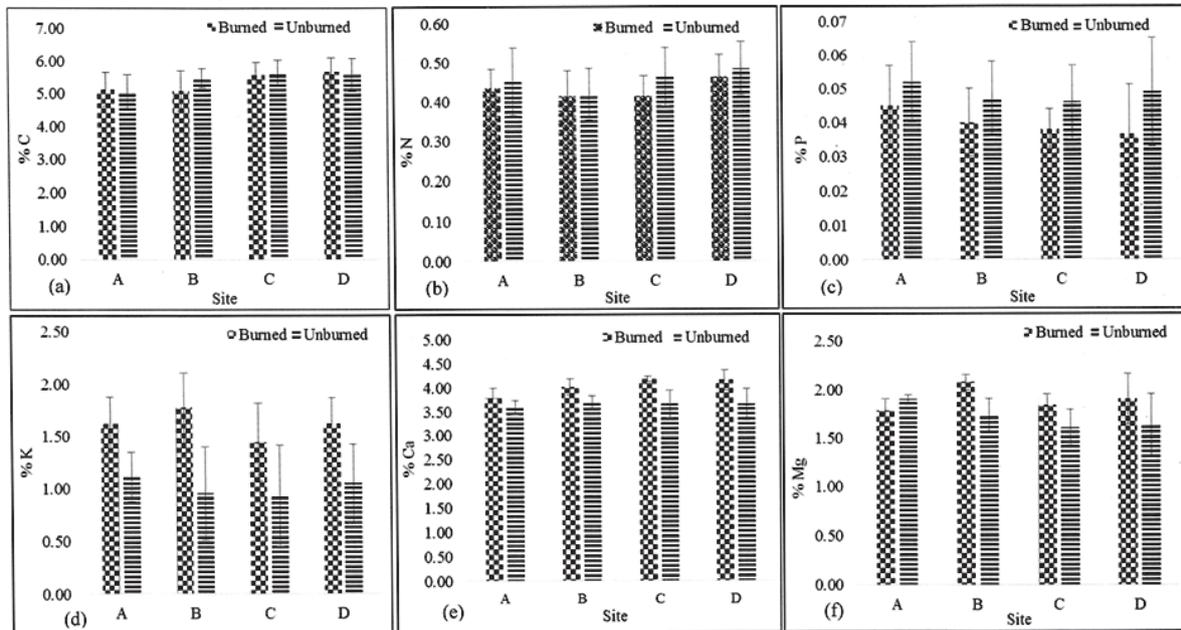

Fig. 2. Average biomass (g m^{-2}) at burned and unburned sites.

feature of savanna vegetation (Rodríguez-Iturbe et al., 1999). The species abundance and higher biomass of the burned zones confirm the stimulatory effect of fire on the growth of some species. This is evident as species such as *Albizia zygia, Brachiaria lata, Daniellia oliveri* and *Mimosa pigra* occurred only in the burned zones. The dominance of species like *Megathyrsus maximus*, *Digitaria nuda* and *Desmodium tortuosum* across the sites reveals their adaptation to the varying environmental conditions in this ecosystem. Pyke et al. (2010) reported that fire changes plant communities by reducing the dominance of some plant species while enhancing the abundance of others. Despite avoiding tree stands in the choice of sites, seed dispersal and the activation of previously accumulated seedbanks in the soil possibly accounted for the occurrence of *Daniellia oliveri* in our sampling. The particularity of *Rottboellia cochinchinensis*, *Cyperus tuberosus* and *Mariscus alternifolius* in only the unburned zones could be due to the fire-sensitivity of these species, as heat damage to the seeds of itchgrass (*Rottboellia cochinchinensis*) has earlier been reported by Bolfrey-Arku et al. (2011), where germination was reduced by 50% at temperatures of 151°C and no seeds germinated at ≥180°C.

Effect on soil fertility

There were no significant differences between the burned and unburned zones for the soil nutrients assessed (Figs. 3a-f). Soil organic carbon content in the burned and unburned zones was not statistically dif-
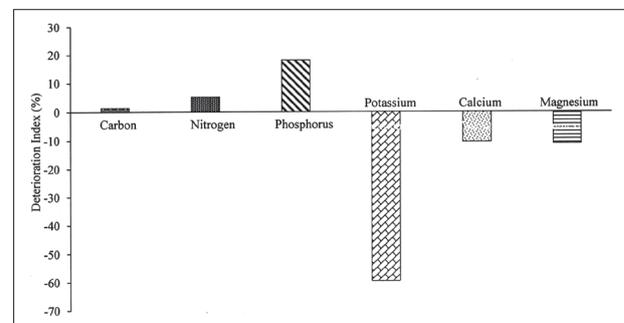
Fig 3. Percentage composition of (a) carbon (b) nitrogen (c) phosphorus (d) potassium (e) calcium and (f) magnesium in burned and unburned soils of four sites. Note: n=10.

ferent (p>0.05) in Sites A, C and D, but was lower in the burned zone (5.08%) of Site B than the unburned zone (5.48%) (Fig. 3a). Total N averaged between 0.41% and 0.49%, with lower levels in the burned zones than in the unburned zones (Fig. 3b). Available P was highest in the unburned zone of Site D (0.05%) and lowest in the burned zone of Site D (0.04%). The level was generally lower in the burned zones than in the unburned zones (Fig. 3c). The highest level of available K was in the burned zone of Site B (1.77%), and lowest the unburned zone of Site C (0.93%) (Fig. 3d). Soil Ca ranged from 3.66-4.18% (Fig. 3e). Higher levels were observed in the burned zones. The lowest level of Mg was observed in the unburned zone of Site C (1.61%) and the burned zone of Site A (1.78%). The highest level of soil Mg was in the burned zone of Site B (2.08%) (Fig. 3f).

Despite no statistical difference in the concentrations of soil nutrients between burned and unburned zones of most sites, varying levels of deterioration/improvement of the nutrients were noticed in the burned sites compared to the unburned (control) sites (Fig.

4). The results of deterioration index (DI) revealed 1.42% deterioration for soil organic carbon (SOC) in the burned sites. Total N declined by 5.17%, while P decreased the most with a DI of 18.07%. The concentrations of all soil cations improved, with K having the highest DI (-59.79%), followed distantly by Mg (-11.28%) and Ca (-10.53%) (Fig. 4).

Fire is believed to greatly influence the chemical and mineralogical properties of the soil. The effects of fire are related to peak temperatures and duration of the fire (Certini, 2005). The lack of significant

Fig. 4. Deterioration index (DI) of soil nutrients in the burned sites.

difference in soil nutrients between burned and unburned zones in this study could be due to the depth of soil sampling (0-15 cm). Huffman et al. (2001) in their study of fire effects on pine forest soil also concluded that such fire-effects on soil physicochemical properties rarely exceed 6-8 cm, hence the bulking of fire-affected surface soil with unaffected below soil may nullify such fire-effects. However, our results for the deterioration index (DI) for C, N and P in the burned plots reflect some disparity in relation to the unburned plots. Organic matter loss by combustion during bushfires seems inevitable (Simard et al., 2001). Kutiel and Naveh (1987) in their study of pine forest soil also reported decreased N by up to 25% following burning. According to their results, total P increased at first but decreased significantly two months later. The National Wildlife Coordinating Group (2001) also reported that volatilization loss significantly affected N, and to a lesser extent P. In this study, the DI for the available P was different as the change in N was much lower. Certini (2005) affirmed that fire does not necessarily impact soil P to the same extent as N. The higher levels of K, Mg and Ca in the burned zones are in agreement with the report of Khanna and Raison (1986) that soil cations increase following fire incidence. Even though fire can cause the loss of some soil minerals through means including volatilization, fly-ash and leaching, concentrations of K, Ca and Mg in ash is reported to increase due to releases caused by burning and increased microbial mineralization (NWCG, 2001; Yildiz et al., 2010).

CONCLUSION

The higher ground cover in the burned zones validates the frequent burning of the savanna (by herdsmen) to improve forage yield during the dry season. High dry matter production of some grasses despite the dry spell during the period could dictate their use as forage in pastures. The occurrence of seedlings of deciduous tree species in the burned zones explained why these tree species persist in the savanna belt of Nigeria despite the frequent fires associated with this belt. The absence of significant differences in the levels of soil nutrients could be due to the moderate fire incidence

as well as the depth of soil sampling. The decreased levels of C, N and P in the burned sites prescribes the need to discourage frequent burning of savanna vegetation, considering the importance of these nutrients in the agro-ecological processes of any ecosystem. It is evident that the burning obviously altered the growth (ground cover) and composition of plant species in the short term, but could significantly influence soil nutrient dynamics in the long term, especially with recurring fire events.

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