EARLY-SEASON EFFECTS OF WILDFIRE ON SOIL NUTRIENTS AND WEED DIVERSITY IN TWO PLANTATIONS

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This study assessed early-season effects of spontaneous wildfires on soil fertility and weed diversity in two managed plantations – cashew and teak – in Ilorin, Nigeria. Soil pH and nutrients in the topsoils and subsoils of burned and unburned plantations plots after a spontaneous wildfire were analysed. Species diversity and similarity were determined based on the composition and abundances of weed flora two months post-fire. The fire effects on soil nutrients and weed composition in the plantations were evaluated using the canonical correspondence analysis. Burns incidence significantly improved the organic carbon, organic matter, and Ca contents while reducing total N and Mg in both plantations. Twenty-eight weed species were distributed in 9 angiosperm families. Fire differently affected weed composition, abundance and diversity in the plantations. Burning improved soil organic carbon and organic matter contents and restricted *Tephrosia bracteolata*, *Desmodium tortuosum*, *Daniellia oliveri*, *Senna obtusifolia* and *Zornia latifolia* to the burned cashew plantation. The occurrence of *Euphorbia heterophylla*, *Eriosema psoraleoides* and *Crotalaria retusa* in the burned teak plantation was associated with a direct fire effect on soil Na and Ca contents. Burning influenced soil nutrients in the studied plantations, but weed diversity increased in the teak plantation and was reduced in the cashew plantation.

burning, plantation, soil fertility, species diversity, weeds, woodland savanna

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INTRODUCTION

Bush burning is a component of the traditional farming system in many parts of the world being applied as a management tool in plantations and forest ecosystems (Turner et al., 1994) in activities such as clearing of land for agriculture, pest control, removal of dry vegetation and crop residues to boost agricultural productivity (Hough, 1993). Prescribed burning is carried out to remove accumulated biomass and unpleasant grasses from previous growing season while stimulating re-growth of fresh herbage with a higher nutrient content (Snyman, 2003). It is also a vital tool for clearing off the grassland parasitic insects and preventing encroachment of undesirable invasive species (Sanyaolu, 2015).

More recently, frequent and boundless wildfires have become a major problem in most parts of the world, reshaping the physiognomies of different vegetal covers (Neary, Leonard, 2020). In savannas, such recurring events of fire have been favoured by the extended dry periods and seasonally dry grasslands (Bond, Keane, 2017). Today, fire has evolved inseparable with savanna vegetation of Africa, thus nicknaming the continent a 'fire continent' (Trollope, Trollope, 1996) because of widespread anthropogenic fires that annually burn the savanna vegetation (Mbow et al., 2000; Sheuyange et al., 2005). In the Guinea, Sudanian and Sahelian savanna ecotypes of Nigeria wildfires are constant threat especially during the 'fire season' which lasts from October to April when desiccated vegetation (mostly grasses, annuals and tree litters) ignite at the slightest spark and spread under the influence of north-east trade 'harmattan' winds that characterize the period (Balogun et al., 2004). The frequency of fire events is considered as the principal ecological driver of savannas (Bond, Keeley, 2005) modulating tree–grass coexistence and shaping the different physiognomies in this landscape (Lenza et al., 2017).

The effects of fire on vegetation (Stein et al., 1990) and soil (Kutiel, Inbar, 2007) have continuously been a matter of intense debate. The effect of a fire event on an individual species depends on the intensity and duration of fire, the pre-fire condition of the biota, the period since the last fire incidence and the pre- and post-weather, especially rainfall, which influences soil moisture (Preece et al., 1989; Morrison et al., 1995). Fire can structure communities through its filtering role, selecting those plant species that can survive a fire or regenerate after it (Pausas, Verdu, 2008). Pyke et al. (2010) are of the opinion that fire can change plant communities by reducing dominance of some plants while enhancing the dominance of others. Increased dominance of fire-tolerant species (increasers) as a direct result of recurring fire incidences is a cause for concern in biodiversity conservation (Asiku, 2010).

Apart from its effect on vegetation, biological residues, and microorganisms in aboveground layers, fires also influence belowground environments (DeBano et al., 1998). Soil properties can experience short-term, long-term or permanent fire-induced changes, depending primarily on the property, severity and frequency of fires, and post-fire climatic conditions (Ngole-Jeme, 2019). Fire can cause alterations of soil biogeochemical cycles, consume soil organic matter (OM), alter soil pH, and change availability of soil nutrients (Prieto-Fernandez et al., 1993; Gonzalez-Perez et al., 2004; Neill et al., 2007). Depending on the biome, the influence of fire on vegetation structure and ecosystem processes may differ (Eva, Lambin, 2000).

Despite the vast number of researches on fire disturbances in tropical savannas in Africa (Edroma, 1984; Balogun et al., 2004; Fatubarin, Olojugba, 2014), information on the effects of fire events on soil fertility and weed diversity in managed plantations is scarce. Considering the vast plantations established in tropical savannas to combact desertification in the region and mitigate global climate change, the effects of fires in managed plantations in the region cannot be overlooked. The present study examined the early-season effects of fire on soil nutrients and weed diversity in managed teak and cashew plantations in the Guinea savanna belt of Nigeria to assess the fire impacts and associated transformations and take proper measures in other regions prone to recurring fire incidences.

MATERIAL AND METHODS

Description of study area

The study was conducted in 19-year-old Agroforestry plantations within the University of Ilorin main campus, Ilorin, Kwara State, north-central Nigeria. North-central Nigeria is semi-arid with mean annual rainfall ranging from 300 to 1 200 mm (Ajadi et al., 2011). Rainy season lasts from April to October. The temperature is high throughout the year and varies between 33 °C and 34 °C (Oyedeji et al., 2016). 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 predominant soil textures are sandy loam and sandy clay loam (Oyedeji et al., 2016). The region falls within a Guinea savanna zone classified as woodland savanna vegetation characterized by savanna tree species including *Daniellia oliveri*, *Vitellaria paradoxa*, *Prosopis africana*, *Parkia biglobosa* with an under-storey dominated by annual grasses (Keay, 1953; Oyedeji et al., 2016). Burning in the area is uncontrolled and takes place at any time from late November (early dry season when dry biomass is available) to early April (beginning of rainy season) (Adegbola, Onayinka, 1976). Fire events are basically of anthropogenic origin and linked to herders, who burn biomasses in order to trigger growth of fresh herbage for their livestock (Ogboru, Adejonwo-Osho, 2018).

The University of Ilorin is one of Nigeria's second generation universities with land area of about 15 000 ha with less than 5 % of the area accounting for the built area. Since year 2000, the University management have intensified efforts to converting significant areas of the seasonally burned woodland into monoculture plantations of economic species including teak (*Tectonia grandis*), cashew (*Anacardium occidentale*),

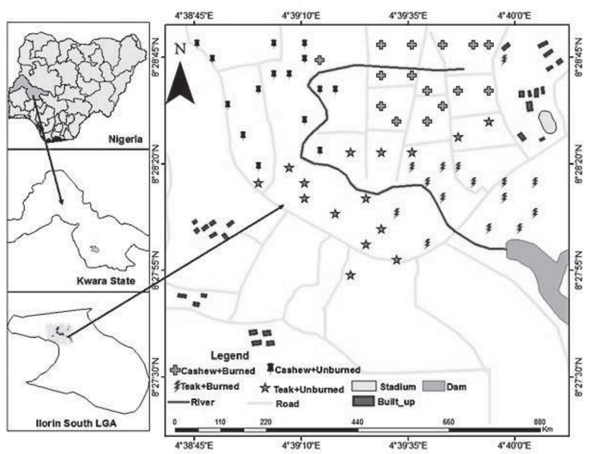

Fig. 1. Map indicating the position of the experimental site within Ilorin South Local Government Area, Kwara state and Nigeria

Table 1. Chemical properties of topsoils and subsoils of the burned and unburned plots in the cashew and teak plantations, Ilorin, Nigeria

Effect	Level	pH	OC	OM	TN	P	Na	K	Ca	Mg
			(%)			(mg kg^{-1})	(cmol kg^{-1})			
Soil depth (D)	top soil	6.794^{b}	2.869^{a}	4.960^{a}	0.157^{a}	5.406^{a}	3.217^{a}	2.091^{a}	3.952^{a}	1.961^{a}
	subsoil	6.978^{a}	2.743^{a}	4.714^{a}	0.148^{a}	5.057^{b}	2.917^{b}	1.950^{a}	3.720^{a}	1.799^{a}
	$LSD_{0.05}$	0.158*	0.195	0.338	0.016	0.304*	0.249*	0.165	0.282	0.246
Fire (F)	burned	6.883^{a}	2.936^{a}	5.054^{a}	0.144^{b}	5.428^{a}	3.208^{a}	2.012^{a}	4.096^{a}	2.168^{a}
	unburned	6.882^{a}	2.588^{b}	4.475^{b}	0.169^{a}	4.904^{b}	2.833^{b}	2.033^{a}	3.402^{b}	1.707^{b}
	$LSD_{0.05}$	0.163	0.202*	0.349*	0.016*	0.373*	0.257*	0.171	0.291*	0.254*
Plantation (P)	cashew	7.027^{a}	2.796^{a}	4.836^{a}	0.159^{a}	5.267^{a}	3.136^{a}	2.006^{a}	3.835^{a}	1.830^{a}
	teak	6.737^{b}	2.816^{a}	4.838^{a}	0.147^{a}	5.197^{a}	2.999^{a}	2.034^{a}	3.837^{a}	1.930^{a}
	$LSD_{0.05}$	0.158*	0.195	0.338	0.016	0.304	0.249	0.165	0.282	0.246

OC = organic carbon, OM = organic matter, TN = total nitrogen

means with the same superscript are not significant for the effect at $P > 0.05$; *significant LSD at $P < 0.05$

drumstick tree (*Moringa oleifera*), date palm (*Phoenix dactylifera*), oil palm (*Elaeis guineensis*), jatropha (*Jatropha curcas*), and citrus species (Aliyu, 2014). Site selection for the study was done after successive wildfire events of moderate intensities of the 1st and the 16th of March, 2017.

Study area delineation

The cashew and teak plantations selected for this study had both fire-affected (burned) and fire-excluded (unburned) areas within close proximity. Fifteen subplots measuring 10 × 10 m were delineated in each of the burned and unburned plots in the cashew and teak plantations. A total of 60 subplots were delineated for the study (Fig. 1).

Soil sampling and analysis

Experimental sampling was conducted in May, 2017 (two months after the start of the rainy season). Soil samples were collected at 0–15 cm (top soil) and 15–30 cm (subsoil) levels within each subplot in the burned and unburned plots of both plantations using a stainless steel Dutch auger. A total of 120 soil samples (15 subplots × 2 soil levels/depths (top/sub-soil) × 2 fire regimes (burned/unburned) × 2 plantations (cashew/teak)) were collected. The soil samples were tested for pH, organic carbon (OC), OM, total nitrogen, available phosphorus, exchangeable cations (sodium, potassium, calcium and magnesium). Soil pH was determined in 1 : 1 soil – 1 N KCl mixture (Thomas, 1996) read with a digital pH meter. Soil OC was determined by the wet oxidation method following Walkley, Black (1934). Soil organic matter (SOM) was calculated from soil organic carbon (SOC) using the formula: % **S**OM = % SOC 1.729.

Soil nitrogen was determined by the macro Kjeldahl method of digestion, distillation and back titration (Bremner, 1996), while available phosphorus was determined by the Bray-P1 method (Kuo, 1996). Soil exchangeable cations were extracted using 1.0 N ammonium acetate (NH_4OAc) buffered to pH 7.0 (Thomas, 1982). The concentrations of Na, K, Ca and Mg in the filtrate were then determined by spectrophotometry. Na and K concentrations were determined using a flame photometer (Jenway PFP7 model) while Ca and Mg were determined using an Atomic Absorption Spectrophotometer (Jenway 6305 model).

Weed composition and diversity analysis

Weed flora composition and diversity analysis in the two plantations were determined using species composition and abundances estimated from counts and identifications of plants within a 4 m^2 quadrat area determined systematically at three points within rows of tree stands in each subplot of burned and unburned plots of teak and cashew plantations. Encountered plants were identified to species level using documented flora (Hutchinson, Dalziel, 1972; Akobundu et al., 2016) and herbarium voucher specimens deposited at the University of Ilorin Herbarium. Density, similarity and diversity indices were computed from species richness and abundances.

Statistical analysis

Data on soil pH, OC, OM, total nitrogen, available phosphorus, exchangeable sodium, potassium, calcium and magnesium in the top- and sub-soils (soil depths) in the burned and unburned plots (fire effects) in cashew and teak plantations were analysed using factorial model in proc ANOVA with SAS 9.1.3 software for Windows. Significant means were separated using Fisher's protected LSD (least significant difference) method at a 0.05 α-level. Bar (mean ± SD) graphs were plotted using MS Excel 2013. Species evenness,

Table 2a. Composition and abundance of weed species in burned and unburned plots in the cashew and teak plantations in Ilorin, Nigeria. Species density per 1 m^2 is given in parenthesis

Species No.	Weed species	Family	Cashew plantation		Teak plantation	
			burned	unburned	burned	unburned
1	*Ageratum conyzoides* Linn.	Asteraceae	232 (5.2)	176 (3.9)	304 (6.8)	101 (2.2)
2	*Chromolaena odorata* (L.) R.M. King	Asteraceae	248 (5.5	144 (3.2)	284 (6.3)	226 (5.0)
3	*Conyza sumatrensis* (Retz.) Walker	Asteraceae	80 (1.8)	16 (0.4)	16 (0.4)	56 (1.2)
4	*Crotalaria retusa* Linn.	Fabaceae	16 (0.4)	144 (3.2)	56 (1.2)	0 (0.0)
5	*Dactyloctenium aegyptium* (L.) P. Beauv.	Poaceae	320 (7.1)	312 (6.9)	340 (7.6)	360 (8.0)
6	*Daniellia oliveri* (Rolfe) Hutch. & Dalz.	Fabaceae	42 (0.9)	10 (0.2)	54 (1.2)	0 (0.0)
7	*Desmodium tortuosum* (Sw.) DC	Fabaceae	128 (2.8)	32 (0.7)	64 (1.4)	24 (0.5)
8	*Eriosema psoraleoides* (Lam.) G. Don	Fabaceae	24 (0.5)	48 (1.1)	88 (2.0)	0 (0.0)
9	*Euphorbia heterophylla* L.	Fabaceae	0 (0.0)	40 (0.9)	64 (1.4)	16 (0.4)
10	*Hyparrhenia involucrata* Stapf.	Poaceae	376 (8.4)	328 (7.3)	424 (9.4)	352 (7.8)
11	*Hyptis suaveolens* Poit.	Lamiaceae	112 (2.5)	104 (2.3)	116 (2.6)	40 (0.9)
12	*Imperata cylindrica* (L.) Raeuschel	Poaceae	504 (11.2)	376 (8.4)	509 (11.3)	336 (7.5)
13	*Malvastrum coromandelianum* (L.) Garcke	Malvaceae	0 (0.0)	24 (0.5)	8 (0.2)	64 (1.4)
14	*Megathyrus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs	Poaceae	480 (10.7)	408 (9.1)	382 (8.5)	496 (11.0)
15	*Mimosa invisa* Mart.	Fabaceae	192 (4.3)	48 (1.1)	64 (1.4)	72 (1.6)
16	*Oldenlandia herbacea* (L.) Roxb.	Rubiaceae	0 (0.0)	32 (0.7)	0 (0.0)	45 (1.0)
17	*Phyllanthus pentandrus* Schum. & Thonn.	Euphorbiaceae	176 (3.9)	232 (5.2)	104 (2.3)	120 (2.7)
18	*Physalis micrantha* Linn.	Solanaceae	0 (0.0)	25 (0.6)	0 (0.0)	5 (0.1)
19	*Sclerocarpus africanus* Jacq. ex Murr.	Asteraceae	112 (2.5)	16 (0.5)	72 (1.6)	152 (3.4)
20	*Senna obtusifolia* (L.) Irwin & Barneby	Fabaceae	35 (0.8)	0 (0.0)	0 (0.0)	0 (0.0)
21	*Setaria longiseta* P. Beauv.	Poaceae	416 (9.2)	240 (5.3)	337 (7.5)	248 (5.5)
22	*Sida linifolia* Juss ex Cav.	Malvaceae	16 (0.4)	72 (1.6)	48 (1.1)	32 (0.7)
23	*Talinum triangulare* (Jacq.) Willd.	Portulacaceae	30 (0.7)	17 (0.4)	0 (0.0)	0 (0.0)
24	*Tephrosia bracteolata* Guill. & Perr.	Fabaceae	88 (2.0)	160 (3.6)	192 (4.3)	152 (3.4)
25	*Tephrosia pedicellata* Bak.	Fabaceae	24 (0.5)	8 (0.2)	0 (0.0)	0 (0.0)
26	*Tridax procumbens* Linn.	Asteraceae	248 (5.5)	216 (4.8)	264 (5.9)	344 (7.6)
27	*Waltheria indica* Linn.	Malvaceae	168 (3.7)	40 (0.9)	88 (2.0)	104 (2.3)
28	*Zornia latifolia* Sm.	Fabaceae	56 (1.2)	8 (0.2)	64 (1.4)	0 (0.0)

richness, similarity, diversity indices were computed from data on weed abundances in the burned and unburned plots using Paleontological Statistics (PAST) Version 3.18. Diversity *t*-test was used to compare the diversity between burned and unburned plots in the plantations. Canonical correspondence analysis (CCA) was used to determine the spatial displacement of the weed species in the burned and unburned plots of the cashew and teak plantations.

RESULTS

Effects of fire on soil nutrients

Burning significantly ($P < 0.05$) affected OC, OM, total N, available P, Na, Ca and Mg in the soils of plantations. Soil pH and K were unaffected by burning. However, pH was significantly influenced by soil depth and plantation type (Table 1). Soil pH was not significantly different, except in the top soil of the cashew plantation (Fig. 2a). Generally, the concentrations of OC, OM and exchangeable Ca increased in the burned plots (Fig. 2b, c, h) while total N and exchangeable Mg decreased (Fig. 2d, i). The top soil of burned cashew plantation had the highest soil OC and OM (2.98 % and 5.15 %) while the subsoil of the unburned site also had the least for both soil parameters (Fig. 2b, c). The top soil of burned teak plantation had the highest Ca (4.19 cmol kg^{-1}). The subsoil of the burned plots in the teak and cashew plantations had the least total N (0.16 %) and exchangeable Mg (1.54 cmol kg^{-1}), respectively (Fig. 2d, i). Available P concentrations increased in the subsoil of burned

Table 2b. Average abundance and density of weed species in burned and unburned plots in the cashew and teak plantations, Ilorin, Nigeria

Plantation	Zone	Abundance	Density (weeds per 1 m^2)
Cashew	burned	147.25 ± 28.90^a	3.28 ± 0.64^a
	unburned	117.00 ± 23.39^a	2.61 ± 0.52^a
	P-value	0.419	0.425
Teak	burned	140.79 ± 28.37^a	3.14 ± 0.63^a
	unburned	119.46 ± 26.81^a	2.65 ± 0.60^a
	P-value	0.587	0.578

mean ± standard error with the same superscript for a variable in a plantation are not significant ($P > 0.05$)

teak (5.55 mg kg^{-1}) and cashew (5.48 mg kg^{-1}) over the unburned plots. This is contrary to the observed decrease in the burned top soils of both plantations (Fig. 2e). The concentration of exchangeable Na varied with depth, but exchangeable K concentration was unaffected by fire and soil depth (Table 1). Except for top soil of burned cashew plantation, Na concentration increased in the burned plots of teak and cashew plantations (Fig. 2f).

Effects of fire on weed species abundance, density and diversity

A total of 28 weed species distributed in 9 angiosperm families were recorded (Table 2a). All these 9 plant families were represented in the unburned plot of cashew plantation while only 7 plant families, excluding Rubiaceae and Solanaceae, were represented in the burned plot of cashew plantation. The burned and unburned plots of teak plantation were devoid of weed species belonging to Portulacaceae. There was no record of members of Rubiaceae and Solanaceae in the burned site of teak plantation. Only 6 and 7 families were represented in the burned and unburned sites of teak plantation, respectively (Table 2a).

Among the grassy weeds, *Imperata cylindrica*, *Hyparrhenia involucrata*, *Megathyrus maximus*, *Setaria longiseta* and *Dactyloctenium aegyptium* had the highest abundances and densities in the two plantations. Unlike the unburned plots, the burned sites of both plantations were dominated by *Ageratum conyzoides*, *Chromolaena odorata*, *Desmodium turtuosum*, *Hyparrhenia involucrata*, *Hyptis suaveolens*, *Imperata cylindrica*, *Setaria longiseta* and *Zornia latifolia*. *Senna obtusifolia* occurred only in the burned plots at the cashew plantation while *Oldelandia herbacea* and *Physalis micrantha* were restricted to unburned plots of cashew and teak plantations. *Talinum triangulare* and *Tephrosia pedicellata* were restricted only to the burned and unburned plots in the cashew plantations (Table 2a).

The weed species abundance and density in the burned and unburned plots of the cashew and teak plantations did not significantly differ ($P > 0.05$). The average abundance of weed species was 147.25 and 117.00 species respectively in the burned and unburned plots of the cashew plantation. The average abundance of weed species was 140.79 and 119.46 respectively in the burned and unburned plots of the teak plantation. The average density of weeds per 1 m^2 in the burned and unburned plots of cashew was 3.28 and 2.61, respectively while that in the teak plantation was 3.14 and 2.65 (Table 2b).

The burned plots of cashew and teak plantations had higher weed abundance (4 123 and 3 942 plants, respectively) than the unburned plots (3 942 and 3 345 plants). The burned cashew plots showed a lower species number (24), species dominance (0.0703) and diversity (2.810), but a higher species evenness (0.692) compared with the unburned plots. Sorenson's index

Table 3. Richness, similarity and diversity indices of weed species in burned and unburned plots in the cashew and teak plantations, Ilorin, Nigeria

Ecological index	Cashew		Diversity *t*-value (*P*)	Teak		Diversity *t*-value (*P*)
	burned	unburned		burned	unburned	
Number of individual plants	4 123	3 276		3 942	3 345	
Species richness (S)	24	27		23	21	
Simpson's index (Dominance)	0.073	0.074	–0.826 (0.409)	0.075	0.084	–5.096 (< 0.001)
Species Evenness (exp^H/S)	0.692	0.618		0.705	0.685	
Shannon-Wiener's index (H')	2.810	2.815	–0.244 (0.807)	2.785	2.666	–6.961 (< 0.001)
Sorenson similarity index	0.902			0.864		

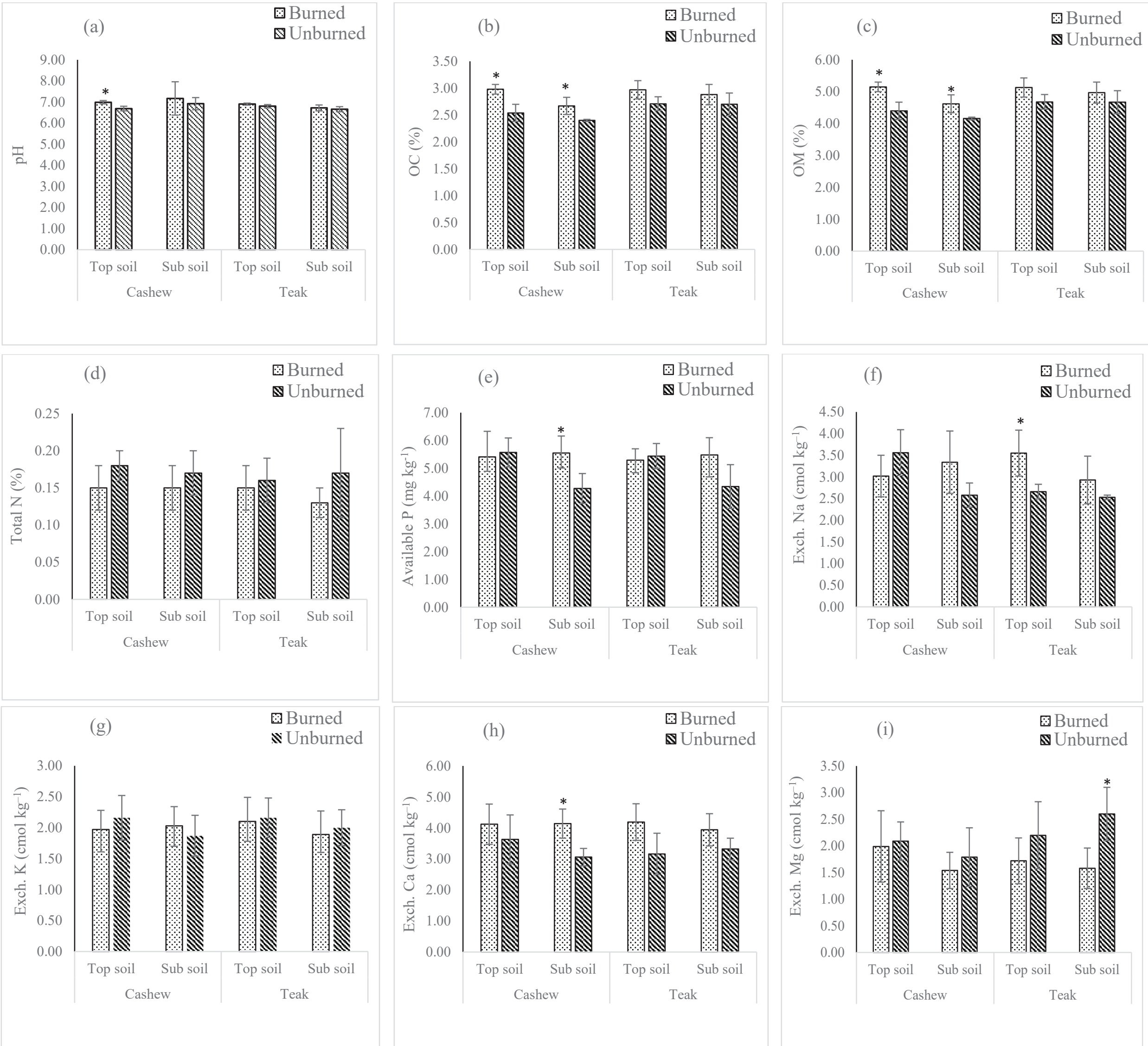

Fig. 2. Chemical analyses of topsoil and subsoil samples from burned and unburned plots of cashew and teak plantations in Ilorin, Nigeria (a) pH, (b) organic carbon, (c) organic matter, (d) total nitrogen, (e) available phosphorus, (f) exchangeable sodium, (g) potassium, (h) calcium, (i) magnesium bars are means ± standard error; *a significantly higher value

indicated a 90.2% similarity in the species composition between the burned and unburned sites in the cashew plantation. The burned teak plantation had a higher number of species (23), species evenness (0.705), diversity (2.785), but lower species dominance (0.075) compared with the unburned one. The indices of species diversity and dominance were significantly different ($P < 0.001$). The species composition similarity in burned and unburned teak was 86.4 % (Table 3).

Effects of fire incidence, soil nutrients and plantation type on weed species composition

The trends stemming from the CCA (Fig. 3) suggest that fire incidence, soil nutrient status and plantation type contributed to delimiting the species to the quadrants. Environmental variables (i.e. soil nutrients and fire incidence) represented by arrows point to the direction of maximum change of each variable in the CCA graph. The length of the arrow for each environmental variable is proportional to its rate of change in the direction of the arrow within a quadrant (Fig. 3). Species that fall outside the 95% confidence level are more likely to be restricted to a zone (quadrant). In Quadrant I, concentrations of soil Na largely determined the presence of weed species in the burned teak plantation. Among the seven plant species in the quadrant, only *Euphorbia heterophylla*, *Eriosema psoraleoides*, *Sida linifolia* and *Crotalaria retusa* were closely linked to the site condition. OC, OM, Ca content in soil and the direct impact of burning largely determined the presence of *Daniellia oliveri*,

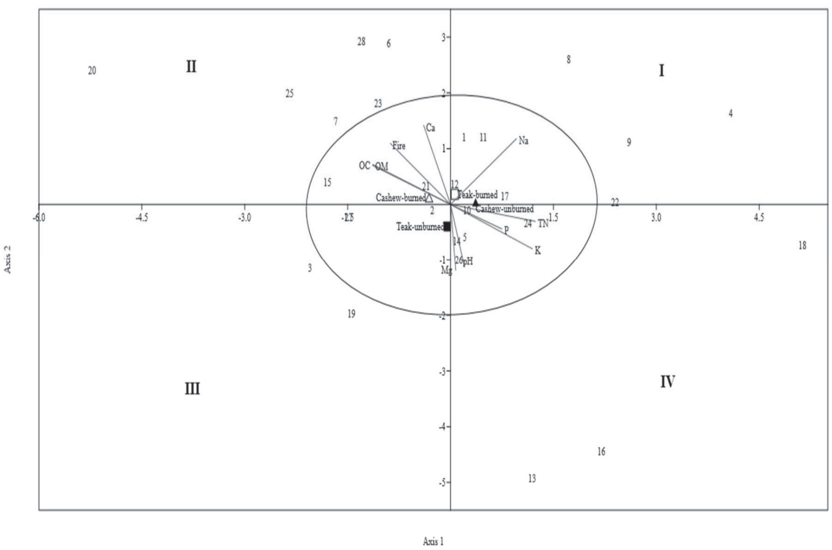

Fig. 3. Canonical correspondence analysis ordination of environmental variables (soil factors and fire incidence) and weed species distribution in burned and unburned plots in the teak and cashew plantations, Ilorin, Nigeria

Keys: △ - burned cashew, ▲ - unburned cashew, □ - burned teak, ■ - unburned teak

1 = *Ageratum conyzoides*, 2 = *Chromolaena odorata*, 3 = *Conyza*, 4 = *Crotalaria retusa*, 5 = *Dactyloctenium aegyptium*, 6 = *Daniellia oliveri*, 7 = *Desmodium tortuosum*, 8 = *Eriosema psoraleoides*, 9 = *Euphorbia heterophylla*, 10 = *Hyparrhenia involucrata*, 11 = *Hyptis suaveolens*, 12 = *Imperata cylindrica,* 13 = *Malvastrum coromandelianum*, 14 = *Megathyrus maximus*, 15 = *Mimosa invisa*, 16 = *Oldenlandia herbacea*, 17 = *Phyllanthus pentandrus*, 18 = *Physalis micrantha*, 19 = *Sclerocarpus africanus*, 20 = *Senna obtusifolia*, 21 = *Setaria longiseta*, 22 = *Sida linifolia*, 23 = *Talinum triangulare*, 24 = *Tephrosia bracteolata*, 25 = *Tephrosia pedicellata*, 26 = *Tridax procumbens*, 27 = *Waltheria indica*, 28 = *Zornia latifolia*

Desmodium tortuosum, *Senna obtusifolia*, *Talinum triangulare*, *Tephrosia pedicellata* and *Zornia latifolia* in burned plots of the cashew plantation in Quadrant II. Species such as *Imperata cylindrica*, *Mimosa invisa* and *Setaria longiseta* were not found in burned cashew plantation with a similar site condition. In Quadrant III, only *Conyza sumatrensis* and *Sclerocarpus africanus* are likely to be restricted to unburned teak plantation. The unburned plots of the cashew plantation contained similar plant species as the burned teak plots in addition to plant species delimited to Quadrant IV. Of the species in Quadrant IV, only *Oldelandia herbacea*, *Physalis micrantha* and *Malvastrum coromandelianum* are directly associated with high soil pH and Mg and P contents as well as low K and total N levels. Thirteen of 28 plant species encountered, including *Ageratum conyzoides*, *Chromolaena odorata*, *Dactyloctenium aegyptium*, *Hyparrhenia involucrata*, *Hyptis suaveolens*, *Imperata cylindrica*, *Imperata cylindrica*, *Mimosa invisa*, *Phyllanthus pentandrus*, *Setaria longiseta*, *Tephrosia bracteolata*, *Tridax procumbens* and *Waltheria indica*, are likely to be found in any of the plantations regardless of the burning effects.

DISCUSSION

The higher soil pH in the burned plots, especially the significant increase in pH in the burned cashew plot, is consistent with earlier reports on the post-fire soil condition (Christensen, 1976; Materechera et al., 1998; Heydari et al., 2017). Change in soil pH may be attributed to combustion of accumulated plant biomass leading to a large release of nutrient pools, especially cations (basic ions) in the ash (DeByle, 1976; Van Reuler, Janssen, 1996). The concomitant increase in OC, OM, calcium and sodium concentrations along with soil pH is in line with earlier reports on soil nutrients in fire-affected plots (Christensen, 1976). The high OM content provides a larger binding surface for basic ions present in the ash (McCauley et al., 2017). The results of pH in the subsoil of cashew plantation as well as top- and sub-soils of the teak plantation showed the burning effect on the parameter varies with depth and plantation type.

Our observation on the OC and OM increases in the burned plots of both plantations is consistent with the results of Pardini et al. (2004) in Spain, Kara, Bolat (2009) in Turkey and Zhao et al. (2012) in China. The OM increase is possibly related to the organic materials presence, including fine roots (Ansley et al., 2006; Zhao et al., 2012), and partly burned tissues reduced by fire that passed through the sieve in the fire-affected soils. Similarly, the increase in available P in the burned plantations subsoil suggests that the occurrence of fires improved the soil nutrients. Numerous studies have shown fire-induced increases in available P directly following burning (e.g. Andriesse, Koopmans, 1984; Juo, Manu, 1996; Slaats et al., 1998).

The high abundance of weeds, especially grasses, in the burned plots of both plantations is probably a result of smoke-induced or heat induced germination of previously dormant seeds (Keeley, Fotheringham, 2000) and re-sprouting of underground organs encouraged by improved soil pH and OM.

Despite the improvement in species abundance, the species diversity was reduced in the burned plots in the cashew plantation due to reduction in the species number. This reduction in weed species richness and diversity is probably related to fire-sensitive species elimination in the burned plots (Pyke et al., 2010). This species richness and diversity reduction in the burned plots in the cashew plantation is in line with the report of Matayaya et al. (2017) who also identified a reduced herbaceous diversity in burned plots. Contrarily, fire improved weed species richness, evenness and diversity in the burned teak plots in the present study.

All 28 weed species encountered had been previously reported in Nigeria by Akobundu, Agyakwa (1998) and Akobundu et al. (2016). Species as *Daniellia oliveri*, *Desmodium tortuosum*, *Senna obtusifolia*, *Talinum triangulare*, *Tephrosia pedicellata* and *Zornia latifolia* associated with the burned cashew plots are likely to be indicators of fire-affected ecosystems. Some of these species, e.g. *Daniellia oliveri* and *Tephrosia pedicellata,* have been reported in burned sites (Oyedeji et al., 2016) and bush regrowth (Akobundu et al., 2016) in Nigeria's savanna ecosystem. A previous report on the fire effects on the species distribution also confirmed *Chromalaena odorata* and *Megathyrus maximus* occurrence was non-selective of site, i.e., they occur in both burned and unburned sites (Oyedeji et al., 2016). Akobundu, Agyakwa (1998) also affirmed the prevalence of *Hyparrhenia involucrata* and *Imperata cylindrica* in dry savanna soils and fire-disturbed areas. Similarly, Fynn et al. (2004) reported that disturbances, such as annual burning, influence the dominance of some weeds, particularly grasses. This confirms the high abundance of species such as *Hyparrhenia involucrata*, *Imperata cylindrica*, and *Setaria longiseta* in the burned plots in the cashew and teak plantations. Non-selective weed species in this study including *Hyptis sauveolens*, *Ageratum conyzoides*, *Tridax procumbens*, *Mimosa invisa* and *Waltheria indica* have previously been associated with cultivated lands and plantations in West Africa (Akobundu, Agyakwa, 1998; Akobundu et al., 2016). The absence of some weeds, especially members of Rubiaceae and Solanaceae, in the burned plots of both cashew and teak can be attributed to the fire-sensitive nature of these species. This is in line with the findings of Tesfaye et al. (2004) that fire can erode soil seed bank especially for heat-sensitive species.

CONCLUSION

This study indicates that fire incidence in the plantations significantly improved soil OC, OM and Ca contents, while decreasing the presence of exchangeable K, Na and Mg. Similarly, weed species increase in both of the burned plots of the studied plantations has been registered. However, species richness and diversity were differentially impacted by burning – there was an increase in the teak plantation and a decrease in the cashew plantation. The CCA ordination revealed that the species association with burned sites may be linked to selected soil nutrients impacted by burning. Adequate understanding of fire effects on soil nutrients and species abundance and diversity will serve as a tool for soil and weed management in plantations especially in savanna ecosystems.

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