

Soil Nutrient Dynamics in a Tropical Oil Palm (*Elaeis guineensis*) Plantation Affected by Bushfire

¹*Paul O. Orobator and ¹Ivbaria A. Omo-Isibor

¹Department of Geography and Disaster Risk Management, Faculty of Environmental Sciences, University of Benin, Benin City, Edo State, Nigeria

*Corresponding Author:

orobosa.orobator@uniben.edu

(<https://orcid.org/0000-0002-5058-0774>)

DOI: <https://doi.org/10.5281/zenodo.18790649>

Abstract.

The study examined soil nutrient dynamics in a tropical oil palm (*Elaeis guineensis*) plantation affected by bushfire. Sand, silt, clay, pH, bulk density (BD), effective cation exchange capacity (ECEC), soil organic matter (SOM), soil organic carbon (SOC), total nitrogen (TN), available phosphorus (Avl P), calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) were analyzed in the laboratory using standard soil analytical procedures. A 100 m × 100 m sample area was demarcated in the unburnt and burnt portions of the *Elaeis guineensis* plantation, from which ten soil samples were collected each using the stratified random sampling technique at 15 m intervals, and at a depth of 0-15 cm (topsoil). The data were statistically analyzed using descriptive statistics and the student's t-test. The findings revealed multifaceted responses of soil properties to bushfire. Results showed that, except for silt (188.00 g kg⁻¹), clay (31.70 g kg⁻¹), ECEC (3.44 g kg⁻¹), Ca (2.38 g kg⁻¹), Na (0.21 g kg⁻¹), and Mg (0.57 g kg⁻¹), the concentration levels of sand (813.10 g kg⁻¹), pH (5.81), SOM (4.06 g kg⁻¹), SOC (2.34 g kg⁻¹), TN (0.17 g kg⁻¹), available P (3.68 g kg⁻¹), and K (0.27 g kg⁻¹) were higher in the burnt areas of the *Elaeis guineensis* plantation. The study demonstrated significant positive impacts on K, while its effects on ECEC, Ca, Mg, and Na were significantly negative.

Keywords: Fire; *Elaeis guineensis*; Tropics; Physicochemical properties

INTRODUCTION

Oil palm (*Elaeis guineensis*) is one of the significant perennial tree crops cultivated in the tropical belts of Africa, Asia, and Latin America (Orobator et al., 2018; Qaim et al., 2020). In Africa, it is grown in vast expanses of acreage (FAO, 2013). Nigeria is the fifth world's largest producer of *Elaeis guineensis* (Shehu & Salleh, 2023), and its domestic production accounts for about 1.5% of the world's palm oil production (Adikaibe et al., 2024). *Elaeis guineensis* is cultivated over large areas of land in Nigeria (Olafisoye et al., 2016). However, bushfires are a major ecological disturbance affecting *Elaeis guineensis* plantations in the tropics (Orobator & Oboh, 2025). Fire as a

biogeographical factor is considered by some ecologists as a physical factor, whereas others classify it as biological because many incidents of fire have been linked to man (Ukpong, 2018). Globally, bushfires are predominant environmental disorders that burn vegetation annually (Giglio et al., 2013, Mendez Cartin et al., 2025), and they can be prompted by human activities such as uncontrolled bush burning, campfires, cigarette smoking, charcoal production, hunting, arson etc. (Orobator & Odjugo, 2024). In addition, Nigeria faces a high risk of bushfire occurrences due to its geographical location within the tropics, along with its diverse floristic forests and

grassland biomes, which provide the fuel for bushfires, particularly during the dry season (Atedhor & Atedhor, 2024).

Soil is the thin layer of the earth's surface that performs several functions vital to life. Soils are significant components of the biogeography of vegetation biomes (Ukpong, 2018), and are among the first to be affected during bushfires due to the loss of flora (Australian Academy of Science, 2020). Bushfires are one of the foremost drivers of soil degradation, resulting in soil functions alterations (Orobator & Ugwa, 2023; Orobator, 2025b), and can affect soil quality by impacting soil nutrient concentration levels and accessibility (Rodríguez et al., 2018). Conserving and improving soil quality in managed ecosystems is essential for soil ecological quality, system productivity, and biological diversity (Orobator, 2017).

The diverse effects of bushfires on soil quality indicators across different flora types and climatic regions have been documented. For instance, in *Pinus brutia* forest, Inbar et al., (2014) found increased SOM contents. In contrast, Badía et al., (2014) reported decreased SOM concentrations in *Pinus halepensis* forest. In grasslands, Liu et al., (2018) observed lower contents of SOC. However, Scharenbroch et al., (2012) found higher concentration levels of SOC in the Oak forest. In *Pinus pinaster* forest, Fernández-García et al., (2019) observed increased avl P. Liu et al., (2018) found higher concentration levels of TN in grassland vegetation, whereas, Dzwonko et al., (2015) reported lower TN contents in Scots pine moist forest. In *Quercus frainetto* forest, Akburak et al., (2018) reported increased soil pH. In contrast, Meria-Castro et al., (2014) observed no impact on pH in *Pinus pinaster* forest. Dzwonko et al., (2015) detected increased base cations in Scots pine moist forest. Bushfire impacts on soil quality indicators are wide-ranging owing to the unique characteristics of specific vegetation ecosystems (Australian Academy of Science, 2020).

Earlier studies have underscored the need to extend investigations into the impact of bushfires on soil quality across other ecosystems. In addition, there is a limited understanding of how soil nutrients in *Elaeis guineensis* plantations respond to bushfires, highlighting the need for plantation-specific assessments. Consequently, this study examined soil nutrient dynamics in a tropical oil palm (*Elaeis guineensis*) plantation affected by bushfire. The findings will provide important up-to-date data on bushfire impacts on soil nutrients in *Elaeis guineensis* plantations, which are crucial for the effective management of tropical *Elaeis guineensis* trees and other perennial trees. As an ecological phenomenon, bushfire remains a significant hurdle to achieving global sustainable development (Atedhor & Atedhor, 2024). Therefore, this study supports Sustainable Development Goal (SDG) 15 (Life on Land) through its focus on bushfires, soil quality indicators, and *Elaeis guineensis* plantations.

MATERIALS AND METHODS

Study area

The research was conducted in an *Elaeis guineensis* plantation affected by bushfire, located in Okunuvbe community, Ovia North East Local Government Area, Edo State, Nigeria (latitudes 6° 37' 05.24" N - 6° 36' 46.97" N and longitudes 5° 45' 53.88" E - 5° 45' 49.16" E) (Figure. 1). According to the plantation owners, the bushfire that affected the *Elaeis guineensis* plantation resulted from bush burning on adjoining farms, a common pre-planting practice in the tropics. Orobator and Odjugo (2023) reported that fires set on the farms to burn gathered dry debris often become uncontrolled, and spread to the nearby farms or perennial tree plantations. The bushfire was a one-off event and it affected mainly the trunk and the fibrous leaf-base scars of the bark of the *Elaeis guineensis* trees. The study area is classified as tropical rainforest, and the soil type is the ferrallitic soil (Orobator & Daniel, 2023).

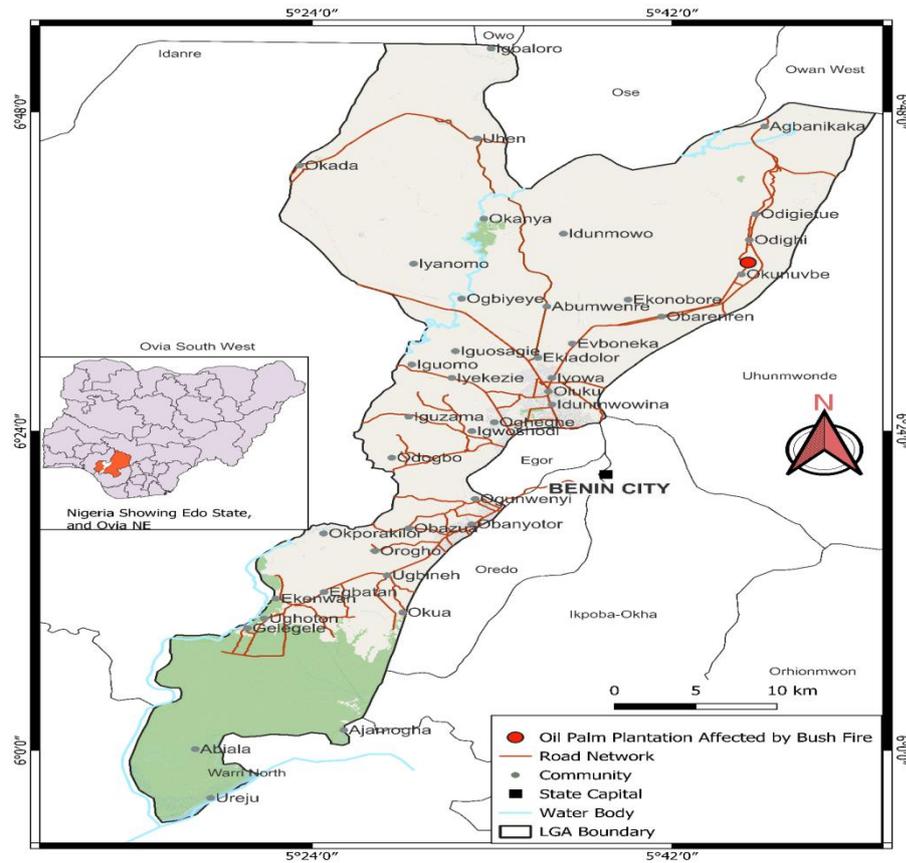


Figure 1. Study Site in Ovia North East Local Government Area

Field measurements and soil sampling

Using the stratified random sampling technique, as adopted by Orobator (2019), a 100 m × 100 m sample area was delineated in the unburnt and burnt portions of the *Elaeis guineensis* plantation. Ten soil samples were collected from each site at 15 m intervals and at a depth of 0–15 cm (topsoil). In total, twenty soil samples were collected during the dry season for the study. The soil samples were collected from the *Elaeis guineensis* plantation one year after bushfire incidence. The choice of the topsoil is justified on the ground that most significant changes in soil properties under any flora, particularly in the tropics, are largely restricted to the topmost layer of the soil profile (Adejuwon & Ekanade, 1988).

Laboratory analysis

Soil texture was calculated with the aid of the revised pipette method of Kettler et al., (2001). BD was determined from undisturbed soil samples using core samplers

(Kowalenko, 1985). Soil pH was measured in 1:1 (soil: deionized) water pastes (Scharenbroch et al., 2012). ECEC and exchangeable cations were determined after extracting the soil samples by ammonium acetate (1N NH₄OAC) at pH 7.0. SOC and TN were determined by automatic dry combustion with an Elementar Vario EL III CHNOS analyzer (Nelson & Sommers 1996). SOC values were converted into those of SOM by multiplying by a factor of 1.724 (Aweto, 1981). Avl P was determined with the Bray P-1 extraction and extracts were analyzed calorimetrically at 882 nm on a spectrophotometer (Olsen & Sommers, 1982).

Statistical analysis

Descriptive and inferential statistics were employed for data analysis. Data were entered in Microsoft Excel and the Statistical Package for Social Sciences (SPSS, version 22) was used for all the statistical analyses. Tables aided to simplify, summarize, and elucidate the data, making it easier to

comprehend and connect information correctly (Schiller et al., 2012). The mean provided the central tendency of soil properties; the range showed the extremes, while the coefficient of variation (CV) was computed to understand comparative variability to enhance soil management practices (Abdu et al., 2023). Student t-test was used to test for significant difference in the soil quality indicators between the unburnt and burnt areas, and the impact of bushfire was achieved by comparing each soil quality indicator between both sites (Mishra et al., 2019). Differences were

considered statistically significant at $p < 0.05$.

RESULTS AND DISCUSSION

Soil properties concentration levels in the bushfire-unaffected and bushfire-affected areas of the *Elaeis guineensis* plantation are indicated in Table 1. Sand revealed higher concentration level in the bushfire-affected area of the *Elaeis guineensis* plantation (813.10 gkg⁻¹) compared to the unburnt area (780.30 gkg⁻¹). Compared to the burnt site (161.60 gkg⁻¹), a higher silt concentration level was found in the unburnt area of the plantation (188.00 gkg⁻¹).

Table 1. Soil quality indicators of unburnt and burnt areas of an *Elaeis guineensis* plantation

Soil quality Parameter	Unburnt part of the <i>Elaeis guineensis</i> plantation				Burnt part of the <i>Elaeis guineensis</i> plantation				p-value
	Range	Mean	Std.	CV	Range	Mean	Std.	CV	
Sand (gkg ⁻¹)	690 - 832	780.30	51.73	6.63	800 - 850	813.10	19.75	2.43	0.06
Silt (gkg ⁻¹)	150 - 290	188.00	53.49	28.46	100 - 180	161.60	25.22	15.61	0.13
Clay (gkg ⁻¹)	18 - 80	31.70	19.32	60.95	16 - 45	25.30	9.74	38.50	0.20
BD (Mg m ⁻³)	1.31 - 1.47	1.39	0.04	3.21	1.35 - 1.47	1.39	0.03	2.61	0.41
pH	5.20 - 6.30	5.66	0.32	5.59	5.30 - 6.00	5.81	0.20	3.49	0.07
ECEC(cmol kg ⁻¹)	2.56 - 5.77	3.44	0.94	27.28	1.45 - 3.18	2.48	0.60	24.38	0.00*
SOM (g kg ⁻¹)	2.00 - 5.20	3.76	1.01	26.98	2.80 - 5.60	4.06	0.89	21.91	0.24
SOC (g kg ⁻¹)	0.28 - 3.48	2.03	1.00	49.40	1.08 - 3.88	2.34	0.89	38.02	0.24
TN (g kg ⁻¹)	0.02 - 0.24	0.14	0.07	49.01	0.08 - 0.28	0.17	0.06	38.54	0.23
Avl P (mg kg ⁻¹)	0.46 - 5.68	3.14	1.77	56.47	1.24 - 6.55	3.68	1.74	47.13	0.24
Ca (cmol kg ⁻¹)	1.78 - 4.00	2.38	0.65	27.24	1.00 - 2.20	1.72	0.42	24.64	0.00*
Na (cmol kg ⁻¹)	0.15 - 0.34	0.21	0.06	27.33	0.10 - 0.21	0.16	0.34	23.24	0.00*
Mg (cmol kg ⁻¹)	0.43 - 0.97	0.57	0.16	27.59	0.23 - 0.53	0.41	0.10	25.22	0.00*
K (cmol kg ⁻¹)	0.12 - 0.25	0.19	0.04	22.71	0.20 - 0.46	0.27	0.07	28.44	0.00*

Source: Authors' fieldwork (2022)

Clay indicated higher concentration level in the unburnt part of the plantation

(31.70 gkg⁻¹) compared to the bushfire-affected area (25.30 gkg⁻¹).The observed

higher sand concentration level compared to silt and clay inferred that whereas bushfire impacts were positive on sand, its effects were negative on silt and clay. The higher concentration level of sand can be ascribed to the formation of unstable aggregates (Afif & Oliveira, 2006). The lower concentration levels of silt and clay maybe due to the loss of the original structure of the soil owing to the washing away of finer particles (Salgado et al., 2024). The outcomes of the study aligned with Pierson et al., (2008), who reported lower clay contents but higher values for sand in coarse-textured soils. The differences in sand, silt and clay were not statistically significant ($p > 0.05$). These results inferred that bushfire positive impacts on sand, and the negative effects on silt and clay, were not statistically significant. Similar findings were reported by Granged et al., (2011) for a study undertaken in a *Eucalyptus* forest.

The BD value in the burnt area of the *Elaeis guineensis* plantation (1.39 Mg m^{-3}) was similar to that in the unburnt area (1.39 Mg m^{-3}). The difference in BD is not statistically significant ($p > 0.05$). The related BD values suggested that soil BD may have returned to pre-fire levels after one year of bushfire incidence, due to biological activities (e.g., roots, earthworms, and microbes) and natural processes such as wet-dry cycles (Arunrat et al., 2024). Similar findings were observed in *Saccharin angustifolium*, *Aristida laevis*, *Eryngium pandanifolium*, and *Paspalum ssp* vegetation biomes by Almeida Santana et al., (2018). However, Heydari et al., (2017) detected increased BD in an oak forest. Alcañiz et al., (2018) noted that the reduction of SOM may account for the higher soil BD. In contrast to the findings of the current study, in a pine forest, Li et al., (2021) reported lower BD values in burnt site (0.97 g/cm^3) compared to the unburnt plot (1.12 g/cm^3). They noted that the penetrating and mixing of finer ash particles with soil materials may account for it. The non-significant difference in BD deduced that bushfire impact on BD was not significant.

The soil pH concentration level was higher in the bushfire-affected area of the plantation (5.81) than in the bushfire-unaffected part (5.66). Non-statistically significant ($p > 0.05$) difference was found. The higher pH concentration level in the burnt area of the plantation indicated that the soils were comparatively less acidic than the unburnt site. This increase is largely due to the combustion of SOM and ash production (Xue et al., 2014). Similarly, the leaching of alkaline metals from the ash into the soil and the depletion of hydrogen ions in the formation of water can lead to increase in pH values (Granged et al., 2011). The findings of the study aligned with Arunrat et al., (2023), who reported an increase in pH.

A lower ECEC concentration value was observed in the burnt section of the *Elaeis guineensis* plantation ($2.48 \text{ cmol kg}^{-1}$) compared to the bushfire-unaffected area ($3.44 \text{ cmol kg}^{-1}$), with the difference being statistically significant ($p < 0.05$). The results suggested that the impact of bushfire on ECEC in *Elaeis guineensis* plantations is negative, possibly due to structural modifications of clay minerals, combustion of SOM, and the transformation of clay fractions into sand-sized particles (Marcos et al., 2007). Furthermore, the development of coarse particles can decrease ECEC in the soil (Wondafrash et al., 2008). In the current study, a higher sand fraction was observed in the burnt plantation (813.10 g kg^{-1}). The findings of the study are consistent with Thomaz et al., (2014) who reported lower ECEC concentrations in the Prudentópolis municipality.

The SOM concentration level was higher in the burnt area of the *Elaeis guineensis* plantation (4.06 g kg^{-1}) than in the bushfire-unaffected area (3.76 g kg^{-1}). A non-statistically significant difference ($p > 0.05$) was observed. The observed increase in SOM in the burnt area of the *Elaeis guineensis* plantation indicated that the impact of bushfire on SOM is positive. This may be due to the higher carbon content of the habitat in the fire-affected area of the *Elaeis guineensis*, and despite some carbon

loss, more carbon remained. In consistent with the current study, Orobator (2025a) reported higher concentration levels in SOM (1.74 g kg^{-1}) in burnt rubber plantation compared to the unburnt site (1.47 g kg^{-1}). In contrast, Granged et al., (2011) reported lower levels in SOM concentration in a Mediterranean heathland. However, in a *Pinus pinaster* plantation, Meira-Castro et al., (2014) observed no changes in the concentration levels of SOM. The impacts of bushfire on SOM are varied depending mostly on the vegetation type.

The concentration level of SOC was higher in the burnt section of the *Elaeis guineensis* plantation (2.34 gkg^{-1}) compared to the unburnt area (2.03 gkg^{-1}). No statistically significant differences ($p > 0.05$) were detected. The higher concentration level of SOC in the burnt area of the plantation implied that the impact of bushfire on SOC is positive. The charred remains left on the soil can be credited to the increased SOC concentrations in the burnt *Elaeis guineensis* (Scharenbroch et al., 2012), as combustion primarily releases as carbon dioxide (CO_2) while leaving behind carbon-rich char. Higher concentrations of SOC are anticipated to be associated to the amplified deposition of charred materials in the topsoil as fallout of exterior inputs, largely from combusted materials (González-Pérez et al., 2004). The findings of the research aligned with Liu et al., (2018) for grasslands in China; they reported increases in soil organic carbon (SOC) of 11.2%.

In the burnt area of the *Elaeis guineensis* plantation, a higher concentration of total nitrogen (TN) (0.17 g kg^{-1}) was observed compared to the unburnt section (0.14 g kg^{-1}). The higher concentration of total nitrogen in the burnt site of the plantation indicated a positive impact of bushfire on TN. The observed higher concentrations of TN in the burnt *Elaeis guineensis* plantation maybe due to: 1) volatilization of organic N from the topsoil, 2) condensation of N in the soil profile, and 3) increased N mineralization from changed pH (Knoepp & Swank, 1993). The findings

of the study agreed with LIU et al., (2018); they observed increased TN in topsoil after fire in grassland vegetation. The difference in TN for the current study is not statistically significant ($p > 0.05$), deducing that the positive impact of bushfire on TN is not notable.

Avl P indicated a higher concentration level in the burnt area of the *Elaeis guineensis* plantation (3.68 gkg^{-1}) than the bushfire-unaffected area (3.14 gkg^{-1}). The higher concentration level of Avl P in the burnt area of the plantation deduced a positive impact of bushfire on Avl P. Avl P increase can be credited to the transformation of organic P to Avl P by mineralization and ash accumulation on the topsoil (Alcañiz et al., 2016). Similarly, Fernández-García et al., (2019) reported higher Avl P in burnt *P. pinaster* forest. The difference in Avl P is not statistically significant ($p > 0.05$), inferring that the positive impact of bushfire is not significant. However, in a *Pinus halepensis* Mill forest, Moya et al., (2019) observed a significant difference in Avl P in the topsoil between the burnt and unburnt plots.

Amongst the exchangeable cations (Ca, Na, K, and Mg), only K had higher concentration level in the burnt area of the plantation. The higher concentration level of only K indicated that while the effect of bushfire on Ca, Na, and Mg was negative, its impact on K was positive. The lower concentration levels of Ca, Mg and Na may be due to plant uptake during post-fire succession (Caon et al., 2014). The higher concentration level of K is connected with the burning of organic materials which emits ions into the soil medium as ash (Lucas-Borja et al., 2021). The findings of the study agreed with Maynard et al., (2014), who reported higher K concentration level in burnt boreal stand. The differences in Ca, Na, Mg, and K were statistically significant ($p < 0.05$), showing that bushfire had a significant negative impact on Ca, Na, and Mg, but a significant positive impact on K. These results indicated the complex bushfire impacts on exchangeable cations in *Elaeis guineensis* plantations.

CONCLUSION

Soil nutrient dynamics in a tropical oil palm (*Elaeis guineensis*) plantation affected by bushfire were assessed, revealing diverse effects. Sand, pH, SOM, SOC, TN, Avl P, and K concentration levels were higher in the burnt area of the *Elaeis guineensis* plantation, whereas silt, clay, ECEC, Ca, Na, and Mg were lower. Statistically significant differences were detected in ECEC, Ca, Na, Mg, and K between the unburnt and burnt areas of the plantation. The research concluded that bushfire significantly influenced K

positively, while it had significant negative impacts on ECEC, Ca, Mg, and Na. To improve the low concentrations of silt, clay, ECEC, Ca, Mg, and Na in the soils of the burnt parts of the *Elaeis guineensis* plantation, the study recommended the application of organic materials and lime to the soils. The available evidence from this research will aid to make empirical-based decisions for the formulation of soil management policies vital for the sustainable productivity of *Elaeis guineensis* plantations in the tropics.

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