Article in Press: JJEES 16(2), June 2025.
This article has been accepted for publication and will appear in the upcoming issue. The final published version will be available through the journal website after copyediting, typesetting and proofreading.

Effect of Bushfire on Soil Physicochemical Properties in Rubber (*Hevea Brasiliensis*) Plantations of Tropical Nigeria

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Received on December 5, 2023, Accepted on January 12, 2025

Abstract

The study examined the effect of bushfire on soil physicochemical properties in rubber (Hevea brasiliensis) plantations of tropical Nigeria. The objectives of the study were to: (i) determine the concentration levels of the physicochemical properties of soil in the burnt and unburnt H. brasiliensis plantations, and (ii) evaluate the differences in the soil quality properties of soil in the burnt and unburnt H. brasiliensis plantations. Forty composite soil samples were collected from both H. brasiliensis plantations at 0-15cm and 15-30cm soil depths. Soil physicochemical properties were analyzed using standard laboratory procedures. At the same time, data obtained were statistically examined using both descriptive (range, mean, standard deviation, and coefficient of variation) and inferential (student t-test) statistics. The results revealed that compared to the unburnt H. brasiliensis plantation; soil pH, effective exchange cation capacity, soil organic matter, total organic carbon, total nitrogen, phosphorus, potassium, copper, and manganese had higher values in the burnt H. brasiliensis plantation, whereas, the values of calcium, sodium, magnesium, iron and zinc were lower. Significant differences ($p < 0.05$) in clay, phosphorus, iron, zinc, and calcium were detected. The study concluded that bushfire has a positive impact on soil pH, effective exchange cation capacity, soil organic matter, total organic carbon, total nitrogen, phosphorus, potassium, copper, and manganese, while the effect on calcium, sodium, magnesium, iron, and zinc was negative.

Keywords: Fire, Impacts, Physicochemical properties, Rubber tree, Soil quality

1. Introduction

Fires are a significant cause of disruption in a number of different environments (Bowman et al., 2009 cited in Hamad et al., 2013). Presently, bushfires are extensive ecological incidences, affecting over 100 million hectares of forest biomes, which suffer their detrimental effects (Blinkova *et al.,* 2025). Bushfire is a major ecological phenomenon in most tropical

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agricultures. Rubber (*Hevea brasiliensis*) plantation evolutions are both environmentally and economically consequential at global, national, and local scales. Globally, whereas previous research (Al−Khayri & Khan, 2024; Kukavskaya et al., 2024; Samburova *et al.*, 2023; Amoako & Gambiza, 2022; Xifré-Salvadó et al., 2021; Chungu et al., 2020; Alcañiz et al., 2018; Keesstra et al., 2017; Muñoz-Rojas et al., 2016; Muqaddas et al., 2015; Xue et al., 2014; Nabatte & Nyombi, 2013; Aref et al., 2011; Kara and Bolat, 2009; Ekinci, 2006; Certini, 2005; etc.) had examined and documented findings of the effect of fire on soil properties in varied flora ecosystems. Empirical data on bushfire impacts on the physicochemical properties of soil in *H. brasiliensis* plantations are unavailable.

In tropical Nigeria, prior in-depth studies (Itohanmwen & Umweni, 2024; Orobator & Odjugo, 2024; Orobator and Odjugo, 2023; Orobator, 2022; Orobator et al., 2020; Umar et al., 2012; Umar et al., 2010; Orimoloye et al., 2012; Ugwa et al., 2005; Esekhade & Ugwa, 2008; Aweto, 1987; Onuwaje &Uzu, 1982; etc.) have been undertaken in *H. brasiliensis* plantations. However, these investigations did not also examine the impacts of bushfires on soil physicochemical properties in *H. brasiliensis* plantations. Soil is a significant resource for life that offers a diversity of goods and services to meet the needs of humans on earth (Anache et al., 2017 cited in Attah et al., 2022). Soil physicochemical properties (sand, silt, clay, bulk density, water repellency, pH, effective cation exchange capacity, soil organic matter, organic carbon, nitrogen, phosphorus, calcium, sodium, magnesium, potassium, iron, copper, manganese, zinc, etc.) are significant quantifiable soil quality indicators that impact the capability of soils to sustain crop production (Orobator, 2019). Nevertheless, these soil quality parameters can be influenced by fire (Xifré-Salvadó *et al.*, 2021; García-Redondo *et al.*, 2024; Blinkova *et al.*, 2025). Every year, bushfire incidences are widespread in most parts of Nigeria particularly during the dry season (Orobator and Odjugo, 2023). Esekhade et al., (2005) stated that the impact of bushfires on *H. brasiliensis* plantations should not be underestimated because of its ecological significance. Consequently, Certini (2005) reported that inquiries on bushfire's effect on soil quality properties demand exigent and unbroken responsiveness from environmental researchers. Recently, Garrido-Ruiz *et al.*, (2022) recommended that more empirical studies be carried out to reveal the impact of bushfire on soil properties in agricultural land uses.

The incidence of no existing experiential evidence on the effect of bushfire on soil physicochemical properties in *H. brasiliensis* plantations makes it challenging to understand and predict bushfire effects on soil physicochemical properties in *H. brasiliensis* plantations. This drawback further limits the development of sustainable approaches that are aimed at managing and conserving soils affected by bushfires in *H. brasiliensis* plantations. Therefore, the need to investigate the bushfire impact on the physicochemical properties of soils in *H. brasiliensis* plantations is currently compelling and essential. To fill this research gap, this study aimed to investigate through an empirical assessment, the effect of bushfire on soil physicochemical properties in *H. brasiliensis* plantations of tropical Nigeria. The objectives of the research were to: (i) determine the level of concentrations of the physicochemical properties of soil in the burnt and unburnt *H. brasiliensis* plantations, and (ii) examine the differences in the soil quality properties between the burnt and unburnt *H. brasiliensis* plantations. The positive and negative impacts of bushfire on soil physicochemical properties, revealed by this research, will offer contemporary data that will support the task of bio-geographers, soil geographers, soil scientists, fire ecologists, and tree plantation managers toward evolving strategies for the sustainable management of soil quality in burnt *H. brasiliensis* plantations.

2. Material and methods

2.1. Study area

The study was carried out in Rubber Research Institute of Nigeria (RRIN), Iyanomo, Ikpoba Okha Local Government Area, Edo State, Nigeria. RRIN lies within latitudes 60 08' 54.99'' – 60 10' 0.48''N and longitudes 50 34' 9.12'' – 50 36' 44.64''E respectively (Figure 1). The total land area is 2,078 hectares, out of which 496 hectares is occupied with matured *H. brasiliensis* trees. 109 hectares is cultivated with young *H. brasiliensis* plantations, while the nursery beds occupy 4.2 hectares (Umar *et al.*, 2012). Whereas the soils are typically the ferrallitic soil type (Areola, 1991), the climate is tropical rainforest. The rainfall pattern is bimodal, characterized by an extended rainy season that begins in early March with short rainy period stretching from September to late October (Ugwa *et al.*, 2005). RRIN is bordered by Obagie, Uhie, Iyanomo, Obaretin, Obayantor I, and Ogbekpen communities respectively (Fig.1). The locals of these communities are mostly farmers whose farms are adjacent to the *H. brasiliensis* plantations in RRIN.

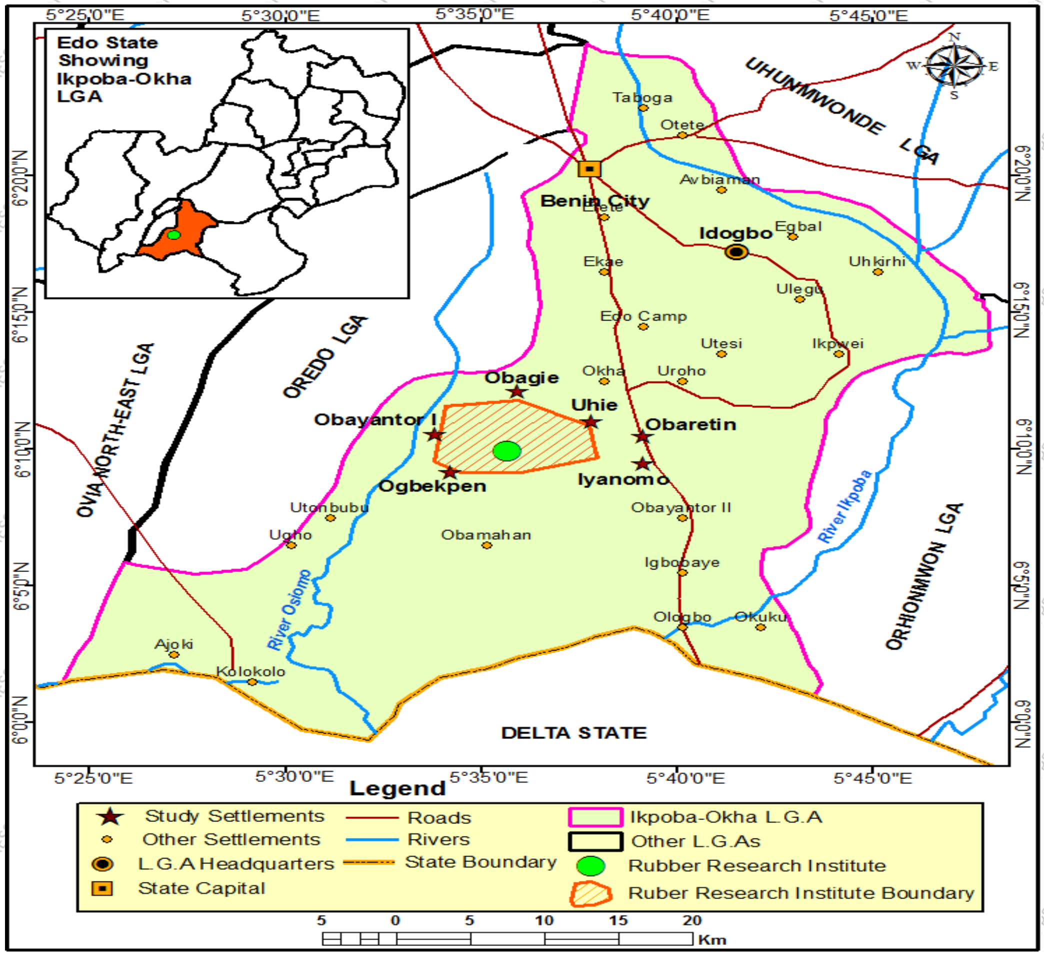

Figure 1: Location of Rubber Research Institute of Nigeria (RRIN), Iyanomo, Edo State, Nigeria

2.2. Fieldwork

After a detailed reconnaissance survey, two *H. brasiliensis* plantations (unburnt and burnt) adjacent to each other with similar ecological characteristics (soil type, climate, topography, and age) and situated in the premises of RRIN were identified and adopted for the investigation. Information from the staff of RRIN indicated that the fire that affected the burnt *H. brasiliensis* plantation was anthropogenically triggered. Soil samples were collected from the unburnt (control plot) and burnt *H. brasiliensis* plantations (treatment site) from two sampling points randomly selected from 10 plots of 20 × 20m at prearranged soil depths of 0 – 15cm and

15 – 30cm. Initial 40 soil samples were augured from each of the burnt and unburnt *H. brasiliensis* plantations, making a total of 80 soil samples. In making a composite soil sample, 2 composite soil samples emerged from the 20 plots of 20 × 20m, making 40 soil samples. A total of 40 composite soil samples were collected, air-dried, crushed, and thoroughly mixed and sieved through a 2 mm mesh and analyzed for soil physicochemical properties.

2.3. Laboratory analyses

Soil texture was analyzed by hydrometer method (Gee and Or, 2002; Khudhur et al., 2018). Bulk density was determined by the core method (Nnaemeka et al., 2013). Soil water repellency (SWR) was analyzed with the classical Water Drop Penetration Time (WDPT) (Wietinga *et al.*, 2017). Soil pH was determined electrometrically in 1:2.5 soil/water ratios (Hendershot *et al.*, 1993) and organic carbon was determined using the method defined by Nelson and Sommers (1996). Total nitrogen was analyzed using modified micro Kjeldahl method (Bremner and Milvaney, 1982). Soil organic matter content (SOM) was measured by the potassium dichromate oxidation method (Nelson and Sommers, 1996). The Bray II method was used to determine total available phosphorus (Olsen and Sommers, 1982). Extract for available P was prepared with ammonium fluoride and P obtained by means of molybdenum blue method (Murphy and Riley, 1962). For estimation of exchangeable Ca, Mg, K and Na, soil samples was first percolated with 1N ammonium acetate solution (pH = 7.0). The atomic absorption spectrophotometer was adopted to analyze for exchangeable Ca and Mg whereas the digital flame photometry was used to estimate exchangeable Na and K (Onyekwelu *et al.*, 2008). Effective cation exchange capacity was determined by saturating 10g of soil with normal natural ammonium acetate solution, washing out the excess ammonium with methanol and afterward distillation of the absorbed ammonium into boric solution. The distillate will titrate alongside standard hydrochloric acid (Nnaemeka *et al.*, 2013). The amount of potassium in the samples was analyzed using the flame photometer (Adekunle, 2011). Manganese, copper, iron and zinc were determined by the atomic absorption spectrophotometry method (Tan *et al.*, 2012).

2.4. Data analysis

Descriptive statistics (range, mean, standard deviation and coefficient of variation) was used to analyze the data. Descriptive statistics aided the soil physicochemical properties' concentration values to be presented in a meaningful and comprehensible way, which in turn, permitted for a simplified explanation of the data set. Comparative analysis was also performed using the student's t-test to determine statistically significant differences. The student's t-test compared the means of each soil quality property (Al-Achi, 2019). This was done between the unburnt and burnt *H. brasiliensis* plantations. Levels of significance are described as non-significant ($p > 0.05$) and significant ($p < 0.05$) respectively. The statistical techniques were adapted to achieve the objectives of the study specifically. IBM Statistical Package for Social sciences (SPSS) 20.0 and Microsoft Excel version 2010 were used for the statistical analyses.

3. Results

3.1. Sand, Silt, Clay, BD, and SWR

Soil physical and chemical properties of unburnt and burnt *H. brasiliensis* plantations are indicated in Table 1 and Table 2**.** Sand showed higher concentration levels in the topsoil of the unburnt *H. brasiliensis* plantation (742 gkg^{-1}) compared to the burnt *H. brasiliensis* plantation (730 gkg^{-1}), and no statistically significant differences were detected between both *H.*

brasiliensis plantations ($p > 0.05$). Compared to the burnt *H. brasiliensis* plantation (189 gkg^{-1}), a higher concentration level of silt was observed in the topsoil of the unburnt *H. brasiliensis* plantation (205 gkg^{-1}). A non-significant difference was observed ($p > 0.05$). The concentration level of clay in the unburnt *H. brasiliensis* plantation at the topsoil (58 Mg m^{-3}) was lower than the burnt *H. brasiliensis* plantation (81 Mg m^{-3}). Significant difference was observed in clay contents ($p < 0.05$) in the subsoil.

Table 1: Soil physical properties of unburnt and burnt *H. brasiliensis* plantations

Soil parameter	**Depth (cm)**	**Unburnt *H. brasiliensis* plantation**				**Burnt *H. brasiliensis* plantation**				***p*-value**
		Range	**Mean**	**Std.**	**CV (%)**	**Range**	**Mean**	**Std.**	**CV (%)**	
Sand (gkg-^{1})	0 - 15	680 - 800	742	43.60	5.88	580 - 880	730	77.10	10.56	0.32
	15 - 45	520 – 660	589	49.00	8.32	510 - 710	620	68.10	10.98	0.08
Silt (gkg-^{1})	0 - 15	140 - 290	205	53.10	25.90	100 - 250	189	44.30	23.44	0.23
	15 - 45	180 – 280	239	33.10	13.84	190 - 320	244	51.80	21.23	0.38
Clay (gkg-^{1})	0 - 15	20 - 100	58	27.80	47.93	20 - 170	81	52.10	64.32	0.13
	15 - 45	120 – 220	172	29.70	17.27	50 - 200	136	49.20	35.39	0.01*
BD (Mg m^{-3})	0 - 15	0.23 - 1.94	1.04	0.58	55.76	0.57 - 1.73	1.12	0.36	32.14	0.38
	15 - 45	0.63 - 1.94	1.26	0.51	40.47	0.69 - 1.92	1.20	0.42	35.00	0.35
SWR	0 - 15	15.11 - 20.67	18.00	2.18	12.11	12.87 - 19.91	17.07	2.51	14.70	0.20
	15 - 45	15.97 - 23.6	19.07	2.36	12.38	15.78 - 23.30	20.04	2.25	11.23	0.16

Note: BD = Bulk density, SWR =Soil water repellency
** Statistically significant differences at $p < 0.05$.*

Higher mean value of SWR was detected in the unburnt *H. brasiliensis* plantation (18.00) than the burnt *H. brasiliensis* plantation (17.07) at the topsoil, nevertheless, no statistically significant differences were found.

3.2.Soil pH, ECEC SOM, TOC, TN and P

Soil pH indicated lower values in the topsoil (4.75) and subsoil (4.51) of the unburnt *H. brasiliensis* plantation than the topsoil (4.82) and subsoil of the burnt *H. brasiliensis* plantation

(4.57), however, no statistically significant differences were detected between both *H. brasiliensis* plantations ($p > 0.05$). ECEC concentration levels were lower in the topsoil (1.07 cmol kg^{-1}) and subsoil (151 cmol kg^{-1}) of the unburnt *H. brasiliensis* plantation than the topsoil (1.42 cmol kg^{-1}) and subsoil of the burnt *H. brasiliensis* plantation (166 cmol kg^{-1}). Nonetheless, no statistically significant differences were detected between both *H. brasiliensis* plantations ($p > 0.05$).

Table 2: Soil chemical properties of unburnt and burnt *H. brasiliensis* plantations

Soil parameter	**Depth (cm)**	**Unburnt *H. brasiliensis* plantation**				**Burnt H. *brasiliensis* plantation**				***p*-value**
		Range	**Mean**	**Std.**	**CV (%)**	**Range**	**Mean**	**Std.**	**CV (%)**	
pH	0 - 15	4.16 - 5.43	4.75	0.50	10.52	4.32 - 5.36	4.82	0.34	7.05	0.36
	15 - 45	4.06 - 5.17	4.51	0.38	8.42	3.89 - 5.11	4.57	0.37	8.09	0.35
ECEC	0 - 15	0.31 - 2.59	1.01	0.75	74.25	0.31 - 2.59	1.42	0.54	38.02	0.12
(cmol kg^{-1})	15 - 45	0.57 - 3.28	1.57	0.94	59.87	0.92 - 3.25	1.66	0.71	42.77	0.41
SOM	0 - 15	0.15 - 2.50	1.47	0.73	49.65	0.40 - 3.00	1.74	0.78	44.82	0.22
(g kg^{-1})	15 - 45	0.24 - 1.19	0.74	0.33	44.59	0.19 - 1.28	0.72	0.39	54.16	0.43
TOC	0 - 15	0.64 - 1.45	0.94	0.31	32.97	0.23 - 1.74	1.00	0.45	45.00	0.35
(g kg^{-1})	15 - 45	0.14 - 0.69	0.43	0.19	44.18	0.11 - 0.74	0.41	0.22	53.65	0.43
TN	0 - 15	0.07 - 0.18	0.12	0.04	33.33	0.04 - 0.21	0.13	0.06	46.15	0.27
(g kg^{-1})	15 - 45	0.02 - 0.09	0.05	0.02	40.00	0.01 - 0.12	0.05	0.03	60.00	0.41
P	0 - 15	1.43 - 8.36	4.41	2.43	55.10	2.42 - 10.64	6.52	2.70	41.41	0.04*
(mg kg^{-1})	15 - 45	0.7 - 7.16	3.24	1.94	59.87	1.75 - 7.28	3.66	2.10	57.37	0.31
Ca	0 - 15	5.76 - 43.78	18.71	10.52	56.22	6.78 - 32.14	15.90	7.51	47.23	0.27
(cmol kg^{-1})	15 - 45	7.67 - 33.66	13.40	7.51	56.04	4.48 - 15.86	8.44	3.32	39.33	0.04*
Na	0 - 15	23.29 - 195.83	94.40	52.40	55.50	30.33 - 129.97	74.55	32.68	43.83	0.21
(cmol kg^{-1})	15 - 45	32.82 - 132.59	63.99	32.48	50.75	25.38 - 118.94	48.48	27.25	56.20	0.15
Mg	0 - 15	13.08 - 110.02	53.03	29.44	55.51	17.04 - 73.02	41.88	18.36	43.83	0.81
(cmol kg^{-1})	15 - 45	18.44 - 74.49	35.95	18.25	50.76	14.26 - 66.82	27.23	15.31	56.22	0.15
K	0 - 15	14.64 - 75.20	33.82	18.37	54.31	7.70 - 96.18	37.91	29.96	79.02	0.38
(cmol kg^{-1})	15 - 45	7.88 - 55.91	22.46	14.88	66.25	4.64 - 29.47	16.03	7.70	48.03	0.13
Fe	0 - 15	84.18 - 658.3	312.24	175.88	56.32	97.50 - 219.50	173.08	41.10	23.74	0.02*
(mg kg^{-1})	15 - 45	51.92 - 413.02	194.47	109.74	56.43	76.52 - 358.59	149.10	83.49	55.99	0.17
Cu	0 - 15	6.29 - 32.34	14.54	7.90	54.33	3.31 - 41.36	16.30	12.88	79.01	0.38
(mg kg^{-1})	15 - 45	3.39 - 24.04	9.65	6.40	66.32	2.0 - 12.67	6.89	3.31	48.04	0.13

Mn	0 - 15	1.95-10.02	4.50	2.44	54.22	1.03 - 12.82	5.05	3.99	79.00	0.36
(mg kg^{-1})	15 - 45	1.05-7.45	2.99	1.98	66.22	0.62 - 3.93	2.13	1.02	47.88	0.13
Zn	0 - 15	1.68 - 13.17	6.24	3.51	56.25	0.20 - 4.39	2.89	1.41	48.78	0.01*
(mg kg^{-1})	15 - 45	1.04 - 8.26	3.88	2.19	56.44	1.53 - 7.17	3.48	1.69	48.56	0.33

A higher concentration level of SOM was detected in the burnt *H. brasiliensis* plantation (1.74 g kg^{-1}) than in the unburnt *H. brasiliensis* plantation (1.47 g kg^{-1}) at the topsoil. However, no significant difference ($p > 0.05$) was observed. TOC did not indicate significant differences ($p > 0.05$). TOC showed higher concentration levels in the burnt *H. brasiliensis* plantation (1.00 gkg^{-1}) than in the unburnt *H. brasiliensis* plantation (0.94 gkg^{-1}) at the topsoil. TN indicated a higher concentration level in the burnt plantation (0.13 gkg^{-1}) than the unburnt *H. brasiliensis* plantation (0.12 gkg^{-1}) at the topsoil, but no statistically significant differences were detected between the unburnt and burnt *H. brasiliensis* plantations ($p > 0.05$). A higher concentration level of P was detected in the burnt *H. brasiliensis* plantation (6.52 gkg^{-1}) of the topsoil than in the unburnt *H. brasiliensis* plantation (4.41 gkg^{-1}), and did reveal significant differences ($p < 0.05$) in the topsoil.

3.3. Ca, Na, Mg and K

Ca indicated lower concentration levels in the topsoil (13.40 cmol kg^{-1}) and subsoil (8.44 cmol kg^{-1}) of the burnt *H. brasiliensis* plantation than in topsoil (18.71 cmol kg^{-1}) and subsoil (13.40 cmol kg^{-1}) of the unburnt *H. brasiliensis* plantation. Ca showed no statistically significant differences in the topsoil of the unburnt and burnt *H. brasiliensis* plantations but did so in the subsoil ($p < 0.05$). Lower concentration levels of Na were detected in the topsoil (74.55 cmol kg^{-1}) and subsoil (48.48 cmol kg^{-1}) of the burnt *H. brasiliensis* plantation than in topsoil (94.40

cmol kg^{-1}) and subsoil (63.99 cmol kg^{-1}) of the unburnt *H. brasiliensis* plantation. Na indicated no statistically significant differences ($p > 0.05$). Mg concentration levels were lower in the topsoil (41.88 cmol kg^{-1}) and subsoil (27.23 cmol kg^{-1}) of the burnt *H. brasiliensis* plantation than in topsoil (53.03 cmol kg^{-1}) and subsoil (35.95 cmol kg^{-1}) of the unburnt *H. brasiliensis* plantation. Mg showed no statistically significant differences ($p > 0.05$). K indicated higher level in the burnt *H. brasiliensis* plantation (37.91 cmol kg^{-1}) than the unburnt *H. brasiliensis* plantation (33.82 cmol kg^{-1}) at the topsoil, but no statistically significant ($p > 0.05$) differences were detected between the unburnt and burnt *H. brasiliensis* plantations.

3.4. Fe, Cu, Mn and Zn

The concentration levels of Fe in the unburnt *H. brasiliensis* plantation at the topsoil (312.24 mgkg^{-1}) and subsoil (194.47 mgkg^{-1}) were higher than in the burnt *H. brasiliensis* plantation at the topsoil (173.08 mgkg^{-1}) and subsoil (149.10 mg kg^{-1}). In addition, a statistically significant difference was observed at the topsoil ($p < 0.05$). Cu did not indicate significant differences ($p > 0.05$) in the unburnt and burnt *H. brasiliensis* plantations, but a higher concentration value was observed in the topsoil (16.30 mg kg^{-1}) of the burnt *H. brasiliensis* plantation than in the subsoil (14.54 mg kg^{-1}) of the unburnt *H. brasiliensis* plantation. Lower concentration level of Mn was found in the topsoil (4.50 mgkg^{-1}) of the unburnt *H. brasiliensis* plantation than in the topsoil (5.05 mgkg^{-1}) of the burnt *H. brasiliensis* plantation, and no statistically significant difference ($p > 0.05$) was observed. However, a higher concentration level of Zn was observed in the topsoil (6.24 mg kg^{-1}) of the unburnt *H. brasiliensis* plantation than in the topsoil (2.89mg kg^{-1}) of the burnt *H. brasiliensis* plantation, and a statistically significant difference was observed ($p < 0.05$).

4. Discussion

4.1. Sand, Silt, Clay, BD and SWR

The lower sand values observed in the burnt *H. brasiliensis* plantation suggested the negative impact of bushfire on sand in this biome. This lower value maybe the resultant effect of the decomposition of kaolinized sand grains (Ulery and Graham, 1993). The non-significant difference may account for the similar low variability (< 15 %) of the sand content. This result contrasts with the findings of Edem et al., (2013), who reported a significantly higher mean value of 838.50 gkg^{-1} in the burnt plantation than the unburnt site (772.60 gkg^{-1}). Heydari et al., (2017) reported that this may be the outcome of oxides and hydroxides of Al and Si, created by kaolin obliteration that can prompt fortification of particles, development of aggregates in sand magnitude, and increase in coarse particles proportion due to fire. Alcañiz et al., (2018) also observed an increase in sand content and noted that it may be due to the formation of unstable soil aggregates. Lower silt content in the topsoil of the burnt *H. brasiliensis* plantation than the unburnt *H. brasiliensis* plantation revealed a negative impact of bushfire on silt. Although the findings disagreed with Aref et al., (2011), who reported that fire did not affect silt contents, it is congruent with the non-significant difference that was observed in the study. The higher clay content in the topsoil of the burnt *H. brasiliensis* plantation inferred more bushfire-positive effects on clay. This may be due to the aggregation of clay particles, caused by heating from bushfire (da Silva and Batalha, 2008). The result of the research is similar to the outcomes of Pierson et al., (2008) who reported that clay fractions increased after fire.

The higher BD value in the topsoil of the burnt *H. brasiliensis* plantation implied that bushfire influenced BD positively. This may be accredited to the breakdown of soil masses and clogging of pores by ash and clay minerals (Certini, 2005). The presence of voids in the soil horizon may also account for high BD in the burnt soils (Heydari et al., 2017). Similarly, in a *Pinus massoniana* forest, Xue et al., (2014) reported that compared to unburnt soils, an increase in BD was observed in the burnt plantation. Unlike the unburnt *H. brasiliensis* plantation, the lower BD content in the subsoil of the burnt plantation may be attributed to soil vapor expansion (Alcañiz *et al.*, 2018). The higher soil water repellency (SWR) value in the subsoil of burnt *H. brasiliensis* plantation is indicative of a downward heat gradient (Glenn and Finley, 2009). Dissimilar from the topsoil of the *H. brasiliensis* burnt plantation, the higher SWR value in the unburnt *H. brasiliensis* plantation suggested the effect of climatic conditions, foliage and organic strata is ordinarily made up of hydrophobic substances (Alcañiz *et al.*, 2018). Correspondingly, in in a *Pinus halepensis* forest, Keesstra et al., (2017) reported higher SWR on the topsoil of unburnt plantations.

4.2. Soil pH, ECEC SOM, TOC, TN and P

The higher pH mean value in the burnt *H. brasiliensis* plantation at the topsoil and subsoil inferred that the burnt *H. brasiliensis* plantation is less acidic than the unburnt *H. brasiliensis* plantation. This showed the positive effects of bushfires on soil pH. The lixiviation of alkaline metals from the ash into the soil system and the depletion of hydrogen ions may account for it (Xue *et al.*, 2014). After the incidence of a fire, it is typical for soil pH to experience an increase, primarily owing to the contribution of ashes that offer oxides, carbonates, and basic cations occasioned by the burning of organic matter (Gonzales et al., 2024). The acidic state of the unburnt *H. brasiliensis* plantation may be due to the materialization of new humus and the leaching of bases (Garrido-Ruiz et al., 2022). Similarly, in Zagros oak (*Quercus brantii*

Lindl.) forests, Heydari et al., (2017) noted that pH values were higher in burnt plantations. The detected non-significant difference of pH between the unburnt and burnt *H. brasiliensis* plantations at both soil depths ($p > 0.05$) may be due to the similarity of the pH values. The general high acidic status of the soils can be ascribed to incidences of high rainfall, resulting to the leaching of soil nutrients (Iwara et al., 2011). The oxidation of charred materials may be responsible for the higher ECEC contents in the burnt *H. brasiliensis* plantation at both the topsoil and subsoil.This result indicates the positive impact of bushfire on ECEC. The released soluble inorganic ions during burning of SOM may also be accredited for the higher ECEC concentration values in the burnt site (Granged et al., 2011). The results are similar to those reached by Edem et al., (2013) and Tabi et al., (2013), who reported that the ECEC contents increased in the soils of burnt plantation.

Soil organic matter (SOM) serves as a potent aggregating agent, holding sand, silt, and clay fractions into aggregates (Farid et al., 2024). The higher SOM content in the burnt *H. brasiliensis* plantation implies that bushfire influenced SOM positively. This may be ascribed to the effects of the prevalence of charred materials on the burnt soil (Xifré-Salvadó et al., 2021). This result agreed with Fonseca et al., (2017), who reported that SOM contents were more in burnt plantation than the unburnt plot. Similarly, in a tropical dry forest, Kennard and Gholz (2001) reported a higher concentration of SOM in burnt soils. The integration of unburnt or partly burnt slash fragments into the soil could be accountable for it (Alcañiz et al., 2018). The detected non-significant difference suggested that bushfire did not significantly enhance the SOM concentrations of soils in the burnt *H. brasiliensis* plantation than the unburnt *H. brasiliensis* plantation.

The higher TOC concentration levels in the burnt *H. brasiliensis* plantation at the topsoil revealed bushfire-positive impacts on TOC. This may be attributed to outward feedback of burnt material and ash. The burnt debris returns to the soil as constituents lesser than 2 mm in the form of ash, which is bulked in the top layer, and this instigates an increase in TOC concentrations (Novara et al., 2013). The total aggregate of TOC is a portion of stored SOM (Orobator, 2014). Besides, TOC in soils largely aids in providing energy for soil and microorganisms which help to decompose organic material (Bridges, 1978). Generally, Caon et al., (2014) stated that TOC increases were connected to the formation of charcoal, fusion of ash into the soil, decomposition of partly burnt woody fragments and flora recovery. The findings of the current study aligned with Ferran et al., (2005), who observed higher TOC contents in the burnt soil than in the unburnt soil. In contrast, Kutiel and Naveh (1987) reported that TOC content of the A horizon (0–5 cm) was significantly lower in the burnt sites than the unburnt sites in a mixed oak and pine forest. Fire can cause a significant decline in TOC concentration due to mineralization of C from the soil organic matter (Caon et al., (2014). The insignificant differences in TOC inferred that bushfire did not significantly affect the TOC of soils in the burnt *H. brasiliensis* plantation compared to the unburnt *H. brasiliensis* plantation.

The higher TN content in the topsoil of burnt *H. brasiliensis* plantation inferred bushfire-positive impacts on TN. In burnt plantations, increases in TN concentration are observed largely due to the accumulation of ash (Mataix-Solera and Guerrero, 2007). In addition, owing to fire incidence, Ferran et al., (2005) reported that TN in the soil horizons increased due to the increase in potentially mineralizable N concentrations. This result of the investigation contrasted the findings of Muqaddas et al., (2015) and Emeterio *et al.*, (2016). Nevertheless, the results of the current study aligned with the outcomes of Kutiel and Naveh (1987). Mataix-Solera and Guerrero (2007) reported that TN concentrations diminished due to its absorption through the germination of herbaceous plants. The observed insignificant differences in TN inferred that bushfire did not considerably influence the TN of soils in the burnt *H. brasiliensis* plantation when matched with the unburnt *H. brasiliensis* plantation.

Higher levels of P, detected in both the topsoil and subsoil of the burnt *H. brasiliensis* plantation deduced bushfire positive impacts on P. Bushfire, leads to the enrichment of available P in the soils (Aref *et al.*, 2011), and the deposition of ash after burning helps to fertilize the soil by direct discharge of P (Edem et al., 2013). Besides, the rapid transformation of instantly available P to mineral P and insoluble P forms such as apatite was accountable for the increase of available P in the burnt soil (Pardini et al., 2004). The result of the study agreed with Heydari et al., (2017), who stated that P values were higher in burnt soils. However, the findings contradicted Edem et al., (2013), who reported that that P contents were lower in burnt plantations. These contradictory outcomes of prior studies implied the different ways varied biomes due to their peculiar ecosystem properties respond to fire effects. The significant differences of P deduced that bushfire did significantly impact P contents in the burnt *H. brasiliensis* plantation, compared to the unburnt *H. brasiliensis* plantation. Similarly, in soils of the semi-arid Ebro Valley of northeastern Spain, Badía and Martí (2003) observed a significant increase in P due to fire; implying also a significant positive effect.

4.3. Ca, Na, Mg and K

The lower concentration levels of Ca in the topsoil of the burnt *H. brasiliensis* plantation indicated the negative impact of bushfire on Ca. This may be due to higher thresholds of vaporization and subsequent volatilization (Zhang and Biswas, 2017). Statistically significant differences, detected between the unburnt and the burnt *H. brasiliensis* plantations at the subsoil, deduced that bushfire did substantially improve the Ca. The lower value of Na, detected in the burnt *H. brasiliensis* plantation, inferred that bushfire has a negative influence on Na in *H. brasiliensis* plantations. The lower concentrations of Na in the burnt *H. brasiliensis* plantation may be due to flora uptake during post-fire succession (Caon et al., 2014). However, the insignificant differences in Na suggested that the influence of bushfire on Na in the burnt *H. brasiliensis* plantation was not substantial compared to the unburnt *H. brasiliensis* plantation. The lower Mg contents in the topsoil and subsoil of the burnt *H. brasiliensis* plantation implied the negative effect of bushfire on Mg. This agreed with the findings of Chungu et al., (2020), who found that Mg contents decreased due to fire in a *Eucalyptus grandis* forest. Nonetheless, the insignificant differences in Mg observed for this study implied that the influence of bushfire on Mg was not considerable. Higher contents of K observed in the topsoil of the burnt *H. brasiliensis* plantation deduced that bushfire positively impacted K. This incidence may be due to the effect of burnt wood and ash on the soils (Pereira et al., 2019). Wood ash contains more K (Nottidge and Nottidge, 2012). The findings of the current study agreed with Thomaz et al., (2014) and Ying et al. (2018). Similarly, Scharenbroch et al. (2012) reported higher K values in burnt Oak (*Quercus*) forest. Statistically detected significant differences deduced that bushfire did substantially improved K in the burnt *H. brasiliensis* plantations.

4.4. Fe, Cu, Mn and Zn.

The higher concentration level of Fe in the unburnt *H. brasiliensis* plantation at both the topsoil and subsoil suggested that bushfire has a detrimental effect on Fe. Similarly, the results of

Norouzi and Ramezanpour (2013) revealed that concentrations of Fe were lower in the burnt soil. The significant difference suggested that the observed negative effect of bushfires on Fe was substantial. The higher Cu content in the topsoil of the burnt *H. brasiliensis* plantation inferred the positive effect of bushfire on Cu. This may be due to observed higher levels of SOM in the burnt *H. brasiliensis* plantation. Cu is primarily found to attach to SOM fraction in the soil which is the most vital soil parameter defining Cu bioavailability (Oku et al., 2012). However, the insignificant difference inferred that the observed bushfire impact on Cu was not remarkable. The higher Mn, the higher value observed in the topsoil of the burnt *H. brasiliensis* plantation implied the positive impact of bushfire on Mn. This may be due to a build-up of ash in the form of amorphous and crystal-like oxides (Certini, 2005). However, the insignificant difference inferred that the observed bushfire impact on Mn was not significant. The detected lower Zn concentration in the burnt *H. brasiliensis* plantation revealed the damaging influence of bushfire on Zn in this biota. This may be due to the effect of erosion and leaching in sandy soils of the burnt *H. brasiliensis* plantation especially during the rainy seasons. Sandy soils are highly erodible during heavy rains once the vegetative cover has been reduced by burning (Ladrach, 2009). The significant difference suggested that the observed detrimental influence of bushfires on Zn was substantial.

5. Conclusion

The comprehensive study has generated valuable insights into the impacts of bushfires on the physicochemical properties of soils in tropical *H. brasiliensis* plantations. The results indicated that compared to the unburnt *H. brasiliensis* plantation; the level of concentrations of pH, ECEC, SOM, TOC, TN, P, K, Cu, and Mn were higher in the burnt *H. brasiliensis* plantation, whereas Ca, Na, Mg, Fe and Zn were lower. Significant differences $(p < 0.05)$ in clay, P, Fe, Zn, and Ca were observed between the unburnt *H. brasiliensis* and burnt *H. brasiliensis* plantations. The study results revealed that bushfire has positive effects on pH, ECEC, SOM, TOC, TN, P, K, Cu, and Mn in *H. brasiliensis* plantations. However, the impact of bushfires on Na, Mg, and Zn was negative. The study demonstrated that while bushfire had a significant positive impact on P, it had a significant negative effect on Fe, Zn, Clay, and Ca. The research concluded that bushfires have varying effects (positive and negative) on specific physicochemical properties of soil in *H. brasiliensis* plantations. Future research could compare the impact of bushfires on *H. brasiliensis* plantations with other tropical agricultural systems to determine whether these effects are specific to rubber plantations or prevalent across different tropical tree ecosystems.

References

Adekunle, I. M. (2011). Bioremediation of Soils Contaminated with Nigerian Petroleum Products Using Composted Municipal Wastes. Bioremediation Journal, 15, 30-241.

Al-Achi, A. (2019). The Student’s t-Test: A Brief Description. Research & Reviews: Journal of Hospital and Clinical Pharmacy, 5, 1, 1-3.

Alcañiz, M., Outeiro, L., Francos, M., Úbeda, X. (2018). Effects of prescribed fires on soil properties: A review. Science of the Total Environment, 613–614, 944–957.

Al−Khayri, J.M., and Khan, T. (2024). Impacts of forest fires on soil: Exploring the effects on biotic and abiotic components. SYLWAN, 168(8), 601−614. 0.26202/sylwan.2024031.

Amoako, E. E., and Gambiza, J. (2022). Effects of anthropogenic fires on some soil properties and the implications of fire frequency for the Guinea savanna ecological zone. Ghana. Scientific African, 6.1-11.

Aref, I.M., Atta, H.A., Ghamde, A.R.M. (2011). Effect of forest fires on tree diversity and some soil properties. International Journal of Agriculture and Biology, 13, 659-664.

Areola, O. (1991). Ecology of Natural Resources. Avebury, England. Academic Publishing Group. p116- 118.

Attah, U. E., Chinwendu, O. C., Ekene, B. (2022). Anthropogenic Influence on Soil Quality Dynamics and Potential Ecological Risk in Agricultural Soils of the Nworie River Watershed, Nigeria. Jordan Journal of Earth and Environmental Sciences. JJEES, 13(2), 130-145.

Aweto, A.O. (1987). Physical and nutrient status of soils under rubber (*H. brasiliensis*) of different ages in south-western Nigeria. Agricultural Systems, 23, 63-72.

Badía, D., and Martí, C., (2003). Plant ash and heat intensity effects on chemical and physical properties of two contrasting soils. Arid Land Research and Management, 17, 23–41.

Blinkova, O., Raichuk, L., McDonald.I. (2025). First-year post-fire alterations of Scots pine forest: composition, relationships, and ecological consequences. Landscape Ecology, 40, 9.https://doi.org/10.1007/s10980-024-02022-8.1-19.

Bremner, J.M., and Mulvaney, C.S. (1982). Nitrogen-total. In Methods of Soil Analysis. Miller, R. H.,Keeney, D.R. (Eds.) Chemical and Microbiological Properties,2:595-624. Madison, WI:American Society of Agronomy. Retrieved from https://www.scirp.org/(S(351jmbntvnsjt1aadkposzje))/.../ReferencesPapers.aspx.

Bridges, E.M. (1978). Interaction of soil and mankind in Britain. European Journal of Soil Science, 29,125-139.

Caon, L., Vallejo, V.R., Ritsema, C.J., Geissen, V. (2014). Efects of wildfire on soil nutrients in Mediterranean ecosystems. Earth-Science Reviews, 139, 47–58.

Certini, G. (2005). Effects of fire on properties of forest soils: a review. Oecologia, 143, 1 - 10.

Chungu, D., Ng'andwe, P., Mubanga, H., Chileshe, F.(2020).Fire alters the availability of soil nutrients and accelerates growth of *Eucalyptus grandis* in Zambia. Journal of Forest Research, 31, 1637 - 1645.10.1007/s11676-019-00977-y.

da Silva, D.M., Batalha, M.A. (2008). Soil–vegetation relationships in cerrados under different fire frequencies. Plant Soil, 311, 87–96.

Edem, I. D., Usoroh, A.D., Ijah, C.J. (2013). Soil properties dynamics induced by passage of fire during agricultural burning. International Journal of Plant and Soil Science. 2,111-126.

Ekinci, H. (2006). Effects of forest fire on some properties of soil. International Journal of Agriculture and Biology, 8,102-106.

Esekhade, T.U., and Ugwa, I.K. (2008). Nutrient uptake in rubber and banana cultivar intercrop on an ultisol in Nigeria. In proceedings of the 42nd Annual Conference of the Agricultural Society of Nigeria. Ebonyi State University. Abakaliki, Nigeria. pp 44 - 447.

Esekhade, T.U., Monkwunye, M.U.B.,Adeoye, G.O. (2005). Effect of rubber based cropping systems on vegetative traits; below-ground interaction and yield of inter crops. Proceedings of 39th Annual Conference of Agriculture Society of Nigeria. University of Benin. Benin City. p262 - 265.

Emeterio, L.S., Múgica, L., Ugarte, M. D., Goica, T., Canals, R.M. (2016). Sustainability of traditional pastoral fires in highlands under global change: Effects on soil function and nutrient cycling. Agriculture Ecosystems & Environment, 235,155-163.

Farid, A., Alam, M.K., Goli, V.S.N.S., Akin, I.D., Akinleye, T., Chen, X., Cheng, Q., Cleall, P., Cuomo, S., Foresta, V. (2024). A review of the occurrence and causes for wildfires and their impacts on the geoenvironment. Fire, 7, 295. https://doi.org/10.3390/fire7080295.

Ferran, A., Delitti, W., Vallejo, V.R., (2005). Effects of fire recurrence in *Quercus coccifera L.* shrublands of the Valencia Region (Spain): II. plant and soil nutrients. Plant Ecology, 177, 71–83.

Fonseca, F., Figueiredo, T., Nogueira, C., and Queirós, A. (2017). Effect of prescribed fire on soil properties and soil erosion in a Mediterranean mountain area. Geoderma, 307,172 - 180.

García-Redondo, C., Díaz-Raviña, M., Regos, A. (2024). Long-Term Cumulative Effects of Wildfires on SoilVegetation Dynamics in the “Baixa Limia–Serra do Xurés” Natural Park. Spanish Journal of Soil Science, 14, 13103. doi: 10.3389/sjss.2024.13103.

Garrido-Ruiz, C., Sandoval, M., Stolpe, N., and Sanchez-Hernandez, J.C. (2022). Fire impacts on soil and post fire emergency stabilization treatments in Mediterranean-climate Regions. Chilean Journal of Agricultural Research, 82, 335-347.

Gee, G.W., and Or, D. (2002). Particle Size Analysis. In: Dane, J.H. and Topp, G.C., Eds., Methods of Soil Analysis, Part 4, Physical Methods, Soils Science Society of America, Book Series 5: 255-293.

Glenn, N.F., and Finley, C.D. (2009). Fire and vegetation type effects on soil hydrophobicity and infiltration in the sagebrush-steppe. Journal of Arid Environments, 74, 653-659.

Gonzales, H., Ocana,C.L., Cubas, J.A., Vega-Nieva, D.S., Ruíz, M., Santos, A. and Barboza, E. (2024). Impact of forest fire severity on soil physical and chemical properties in pine and scrub forests in high Andean zones of Peru. Trees, Forests and People, 18,1-12.100659.

Granged, A. J. P., Jordán, A., Zavala, L.M., Muñoz-Rojas, M., Mataix-Solera, J. (2011). Short-term effects of experimental fire for a soil under eucalyptus forest (SE Australia). Geoderma, 167–168.

Hamad, A. Abu., Jasper, A., Uhl, D. (2013). Charcoal Remains from the Mukheiris Formation of Jordan – the First Evidence of Palaeowildfire from the Anisian (Middle Triassic) of Gondwana. Jordan Journal of Earth and Environmental Sciences, 5,1,17- 22.

Heydari, M., Rostamy, A., Najafi, F., Dey, D.C. (2017). Effect of fire severity on physical and biochemical soil properties in Zagros oak (*Quercus brantii Lindl*.) forests in Iran. Journal of Forestry Research, 28, 95-104.

Hendershot, H.W., Lalande, H.L., and Duquette, M. (1993).Soil Reaction and Exchangeable Acidity in: Soil Sampling and Methods of Analysis. Cartar, M.R. (Ed.), Canadian. Society of Soil Science. London, pp.141-145.

Itohanmwen, F.E. and Umweni, A.S. (2024).Land Suitability Evaluation Study for Oil Palm (*Eleais guineensis*) and Rubber (*Hevea brasiliensis*) Cultivation in Esan North East Local Government Area of Edo State, Nigeria. African Scientist, 25(2), 182-197.

Iwara, A.I., Ewa, E. E., Ogundele, F.O., Adeyemi, J. A., Otu, C. A. (2011). Ameliorating Effects of Palm Oil Mill Effluent on the Physical and Chemical Properties of Soil in Ugep, Cross River State, South-Southern Nigeria. International Journal of Applied Science and Technology, 1, 106 – 112.

Kara, O., and Bolat, I. (2009). Short-term effects of wildfire on microbial biomass and abundance in black pine plantation soils in Turkey. Ecological Indicators, 9,1151–1155. https://doi.org/10.1016/j.ecolind.2009.01.002.

Keesstra, S., Wittenberg, L., Maroulis, J., Sambalino, F., Malkinson, D., Cerdà, A., Pereira, P. (2017).The influence of fire history, plant species and post-fire management on soil water repellency in a Mediterranean catchment: The mount Carmel range, Israel. Catena, 149,857-866.

Kennard, D.K. and Gholz, H.L. (2001). Effects of high-intensity fires on soil properties and plant growth in a Bolivian dry forest. Plant Soil, 234,119–129.

Khudhur, N.S., Khudhur, S.M., Ahmad, I.N. (2018). An Assessment of Heavy Metal Soil Contamination in a Steel Factory and the Surrounding Area in Erbil City. Jordan Journal of Earth and Environmental Sciences,9,1,1 – 11.

Kukavskaya, E.A., Bogorodskaya, A.V., Buryak, L.V., Kalenskaya, O.P. and Conard, S.G. (2024).Effects of Wildfire and Logging on Soil CO_2 Efflux in Scots Pine Forests of Siberia. Atmosphere, 15, 1117.10.3390/atmos15091117.

Kutiel, P., and Naveh, Z. (1987). Effect of fire on nutrients in a pine forest soil. Plant and Soil, 104,269-274.

Ladrach, W. (2009). The effects of fire in agriculture and forest ecosystems. International Society of Tropical Foresters (ISTF NEWS). Special Report. 12.

Mataix-Solera, J., and Guerrero, C. (2007). Efectos de los incêndios forestales en las propriedades edáficas. In: Mataix-Solera,Jorge et al. Incendios Forestales, Suelos y Erosion Hídrica. Alicante, España: CEMACAM Font RojaAlcoi, 5- 40.

Muñoz-Rojas, M., Lewandrowski, W., Erickson, T.E., Dixon, K.W., Merritt, D.J. (2016). Understanding environmental drivers in the regulation of soil respiration dynamics after fire in semi-arid ecosystems.Geophysical Research Abstracts, 18, 1-3.

Muqaddas, B., Zhou, X., Lewis, T., Wild, C., Chen, C. (2015). Long-term frequent prescribed fire decreases surface soil carbon and nitrogen pools in wet sclerophyll forest of Southeast Queensland, Australia. Science of the Total Environment, 536, 39-47.

Murphy, J., and Riley, J.P. (1962). A modified single solution for determination of phosphate in natural water. Analytica Chemica Acta, 27, 31-36.

Nabatte, P., and Nyombi, K. (2013). Effects of pine plantation surface fires on soil chemical properties in Uganda. Research Journal of Agriculture and Forestry Sciences, 1, 10-14.

Nelson, D.W., and Sommers, L.E. (1982). Total Carbon, Organic Carbon and Organic Matter in: Sparks, D. L. (Eds.), Methods of Soil Analysis. Part 3. SSSA Books Series No 5, SSSA Madison.

Nnaemeka, C.C., Esio, U.O., Igba, A.J. (2013). Physical and chemical characteristics of forest soil in southern Guinea Savanna of Nigeria. Agriculture, Forestry and Fisheries, 2.229-234.

Nottidge, D. O. and Nottidge, C. C. (2012). Effect of different rates of wood ash on exchangeable aluminum, growth, nodulation, nitrogen accumulation and grain yield of soybean (*Glycine max (l.) merrill*) in an acid ultisol. Global Journal of Agricultural Sciences, 11, 2, 81-87.

Norouzi, M., and Ramezanpour, H. (2013). Effect of Fire on Chemical Forms of Iron and Manganese in Forest Soils of Iran. Environmental Forensics, 14,169-177.

Novara, A., Gristina, L., Rühl, J., Pasta, S., D'Angelo, G., La Mantia, T., Pereira, P. (2013). Grassland fire effect on soil organic carbon reservoirs in a semiarid environment. Solid Earth, 4,381-385.

Oku, E., Iwara, A., Ekukinam, E. (2012). Effects of age of rubber (*H. brasiliensis Muell Arg.*) plantation on pH, organic carbon, organic matter, nitrogen and micronutrient status of Ultisols in the humid forest zone of Nigeria. Kasetsart Journal of Social Sciences,46,684-693.

Olsen, S.R., and Sommers, L.E. (1982). Phosphorus in: Methods of Soil Analysis. Page, A. L., Miller, R. H., Keeney, D.R. (eds). Maidson, W. I American Society of Agronomy. 1572.

Onuwaje, O.U., and Uzu, F. (1982). Growth response of rubber seedlings to N, P and K fertilizer in Nigeria, Nutrient Cycling in Agroecosystems, 3,169-175.

Onyekwelu, J.C., Mosand, R., Stimm, B. (2008). Tree species diversity and soil status of primary and degraded tropical rainforest ecosystems in South-Western Nigeria. Journal of Tropical Forest Science, 20,193-204.

Orimoloye, J.R., Akinbola, G.E., Idoko, S.O., Waizah, Y., Esemuede, U. (2012). Effects of rubber cultivation and associated land use types on the properties of surface soils. Nature and Science, 10, 48-52.

Orobator, P. O. and Odjugo P. A. O. (2024). Natives' perception on causes and mitigation of bushfire in rubber plantations: A social-ecological system approach. Acta Geographica Universitatis Comenianae (AGUC), 68 (1), 113-138.

Orobator, P.O., and Odjugo, P.A.O. (2023). Do locals' perception of bushfire impact on rubber trees match or mismatch with empirical data? Evidence from Edo State, Nigeria. Kastamonu University Journal of Forestry Faculty, 23, 52-63.

Orobator, P.O. (2022). Effect of bushfire on soil bacteria and fungi in perennial tree plantation Ecosystems. Journal of Geographic Thought and Environmental Studies (JOGET), 17, 1-11.

Orobator, P.O., Ekpenkhio, E., Noah, J. (2020). Effects of rubber (*Hevea brasilensis*) plantation of different age stands on topsoil properties in Edo State. Nigeria, Journal of Geographic Thought and Environmental Studies (JOGET), 15, 15-23.

Orobator, P.O. (2019). Impact of bushfire on soil and vegetation properties of *Hevea brasiliensis* (rubber) plantations in Iyanomo, Edo State, Nigeria. Ph.D. Thesis, University of Benin.

Orobator, P.O. (2014). Soil quality under different land uses in Okodobo village, Benin City, Edo State. M.Sc. Thesis, University of Benin.

Pardini, G., Gispert, M., Dunjó, G., (2004). Relative influence of wildfire on soil properties and erosion processes in different Mediterranean environments in NE Spain. Science Total Environment, 328, 237–246.

Pereira, P., Mataix- Solera, J., Úbeda, X., Rein, G., and Cerdà, A. (2019). Fire effects on soil properties. CSIRO Publishing, Clayton South, Victoria, Australia, p390.

Pierson, F.B., Robichaud, P.R., Moffet, C.A., Spaeth, K.E., Williams, C.J., Hardegree, S.P., Clark, P.E. (2008).Soil water repellency and infiltration in coarse-textured soils of burned and unburned sagebrush ecosystems. Catena, 74, 98-108.

Samburova, V., Schneider, E., Rüger, C.P., Inouye, S., Sion, B., Axelrod, K., Bahdanovich, P., Friederici, L., Raeofy, Y., Berli, M., Lutz, A., Zimmermann, R., Moosmüller, H. (2023).Modification of soil hydroscopic and chemical properties caused by four recent California, USA Megafires. Fire, 6,1-26. https://doi.org/10.3390/fire6050186.

Scharenbroch, B.C., Nix, B., Jacobs, K.A., Bowles, M.L. (2012).Two decades of low-severity prescribed fire increases soil nutrient availability in a Midwestern, USA oak (*Quercus*) forest. Geoderma, 183–184.

Tabi, F. O., Mvondo Ze, A. D., Boukong , A., Mvondo, R.J., Nkoum, G. (2013). Changes in soil properties following slash and burn agriculture in the humid forest zone of Cameroon. African Journal of Agricultural Research, 8, 1990-1995.

Tan, D., Jin, J., Jiang, L., Huang, S., Liu, Z. (2012). Potassium assessment of grain producing soils in North China. Agriculture, Ecosystems and Environment, 148, 65–71.

Thomaz, E.L., Antoneli, V., Doerr, S.H. (2014) Effects of fire on the physicochemical properties of soil in a slash-and-burn agriculture. Catena, 122,209–215.

.

Ugwa, I.K., Orimoloye, J.R., Esekhade, T.U. (2005). Nutrients status of some soils supporting rubber (*Hevea brasiliensis Arg. Muell*) in Midwestern Nigeria, Nigeria Agricultural Journal, 36, 169-176.

Ulery, A.L. and Graham, R.C. (1993). Forest fire effects on soil color and texture. Soil Science Society of America Journal, 57(1), 135-140.

Umar, H.Y., Ugwa, I. K., Uche, U. (2012). Economy of coagula production in Rubber Research Institute of Nigeria (RRIN): trend analysis. International Research Journal of Library, Information and Archival Studies, 2, 38-42.

Umar, H.Y., Esekhade, T.U., Idoko, S.O., Ugwa, I.K. (2010). Production analysis of budded rubber stumps in Rubber Research Institute of Nigeria (RRIN). Journal of Agricultural Sciences, 1, 34-43.

Wietinga, C., Ebel, B.A., Singh, K. (2017). Quantifying the effects of wildfire on changes in soil properties by surface burning of soils from the Boulder Creek Critical Zone Observatory. Journal of Hydrology, 13, 43-57.

Xifré-Salvadó, M.À., Prat-Guitart, N., Francos, M., Úbeda, X., Castellnou, M. (2021). Effects of Fire on the Organic and Chemical Properties of Soil in a *Pinus halepensis Mill*, Forest in Rocallaura, NE Spain. Sustainability, 13, 5178.

Xue, L., Li, Q., and Chen, H. (2014). Effects of a bushfire on selected physical, chemical and biochemical soil properties in a *Pinus massoniana* Forest in South China. Forests, 52947-2966.

Ying, H.S., Bin Wasli, M.E., Perumal, M. (2018). Soil characteristics under intensified shifting cultivation for upland rice cultivation in upland Sabal, Sarawak, Malaysia. Biotropia, 25, 72–83.

Zhang Y. and Biswas A (2017). The effects of forest fire on soil organic matter and nutrients in boreal forests of North America: a review. Adaptive Soil Management, 465–476.