

## Bushfire Effects on Micronutrients in a Tropical *Elaeis guineensis* (Oil Palm) Plantation

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### Abstract

The study investigated bushfire effects on micronutrients in a tropical *Elaeis guineensis* (oil palm) plantation. The objectives of the research were to determine the concentration levels of Zinc (Zn), Copper (Cu), Iron (Fe), and Manganese (Mn) in the unburnt and burnt areas of an *Elaeis guineensis* plantation; analyze significant differences in micronutrient levels between both sites in the *Elaeis guineensis* plantation; and assess whether bushfire had significant effects on Zn, Cu, Fe and Mn. Adopting the systematic random sampling technique, soil samples were collected 15 m apart from each sampling point at a soil depth of 0-15cm, with 10 samples taken from both the unburnt and burnt areas of the *Elaeis guineensis* plantation. The soil samples were analyzed for Zn, Cu, Fe and Mn. Descriptive statistics (range, mean, standard deviation and coefficient of variation) and inferential statistics (student t-test) were used to evaluate the data. The results indicated that except for Cu (0.98 mg kg<sup>-1</sup>), the concentration levels of Fe (62.68 mg kg<sup>-1</sup>), Zn (12.04 mg kg<sup>-1</sup>), and Mn (2.55 mg kg<sup>-1</sup>) were higher in the burnt areas of the *Elaeis guineensis* plantation. Significant differences were observed only for Zn and Mn between the unburnt and burnt areas of the *Elaeis guineensis* plantations. Bushfire has positive effects on Zn, Fe and Mn while the effect was negative on Cu. However, the positive effects of bushfire were significant only on Zn and Mn. In conclusion, bushfire enriched Zn, Fe and Mn contents in the *Elaeis guineensis* plantation. To enhance the low concentration levels of Cu in the burnt site, the study recommended the application of Copper Sulfate (CuSO<sub>4</sub>·5H<sub>2</sub>O) to the soil.

**Key words:** Fire, influence, oil palm plantations, soil micronutrients, tropics

### 1. Introduction

Tree plantations are one of the prevalent ecosystems in the tropics. However, a recurrent ecological disturbance that profoundly affects tropical tree ecosystems is bushfire (Orobator, 2019; Orobator & Odjugo, 2023; Orobator & Ugwa, 2023; Orobator & Odjugo, 2024, Orobator, 2025). Fire, a significant biogeographical factor, is considered both a physical and an anthropogenic factor, because many fire occurrences result from human activities (Ukpong, 2018). Oil palm (*Elaeis guineensis*) plantations in Nigeria are significant managed agricultural ecosystems that are often affected by bushfires, which are principally instigated by anthropogenic uncontrolled bush burning (Orobator, 2025). Bushfires are significant drivers of the structure and function of ecosystems (Augustine et al., 2014), and they leave temporary or lasting impacts on the soil properties (Ershad et al., 2013). Bushfire affects soil through its capacity to change soil and ecosystem properties (Hatten et al., 2005), and can have twin impacts on soil nutrients; causing losses through volatilization and burning of organic matter or releasing nutrients from burned vegetal organic materials (Arunrat et al., 2024).

Essential micronutrients that exist as cations in soils are Zinc (Zn), Copper (Cu), Iron (Fe) and Manganese (Mn), and their availability is particularly sensitive to changes in soil environment (Orobator & Odjugo, 2016). Soil micronutrients are very important for crop cultivation (Orobator et al., 2022), and are increasingly known as significant regulators of ecological and biogeochemical processes (Moreno-Jiménez et al., 2023). Although required in small quantities, they are highly important soil fertility indicators in terms of sustainable use of soils. Terrestrial organisms including floras and faunas satisfy their micronutrient

necessities from the soil (Spears, 2000). Soil micronutrients concentrations can interfere with typical functioning of floras, instigating plant cellular stress reactions (Stankov Jovanovic et al., 2011). Low micronutrient contents in soils can instigate mineral deficiencies that can result to disorders in the soil flora and fauna dynamics development (Spears, 2000).

Micronutrient deficiencies, also referred to as “hidden hunger”, remain a major concern in many countries in sub Saharan Africa (Gashu et al., 2021), and lessening “hidden hunger” is goal 2.2 of the United Nations Sustainable Development Goals (SDGs). Consequently, information on the status of micronutrient in soils is currently of utmost concern (Isaac et al., 2024). However, the response of micronutrients to bushfire is not well known because of dearth of studies in particular ecosystems (Certini, 2005; Parlak, 2022); although a few limited investigations do exist. García-Marco and González-Prieto (2008) reported short-term deviations in the soil micronutrients availability, increasing that of Mn and Zn and decreasing that of Fe; they observed no effect on Cu availability. Pereira and Úbeda (2010) found that bushfire induced a higher variability in Fe and Zn spatial distribution in comparison with Mn. Notably, Mn and Zn concentrations increased in the post-burn environment of a legacy mine site in Central Victoria, Australia (Abraham et al., 2018a). The changes in micronutrients induced by bushfire can lead to contrasting impacts in different biomes (Lucas-Borja et al., 2022). Norouzi and Ramezanzpour (2013) noted that further ecological studies are needed to understand the effects of fire on Fe, Mn and other micronutrients holistically. The response of bushfire on micronutrients in the tropics remains unclear. Moreover, to date, there is no empirical evidence on bushfire impacts on micronutrients specifically in tropical *Elaeis guineensis* plantations.

In addition to advancing research, contemporary empirical data on the influence of bushfire on micronutrients are needed to provide valuable insights into the impact on the recovery of soils and plants of post-fire tropical ecosystems (Bogacz et al., 2013), and to understand the resilience and continuing fitness of affected biomes (Arunrat et al., 2024). An understanding of the concentrations and fate of soil micronutrients in *Elaeis guineensis* plantation affected by bushfire is crucial. Consequently, the present research was undertaken in unburnt and burnt areas of an *Elaeis guineensis* plantation with similar lithologic and climatic conditions. Here, we examined bushfire effects on micronutrients, specifically aiming to determine the concentration levels of zinc (Zn), copper (Cu), iron (Fe) and manganese (Mn) in the unburnt and burnt sites of the *Elaeis guineensis* plantation; analyze significant differences in micronutrient levels between the bushfire-affected and bushfire-unaffected parts of the *Elaeis guineensis* plantation; and determine significant effects of bushfire on Zn, Cu, Fe and Mn. The research hypothesized that bushfire will not significantly impact Zn, Cu, Fe and Mn. The findings can be used as important ecological data to develop soil quality management strategies in *Elaeis guineensis* plantations and other related tropical perennial tree ecosystems.

## 2. Materials and Methods

The research was undertaken in Okunuvbe community, Ovia North East Local Government, Edo State, Nigeria. Okunuvbe community is located within Latitudes 6° 37' 5.24" N - 6° 36' 46.97" N and Longitudes 5° 45' 53.88" E - 5° 45' 49.16" E (Figure 1). The study sites are the unburnt and burnt areas of an *Elaeis guineensis* plantation situated in Okunuvbe community. Uncontrolled bush burning from adjoining farms was responsible for the incidence of bushfire in the *Elaeis guineensis* plantation. Odigute village bounds Okunuvbe community in the north while it is bounded by Igbakhue village in the southwest. The study area has a tropical rainforest climate, characterized by relatively wet and dry seasons and they belong to the Af category of Koppen's climatic classification. Ferralitic soils are the prevalent soil type in the study area, similar to those found in Benin City (Orobator, 2019). The study area is drained by river Okhuo, a tributary to the Ovia River. The major perennial tree crops cultivated in the study area are oil palm (*Elaeis*

*guineensis*) and rubber trees (*Hevea brasiliensis*). Nonetheless, trees like Mahogany (*Swietenia macrophylla*) and Iroko (*Milicia excelsa*) are also speckled within the area. The dominant grass species are Bluestem grasses or Broomsedge (*Andropogon Spp*), Fountain grass or Elephant grass (*Pennisetuna Spp*), and Siam weed (*Chromolaena odoranta*).

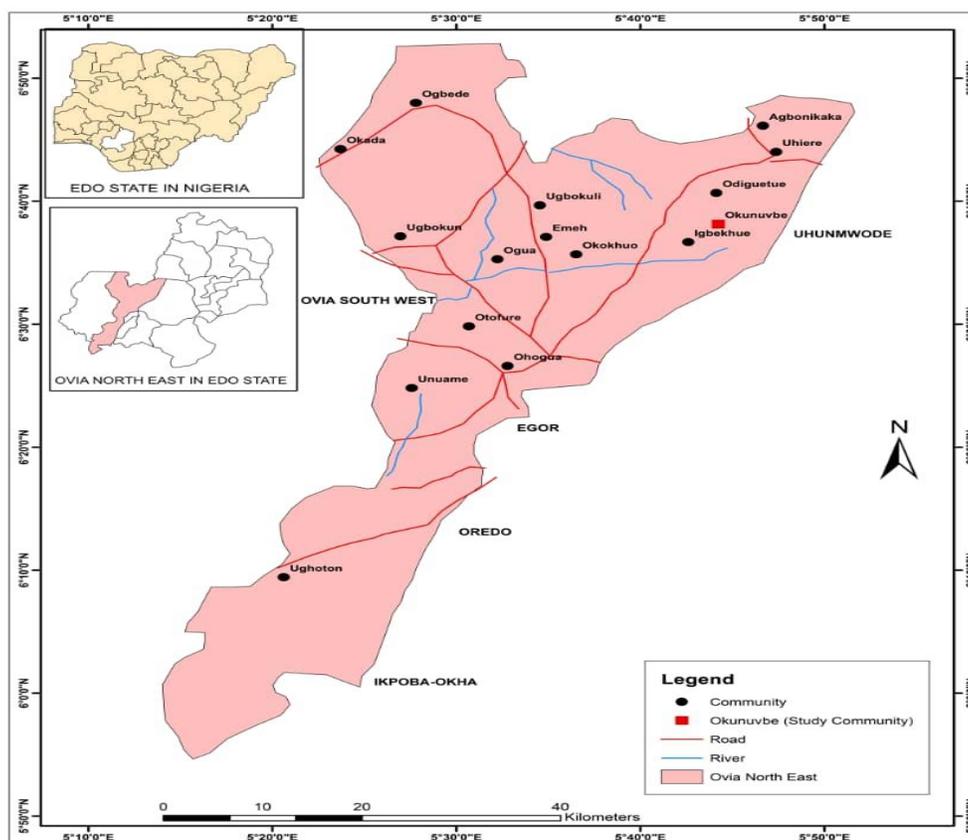


Figure 1. Location of study area

Two sites were selected for this study; unburnt and burnt areas of the *Elaeis guineensis* plantation. The selection of both sites for the research was based on their similarities in soil type (ferralitic), climate (tropical rainforest), and vegetation (oil palm trees). These similarities made notable comparisons possible, and aided to achieve the aim and objectives of the study. In addition, the bushfire-affected area (altered condition) was taken as the control site while the bushfire-unaffected area (baseline condition) of the plantation served as the treatment site. A sampled area measuring  $100 \times 100$  m was delineated for soil samples collection at each of the sites in the *Elaeis guineensis* plantation. The systematic random methodology was adopted for the research. The systematic random sampling method offers an advantage of even cover of the sampling area (Dixon and Leach, 1973). Consequently, at distance of 15 m apart from each sampling point, and with the aid of a soil auger, the soil samples were randomly collected at a depth of 0 -15 cm. This soil depth is referred to as the topsoil (Adejuwon & Adesina, 1990). Odegbare and Aweto (2017) reported that significant changes in the soil profile mainly occur in the topsoil. Ten (10) soil samples were collected from each study site. Therefore, a total of twenty (20) soil samples were collected for the purpose of the study. With the aid of a Garmin GPSMAP 65s Multi-band/multi-GNSS handheld with sensors, the locations and elevations of the sampling points in both the bushfire-unaffected and bushfire-affected areas of the *Elaeis guineensis* plantations were recorded (Table 1).

**Table 1: Locations and elevations of sampling points in the unburnt and burnt sites of the *Elaeis guineensis* plantation**

Study site	Sampling point	Location of sampling point	Elevation (m)
Unburnt area <i>Elaeis guineensis</i> plantation	U <sub>1</sub>	N 06° 34.148' E 005° 35.765'	37
	U <sub>2</sub>	N 06° 34.144' E 005° 35.762'	37
	U <sub>3</sub>	N 06° 34.146' E 005° 35.764'	38
	U <sub>4</sub>	N 06° 34.143' E 005° 35.754'	37
	U <sub>5</sub>	N 06° 34.149' E 005° 35.752'	35
	U <sub>6</sub>	N 06° 34.142' E 005° 35.750'	36
	U <sub>7</sub>	N 06° 34.153' E 005° 35.752'	37
	U <sub>8</sub>	N 06° 34.159' E 005° 35.755'	35
	U <sub>9</sub>	N 06° 34.157' E 005° 35.763'	34
	U <sub>10</sub>	N 06° 34.161' E 005° 35.766'	32
Burnt area <i>Elaeis guineensis</i> plantation	B <sub>1</sub>	N 06° 34.100' E 005° 35.793'	58
	B <sub>2</sub>	N 06° 34.098' E 005° 35.789'	55
	B <sub>3</sub>	N 06° 34.098' E 005° 35.785'	49
	B <sub>4</sub>	N 06° 34.103' E 005° 35.785'	50
	B <sub>5</sub>	N 06° 34.103' E 005° 35.781'	55
	B <sub>6</sub>	N 06° 34.098' E 005° 35.777'	55
	B <sub>7</sub>	N 06° 34.104' E 005° 35.771'	52
	B <sub>8</sub>	N 06° 34.096' E 005° 35.767'	52
	B <sub>9</sub>	N 06° 34.100' E 005° 35.762'	50
	B <sub>10</sub>	N 06° 34.095' E 005° 35.760'	51

The soil samples were air-dried and ground to pass through a sieve of 2 mm mesh size (Nunbere & Obanye, 2023). The concentrations of Zn, Cu, Fe and Mn were extracted from soils of the unburnt and burnt sites of the *Elaeis guineensis* plantation as described by Lindsay and Norvell (1978): i) the extracting solution consisted of 0.005 M DTPA (Diethylene-triaminepentaacetic acid), 0.01 M CaCl<sub>2</sub> and 0.1 M TEA (Triethanolamine) buffered at pH 7.30; ii) the extraction ratio (w/v) was 1:2; and iii) the shaking time was 2 h, though, in the place of a horizontal shaker, a rotatory shaker was utilized (García-Marco & González-Prieto, 2008). Extracts were analyzed for Zn, Cu, Fe and Mn by inductively attached plasma optical emission spectrometry (Varian Vista Pro simultaneous ICP-OES).

The concentrations of Zn, Cu, Fe and Mn were analyzed using the personal computer (PC) applications for the Statistical Package for Social Sciences and Excel. The study utilized the descriptive and inferential statistics. Descriptive statistics aided to provide basic relevant information (range, mean, standard deviation and coefficient of variation) about the values of Zn, Cu, Fe and Mn in both sites of the *Elaeis guineensis* plantation. Descriptive statistics was used also to identify differences in mean values of each soil micronutrient (Zn, Cu, Fe and Mn). Student's t-test is useful for assessing the statistical significance of the difference between two sample means (Tamhane & Dunlop, 2000; Mishra et al., 2019). For this investigation, student t -test was used to ascertain significant differences in Zn, Cu, Fe, and Mn concentration levels between the unburnt and burnt areas of the *Elaeis guineensis* plantation. This was attained by comparing the means of each soil micronutrient between the unburnt and burnt sites. Differences were considered significant at  $p < 0.05$  and non-significant at  $p > 0.05$ .

### 3. Results and Discussion

#### Zinc (Zn)

Zn is an exceedingly abundant metal; second most after iron (Fe), and its natural concentration in soil ranges between 10 to 300 mg kg<sup>-1</sup> with the mean level being 50 mg kg<sup>-1</sup> (Kaur et al., 2024). Zinc is an indispensable trace element that plants, animals, and humans need in small quantities for the normal functioning of diverse metabolic processes (Khokhar et al., 2024). The values of Zn in the unburnt area of the *Elaeis guineensis* plantation vary from 7.62 to 13.20 mg kg<sup>-1</sup> with mean value of 9.94 mg kg<sup>-1</sup> and 8.85 to 16.84 mg kg<sup>-1</sup> with mean value of 12.04 mg kg<sup>-1</sup>, in the burnt site of the *Elaeis guineensis* plantation (Table 2).

**Table 2. Zinc (Zn), Copper (Cu), Iron (Fe), Manganese (Mn) concentrations in unburnt and burnt areas of the *Elaeis guineensis* plantations**

Soil Micronutrient	Unburnt sites of the <i>Elaeis guineensis</i> Plantation				Burnt sites of the <i>Elaeis guineensis</i> Plantation				p-value
	Range	Mean	Std.	CV (%)	Range	Mean	Std.	CV (%)	
Zn (mg kg <sup>-1</sup> )	7.62 - 13.20	9.94	1.79	18.03	8.85 - 16.84	12.04	2.98	24.77	0.03*
Cu (mg kg <sup>-1</sup> )	0.74 - 1.46	0.98	0.24	24.97	0.69 - 1.10	0.87	0.13	15.44	0.11
Fe (mg kg <sup>-1</sup> )	54.20 - 64.52	59.11	3.77	6.38	55.40 - 72.60	62.68	6.68	10.66	0.07
Mn (mg kg <sup>-1</sup> )	1.38 - 2.60	2.20	0.39	17.64	1.62 - 3.10	2.55	0.42	16.56	0.00*

The result showed that Zn concentrations were higher in burnt *Elaeis guineensis* plantation site. The higher Zn concentration level may be due to Zn mobilization owing to bushfire influence. Young and Jan (1977) reported that bushfire mobilized substantial amounts of Zn on the soils. The increase in Zn concentrations is considered to be due to the accretion of ash during the bushfire occurrence (Abraham et al., 2018a; Alexakis et al., 2021). In addition, Pereira and Úbeda (2010) stated that Zn is typically of anthropogenic origin. The higher Zn concentrations may be also ascribed to the effect of the burnt flora and organic materials present on the floor of the *Elaeis guineensis* plantation. Stankov Jovanovic et al., (2011) noted that organic materials were enriched in Zn in burnt soils. The higher Zn concentrations can also be attributed to the release of water-soluble Zn in ashes in the soils (Terzano et al., 2021). The increase could be accredited to the Zn provided by the vegetal-derived ashes, which contain significant quantities of Zn (Khanna et al., 1994). The ash produced by bushfire penetrates 0–5 cm below the topsoil, and becomes immobile, resulting in increased concentrations of Zn in the upper soil layers of the soil profile (Rao et al., 2024).

The outcomes of the study aligned with Bogacz et al., (2011) and Stankov Jovanovic et al., (2011) who reported that the soils of the burnt site were enhanced in Zn relative to unburnt mainly in surface horizons. Bartkowiak and Lemanowicz (2017) found the highest concentration level of Zinc in surface horizons of the burnt site in Scots pine (*Pinus sylvestris*). Carrión-Paladines et al., (2022) observed higher concentrations of Zn the burnt soils in a Humid Montane Scrublands Ecosystem in Southern Ecuador. In the

Mediterranean ecosystem, Parlak (2022) observed higher Zn concentrations in the burnt site. Jordanova et al., (2019) reported that fire-affected soils showed enrichment with Zn. In like manner, García-Marco and González-Prieto (2008) stated increasing concentrations of Zn. In contrast to the findings of the study, Marafa and Chau (1999) reported a reduction in the concentrations of Zn by 4%.

The higher Zn concentrations in the burnt area of the *Elaeis guineensis* plantation suggest the positive impacts of bushfire on Zn in *Elaeis guineensis* plantation. The significant difference ( $p < 0.05$ ) in Zn contents between both sites in the *Elaeis guineensis* plantation demonstrated that Zn was significantly higher in burnt *Elaeis guineensis* plantation site, and that the positive impact of bushfire on Zn was significant. Zn indicated significant changes in the standard deviation values when comparing the two sites of the *Elaeis guineensis* plantation (1.79 to 2.98). Similarly, Abraham et al., (2018b) reported significant differences in Zn concentrations. The results of Rao et al., (2024) also indicated that the concentrations of Zn were significantly higher in the Liangshan Yi autonomous region. Likewise, Zn was significantly mobilized owing to soil burning, as demonstrated by the high concentrations of its reducible fraction in soil after fire (up to 98.5 mg kg<sup>-1</sup>) (Stankov Jovanovic et al., 2011).

### Copper (Cu)

Cu, a trace nutrient, is vital for efficient ecosystem functioning as it is engaged in different plant biochemical and physiological activities connected to plant growth and development (Kaur et al., 2023). Cu occurs in the soil almost entirely in divalent form and the largest fraction of Cu is customarily present in the crystal lattices of primary and secondary minerals (Mengel et al., 2001). Background Cu concentrations in soil hinge on geology and characteristically vary between 2 and 50 mg kg<sup>-1</sup> (Oorts, 2013). The values of Cu concentrations in the bushfire-unaffected area of the *Elaeis guineensis* plantation vary from 0.74 - 1.46 mg kg<sup>-1</sup>, with mean value of 0.98 mg kg<sup>-1</sup>, and 0.69 - 1.10 mg kg<sup>-1</sup> with mean value of 0.87 mg kg<sup>-1</sup>, in the bushfire-affected site of the *Elaeis guineensis* plantation (Table 2). The results indicated that Cu concentrations were lower in the burnt section of the *Elaeis guineensis* plantation. The detected lower contents of Cu may be due to volatilization (Abraham et al., 2018a). This is consistent with findings of Panico et al., (2023) who detected lower concentration values of Cu in burnt forest (2.5 mg kg<sup>-1</sup>) compared with forest soils (3.2 mg kg<sup>-1</sup>). In post-fire soils, *T. chamaedrys* and *A. alpinus* demonstrated a decrease in Cu levels (Stankov Jovanovic et al., 2011). Equally, in boreal forest soils, there were reductions in Cu contents as reported by Kelly et al., (2021). However, the findings of Rao et al., (2024) revealed that the concentrations of Cu were higher in burnt soils than those in reference soils. The higher Cu concentrations values may be due to enrichment due to bushfire (Campos et al., 2016). Rather unpredictably, Elakiya et al., (2023); Bartkowiak & Lemanowicz (2017) reported the content of Cu did not change due to bushfire. Likewise, García-Marco and González-Prieto (2008) stated that they found no influence on Cu availability. In an earlier study, Marafa and Chau (1999) noted that Cu contents were not affected by fire in the upland soils of Hong Kong.

The varied responses imply the different ways Cu reacts to bushfire in different ecosystems, owing to the peculiar properties of the biomes. In addition, it shows that bushfire has opposite and variable effects on Cu. The deviations in concentrations may be described by the accumulative ability of the different flora types and soil properties. The lower Cu concentrations in the burnt site of the *Elaeis guineensis* plantation suggest the negative impacts of bushfire on Cu in *Elaeis guineensis* plantation. The non-significant difference ( $p > 0.05$ ) in Cu contents between both the bushfire-unaffected and bushfire-unaffected areas of the *Elaeis guineensis* plantations demonstrated that Cu was not significantly higher in the unburnt site of the *Elaeis guineensis* plantation, and that the negative impact of bushfire on Cu was not substantial. Equally, no significant differences were detected for the concentrations of Cu in burnt soils (Abraham et al., 2018a; Campos et al., 2016)

## Iron (Fe)

Fe is comparatively abundant in many cultivated soils with an average total concentration of 20 to 40 g kg<sup>-1</sup> (Cornell & Schwertmann, 2003). Fe is important for plants and animals; it is the fourth most common element and is essential for the biogenesis and functioning of chlorophyll, energy transmission, metabolism of cells, fixation of nitrogen (N), and respiration of plants (Patra et al., 2021). Fe deficiency will have a damaging effect on soil fertility in the future (Norouzi & Ramezanpour, 2013). The values of Fe concentrations in unburnt area of the *Elaeis guineensis* plantation ranged from 54.20 to 64.52 mg kg<sup>-1</sup>, with mean value of 59.11 mg kg<sup>-1</sup> and 55.40 to 72.60 mg kg<sup>-1</sup>, with mean of 62.68 mg kg<sup>-1</sup> in the burnt site. The results indicated that the concentrations of Fe were higher in the bushfire-affected area of the *Elaeis guineensis* plantation. This higher content of Fe is attributed to the addition of ash during the bushfire incidence (Alexakis et al., 2021). Fe concentrations may also be due to the biophysical features of the site (Pereira & Úbeda, 2010). The findings of the study is consistent with Alexakis et al., (2021) reported that Fe contents were significantly higher in burnt compared to unburnt topsoil. However, García-Marco and González-Prieto, (2008) found lower Fe levels. Likewise, in the forest soils of Iran, Norouzi and Ramezanpour (2013) reported that fire significantly decreased available iron. García-Marco and González-Prieto (2008) also reported decreasing concentrations of Fe.

Equally, Marafa and Chau (1999) reported a reduction in the concentrations of Fe by 12%. The different behavior of Fe depends both on the chemical composition of ashes of the burnt flora of specific biomes released in the surface soil after the bushfire, as well as the soil buffering capability and their different climatic and edaphic factors (Úbeda et al., 2005). Fires can change iron minerals in soils (Cornell & Schwertmann, 2003). The higher Fe concentration levels in the burnt site of the *Elaeis guineensis* plantation suggest the positive impacts of bushfire on Fe in *Elaeis guineensis* plantation. However, the non-significant difference ( $p > 0.05$ ) in Fe contents between both *Elaeis guineensis* plantations demonstrated that Fe was not significantly higher in bushfire-impacted area of the *Elaeis guineensis* plantation, and that the positive impact of bushfire on Fe was not substantial. Similarly, Gómez-Rey et al. (2013) showed that fire in NW Spain did not change soil Fe levels significantly.

## Manganese (Mn)

Mn is an essential micronutrient for plants, playing a fundamental role in soil–plant–microbial interfaces and it is involved in different physiological and biochemical processes, making it indispensable for plant growth and development (Alejandro et al., 2020). Mn is needed in relatively small amounts when matched to macronutrients like nitrogen, phosphorus, and potassium, but its accessibility is still significant for optimum plant growth and development (Khoshru et al., 2023). Mn concentration values vary from 1.38 to 2.60 mg kg<sup>-1</sup>, with mean value of 2.20 mg kg<sup>-1</sup> in bushfire-unaffected site, and 1.62 to 3.10 mg kg<sup>-1</sup> with mean value of 2.55 mg kg<sup>-1</sup> in burnt site (Table 2). This result showed the positive effect of bushfire on Mn in burnt *Elaeis guineensis* plantation. The higher Mn contents could be due to the emission from the fires that occurred in the investigated area (Memol et al., 2018). Also, with bushfire-generated ash, Mn is released into soil in amorphous and crystalline oxide forms (Parlak, 2022). The soil improvement by Mn in the burnt site can be ascribed to combustion of vegetation and ash interfaces with soil, in agreement with earlier studies (Stankov Jovanovic et al., 2011; Costa et al., 2014). Correspondingly, Gonzalez Parra et al. (1996) stated a significant increase of Mn, and ascribed it to the deposition of the ashes which are rich in Mn oxides. The increase in contents of Mn is linked to burning of flora leaves which is a constituent of the photosynthesis (the water splitting complex) (Shao et al., 2017).

In agreement with the findings, Panico et al., (2023) found that Mn were higher in wildfire forest soils than urban soils. Equally, Gómez-Rey et al., (2013) reported that Mn concentrations were higher in burnt than in unburnt soils. Also, García-Marco and González-Prieto (2008) observed increasing Mn concentrations owing to fire. In contrast, there were decreases in Mn concentrations as stated in the study of Kelly et al., (2021). Similarly, Marafa and Chau (1999) reported a reduction in the concentrations of Mn by 14%. As the quantity and the chemical constituents of ashes vary depending on the vegetation characteristics (Carreira & Niell, 1995), contrasting outcomes have been stated on post-fire Mn availability (García-Marco & González-Prieto, 2008). The higher Mn concentrations in the burnt *Elaeis guineensis* plantation site suggest the positive impacts of bushfire on Mn in *Elaeis guineensis* plantation. The significant difference ( $p < 0.05$ ) in Mn contents between both *Elaeis guineensis* plantations demonstrated that Mn was significantly higher in burnt *Elaeis guineensis* plantation, and that the positive impact of bushfire on Mn was significant. Mn indicated significant changes in the standard deviation values when comparing the two *Elaeis guineensis* plantations (0.39 to 0.42). This outcome of the study is supported by the work of Chandra et al., (2015) and Certini (2005) who found a significant increase in Mn. Compared to burnt soils, Campos et al., (2016) stated that increased significantly 13.4 times higher in burnt soils in eucalypt and pine forest plantations. Similarly, in a pine grove (*Pinus pinaster Ait.*), Gonzalez Parra et al., (1996) observed that there was a significant increase in the total content of Mn following forest fires.

#### 4. Conclusion and Recommendations

This research examined bushfire effects on micronutrients in tropical oil palm (*Elaeis guineensis*) plantations. The outcomes of the investigation revealed that apart from Cu, the concentrations of Zn, Fe and Mn were higher in the bushfire-affected area of the *Elaeis guineensis* plantation than the unburnt site of the *Elaeis guineensis* plantation. Whereas the effect of bushfire was positive on Zn, Mn and Fe, it was negative on Cu. There were statistically significant differences only in Zn and Mn between the unburnt and burnt areas of the *Elaeis guineensis* plantation. The study concluded that bushfire enhanced Zn, Fe and Mn contents in the soils of the burnt *Elaeis guineensis* plantation, and that the positive impacts of bushfire on Zn and Mn in burnt *Elaeis guineensis* plantation were significant. To reduce the negative effect of bushfires on Cu, it is recommended that copper fertilizer can be broadcast or banded with nitrogen, phosphorus, and potassium fertilizers and applied on the soils of the burnt *Elaeis guineensis* plantation. In view of the higher concentrations of Zn, Fe, and Mn in the soils of the burnt *Elaeis guineensis* plantation, their effect on vegetation regeneration warrants further research.

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