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Research Article

Correlation of Soil Quality Properties in a Tree Biosphere: A Case Study of Burnt and Unburnt *Hevea brasiliensis* Plantations

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Abstract

Aim of study: The study examined the correlations of soil quality properties in a tree biosphere: a case study of burnt and unburnt *Hevea brasiliensis* plantations.

Area of study: The research was conducted in burnt and unburnt *Hevea brasiliensis* plantations in Edo State, Nigeria.

Material and method: Soil samples were collected from sampled areas within the burnt and unburnt rubber plantations using the grid sampling method. Samples were obtained from both topsoil and subsoil layers and analyzed for soil properties using standard soil analytical procedures. The Pearson Product Moment Correlation (PPMC) statistical technique was used to determine correlations among soil quality properties.

Main results: Soil pH showed a significant positive correlation with calcium (Ca) (0.68), magnesium (Mg) (0.76), potassium (K) (0.73), iron (Fe) (0.76), zinc (Zn) (0.76), copper (Cu) (0.73), manganese (Mn) (0.69), and clay (0.67) at $p < 0.05$, and with exchangeable acidity (EA) (0.61) and effective cation exchange capacity (ECEC) (0.62) at $p < 0.01$ in the topsoil of the unburnt rubber plantation. Silt showed a significant negative correlation with sand (-0.81) at $p < 0.05$ and with K (-0.63), Cu (-0.63), and Mn (-0.63) at $p < 0.01$ in the subsoil. Soil organic matter (SOM) revealed a significant positive correlation with total organic carbon (TOC) (0.96) at $p < 0.05$ in the topsoil of the burnt rubber plantation. Zinc (Zn) demonstrated a significant negative correlation with phosphorus (P) (-0.61) at $p < 0.01$ in the topsoil of the burnt rubber plantation. Clay showed a significant positive correlation with pH (0.67), EA (0.64), and ECEC (0.68) at $p < 0.05$ and with K (0.60) and Cu (0.60) at $p < 0.01$ in the topsoil of the unburnt site. Total heterotrophic bacteria count (THBC) indicated a significant positive correlation with Fe (0.95) at $p < 0.05$ in the topsoil of the burnt rubber plantation. THBC also showed significant positive correlations with Ca (0.74), Mg (0.83), Na (0.83), K (0.74), Fe (0.82), Zn (0.69), Cu (0.74), and Mn (0.74) at $p < 0.05$ in the subsoil.

Research highlights: The study revealed significant relationships among soil properties, which have important implications for soil quality management in burnt and unburnt rubber plantations. The findings also provided reliable empirical data on soil quality properties that can support precision agriculture and aid in the establishment and management of rubber plantations.

Keywords: Bushfire, Correlation, Soil Quality, Significant Relationships, Rubber Plantations

Ağaç Biyosferinde Toprak Kalitesi Özelliklerinin Korelasyonu: Yanmış ve Yanmamış Hevea brasiliensis Plantasyonları Üzerine Bir Vaka Çalışması

Öz

Çalışmanın Amacı: Bu çalışma, bir ağaç biyosferinde toprak kalite özelliklerinin korelasyonlarını incelemiştir: Yanmış ve yanmamış *Hevea brasiliensis* plantasyonları üzerine bir vaka çalışması.

Çalışma Alanı: Araştırma, Nijerya'nın Edo Eyaleti'nde bulunan yanmış ve yanmamış Hevea brasiliensis plantasyonlarında gerçekleştirilmiştir.

Materyal ve Yöntem: Toprak örnekleri, yanmış ve yanmamış kauçuk plantasyonlarındaki örnekleme alanlarından ızgara (grid) örnekleme yöntemi kullanılarak toplanmıştır. Örnekler hem üst toprak (topsoil) hem de alt toprak (subsoil) katmanlarından alınmış ve toprak özellikleri, standart toprak analiz yöntemleri kullanılarak incelenmiştir. Toprak kalite özellikleri arasındaki korelasyonları belirlemek için Pearson Çarpım Moment Korelasyonu (PPMC) istatistiksel tekniği uygulanmıştır.

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Temel sonuçlar: Toprak pH'ı, yanmamış kauçuk plantasyonunun üst toprak katmanında kalsiyum (Ca) (0.68), magnezyum (Mg) (0.76), potasyum (K) (0.73), demir (Fe) (0.76), çinko (Zn) (0.76), bakır (Cu) (0.73), mangan (Mn) (0.69) ve kil (0.67) ile $p < 0.05$ düzeyinde; değişebilir asitlik (EA) (0.61) ve etkili katyon değişim kapasitesi (ECEC) (0.62) ile $p < 0.01$ düzeyinde anlamlı pozitif korelasyon göstermiştir. Alt toprakta silt, kum (-0.81) ile $p < 0.05$ düzeyinde ve K (-0.63), Cu (-0.63) ve Mn (-0.63) ile $p < 0.01$ düzeyinde anlamlı negatif korelasyon göstermiştir. Yanmış kauçuk plantasyonunun üst toprak katmanında toprak organik maddesi (SOM), toplam organik karbon (TOC) (0.96) ile $p < 0.05$ düzeyinde anlamlı pozitif korelasyon göstermiştir. Yanmış plantasyonun üst toprak katmanında çinko (Zn), fosfor (P) (-0.61) ile $p < 0.01$ düzeyinde anlamlı negatif korelasyon göstermiştir. Kil, yanmamış plantasyonun üst toprak katmanında pH (0.67), EA (0.64) ve ECEC (0,68) ile $p < 0.05$ düzeyinde; K (0.60) ve Cu (0.60) ile $p < 0.01$ düzeyinde anlamlı pozitif korelasyon göstermiştir. Toplam heterotrofik bakteri sayısı (THBC), yanmış kauçuk plantasyonunun üst toprak katmanında Fe (0.95) ile $p < 0.05$ düzeyinde anlamlı pozitif korelasyon göstermiştir. THBC ayrıca alt toprak katmanında Ca (0.74), Mg (0.83), Na (0.83), K (0.74), Fe (0.82), Zn (0.69), Cu (0.74) ve Mn (0.74) ile $p < 0.05$ düzeyinde anlamlı pozitif korelasyonlar göstermiştir.

Araştırma vurguları: Çalışma, toprak özellikleri arasında önemli ilişkiler bulunduğunu ortaya koymuştur; bu durum, yanmış ve yanmamış kauçuk plantasyonlarında toprak kalitesinin yönetimi açısından önemli sonuçlar doğurmaktadır. Elde edilen bulgular ayrıca, hassas tarım uygulamalarını destekleyebilecek ve kauçuk plantasyonlarının kurulması ile yönetimine katkı sağlayabilecek güvenilir ampirik veriler sunmaktadır.

Anahtar Kelimeler: Orman Yangını, Korelasyon, Toprak Kalitesi, Anlamlı İlişkiler, Kauçuk Plantasyonları

Introduction

Globally, bushfire has been an essential part of the evolutionary history of most ecosystems and is an important ecological disorder affecting the quality of soil in different biomes (Orobator, 2022). In Nigeria, bushfire incidences are prevalent and considered as one of the most detrimental disruptions in forest, savannah and tree plantation ecosystems (Orobator & Ugwa, 2023). Plantation tree crops are high-worth flora of immense economic relevance and have achieved widespread adoption in nations such as India, Indonesia, Thailand, Malaysia, Nigeria etc. *Hevea brasiliensis* (rubber) is one of the commercial tree crops cultivated in plantations and is vital for the socio-economic survival of most countries (National Agricultural Extension and Research Liaison Services, 2000). Proceeds from rubber latex exportation have resulted to financial advancement for thousands of farmers and plantation owners' world-wide (Guo et al., 2016). The accelerative demand for latex has stirred up rubber plantations development since the last century (Singh et al., 2021). By 2050, the land use area of rubber plantations is anticipated to double or even experience quadruple increase globally (Liu et al., 2023).

Soil quality denotes either the general ecological status of soil or a model for soil current and future functional capabilities (Orobator, 2022). Soil quality is the most essential factor in forest management decisions and is largely determined by soil fertility indicators (Kogge et al., 2016). Soil quality does not rely on one property but the combination of physical, chemical and biological parameters (Shekhovtseva & Mal'tseva, 2015). The correlation analysis of soil properties is a bivariate analysis which establishes the strength and direction of their associations (Puth et al., 2014). The interrelations that exist among the soil properties can be used to assess the dependableness and consistency of soil analytic data (Yerima et al., 2009). This is particularly significant for soil management of tropical rubber plantations which are vulnerable to bushfire; a foremost human induced ecological hazard in most tropical biomes. The correlation among soil properties can predicate the availability of soil resources (Xie et al., 2020). However, little or no information exists on the use of correlation analysis to examine associations among the physicochemical and biological properties of soils in tropical rubber plantations.

Prior investigations in *H. brasileinsis* plantations (Orimoloye et al., 2012; Orobator et al., 2020; Ndakara & Ohwo, 2022; Orobator, 2022; Orobator & Odjugo, 2023; Orobator & Ugwa, 2023; Orobator, 2025 etc.) have significant statistical drawbacks in finding self-reliant correlations among soil quality properties and comprehending the interdependence of the physicochemical and biological properties of soils. To address this gap in research, this investigation proposed a comprehensive study of correlations among soil properties, which are key factors influencing growth and development of floras (Kim et al., 2021), even in ecosystems affected by bushfire, where soils release mineralizable nutrients (Vanilarasu & Balakrishnamurthy, 2014). Establishing strong quantitative associations between physicochemical and biological properties of soils in tree biomes affected by bushfire, makes it possible to predict soil quality indicators that are important to design more consistent soil quality model systems for the sustainable management of rubber plantations, as well as offer data on significant experiential soil quality properties for precision agriculture that will support the establishment of rubber plantation on specific soil type. Boruvka et al. (2002) noted that correlation of soil properties denotes a significant beginning for precision agriculture. Karyati et al. (2018) reported that the empirical evidence on correlations is important for addressing future management and sustainability of biomes. Consequently, the goal of the study is to examine the correlation of soil quality properties in burnt and unburnt *Hevea brasiliensis* plantations. The observed defined relationships among the physicochemical and biological properties of soils in the burnt and unburnt rubber plantations from this study will serve as scientific foundations for policies on site-specific management for burnt and unburnt rubber plantations.

Material and Methods

Study Area

Rubber Research Institute of Nigeria (RRIN), Iyanomo is located in Ikpoba-Okha Local Government Area, Edo State, Nigeria. It lies within Latitudes 6° 08′ 54.99″ – 6° 10′ 0.48″ N and Longitudes 5° 34′ 9.12″ – 5° 36′ 44.64″ E (Figure 1) and is situated about 29 kilometers away from Benin City (Orobator et al., 2020). RRIN experiences the typical tropical rainforest climate with a total amount of rainfall ranging from 2000-2500 mm annually (Orobator et al., 2020). RRIN has a mean monthly temperature of 28 °C and have its place in Af category of Koppen’s climatic classification (Orobator, 2022). The rainy season starts in March/April and ends in October/November. The soils of RRIN are deep, porous, non-mottled and non-concretionary red soils (Izevbigie et al., 2011).

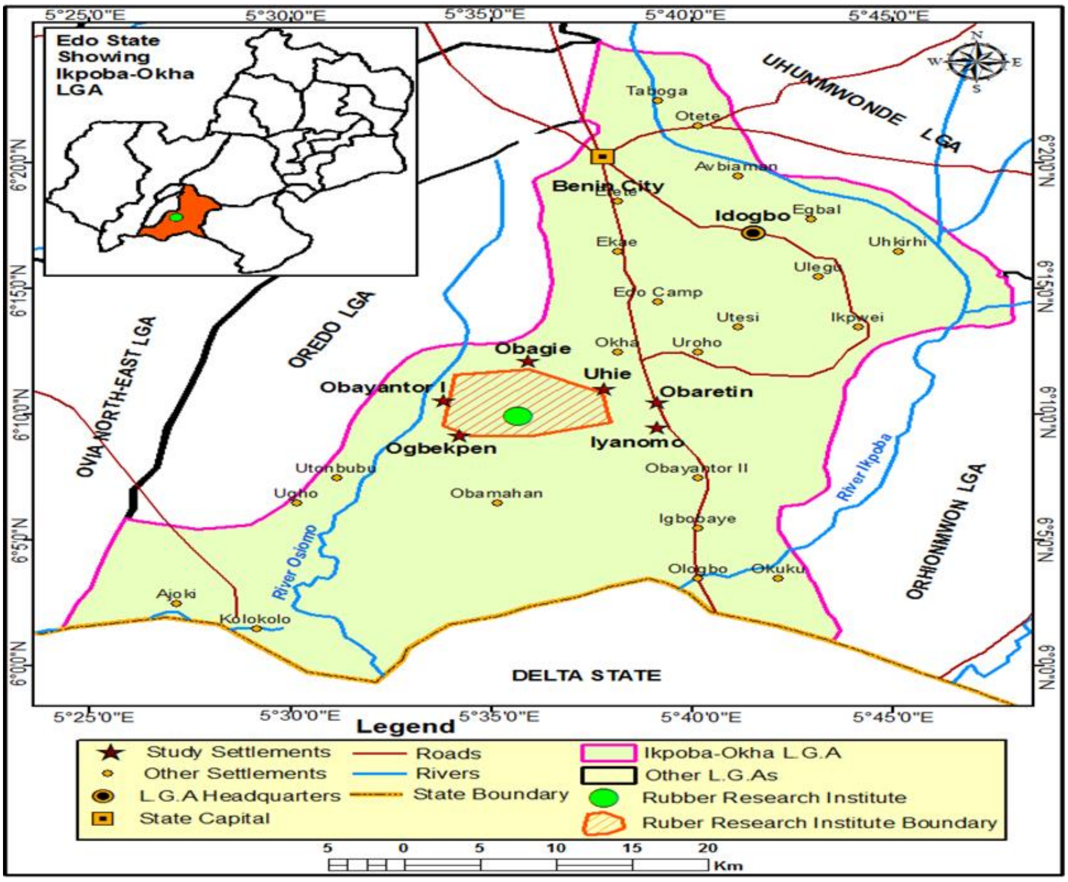

Figure 1. Ikpoba-Okha Local Government Area showing Rubber Research Institute of Nigeria, Iyanomo, Edo State, Nigeria

Selection of Study Sites

A reconnaissance survey was undertaken among different rubber plantations in southern Nigeria. RRIN was selected as the most suitable study area for this research. Two rubber plantations (unburnt and burnt rubber plantations) located within RRIN were adopted as the study sites. The burnt rubber plantation is located at Latitude 06° 10′.142″ N and Longitude 005° 36′.071″ E. It is code-named Old nursery, while the unburnt rubber plantation is and located at Latitude 06° 09′.459″ N and Longitude 005° 39′.009″ E in RRIN. It is known as LK 21 and 22.

Research Design and Soil Sampling

To find stable correlations, it is indispensable to take samples from related pedologic environments (Ibanez-Asensio et al., 2013). Soil samples were collected from a sampled area within the unburnt and burnt rubber plantations using the grid sampling method. Due to homogeneity of the soils and flora in the unburnt and burnt rubber plantations, the study adopted one hectare (100 m × 100 m) as the sample area and a plot size of 20 m × 20 m for each of the study site. Each of the sampled area in the unburnt and burnt rubber plantation was divided in 25 plots of 20 m × 20 m. Ten 20 m × 20 m plots from each of the sampled area in the burnt and unburnt rubber plantation were randomly selected. Consequently, a total of twenty 20 m × 20 m plots were adopted for this study. Forty soil samples were augered at 0-15 cm (topsoil) and 15-45 cm (subsoil) (twenty each soil depth). Since there are two sampled sites (unburnt and bunt rubber plantations), a total of eighty (80) soil samples were collected. In making a composite soil sample, two soil samples were collected from the topsoil and subsoil per plot and bulked to give one composite sample, making a total of forty soil samples collected, air-dried, crushed, thoroughly mixed and sieved through a 2 mm mesh and analyzed for physicochemical and biological indicators.

Laboratory Analysis

Soil texture was determined following the procedures of Raij et al. (2001) whereas bulk density (BD) was determined by core method. Soil pH was determined using 1: 2.5 soil-water suspension ratio (McLean, 1982). Soil organic matter (SOM) was obtained by the Walkley–Black method. Total organic carbon (TOC) was determined from SOM. TOC was determined by multiplying the average of the two soil organic matter measurements by 0.5 (Brady & Weil, 2002). Total nitrogen (TN) was determined through the revised micro Kjeldahl method (Bremner & Mulvaney, 1982). Effective cation exchange capacity (ECEC) was extracted by using sodium acetate at a pH 8.2 (Chapman, 1965). Copper (Cu), zinc (Zn), iron (Fe) and manganese (Mn) were extracted using diethylenetriamine penta-acetic acid (DTPA) and evaluated by atomic absorption spectrophotometry method (Lindsay & Norvell, 1978). Calcium (Ca) and Magnesium (Mg) was determined using the atomic absorption spectrophotometer while exchangeable Sodium (Na) and Potassium (K) was estimated using the digital flame photometry (Onyekwelu et al., 2008). Soil water repellency (WR) was determined using the classical Water Drop Penetration Time (Wietinga et al., 2017). Bray II method was used to determine phosphorus (P) (Olsen & Sommers, 1982). Exchangeable acidity (EA) was determined in IN KCl extract by titration (Black, 1965). Total heterotrophic bacteria count (THBC) and Total heterotrophic fungi count (THFC) were determined using procedures stated by Phil-Eze, (2010) and Ogwu and Osawaru (2015). The data of the physicochemical and biological properties of the unburnt and burnt rubber plantations are shown in Table 1.

Table 1. Physicochemical and biological characteristics of investigated soils

Soil property	Depth (cm)	Unburnt rubber plantation (Values)	Burnt rubber plantation (Values)
Sand (gkg^{-1})	0 - 15	742	730
	15 - 45	589	620
Silt (gkg^{-1})	0 - 15	205	189
	15 - 45	239	244
Clay (gkg^{-1})	0 - 15	58	81
	15 - 45	172	136
BD ($Mg\ m^{-3}$)	0 - 15	1.04	1.12
	15 - 45	1.26	1.20
WR	0 - 15	18.00	17.07
	15 - 45	19.07	20.04
pH	0 - 15	4.75	4.82
	15 - 45	4.51	4.57
ECEC ($cmol\ kg^{-1}$)	0 - 15	1.01	1.42
	15 - 45	1.57	1.66
EA ($cmol\ kg^{-1}$)	0-15	0.68	0.81
	15 - 45	1.06	0.70
SOM ($g\ kg^{-1}$)	0 - 15	1.47	1.74
	15 - 45	0.74	0.72
TOC ($g\ kg^{-1}$)	0 - 15	0.94	1.00
	15 - 45	0.43	0.41
TN ($g\ kg^{-1}$)	0 - 15	0.12	0.13
	15 - 45	0.05	0.05
P ($mg\ kg^{-1}$)	0 - 15	4.41	6.52
	15 - 45	3.24	3.66
Ca ($cmol\ kg^{-1}$)	0 - 15	18.71	15.90
	15 - 45	13.40	8.44
Na ($cmol\ kg^{-1}$)	0 - 15	94.40	74.55
	15 - 45	63.99	48.48
Mg ($cmol\ kg^{-1}$)	0 - 15	53.03	41.88
	15 - 45	35.95	27.23
K ($cmol\ kg^{-1}$)	0 - 15	33.82	37.91
	15 - 45	22.46	16.03

Table 1 (Continued)

Soil property	Depth (cm)	Unburnt rubber plantation (Values)	Burnt rubber plantation (Values)
Fe (mg kg^{-1})	0 - 15	312.24	173.08
	15 - 45	194.47	149.10
Cu (mg kg^{-1})	0 - 15	14.54	16.30
	15 - 45	9.65	6.89
Mn (mg kg^{-1})	0 - 15	4.50	5.05
	15 - 45	2.99	2.13
Zn (mg kg^{-1})	0 - 15	6.24	2.89
	15 - 45	3.88	3.48
THBC cfu/g	0 – 15	3.61	6.05
	15 – 45	5.85	5.21
THFC cfu/g	0 – 15	1.34	2.05
	15 – 45	2.21	2.02

Statistical Analysis

The study adopted the Pearson Product Moment Correlation (PPMC) statistical technique. It determined the strength of an association between soil physicochemical and biological properties (Ibanez-Asensio et al., 2013). A correlation coefficient of >0.7 indicates a strong relationship between two variables, while a value of zero denotes no relationship. Furthermore, correlation coefficients of 0.4 to 0.7 depict a moderate relationship and >0.4 reveal a poor relationship between two variables.

Results and Discussion

The results of the correlation coefficients are shown in Tables 2, 3, 4 and 5. Soil pH showed a significant positive correlation with Ca (0.68), Mg (0.76), K (0.73), Fe (0.76), Zn (0.76), Cu (0.73), Mn (0.69) and clay (0.67) at p<0.05, and with EA (0.61) and ECEC (0.62) at p<0.01 in the topsoil of unburnt rubber plantation (Table 2). This demonstrated that increases in soil pH in the topsoil of the unburnt rubber plantation are associated with higher concentrations of Ca, Mg, K, Fe, Zn, Cu, Mn, clay, EA, and ECEC, suggesting that soil pH is a vital driver of the fertility of soil, and can act as a pointer to the quality of soils in in the topsoil of unburnt rubber plantation. However, a significant negative correlation was observed for WR (-0.99) at p<0.05. This indicated that lower soil pH at this soil depth in the plantation is associated with higher WR, suggesting that acidic soils are more water repellent, thereby enhancing hydrophobicity. pH revealed a significant positive correlation with Ca (0.68), Mg (0.64), Na (0.64) at p<0.05, and with Fe (0.63) and Zn (0.63) at p<0.01 in the subsoil (Table 3). Similarly, a significant negative correlation was observed for WR (-0.73) at p<0.05 in the subsoil. The results contradicted Mar et al. (2020) which reported that pH exhibited a highly significant but negative correlation with TN (r=-0.416).

A significant negative correlation was observed for WR in the topsoil (-0.91), while a significant positive correlation was detected at the subsoil (0.74) for pH in burnt rubber plantation (Tables 4 and 5) at p<0.05. These negative and positive correlations between WR and pH indicate the role of bushfire in influencing soil pH interaction with hydrophobic compounds at both soil depths. In unburnt rubber plantation, Ca exhibited a significant positive relationship with pH (0.68) at p<0.05 in the topsoil (Table 2). Similarly, a positive significant relationship was observed between Ca and pH (0.68) in the subsoil (Table 3) at p<0.05. The relationship suggested the nature of constituents of the parent materials of the soils in the study, and that Ca plays a fundamental role in controlling the acidity of the soils at both soil depths, thus aiding the stability of the chemical status of the soils in the unburnt rubber plantation.

Table 2. Correlation coefficients of soil properties in unburnt rubber plantation at 0 -15 cm

	pH	Ca	Mg	Na	K	TOC	SOM	TN	EA	ECEC	P	Fe	Zn	Cu	Mn	BD	WR	Sand	Silt	Clay	THBC	THFC
pH	1.00																					
Ca	0.68*	1.00																				
Mg	0.76*	0.87*	1.00																			
Na	-0.21	0.06	0.23	1.00																		
K	0.73*	0.84*	0.80*	-0.22	1.00																	
TOC	0.25	0.53	0.59**	0.23	0.46	1.00																
SOM	-0.26	-0.55**	-0.30	0.24	-0.62**	0.13	1.00															
TN	0.07	0.02	0.16	0.24	-0.09	0.59**	0.78*	1.00														
EA	0.61**	0.52	0.49	-0.02	0.55**	0.22	-0.51	-0.35	1.00													
ECEC	0.62**	0.55**	0.48	-0.13	0.63**	0.21	-0.48	-0.24	0.92*	1.00												
P	0.49	0.42	0.75*	0.44	0.35	0.44	0.04	0.12	0.45	0.33	1.00											
Fe	0.76*	0.87*	0.95*	0.26	0.79*	0.60**	-0.30	0.15	0.54	0.53	0.77*	1.00										
Zn	0.76*	0.87*	0.98*	0.26	0.79*	0.60**	-0.30	0.15	0.54	0.53	0.77*	0.98*	1.00									
Cu	0.73*	0.84*	0.80*	-0.22	0.96*	0.46	-0.62	-0.09	0.55	0.63**	0.35	0.79*	0.79*	1.00								
Mn	0.69*	0.83*	0.81*	-0.15	0.97*	0.50	-0.51	0.03	0.49	0.65*	0.37	0.81*	0.81*	0.97*	1.00							
BD	0.39	0.35	0.27	-0.09	0.38	0.22	-0.21	-0.01	0.62**	0.79*	0.06	0.31	0.31	0.38	0.47	1.00						
WR	-0.99*	-0.69*	-0.77*	0.21	-0.75*	-0.27	0.31	-0.01	-0.69*	-0.67*	-0.54	-0.77*	-0.77*	-0.75*	-0.70*	-0.37	1.00					
Sand	-0.11	0.01	-0.07	-0.11	0.01	-0.30	-0.32	-0.38	-0.18	-0.33	-0.01	-0.10	-0.10	0.01	-0.12	-0.80*	0.05	1.00				
Silt	-0.31	-0.20	-0.18	0.26	-0.36	0.26	0.54	0.53	-0.26	-0.12	-0.17	-0.16	-0.16	-0.36	-0.21	0.47	0.38	-0.85*	1.00			
Clay	0.67*	0.44	0.33	-0.41	0.60**	-0.15	-0.55	-0.37	0.64*	0.68*	0.11	0.33	0.33	0.60**	0.53	0.21	-0.72*	0.32	-0.71*	1.00		
THBC	0.06	0.03	0.03	0.30	-0.20	-0.19	0.23	0.18	-0.02	0.04	0.20	0.04	0.04	-0.20	-0.11	-0.24	-0.07	0.36	-0.25	0.32	1.00	
THFC	0.02	0.05	-0.03	0.21	-0.20	-0.20	0.18	0.18	-0.07	0.04	0.07	-0.02	-0.02	-0.20	-0.11	-0.26	-0.03	0.40	-0.26	0.33	0.99	1.00

** = Correlation is significant at 0.01 (2-tailed); * = Correlation is significant at 0.05 (2 tailed)

Table 3. Correlation coefficients of soil properties in unburnt rubber plantation at 15 - 30 cm

	pH	Ca	Mg	Na	K	TOC	SOM	TN	EA	ECEC	P	Fe	Zn	Cu	Mn	BD	WR	Sand	Silt	Clay	THBC	THFC
pH	1.00																					
Ca	0.68*	1.00																				
Mg	0.64*	0.80*	1.00																			
Na	0.64*	0.80*	0.98*	1.00																		
K	-0.05	0.27	0.47	0.47	1.00																	
TOC	0.13	0.33	0.37	0.37	0.36	1.00																
SOM	0.13	0.32	0.37	0.37	0.36	0.97*	1.00															
TN	0.09	0.25	0.36	0.36	0.26	0.94*	0.94*	1.00														
EA	0.41	0.73*	0.86*	0.86*	0.48	0.08	0.08	0.09	1.00													
ECEC	0.34	0.48	0.70*	0.70*	0.09	0.53	0.53	0.51	0.60**	1.00												
P	0.10	-0.11	0.40	0.40	0.50	0.36	0.37	0.33	0.20	0.43	1.00											
Fe	0.63**	0.80*	0.97*	0.97*	0.49	0.29	0.29	0.22	0.84*	0.65*	0.43	1.00										
Zn	0.63**	0.80*	0.97*	0.97*	0.49	0.29	0.29	0.22	0.84*	0.65*	0.43	0.98*	1.00									
Cu	-0.05	0.27	0.47	0.47	0.98*	0.36	0.36	0.26	0.48	0.09	0.50	0.49	0.49	1.00								
Mn	-0.05	0.27	0.47	0.47	0.95*	0.36	0.36	0.26	0.48	0.09	0.50	0.49	0.49	0.98*	1.00							
BD	0.25	0.41	0.71*	0.71*	0.35	0.13	0.13	0.16	0.86*	0.77*	0.48	0.69*	0.69*	0.35	0.35	1.00						
WR	-0.73*	-0.30	-0.27	-0.27	0.41	-0.02	-0.02	-0.19	-0.12	-0.16	0.17	-0.13	-0.13	0.41	0.41	-0.08	1.00					
Sand	-0.51	-0.51	-0.33	-0.33	0.39	0.03	0.02	0.06	-0.15	-0.30	0.14	-0.37	-0.37	0.39	0.39	0.02	0.29	1.00				
Silt	0.35	0.18	0.16	0.16	-0.63**	0.15	0.15	0.23	-0.07	0.46	-0.02	0.10	0.10	-0.63**	-0.63**	0.02	-0.46	-0.81*	1.00			
Clay	0.45	0.65*	0.37	0.37	0.06	-0.20	-0.21	-0.35	0.32	-0.03	-0.22	0.49	0.49	0.06	0.06	-0.05	0.04	-0.75*	0.22	1.00		
THBC	-0.26	-0.38	-0.20	-0.20	0.11	-0.12	-0.12	0.08	-0.24	-0.41	0.27	-0.23	-0.23	0.11	0.11	-0.20	0.03	0.11	-0.02	-0.15	1.00	
THFC	-0.22	-0.38	-0.10	-0.10	0.17	-0.17	-0.16	0.04	-0.11	-0.32	0.39	-0.12	-0.12	0.17	0.17	-0.03	0.01	0.19	-0.10	-0.21	**0.97***	1.00

** = Correlation is significant at 0.01 (2-tailed); * = Correlation is significant at 0.05 (2 tailed)

Table 4. Correlation coefficients of soil properties in burnt rubber plantation at 0 - 15 cm

	pH	Ca	Mg	Na	K	TOC	SOM	TN	EA	ECEC	P	Fe	Zn	Cu	Mn	BD	WR	Sand	Silt	Clay	THBC	THFC
pH	1.00																					
Ca	0.30	1.00																				
Mg	0.30	0.92*	1.00																			
Na	0.30	0.92*	0.97*	1.00																		
K	0.29	0.74*	0.91*	0.91*	1.00																	
TOC	0.17	0.10	0.34	0.34	0.48	1.00																
SOM	0.17	0.10	0.34	0.34	0.48	0.96*	1.00															
TN	0.08	-0.02	0.19	0.19	0.25	0.94*	0.94*	1.00														
EA	0.09	0.63**	0.57**	0.57**	0.51	0.97*	0.98*	-0.07	1.00													
ECEC	0.29	0.37	0.12	0.12	0.01	-0.37	-0.37	-0.43	0.61**	1.00												
P	0.45	0.62**	0.48	0.48	0.40	-0.19	-0.19	-0.39	0.22	0.37	1.00											
Fe	0.17	0.09	0.18	0.18	0.08	0.13	0.13	0.12	0.21	0.21	-0.02	1.00										
Zn	0.10	-0.11	-0.04	-0.04	-0.08	-0.05	-0.05	0.06	0.24	0.13	-0.61**	0.43	1.00									
Cu	0.29	0.74*	0.91*	0.91*	0.95	0.48	0.48	0.25	0.51	0.01	0.40	0.08	-0.08	1.00								
Mn	0.29	0.74*	0.91*	0.91*	0.97	0.48	0.48	0.25	0.51	0.01	0.40	0.08	-0.08	0.91*	1.00							
BD	0.46	0.60**	0.43	0.43	0.34	-0.14	-0.14	-0.27	0.61**	0.90*	0.57**	0.17	-0.05	0.34	0.34	1.00						
WR	-0.91*	-0.33	-0.42	-0.42	-0.45	-0.27	-0.27	-0.17	-0.01	-0.15	-0.43	-0.20	-0.02	-0.45	-0.44	-0.45	1.00					
Sand	-0.24	0.27	0.46	0.46	0.62**	0.41	0.41	0.20	-0.04	-0.51	0.33	-0.21	-0.61**	0.62**	0.62**	-0.24	0.05	1.00				
Silt	-0.16	-0.41	-0.56**	-0.56**	-0.73	-0.74*	-0.74*	-0.55**	-0.23	0.25	-0.32	0.25	0.50	-0.73*	-0.73*	-0.07	0.25	-0.76*	1.00			
Clay	0.50	-0.05	-0.20	-0.20	-0.29	0.03	0.03	0.17	0.24	0.55	-0.21	0.10	0.47	-0.29	-0.29	0.41	-0.29	-0.83	0.27	1.00		
THBC	0.17	0.09	0.19	0.19	0.08	0.13	0.13	0.13	0.22	0.21	-0.02	0.95*	0.43	0.08	0.08	0.17	-0.20	-0.21	0.24	0.10	1.00	
THFC	0.14	0.24	0.40	0.40	0.29	0.35	0.35	0.34	-0.42	-0.46	0.04	0.36	0.04	0.29	0.29	-0.24	-0.34	0.29	-0.08	-0.35	0.36	1.00

** = Correlation is significant at 0.01 (2-tailed); * = Correlation is significant at 0.05 (2 tailed)

Table 5. Correlation coefficients of soil properties in burnt rubber plantation at 15 -30 cm

	pH	Ca	Mg	Na	K	TOC	SOM	TN	EA	ECEC	P	Fe	Zn	Cu	Mn	BD	WR	Sand	Silt	Clay	THBC	THFC
pH	1.00																					
Ca	0.07	1.00																				
Mg	-0.04	0.96*	1.00																			
Na	-0.04	0.96*	0.94*	1.00																		
K	-0.20	0.77*	0.74*	0.74*	1.00																	
TOC	-0.47	-0.34	-0.37	-0.37	-0.38	1.00																
SOM	-0.47	-0.34	-0.37	-0.37	-0.37	0.96*	1.00															
TN	-0.43	-0.51	-0.48	-0.48	-0.50	0.94*	0.94	1.00														
EA	-0.11	0.82*	0.83*	0.83*	0.54	0.02	-0.01	-0.16	1.00													
ECEC	-0.03	0.85*	0.85*	0.85*	0.56**	-0.20	-0.20	-0.37	0.96*	1.00												
P	-0.08	0.89*	0.84*	0.84*	0.57**	0.03	-0.01	-0.22	0.86*	0.85	1.00											
Fe	-0.08	0.96*	0.93*	0.98*	0.76*	-0.33	-0.33	-0.44	0.84*	0.85*	0.86*	1.00										
Zn	0.20	0.74*	0.79*	0.79*	0.50	-0.45	-0.45	-0.48	0.76*	0.80*	0.60**	0.79*	1.00									
Cu	-0.20	0.77*	0.74*	0.74*	0.97*	-0.37	-0.37	-0.50	0.54	0.56	0.57**	0.76*	0.50	1.00								
Mn	-0.20	0.77*	0.74*	0.74*	0.95*	-0.38	-0.37	-0.50	0.54	0.56**	0.57**	0.76*	0.50	0.97*	1.00							
BD	-0.03	0.77*	0.73*	0.73*	0.49	-0.07	-0.07	-0.28	0.94*	0.97*	0.85*	0.74*	0.73*	0.49	0.49	1.00						
WR	-0.74*	0.01	0.02	0.02	0.46	0.17	0.17	0.04	0.04	0.05	-0.04	0.02	-0.21	0.46	0.46	0.07	1.00					
Sand	0.23	-0.14	-0.33	-0.33	0.16	-0.21	-0.21	-0.35	-0.33	-0.26	-0.22	-0.32	-0.39	0.16	0.16	-0.15	0.29	1.00				
Silt	-0.26	-0.09	0.10	0.10	-0.35	-0.07	-0.07	0.06	-0.07	-0.04	-0.10	0.07	0.14	-0.35	-0.35	-0.17	-0.17	-0.69*	1.00			
Clay	-0.04	0.29	0.35	0.35	0.15	0.36	0.36	0.42	0.54	0.39	0.41	0.37	0.39	0.15	0.15	0.38	-0.22	-0.65*	-0.09	1.00		
THBC	-0.09	0.74*	0.83*	0.83*	0.74*	-0.55	-0.55	-0.55	0.49	0.53	0.44	0.82*	0.69*	0.74*	0.74*	0.35	0.15	-0.35	0.28	0.19	1.00	
THFC	0.03	0.83*	0.80*	0.80*	0.36	-0.07	-0.07	-0.28	0.87*	0.88*	0.92*	0.80*	0.61**	0.36	0.36	0.86*	-0.16	-0.26	0.07	0.29	0.38	1.00

** = Correlation is significant at 0.01 (2-tailed); * = Correlation is significant at 0.05 (2 tailed)

This disagreed with the findings of Chimdi et al. (2012) which observed an insignificant positive relationship between pH with Ca.

In unburnt rubber plantation, Mg showed a positive significant relationship with pH in the topsoil (Table 2). This agreed with the findings of Chimdi et al. (2012) which reported a significant positive correlation of pH with Mg. As indicated in Table 2, topsoil Mg showed a positive significant relationship with Ca (0.87) at $p<0.05$. This disagreed with the outcomes of Ramesh et al. (2016) which observed that Mg demonstrated a significant negative correlation with Ca. Mg exhibited a moderate positive significant relationship with pH (0.64) and a strong significant positive relationship with Ca (0.80) in the subsoil (Table 3) at $p<0.05$. Mg also showed a significant positive correlation with Ca at both soil depths (0.92 and 0.96) at $p<0.05$ in burnt rubber plantation (Tables 4 and 5). These results suggested that Mg is positively related with Ca and pH, demonstrating that higher Mg levels are associated with higher Ca concentrations and increased pH, implying improved chemical stability and fertility status of the soils in unburnt rubber plantation. A significant positive relationship was observed between Na with pH (0.64), Ca (0.80) and Mg (0.98) at $p<0.05$ in the subsoil layer (Table 3), inferring that higher Na levels are associated with higher concentrations of Ca and Mg, as well as higher soil pH.

Na indicated a significant positive correlation with Ca (0.92) and Mg (0.97) in the topsoil of the burnt site (Table 4) at $p<0.05$. Also, Na revealed a significant positive correlation ($p<0.05$) with Ca (0.96) and Mg (0.94) in the subsoil of the burnt site (Table 5). This inferred that that higher Na levels are associated with higher concentrations of Ca and Mg, possibly improving soil nutrient availability in the topsoil of the burnt site. The results contradicted Ramesh et al. (2016) who reported a significant positive correlation between Na and EC (r=0.638, p=0.011). K showed a significant positive relationship ($p<0.05$) with pH (0.73), Ca (0.84) and Mg (0.80) in the topsoil of unburnt rubber plantation (Table 2). At both soil depths in burnt rubber plantation (Tables 4 and 5), a strong significant positive ($p<0.05$) was observed for Ca (0.74 and 0.77), Mg (0.91 and 0.74), and Na (0.91 and 0.74). These revealed the strong inter-relationships existing among the exchangeable cations, and may be due to the similar parent materials of both the unburnt and burnt rubber plantations. The results were not in conformity with Mar et al. (2004) who reported that K showed a significant positive correlation with SOM and a significant negative correlation with P.

TOC exhibited a significant positive correlation with Mg (0.59) at $p<0.01$ in unburnt rubber plantation in the topsoil (Table 2). The finding contradicted Tsozué and Yakouba (2016) which observed a significant positive correlation between TOC and sand. In unburnt rubber plantation, SOM showed a significant negative correlation with Ca (-0.55) and K (-0.62) at $p<0.01$ in the topsoil (Table 2). Topsoil SOM demonstrated a significant positive correlation with TOC (0.96) in burnt rubber plantation (Table 4) at $p<0.05$. Table 5 showed that subsoil SOM revealed a strong significant positive correlation ($p<0.05$) with TOC (0.96) in the burnt rubber plantation. These correlations at both soil depths demonstrate that TOC closely echoes the SOM, suggesting that SOM is a dependable indicator of carbon storage and soil fertility within the topsoil and subsoil, even in biomes that have been affected by bushfire. SOM is the soil nutrient reservoir and its fluctuations will upset the status of the fertility of soils (Fisher & Binkley, 2000).

In the topsoil of unburnt rubber plantation, Table 2 revealed that TN showed a positive significant relationship with SOM (0.78) at $p<0.05$ and with TOC (0.59) at $p<0.01$. This suggested that higher TN levels are associated with higher concentrations of SOM and TOC at topsoil, inferring improved retention of soil nutrients, structure, and microbiological activities in the topsoil of the unburnt rubber plantation. Similarly, TN also showed a significant positive correlation with TOC (0.94) and SOM (0.94) at the subsoil at $p<0.05$ (Table 3). Topsoil TN indicated a strong significant positive with SOM (0.94) and TO (0.94) in the burnt rubber plantation (Table 4) at $p<0.05$. Likewise, in the subsoil (Table 5), TN showed a significant positive correlation ($p<0.05$) with TOC (0.94). Most TN in soils is found in SOM, elucidating the significant positive correlation between the TOC and N contents in several biomes (Stevenson & Cole, 1999). The significant positive correlation between TN with SOM and TOC in the burnt rubber plantation could due to the release of mineralizable nitrogen from SOM in proportionate amounts and the absorption of NH_4–N by humus complexes in soil (Vanilarasu & Balakrishnamurthy, 2014). The correlation between TOC and TN contents may be connected to the emissions of soil CO_2 and N_2O (Xu et al., 2008). The consistent dependence of TN on TOC shows an inclusive convergence in the accessibility of TN to plants, which aids foliar N content and foliar traits (Ordoñez et al., 2009).

EA in the unburnt plantation demonstrated a significant positive correlation with pH (0.61) and K (0.55) at p<0.01 in the topsoil (Table 2). In the subsoil (Table 3), EA indicated a significant positive correlation with Ca (0.73), Mg (0.86), and Na (0.86) at p<0.05. In contrast, in burnt rubber plantation, EA showed a significant positive correlation with SOM (0.98) and TOC (0.97) at p<0.05 and with Ca (0.63), Mg (0.57) and Na (0.57) at p<0.01 at the topsoil (Table 4). At the subsoil (Table 5), EA revealed a significant positive correlation with (Ca 0.82), Mg (0.83) and Na (0.83) at p<0.05. In the topsoil of unburnt site (Table 2), P showed a significant positive correlation with Mg (0.75) at p<0.05. As shown in Table 4, topsoil P of burnt rubber plantation revealed a significant positive correlation with Ca (0.62) at p<0.01. However, in subsoil (Table 5), P showed a significant positive correlation (p<0.05) with Ca (0.89), Mg (0.84), Na (0.84), EA (0.86), ECEC (0.85), and also with K (0.57) at p<0.01. These results suggested that in the topsoil, higher P levels are associated primarily with Ca, whereas in the subsoil, P is associated with higher concentrations of Ca, Mg, Na, EA, ECEC, and K. This implied the differences in P dynamics between the topsoil and the subsoil layers, which could influence the fertility and nutrient management of the soils of the burnt rubber plantation. The results disagreed with Tsozué and Yakouba (2016) which observed that P showed a significant positive correlation with TN and TOC. Likewise, Ramesh et al. (2016) observed a significant positive correlation between P and Si (r=0.698, p=0.004).

ECEC in the topsoil indicated a significant positive correlation with EA (0.92) at p<0.05 and with pH (0.62), Ca (0.55), and K (0.63) at p<0.01 in unburnt rubber plantation (Table 2). ECEC demonstrated a significant positive correlation (p<0.05) with Mg (0.70), Na (0.70) and with EA (0.60) at p<0.01 in the subsoil (Table 3). Topsoil ECEC in burnt rubber plantation (Table 4) showed a significant positive correlation with EA (0.61) at p<0.01. Contrarily, ECEC exhibited a significant positive correlation (p<0.05) with Ca (0.85), Mg (0.85), Na (0.85), EA (0.96) and with K (0.56) at p<0.01 in the subsoil (Table 5). These results suggest that higher ECEC values are associated with higher concentrations of Ca, Mg, Na, EA, and K, demonstrating that soils with higher ECEC have a greater capability to retain nutrients for rubber tree uptake. This contradicted the results of Olorunfemi et al. (2018) which observed that ECEC showed positive significant correlation with SOC and SOM.

Fe in the topsoil indicated a significant positive correlation (p<0.05) with pH (0.76), Ca (0.87), Mg (0.95), K (0.79), P (0.77) and at p<0.01 with TOC (0.60) in unburnt rubber plantation (Table 2). Fe showed a significant positive correlation (p<0.05) with Ca (0.80), Mg (0.97), Na (0.97), EA (0.84), ECEC (0.65) and at p<0.01 with pH (0.63) in the subsoil (Table 3). As indicated in Table 5, Fe demonstrated a significant positive correlation (p<0.05) with Ca (0.96), Mg (0.93), Na (0.96), K (0.76), EA (0.84), ECEC (0.85) and P (0.86). Zn indicated a significant positive correlation (p<0.05) with pH (0.76), Ca (0.87), Mg (0.98), K (0.79), P (0.77), Fe (0.98) and at p<0.01 with TOC (0.60) in topsoil of unburnt rubber plantation (Table 2). In subsoil (Table 3), Zn showed a significant positive correlation with Ca, Mg, Na, EA, ECEC (p<0.05) and with pH at p<0.01. Zn revealed a significant negative correlation (p<0.01) with P (-0.61) in the topsoil of burnt rubber plantation (Table 4). The correlations between trace elements suggested that the soil quality property pairs do connect in their geochemical dynamics.

Cu showed a significant positive correlation (p<0.05) with pH (0.73), Ca (0.84), Mg (0.80), K (0.96), Fe (0.79) Zn (0.79) and at p<0.01 with ECEC (0.63) in

Table 2 at the topsoil. In the subsoil (Table 3), Cu only showed a significant positive correlation ($p<0.05$) with K (0.98). Cu indicated a significant positive correlation ($p<0.05$) with Ca (0.74), Mg (0.91), Na (0.91) in the topsoil of burnt rubber plantation (Table 4). However, Cu demonstrated a significant positive correlation ($p<0.05$) with Ca (0.77), Mg (0.74), Na (0.77), K (0.97), Fe (0.79), and with P (0.57) at $p<0.01$ in the subsoil (Table 5). In the topsoil of unburnt rubber plantation (Table 2), Mn revealed a significant positive correlation ($p<0.05$) with pH (0.69), Ca (0.83), Mg (0.81), K (0.97), ECEC (0.65), Fe (0.81), Zn (0.81) and Cu (0.97). However, subsoil Mn (Table 3) showed a significant positive correlation ($p<0.05$) only with K (0.95) and Cu (0.98). In burnt rubber plantation (Table 4), topsoil Mn showed a significant positive correlation ($p<0.05$) with Ca (0.74), Mg (0.91), Na (0.91) and Cu (0.91). However, Mn indicated a significant positive correlation ($p<0.05$) with Ca (0.77), Mg (0.74), Na (0.74), K (0.95), Fe (0.76), Cu (0.97) and with ECEC (0.56) and P (0.57) at $p<0.01$ in the subsoil (Table 5). This disagreed with Chimdi et al., (2012), which observed highly significant positive relationships between Fe and Mn.

BD showed a significant positive correlation with ECEC (0.79) at $p<0.05$ and with EA (0.62) at $p<0.01$ in unburnt rubber plantation (Table 2) in the topsoil. In the subsoil (Table 3) and in contrast, BD revealed a significant positive correlation with Mg (0.71), Na (0.71), EA (0.86), ECEC (0.77), Fe (0.69) and Zn (0.69) at $p<0.05$. In burnt site, BD demonstrated a significant positive correlation with ECEC (0.90) at $p<0.05$ and with EA (0.61), Ca (0.60) and P (0.57) at $p<0.01$ in the topsoil (Table 4). In the subsoil (Table 5), BD indicated a significant positive correlation with Ca (0.77), Mg (0.73), Na (0.73), EA (0.94), ECEC (0.97), P (0.85), Fe (0.74) and Zn (0.73) at $p<0.05$. The findings contradicted Chimdi's et al. (2012) which observed a significant negative correlation between BD and ECEC. Similarly, Morisada et al. (2004) observed that the negative correlation between BD and SOM of soils was strong. Upsurges in BD have been revealed to decrease levels of SOM (Brevik & Fenton, 2012), since it diminishes root penetration, soil aeration and makes it more challenging for organisms to move and undertake characteristic activities (Guo et al., 2016). In unburnt rubber plantation, WR showed a significant negative correlation with pH (-0.99), Ca (-0.69), Mg (-0.77), K (-0.75), EA (-0.69), ECEC (-0.67), Fe (-0.77), Zn (-0.77), Cu (-0.75) and Mn (-0.70) at $p<0.05$ in the topsoil (Table 2). However, WR revealed a significant negative correlation with pH (-0.73) at $p<0.05$ in the subsoil (Table 3). Similarly, in the burnt rubber plantation, WR indicated a significant negative correlation with pH (-0.91) at $p<0.05$ at the topsoil (Table 4) and subsoil (0.74) (Table 5) respectively.

Sand indicated a significant negative correlation with BD (-0.80) at $p<0.05$ in unburnt rubber site (Table 2) at the topsoil. In burnt rubber plantation (Table 4), sand revealed a significant positive correlation with K (0.62), Cu (0.62), Zn (0.62) and Mn (0.62) at $p<0.01$. Silt revealed a significant negative correlation with sand (-0.81) at $p<0.05$ and with K (-0.63), Cu (-0.63) and Mn (-0.63) at $p<0.01$ in the subsoil (Table 3). In the burnt rubber plantation (Table 4), silt showed a significant negative correlation with TOC (-0.74), SOM (-0.74), Cu (-0.73), Mn (-0.73), sand (-0.76) at $p<0.05$, and with Mg (0.56), Na (0.56) and TN (0.55) at $p<0.01$. Silt also revealed a significant negative correlation with sand (-0.69) at $p<0.05$ in the subsoil (Table 5). These negative correlations at both soil depths suggest that silt affects the distribution of soil nutrients as well as SOM accumulation in the burnt rubber plantation.

Clay showed a significant positive correlation with pH (0.67), EA (0.64), ECEC (0.64) at $p<0.05$ and K (0.60) and Cu (0.60) at $p<0.01$ in the unburnt rubber plantation at the topsoil (Table 2). Rengasamy and Sumner (1998) stated that K can instigate clay swelling and dispersion being a monovalent cation. However, clay indicated a significant negative correlation with WR (-0.72) and silt (-0.71) at $p<0.05$. Clay revealed a significant positive correlation with Ca (0.65) at $p<0.05$ but a significant negative correlation with sand (-0.75) in the subsoil (Table 3). On the contrary, Dieckow et al. (2009) demonstrated that clay and iron oxide contents were strongly correlated with TOC. In the subsoil (Table 5), clay demonstrated a significant negative correlation with sand (-0.65) at $p<0.05$. This differed from the results of Chimdi et al., (2012) which observed that clay showed a negative insignificant relationship with sand. The observed correlation of selected soil quality indicators with clay and sand contents at both soil depths may be ascribed to similarity of the parent material (Thapa & Yila, 2012).

In burnt rubber plantation, THBC showed a significant positive correlation with Fe (0.95) at $p<0.05$ in the topsoil (Table 4). However, THBC indicated a significant positive correlation with Ca (0.74), Mg (0.83), Na (0.83), K (0.74), Fe (0.82), Zn (0.69), Cu (0.74) and Mn (0.74) at $p<0.05$ in the subsoil (Table 5). On the contrary, THBC demonstrated a negative correlation with TOC (-0.55), SOM (-0.55) and TN (-0.55) in the subsoil at $p<0.01$. This suggested that THBC will be vulnerable to positive changes in TOC, SOM and TN. THFC indicated a significant positive correlation with THBC (0.97) at $p<0.05$ in the subsoil (Table 3). This implied that higher levels of THFC are associated to increases in THBC. THFC revealed a significant positive correlation with Ca (0.83), Mg (0.80), Na (0.80), EA (0.87), ECEC (0.88), P (0.92), Fe (0.80), BD (0.86) at $p<0.05$ and Zn (0.61) at $p<0.01$ in the subsoil of burnt rubber plantation, indicating the positive role of exchangeable cations and micronutrients on subsoil fungal activities in the burnt rubber plantation.

Conclusion

The relationships among soil properties in burnt and unburnt rubber plantations were studied. The findings revealed that soil pH indicated a significant positive correlation with Ca, Mg, K, Fe, Zn, Cu, Mn, clay, EA, and ECEC in the topsoil of unburnt rubber plantation. SOM demonstrated a significant positive correlation with TOC at the topsoil in burnt rubber plantation. Zn revealed a significant negative correlation with P in the topsoil of burnt rubber plantation. Silt indicated a significant negative correlation with sand, K, Cu and Mn in the subsoil. Clay revealed a significant positive correlation with pH, EA, ECEC, K and Cu in the unburnt site at the topsoil. THBC showed a significant positive correlation with Fe in burnt rubber plantation at the topsoil. Nonetheless, THBC showed a significant positive correlation with Ca, Mg, Na, K, Fe, Zn Cu and Mn in the subsoil. The study concluded that the reliable relationships can have significant implications for managing the quality of soils in tropical rubber plantations, and provide foundation for precision plantation agricultural systems.

Ethics Committee Approval

N/A

Peer-review

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Author Contributions

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Conflict of Interest

The authors declare that they have no conflict of interest.

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