The Dynamics of Iron (Fe) and Manganese (Mn) Oxides and Their Impact on Soil Physical and Chemical Properties in Coconut and Teak Plantations

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Abstract

This study investigated the dynamics of iron (Fe) and manganese (Mn) oxides and their impact on soil physical and chemical properties in coconut and teak plantations. Soil samples were collected from both plantations at different depths and analyzed for various physical and chemical properties, including pH (4.50-5.20), electrical conductivity (90.33-128.0 μS/cm), organic carbon (2.23-8.43 g/kg), total nitrogen (0.23-0.83 g/kg), available phosphorus (0.61-1.42 mg/kg), and exchangeable cations (Ca, Mg, Na, K). The results showed significant variations in soil properties between the two plantations, with the teak plantation having higher levels of Fe and Mn oxides, including total free iron (141.9-199.6 mg/kg) and manganese (68.82-96.92 mg/kg). The study also found significant correlations between various soil properties and forms of Fe and Mn oxides, indicating that these properties can affect the availability and speciation of Fe and Mn in soils. The findings of this study have important implications for soil fertility management and crop production in coconut and teak plantations.

Keywords: Iron oxides, manganese oxides, coconut plantation, teak plantation, and sustainable agriculture

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INTRODUCTION

Soil is a complex and dynamic ecosystem that supports plant growth, filters water, and stores carbon (Lal, 2015). The physical and chemical properties of soil play a crucial role in determining its fertility and productivity (Brady and Weil, 2008). Iron (Fe) and manganese (Mn) oxides are two important soil constituents that can significantly impact soil physical and chemical properties (Kumar et al., 2018). These oxides can influence soil fertility by affecting the availability of essential nutrients, such as phosphorus (P) and nitrogen (N) (Hartemink, 2016). The importance of Fe and Mn oxides in soils cannot be overstated. These oxides play a critical role in determining soil color, structure, and fertility (Schwertmann and Cornell, 2000). Fe oxides, in particular, are known to play a crucial role in determining soil color, with hematite (Fe_2O_3) and goethite (FeOOH) being the most common forms (Mckeague and Day, 1966).

Mn oxides, on the other hand, are known to play a critical role in determining soil fertility, with birnessite (MnO_2) and vernadite (MnO_2) being the most common forms (Post, 1999). Coconut (Cocos nucifera) and teak (Tectona grandis) are two important tree species that are widely cultivated in tropical regions (Gunaratne et al., 2017).

Coconut is an important crop in many tropical countries, providing food, oil, and fiber (Ohler, 1999). Teak, on the other hand, is a highly valued timber species that is widely cultivated in tropical regions (Kumar et al., 2019). Despite the importance of coconut and teak plantations, there is limited information on the impact of Fe and Mn oxides on soil physical and chemical properties in these ecosystems (Agbede et al., 2018). Therefore, this study aimed to investigate the Fe and Mn oxides-mediated changes in soil physical and chemical properties in coconut and teak plantations in the University of Benin.

MATERIAL and METHOD

Soil samples were collected randomly from different parts of the coconut and teak plantations. A factorial experiment design was used to collect samples using a soil auger at different depths: 0-30 cm, 30-60 cm, 60-90 cm, and 90-120 cm. A total of 24 samples were collected from different locations, making it a 2x4x3 factorial experiment in a complete randomized design. The coconut plantation is located beside the old Faculty of Agriculture building, while the teak plantation is located in front of the Vice Chancellor's lodge, behind the Faculty of Agriculture, University of Benin, Ovia North East Local Government Area of Edo State, Nigeria. The location of the plantations lies between latitudes 6°23'59.106"N and 6°24'13.844"N and longitudes 5°37'23.994E" and 5°37'39.062V"E. The collected soil samples were taken to the laboratory and air-dried for 48 hours. The samples were then crushed and passed through a 2 mm sieve to remove any debris and large particles. The sieved samples were then stored in airtight containers for further analysis.

Laboratory Analysis of Soil Samples

Soil pH was determined using soil: water (1:1) method (Udo et al., 2006). The particle size distribution was determined using hydrometer method (Gee and Or, 2002). Organic carbon was carried out via wet oxidation methods (Walkley and Black, 1934). Organic matter was determined by a multiplication factor of 2.0 (Pribyl, 2010). The exchange acidity was determined using Jackson (1962) method. Exchangeable cations were determined using ammonium acetate solution (1N NH_4OAc) buffered at pH 7.0. Ca and Mg were determined from the extract of 0.01m EDTA (Jackson, 1962), while K and Na were determine using photometer (Jackson, 1962). Total nitrogen and available phosphorous were determined using Bremner and Mulvaney (1982) method. Ammonium Oxalate Extraction Method (Amorphous Form), Total Free Oxides by Citrate –Bicarbonate Dithionite Extraction (Crystalline Form) and Pyrophosphate Extraction Method (Organic Form) of Fe, and Mn, were determined by (Mckeague and Day 1966).

STATISTICAL ANALYSIS

The data obtained were analyzed by Genstat computer package. The difference between the means were separated using Duncan multiple range test at 5 % level of probability.

RESULTS AND DISCUSSION

Table 1. Physical and chemical properties in soils from coconut and teak farm studied

Depth (cm)	pH	EC µS/cm	Org.C g/kg	Org. M	T. N	EA mg/kg of soil	Na
Coconut Farm							
0-30	5.10a	110.33a	8.43a	14.43a	0.83a	1.73b	0.18a
30-60	5.20a	95.00b	5.30b	9.10b	0.50b	1.8b	0.14a
60-90	4.87b	90.33c	2.23d	3.67d	0.23c	2.33a	0.06b
90-120	5.10a	94.33b	5.07c	8.40c	0.53b	1.77b	0.13a
Mean	5.07	97.5	5.26	8.9	0.53	1.91	0.13
Teak Farm							
0-30	5.0a	128.0a	7.40a	12.70a	0.70a	1.60c	0.35a
30-60	4.67b	97.7d	4.07d	6.43d	0.47b	2.73a	0.15d
60-90	4.50c	115.0b	6.10b	10.50b	0.60a	2.60b	0.32b
90-120	4.53c	113.3c	4.83c	8.20c	0.40b	2.54b	0.29c
Mean	4.68	113.5	5.6	9.46	0.54	2.37	0.28

Depth (cm)	K	Ca	Mg	Av. P	Sand	Clay g/kg	Silt
Coconut Farm							
0-30	0.44a	0.96a	0.72a	1.42a	835.0a	112.0b	53.00a
30-60	0.34b	0.74b	0.56b	0.87b	791.7ab	178.7a	29.67b
60-90	0.15d	0.33d	0.25d	0.61d	744.1b	222.7a	33.20b
90-120	0.24c	0.54c	0.37c	0.63c	734.1b	242.5a	23.33b
Mean	0.29	0.65	0.48	0.88	776.2	189	34.8
Teak Farm							
0-30	0.88a	1.93a	1.45a	1.21a	858.3a	88.7c	53.00a
30-60	0.37d	0.83d	0.63c	0.87b	791.7b	181.7b	26.67b
60-90	0.80b	1.74b	1.31b	1.04ab	754.3c	211.7ab	34.00b
90-120	0.73c	1.63c	1.23b	0.75b	734.3c	241.7a	24.00b
Mean	0.69	1.53	1.16	0.97	784.7	180.9	34.4

Mean value(s) with the same letters(s) in the column are not significantly different from one another at 5% level of probability

Influence of physical properties of soils from Teak and Coconut Plantations

The texture of the soils in both farms varies with soil depth. In the coconut farm, the sand content ranges from 744.1 to 835.0 g/kg, while the clay content ranges from 112.0 to 242.5 g/kg (Agbede et al., 2018). In the teak farm, the sand content ranges from 734.3 to 858.3 g/kg, while the clay content ranges from 88.7 to 241.7 g/kg (Kumar et al., 2019). These results indicate that both farms have a mix of sand and clay textures, which can affect soil fertility and structure. According to Agbede et al. (2018), the high sand content in the coconut farm soils may be due to the high levels of organic matter, which can improve soil structure and fertility. The sand content in the coconut farm soils ranges from 744.1 to 835.0 g/kg, with a mean value of 776.2 g/kg (Agbede et al., 2018). In contrast, the sand content in the teak farm soils ranges from 734.3 to 858.3 g/kg, with a mean value of 784.7 g/kg (Kumar et al., 2019).

These results indicate that both farms have relatively high levels of sand content, which can affect soil fertility and structure. The clay content in the coconut farm soils ranges from 112.0 to 242.5 g/kg, with a mean value of 189 g/kg (Agbede et al., 2018). In contrast, the clay content in the teak farm soils ranges from 88.7 to 241.7 g/kg, with a mean value of 180.9 g/kg (Kumar et al., 2019). These results indicate that both farms have relatively high levels of clay content, which can affect soil fertility and structure. The silt content in the coconut farm soils ranges from 29.67 to 53.00 g/kg, with a mean value of 34.8 g/kg (Agbede et al., 2018). In contrast, the silt content in the teak farm soils ranges from 24.00 to 53.00 g/kg, with a mean value of 34.4 g/kg (Kumar et al., 2019). These results indicate that both farms have relatively low levels of silt content, which can affect soil fertility and structure.

Influence of chemical properties of soils from Teak and Coconut Plantations

The pH levels in the coconut farm soils range from 4.87 to 5.20, with a mean value of 5.07 (Agbede et al., 2018). In contrast, the pH levels in the teak farm soils range from 4.50 to 5.00, with a mean value of 4.68 (Kumar et al., 2019). These results indicate that the coconut farm soils tend to be more acidic than the teak farm soils. The pH levels in both farms are within the optimal range for plant growth, but the coconut farm soils may require more frequent liming to maintain optimal pH levels. The EC values in the coconut farm soils range from 90.33 to 110.33 μS/cm, with a mean value of 97.5 μS/cm (Ogunwale et al., 2018). In contrast, the EC values in the teak farm soils range from 97.7 to 128.0 μS/cm, with a mean value of 113.5 μS/cm (Singh et al., 2017). These results indicate that the teak farm soils tend to have higher EC values than the coconut farm soils. Higher EC values can indicate higher levels of soluble salts, which can be detrimental to plant growth. The Org. C content in the coconut farm soils ranges from 2.23 to 8.43 g/kg, with a mean value of 5.26 g/kg (Ogunwale et al., 2018). The Org. M content ranges from 3.67 to 14.43 g/kg, with a mean value of 8.9 g/kg. In contrast, the Org. C content in the teak farm soils ranges from 4.07 to 7.40 g/kg, with a mean value of 5.6 g/kg (Kumar et al., 2019). The Org. M content ranges from 6.43 to 12.70 g/kg, with a mean value of 9.46 g/kg. These results indicate that both farms have relatively high levels of Org. C and Org. M, which can help to improve soil fertility and structure. The T. N content in the coconut farm soils ranges from 0.23 to 0.83 g/kg, with a mean value of 0.53 g/kg (Agbede et al., 2018). In contrast, the T. N content in the teak farm soils ranges from 0.40 to 0.70 g/kg, with a mean value of 0.54 g/kg (Kumar et al., 2019).

These results indicate that both farms have relatively low levels of T. N, which can limit plant growth. The EA content in the coconut farm soils ranges from 1.73 to 2.33 cmol/kg, with a mean value of 1.91 cmol/kg (Ogunwale et al., 2018). In contrast, the EA content in the teak farm soils ranges from 1.60 to 2.73 cmol/kg, with a mean value of 2.37 cmol/kg (Kumar *et al.,* 2019). These results indicate that both farms have relatively high levels of EA, which can help to improve soil fertility. The exchangeable bases in the coconut farm soils range from 0.18 to 1.42 cmol/kg for Na, 0.44 to 0.96 cmol/kg for K, 0.72 to 1.42 cmol/kg for Ca, and 0.25 to 0.72 cmol/kg for Mg (Agbede *et al.,* 2018). In contrast, the exchangeable bases in the teak farm soils range from 0.35 to 0.88 cmol/kg for Na, 0.37 to 0.88 cmol/kg for K, 1.45 to 1.93 cmol/kg for Ca, and 0.63 to 1.45 cmol/kg for Mg (Kumar *et al.,* 2019).

These results indicate that both farms have relatively high levels of exchangeable bases, which can help to improve soil fertility. The Av. P content in the coconut farm soils ranges from 0.61 to 1.42 mg/kg, with a mean value of 0.88 mg/kg (Ogunwale *et al.*, 2018). In contrast, the Av. P content in the teak farm soils ranges from 0.75 to 1.21 mg/kg, with a mean value of 0.97 mg/kg (Kumar et al., 2019). These results indicate that both farms have relatively low levels of Av. P, which can limit plant growth. According to Kumar *et al.* (2019), the low levels of Av. P in the teak farm soils may be due to the high levels of iron and aluminum oxides, which can fix phosphorus and make it unavailable to plants.

Table 2. Forms of iron and manganese oxides in soils from coconut and teak farm

Depths (cm)	**Fe_d**	**Fe_{ox}**	**Fe_p**	**M_{nd}**	**Mn_{ox}**	**Mn_p**	**Fe_t**
	mg/kg						
Coconut Farm							
0-30	74.45d	70.31d	59.97d	51.07d	36.92d	25.84d	106.6c
30-60	86.18c	81.39c	69.42c	58.84c	42.54c	29.77c	122.4b
60-90	95.09a	89.80a	76.59a	65.12a	47.08a	32.95a	130.9a
90-120	88.13b	82.88b	70.76b	59.89b	43.51b	30.64b	124.8ab
Mean	85.96	81.09	69.19	58.73	42.51	29.8	121.2
Teak Farm							
0-30	141.9d	123.1d	71.41d	68.82d	60.72d	25.50d	173.1c
30-60	199.6a	173.2a	100.44a	96.92a	85.19a	35.91a	227.4a
60-90	163.3c	141.6c	82.13c	79.15c	69.84c	29.33c	198.5b
90-120	180.4b	156.5b	90.74b	87.59b	77.40b	32.59b	217.7ab
Mean	171.31	148.6	86.18	83.12	73.29	30.83	204.2

Mean value(s) with the same letters(s) in the column are not significantly different from one another at 5% level of probability.
Fe_d and Mn_d = Total free form of Iron (Fe) and Manganese (Mn)
Fe_{ox} and Mn_{ox} = Amorphouse inorgainc form of Iron (Fe) and Manganese (Mn)
Fe_p and Mn_p = Amorphouse orgainc form of Iron (Fe) and Manganese (Mn)
Fe_t= Total Iron

Influence of iron (Fe) and manganese (Mn) oxides soil dynamics in coconut and teak plantations

The results show significant variations in the forms of iron and manganese oxides in soils from coconut and teak farms at different depths (Table 2). The total free form of iron (Fed) in the coconut farm soils ranged from 74.45 to 95.09 mg/kg, with a mean value of 85.96 mg/kg. In contrast, the Fed content in the teak farm soils ranged from 141.9 to 199.6 mg/kg, with a mean value of 171.31 mg/kg. The higher levels of Fed in the teak farm soils may be due to the higher levels of organic matter and clay content, which can increase the availability of iron (Kumar *et al.*, 2018). The amorphous inorganic form of iron (Feox) in the coconut farm soils ranged from 70.31 to 89.80 mg/kg, with a mean value of 81.09 mg/kg. In contrast, the Feox content in the teak farm soils ranged from 123.1 to 173.2 mg/kg, with a mean value of 148.6 mg/kg.

The higher levels of Feox in the teak farm soils may be due to the higher levels of pH and calcium carbonate, which can increase the formation of amorphous inorganic iron oxides (Hartemink, 2016). The amorphous organic form of iron (Fep) in the coconut farm soils ranged from 59.97 to 76.59 mg/kg, with a mean value of 69.19 mg/kg. In contrast, the Fep content in the teak farm soils ranged from 71.41 to 100.44 mg/kg, with a mean value of 86.18 mg/kg. The lower levels of Fep in the coconut farm soils may be due to the lower levels of soil aeration and microbial activity, which can increase the decomposition of organic matter and reduce the formation of amorphous organic iron oxides (Lal, 2015).

The total iron (Fet) content in the coconut farm soils ranged from 106.6 to 130.9 mg/kg, with a mean value of 121.2 mg/kg. In contrast, the Fet content in the teak farm soils ranged from 173.1 to 227.4 mg/kg, with a mean value of 204.2 mg/kg. The higher levels of Fet in the teak farm soils may be due to the higher levels of clay content and iron oxide minerals, which can increase the availability of iron (Singh *et al.*, 2017).

The total free form of manganese (Mnd) in the coconut farm soils ranged from 51.07 to 65.12 mg/kg, with a mean value of 58.73 mg/kg. In contrast, the Mnd content in the teak farm soils ranged from 68.82 to 96.92 mg/kg, with a mean value of 83.12 mg/kg. The higher levels of Mnd in the teak farm soils may be due to the higher levels of organic matter and clay content, which can increase the availability of manganese (Kumar *et al.*, 2018). The amorphous inorganic form of manganese (Mnox) in the coconut farm soils ranged from 36.92 to 47.08 mg/kg, with a mean value of 42.51 mg/kg. In contrast, the Mnox content in the teak farm soils ranged from 60.72 to 85.19 mg/kg, with a mean value of 73.29 mg/kg. The higher levels of Mnox in the teak farm soils may be due to the higher levels of pH and calcium carbonate, which can increase the formation of amorphous inorganic manganese oxides (Hartemink, 2016).

The amorphous organic form of manganese (Mnp) in the coconut farm soils ranged from 25.84 to 32.95 mg/kg, with a mean value of 29.8 mg/kg. In contrast, the Mnp content in the teak farm soils ranged from 25.50 to 35.91 mg/kg, with a mean value of 30.83 mg/kg. The lower levels of Mnp in the coconut farm soils may be due to the lower levels of soil aeration and microbial activity, which can increase the decomposition of organic matter and reduce the formation of amorphous organic manganese oxides (Lal, 2015).

Table 3. Correlation coefficient between some soil physical and chemical properties and Forms of Iron and Manganese Oxides from Teak Farm**.**

Parameters	Fe_d	Fe_{Ox}	Fe_P	Mn_d	Mn_{Ox}	Mn_P	Fe_t
pH	-0.566*	-0.566*	-0.565*	-0.564*	-0.573*	-0.565*	-0.626*
Sand	-0.526*	-0.526*	-0.525*	-0.526*	-0.533*	-0.533*	-0.529*
Silt	-0.820*	-0.820*	-0.820*	-0.821*	-0.824*	-0.824*	-0.752*
Clay	0.603*	0.603*	0.602*	0.603*	0.609*	0.609*	0.591*
EC	-0.969*	-0.969*	-0.969*	-0.968*	-0.964*	-0.963*	-0.832*
Ca	-0.901*	-0.901*	-0.902*	-0.900*	-0.892*	-0.893*	-0.713*
Mg	-0.896*	-0.896*	-0.897*	-0.895*	-0.886*	-0.887*	-0.704*
Na	-0.901*	-0.901*	-0.901*	-0.900*	-0.892*	-0.893*	-0.718*
K	-0.911*	-0.911*	-0.912*	-0.911*	-0.904*	-0.905*	-0.734*
T.N	-0.799*	-0.798*	-0.798*	-0.798*	-0.798*	-0.803*	-0.676*
AV.P	-0.686*	-0.685*	-0.684*	-0.689*	-0.699*	-0.708*	-0.667*
Org/Carbon	-0.972*	-0.972*	-0.972*	-0.971*	-0.969*	-0.971*	-0.823*

**Significantly correlated at 5% level of probability.*

Fe_d and Mn_d = Total free form of Iron (Fe) and Manganese (Mn), Fe_{ox} and Mn_{ox} = Amorphouseinorgainc form of Iron (Fe) and Manganese (Mn), Fe_p and Mn_p = Amorphouseorgainc form of Iron (Fe) and Manganese (Mn), and Fe_t= Total Iron.

Table 4. Correlation coefficient matrix showing the relationship between some soil physical and chemical properties and Forms of Iron and Manganese Oxides from Coconut Farm.

Parameters	Fe_d	Fe_{Ox}	Fe_P	Mn_d	Mn_{Ox}	Mn_P	Fe_t
pH	-0.566*	-0.566*	-0.565*	-0.564*	-0.573*	-0.565*	-0.626*
Sand	-0.526*	-0.526*	-0.525*	-0.526*	-0.533*	-0.533*	-0.529*
Silt	-0.820*	-0.820*	-0.820*	-0.821*	-0.824*	-0.824*	-0.752*
Clay	0.603*	0.603*	0.602*	0.603*	0.609*	0.609*	0.591*
EC	-0.969*	-0.969*	-0.969*	-0.968*	-0.964*	-0.963*	-0.832*
Ca	-0.901*	-0.901*	-0.902*	-0.900*	-0.892*	-0.893*	-0.713*
Mg	-0.896*	-0.896*	-0.897*	-0.895*	-0.886*	-0.887*	-0.704*
Na	-0.901*	-0.901*	-0.901*	-0.900*	-0.892*	-0.893*	-0.718*
K	-0.911*	-0.911*	-0.912*	-0.911*	-0.904*	-0.905*	-0.734*
T.N	-0.799*	-0.798*	-0.798*	-0.798*	-0.798*	-0.803*	-0.676*
AV.P	-0.686*	-0.685*	-0.684*	-0.689*	-0.699*	-0.708*	-0.667*
Org/Carbon	-0.972*	-0.972*	-0.972*	-0.971*	-0.969*	-0.971*	-0.823*

**Significantly correlated at 5% level of probability.*

Fe_d and Mn_d = Total free form of Iron (Fe) and Manganese (Mn), Fe_{ox} and Mn_{ox} = Amorphouseinorgainc form of Iron (Fe) and Manganese (Mn), Fe_p and Mn_p = Amorphouseorgainc form of Iron (Fe) and Manganese (Mn), and Fe_t= Total Iron

Correlation coefficient matrix showing the dynamics of iron (Fe) and manganese (Mn) oxides and their impact on soil physical and chemical properties in coconut and teak plantations

The correlation coefficient matrix (Table 4 and 5) shows significant relationships between some soil physical and chemical properties and forms of iron and manganese oxides from the coconut farm. The results indicate that pH was negatively correlated with all forms of iron and manganese oxides, including Fed (r = -0.566*, $p < 0.05$), FeOx (r = -0.566*, $p < 0.05$), FeP (r = -0.565*, $p < 0.05$), Mnd (r = -0.564*, $p < 0.05$), MnOx (r = -0.573*, $p < 0.05$), and MnP (r = -0.565*, $p < 0.05$). This negative correlation between pH and forms of iron and manganese oxides is consistent with the findings of Hartemink (2016), who reported that pH can affect the availability and speciation of iron and manganese in soils. The results also show that sand content was negatively correlated with all forms of iron and manganese oxides, including Fed (r = -0.526*, $p < 0.05$), FeOx (r = -0.526*, $p < 0.05$), FeP (r = -0.525*, $p < 0.05$), Mnd (r = -0.526*, $p < 0.05$), MnOx (r = -0.533*, $p < 0.05$), and MnP (r = -0.533*, $p < 0.05$).

This negative correlation between sand content and forms of iron and manganese oxides is consistent with the findings of Kumar et al. (2018), who reported that sand content can affect the availability and speciation of iron and manganese in soils. In contrast, clay content was positively correlated with all forms of iron and manganese oxides, including Fed (r = 0.603*, $p < 0.05$), FeOx (r = 0.603*, $p < 0.05$), FeP (r = 0.602*, $p < 0.05$), Mnd (r = 0.603*, $p < 0.05$), MnOx (r = 0.609*, $p < 0.05$), and MnP (r = 0.609*, $p < 0.05$). This positive correlation between clay content and forms of iron and manganese oxides is consistent with the findings of Lal (2015), who reported that clay content can affect the availability and speciation of iron and manganese in soils. The results also show that electrical conductivity (EC) was negatively correlated with all forms of iron and manganese oxides, including Fed (r = -0.969*, $p < 0.05$), FeOx (r = -0.969*, $p < 0.05$), FeP (r = -0.969*, $p < 0.05$), Mnd (r = -0.968*, $p < 0.05$), MnOx (r = -0.964*, $p < 0.05$), and MnP (r = -0.963*, $p < 0.05$). This negative correlation between EC and forms of iron and manganese oxides is consistent with the findings of Singh *et al.* (2017), who reported that EC can affect the availability and speciation of iron and manganese in soils.

The results also show that calcium (Ca) was negatively correlated with all forms of iron and manganese oxides, including Fed (r = -0.901*, $p < 0.05$), FeOx (r = -0.901*, $p < 0.05$), FeP (r = -0.902*, $p < 0.05$), Mnd (r = -0.900*, $p < 0.05$), MnOx (r = -0.892*, $p < 0.05$), and MnP (r = -0.893*, $p < 0.05$).

This negative correlation between Ca and forms of iron and manganese oxides is consistent with the findings of Kumar et al. (2018), who reported that Ca can affect the availability and speciation of iron and manganese in soils. Magnesium (Mg) was also negatively correlated with all forms of iron and manganese oxides, including Fed (r = -0.896*, $p < 0.05$), FeOx (r = -0.896*, $p < 0.05$), FeP (r = -0.897*, $p < 0.05$), Mnd (r = -0.895*, $p < 0.05$), MnOx (r = -0.886*, $p < 0.05$), and MnP (r = -0.887*, $p < 0.05$).

This negative correlation between Mg and forms of iron and manganese oxides is consistent with the findings of Lal (2015), who reported that Mg can affect the availability and speciation of iron and manganese in soils. The results also show that sodium (Na) was negatively correlated with all forms of iron and manganese oxides, including Fed (r = -0.901*, p < 0.05), FeOx (r = -0.901*, p < 0.05), FeP (r = -0.901*, p < 0.05), Mnd (r = -0.900*, p < 0.05), MnOx (r = -0.892*, p < 0.05), and MnP (r = -0.893*, p < 0.05).

This negative correlation between Na and forms of iron and manganese oxides is consistent with the findings of Singh *et al.* (2017), who reported that Na can affect the availability and speciation of iron and manganese in soils. Potassium (K) was also negatively correlated with all forms of iron and manganese oxides, including Fed (r = -0.911*, p < 0.05), FeOx (r = -0.911*, p < 0.05), FeP (r = -0.912*, p < 0.05), Mnd (r = -0.911*, p < 0.05), MnOx (r = -0.904*, p < 0.05), and MnP (r = -0.905*, p < 0.05). This negative correlation between K and forms of iron and manganese oxides is consistent with the findings of Kumar *et al.* (2018), who reported that K can affect the availability and speciation of iron and manganese in soils. The results also show that total nitrogen (T.N) was negatively correlated with all forms of iron and manganese oxides, including Fed (r = -0.799*, p < 0.05), FeOx (r = -0.798*, p < 0.05), FeP (r = -0.798*, p < 0.05), Mnd (r = -0.798*, p < 0.05), MnOx (r = -0.798*, p < 0.05), and MnP (r = -0.803*, p < 0.05). This negative correlation between T.N and forms of iron and manganese oxides is consistent with the findings of Lal (2015), who reported that T.N can affect the availability and speciation of iron and manganese in soils. Available phosphorus (AV.P) was also negatively correlated with all forms of iron and manganese oxides, including Fed (r = -0.686*, p < 0.05), FeOx (r = -0.685*, p < 0.05), FeP (r = -0.684*, p < 0.05), Mnd (r = -0.689*, p < 0.05), MnOx (r = -0.699*, p < 0.05), and MnP (r = -0.708*, p < 0.05). This negative correlation between AV.P and forms of iron and manganese oxides is consistent with the findings of Singh *et al.* (2017), who reported that AV.P can affect the availability. Organic carbon (Org/Carbon) was negatively correlated with all forms of iron and manganese oxides, including Fed (r = -0.972*, p < 0.05), FeOx (r = -0.972*, p < 0.05), FeP (r = -0.972*, p < 0.05), Mnd (r = -0.971*, p < 0.05), MnOx (r = -0.969*, p < 0.05), and MnP (r = -0.971*, p < 0.05).

This negative correlation between Org/Carbon and forms of iron and manganese oxides is consistent with the findings of Kumar *et al.* (2018), who reported that Org/Carbon can affect the availability and speciation of iron and manganese in soils. The negative correlations between the various soil properties and forms of iron and manganese oxides suggest that these properties can affect the availability and speciation of iron and manganese in soils. The results of this study are consistent with those of previous studies, which have reported that soil properties such as pH, EC, Ca, Mg, Na, K, T.N, Av. P, and Org/Carbon can affect the availability and speciation of iron and manganese in soils (Hartemink, 2016; Kumar *et al.*, 2018; Lal, 2015; Singh *et al.*, 2017). The results of this study show significant correlations between various soil properties and forms of iron and manganese oxides in soils from the coconut farm. The findings of this study are consistent with those of previous studies, which have reported that soil properties can affect the availability and speciation of iron and manganese in soils.

CONCLUSION

The results of this study demonstrate the critical role of iron (Fe) and manganese (Mn) oxides in shaping soil physical and chemical properties in coconut and teak plantations. The significant correlations between various soil properties (pH, EC, Ca, Mg, Na, K, T.N, AV.P, and Org/Carbon) and forms of Fe and Mn oxides highlight the complex interactions between these elements and soil fertility.

These findings have important implications for soil fertility management, crop production, and environmental sustainability in tropical ecosystems. The study's results suggest that managing Fe and Mn oxides could be a key strategy for improving soil health, reducing nutrient deficiencies, and promoting sustainable agriculture in coconut and teak plantations. Furthermore, the study's findings contribute to our understanding of the biogeochemical cycles of Fe and Mn in tropical soils and have implications for soil conservation, ecosystem services, and climate change mitigation. Overall, this study underscores the need for integrated soil management approaches that consider the complex interactions between soil properties, Fe and Mn oxides, and ecosystem processes.

RECOMMENDATION

To enhance soil fertility and sustainability, farmers and researchers should adopt a holistic approach that encompasses managing iron and manganese oxides, monitoring soil properties, implementing integrated soil management strategies, promoting sustainable agricultural practices, and conducting ongoing research for optimal ecosystem health and resilience**.**

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