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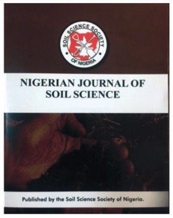

# Influence of forms of iron and manganese oxides on the physical and chemical properties of soils formed over mica-schist in a Northern Guinea Savanna, Nigeria

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## ABSTRACT

Three forms of oxides of iron and manganese were evaluated on soils developed in mica-schist lithology within the basement complex formation of Taraba State, North-eastern Nigeria. The results from the three oxide forms namely; pyrophosphate extractable ($Mn_p/Fe_p$), oxalate extractable ($Mn_{ox}/Fe_{ox}$) and citrate-bicarbonate-dithionite extractable ($Mn_d/Fe_d$) examined were subjected to both descriptive and inferential statistics to analyse their trend and distribution in order to understand their influence on pedogenesis. Content of the three forms of manganese oxides were lower than those of the respective iron oxides ($Mn_p$: mean – 100.44 $mgkg^{-1}$, $Mn_{ox}$: mean – 128.72 $mgkg^{-1}$, $Mn_d$: mean – 144.96 $mgkg^{-1}$ and $Fe_p$: mean – 1212.30 $mgkg^{-1}$, $Fe_{ox}$: mean – 1305.20 $mgkg^{-1}$, $Fe_d$: mean – 2518.00 $mgkg^{-1}$) at their corresponding horizons; and was attributed to the mineralogical constitution of geology of the study area. Content of organic matter (mean, 0.632 %) and organic carbon (mean, 0.366 %) were low (but highly significant - F = 2502, p = 216*** ) and was attributed to high mineralization rate caused by climate of study area (northern guinea savanna); thus, had proportional effect on the oxalate extractable Fe and Mn as they are organic bound. Also, a strong significant difference (F = 187.6, p = 7.777***) between means of $Mn_{ox}$ and $Mn_p$ emphasized reciprocity in their pedogenic interaction. High content of Fe across the three oxide forms examined presupposes high plinthization on soils of the mica-schist.

## 1.0 Introduction

The northern guinea savanna is one of the most intensively farmed areas in Nigeria. Nearly 80 % of West African land surface is covered by savanna vegetation (Sanford *et al*., 1980). According to Jagtap (1995), FAO (1978) and Kassam *et al*. (1975), farmers' choice of the area may have been as a result of the favourable solar radiation during growing season, reliable and well distributed rainfall, and lower night temperatures that promote litter accumulation.

Lithology has major influences on the properties of overlying soils and provides a starting material upon which other soil forming factors act to give rise to soil. It also influences the nature and properties of soil (Esu, 2010, Ibanga, 2006). Consequently, soils formed over a lithology have specific properties, support specific crops and result in a lithosequence of soils (Usul and Dengiz, 2010; Maniyunda, 2012). It is a major determinant of soils response to management (Olaniyan *et al*., 2011). Soils in the northern guinea savanna are mainly developed on the Basement Complex. The complex is made up of migmatite gneiss, schist, older granite and under formed acid dykes (Obaje, 2009) and mainly constitutes igneous and metamorphic rocks, and occupy 50 % of the Nigerian surface area (Ogezi, 1977).

Soils in the Nigerian guinea savanna are generally slightly acid, less leached, coarse textured and consist of sandy loam or loam over gravelly clay loam (Esu and Ojanuga, 1985) with lower clay content in the surface soil (Lawal *et al*. 2013) and are predominantly derived from crystalline Precambrian Basement Complex rocks. Soils of the savanna region are fragile (Salako, 2003) with large proportion of sand and low organic matter content (Adewale and Odoh, 2017) and are gravelly and shallow (Adeoye and Mohammed-Saleem, 1990., Salako *et al*., 2002) in some parts with low nitrogen content (Salako *et al*., 2002). Esu (2010) attributed the low organic matter in the surface soils of the Nigerian Savanna to the rapid rate of mineralization of organic matter and the high degree of sheet erosion as well as the use of grasses in the region for roofing and grazing. Maniyunda *et al.* (2013) attributed the moderate and high variability in soil properties in a lithosequence in the area to land use, management and cultural practices.

Luvisols have been identified as the most common soils in Northern Guinea Savanna of Nigeria (Salako, 2003), while Ogungbile *et al*. (1999) classified similar soils as lithisols. However, Salami *et al.* (2011) described them as potentially fertile, while available P, organic matter, acidity and sand-silt components varied widely within the area. Similarly, textural and fertility variation were reported for the area by Okogun *et al*. (2004). Consequently, soil fertility decline among many factors was identified as the most remarkable for low yield among many factors (Salami *et al*., 2011., Olaniyan, 2015). In a related study, Babalola *et al*. (2019) reported a significant difference in texture between parent materials, indicating the relevance of lithosequences and their influence on soil. Albeit, the fertility status of soils is bound to change when lithology changes and most likely to affect the type of crops supported by the soil.

The presence Fe-Mn concretions in the subsurface soils of the northern guinea savanna of Nigeria have been observed by Babalola *et al*. (2019). Oxides, hydroxides and oxy-hydroxides of Fe, Mn, Al and Ti are together referred to as sesquioxides (Maniyunda *et al*., 2015). They are commonly present as amorphous, crystalline and organic complexes. Pedogenesis as well as soil physical and chemical properties are influenced by the nature, amount and occurrence of these oxides in soils (Schertmann and Taylor, 1989., Jelic *et al*., 2011) and have been used to make predictions of the degree and stage of soil genesis (Durn *et al*., 2001; Igwe *et al*., 2001; Osodeke *et al*., 2005; Kefas *et al*., 2020). For instance, phosphorus is barely available in highly weathered tropical soils (Igwe, 2001) while high Ca availability may result in low solubility of manganese (Troeh and Thompson, 1993). The influence of the oxides and hydroxides of Fe-Mn on soil physical as well as chemical properties cannot be unattended in studies related to agricultural soils.

Agricultural production in the Nigerian northern guinea savanna is focused on crop and livestock production. Crop production in the area is dominated by cereals (millet, sorghum, maize and wheat) and legume (cowpea, groundnut and soybean) production (Ajeigbe *et al*., 2010; Foli, 2012). Though livestock is important in the farming system of the area (Smith *et al*., 1997), it is often integrated with crops (Foli, 2012) as both have reciprocal benefits. Importantly, farmers in the region combine organic and inorganic inputs as well as intercrop cereal-legume mixtures to consciously manage and improve soil fertility status (Harris, 1998., Hoffmann and Gerling, 2001). The need for a robust soil data base has necessitated the present study. Earlier, Raji *et al*. (2000), Igwe (2001), and Ibia (2002) emphasized the forms of oxides in northwest Nigeria, flood plains of Niger, and southeast Nigeria, respectively. The present study goes beyond pedogenesis to assessing the influence of the forms of Fe and Mn on soil physical and chemical properties in the northern guinea savanna of Nigeria.

## 2.0 Materials and methods

### *2.1 Location, geology and climate of the study area*

The study was conducted in Taraba State (6°30′ and 9°30′ N; 9°00′ and 12°00′ E), north eastern Nigeria. The State has a total land area of 60,291.8 km$^2$. Bauchi and Gombe states are located in the north, while Adamawa is in the east of Taraba state. To the south is the Republic of Cameroun, while Benue, Nasarawa and Plateau states are in the western axis. The geology of the study area is undifferentiated Basement Complex rocks with the occurrence of rocks identified as Precambrian granitic, migmatite gneisses and mica-schist with outcrops of the rocks occurring at intervals (Bawden, 1972).

The study area is characterized by tropical climate with distinct wet and dry seasons. The wet and dry seasons last for 5 and 7 months (Fig. 2), respectively with a mean annual rainfall which ranges from 800 mm in the northern part of the state to over 2000 mm in the southern part. Precipitation is lowest in January with an average of 0 mm, while in August, the most precipitation falls with an average of 217 mm. Mean annual temperature is 34 $^{o}$C and varies in mean monthly values between 28.4 $^{o}$C in the coolest month of December and 37 $^{o}$C in the hottest month of March (NIMET, 2009).

Taraba State is characterized by three dominant vegetational zones. The guinea savanna (study area) is found in the northern part of the State. Sub-sudan vegetation is characterized by short grasses with a few short trees. The Mambila plateau area is uniquely marked by a semi-temperate climate with luxuriant pasture and short trees.

### *2.2 Field and laboratory studies*

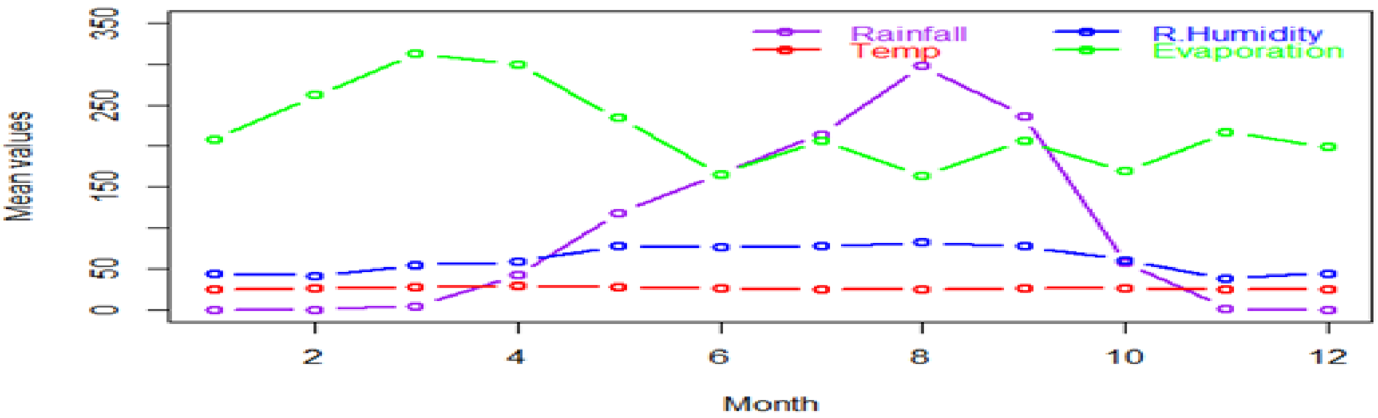

Fig. 1: Climatic data of the study area (1998-2017)
Source: Taraba State Water Board

The sites for the study were identified through reconnaissance visits using the geological map of Taraba State obtained from the Nigerian Geological Survey Agency. Soils on mica-schist were identified and selected because of their vastness and agricultural value. The contour map of the selected areas was produced to aid slope classification. Three soil profile pits were sited at crestal position of the lithology in order to obtain a true to type soil representative. It was dug, described and sampled for laboratory studies.

Particle size distribution was determined by the Bouyoucos hydrometer method with sodium hexametaphosphate acting as dispersing agent (Soil Survey Staff, 2014). Soil pH was determined using a ratio of 1:2.5 soil: liquid in 0.1 *N* $KCl_2$ solution with the aid of glass electrode pH meter(Udo *et al.*, 2009). Organic carbon was determined by the Walkley and Black wet oxidation method and total N by macro Kjeldahl digestion method as modified by Udo *et al.* (2009). Bray 1 method was used to determine available phosphorus while exchangeable bases (Ca, Mg, K, and Na) were determined by neutral $NH_4OAc$ displacement method and read through by atomic absorption spectrophotometer as described by Udo *et al.* (2009). Cation exchange capacity was determined by 1 *N* $NH_4OAc$ at pH 7 while base saturation was calculated by expressing the sum of exchangeable bases as a percentage of the CEC at pH 7. Dithionite and oxalate forms of iron and manganese were determined by the method of Mehra and Jackson (1960) as modified by Udo *et al.* (2009). Saturated hydraulic conductivity (Ksat) was determined by the constant head method using Eijkelkamp laboratory permeameteras described by Youngs (2001). Bulk density was determined by core method as described by Blake and Hartge, (1986) while total porosity (TP) was computed from bulk density (Bd) using the equation below (assumed particle density $p_s$ = 2.65 kg/m$^3$):

$$TP = \left(1 - \frac{Bd}{Ps}\right) x\ 100$$

Where TP = total porosity, Bd = bulk density, Ps = particle density.

*2.3 Data analysis*

Data generated from the laboratory analyses were subjected to statistical analysis using R statistical package.

## 3.0 Results and Discusion

The physical and chemical properties of the soils are presented in Tables 1-3.

The study area was characterized by deep (>100 cm) to very deep (>150 cm) soils (Table 1) indicating a soil of high volume that may provide ample root zone and support greater capacities to store plant nutrients and water. The low content of clay (Table 1) and OM (Table 3) however, will not facilitate the depth advantage for optimum agricultural use. The depth property also indicates a soil that had strong profile development and highly weathered as buttressed by the high content of free Fe - 2518 mgkg$^{-1}$ and free Mn - 144.96 mgkg$^{-1}$ (Table 6). The soil distribution cuts across crestal to lower slope positions. The soils had loamy sand surface soils underlain by sandy loam and loamy sand implying a light textured soil. The light-textured soil was associated to the granitic origin of the lithology. The dominance of sand fraction in a basement complex soils have been reported by other researchers; Ande, 2010; Maniyunda *et al.*, 2014; Olatunji *et al.*, 2015; Shobayo *et al.* 2019.

The pyrophosphate extractable iron ($Fe_p$) and manganese ($Mn_p$) was the lowest fraction of the forms of iron ($Fe_p$: mean – 1191.90 mgkg$^{-1}$, $Fe_{ox}$: mean – 1267.30 mgkg$^{-1}$, $Fe_d$: mean – 2459.00 mgkg$^{-1}$) and manganese ($Mn_p$: mean – 56.17 mgkg$^{-1}$, $Mn_{ox}$: mean – 94.87 mgkg$^{-1}$, $Mn_d$: mean – 150.30 mgkg$^{-1}$) oxides examined (Table 7) in the surface soil on soils on mica-schist. Similarly, subsurface soils mean values of pyrophosphate extractable iron ($Fe_p$) ($Fe_p$: mean – 1221.10 mgkg$^{-1}$, $Fe_{ox}$: mean – 1321.50 mgkg$^{-1}$, $Fe_d$: mean – 2543.00 mgkg$^{-1}$) and pyrophosphate extractable manganese ($Mn_p$) ($Mn_p$: mean – 119.40 mgkg$^{-1}$, $Mn_{ox}$: mean – 143.23 mgkg$^{-1}$, $Mn_d$: mean – 142.67 mgkg$^{-1}$) obtained were lowest. Lowest nevertheless, they contributed more to the CEC of the soils as against the amorphous and free oxide forms.

The three forms of iron and manganese oxides contributed positively (though not statistically significant) to the improvement of the soils' bulk density (BD) which was rated moderate except for the $Fe_p$ that recorded a negative correlation (r = -0.3346, $P< 0.5$) with BD implying that the organic bound iron oxide was so negligible and did not constitute a binding agent. This was further buttressed by its negative correlation (r = -0.0620$^{ns}$, $P< 0.5$) with OM. Contrarily, $Mn_p$, $Mn_{ox}$, $Mn_d$, $Fe_{ox}$ and $Fe_d$ did not contribute to the soil's total porosity (TP) except $Fe_p$. Total porosity of the soil was rated low and was attributed to the high level of free oxides in the soils which had crystallized. Generally, similar observation was noted for the soils' hydraulic conductivity (HC) and water holding capacity (WHC) (rated low). These observations were credited to the granitic origin of the lithology of the study area. Dominance of sand fraction (> 70 gkg$^{-1}$) in fine earth fraction which was associated to the basement complex coupled with the very high free oxides may render the soils agriculturally unproductive except proper soil management which include improving the physical conditions of the soils, addition of organic manure and incorporation of crop residues as well as serve as a source of N and K, which will raise the fertility of the soils. Soil and water conservation measures must be put in place such as to conserve water on the sandy soils along with other farm management practices that improves soil-water conservation.

The $Fe_p$ and $Mn_p$ distributed irregularly with pedal depth (Table 4) in the three profile pits sited on soils on mica-schist. Mean values of surface soils (1191.9 mgkg$^{-1}$ and 56.17 mgkg$^{-1}$ – Table 7) were higher than the mean values observed for subsurface soils (1221.1 mgkg$^{-1}$ and 119.4 mgkg$^{-1}$ respectively for $Fe_p$ and $Mn_p$) (Table 8);a trend that was similar to the mean distribution of organic carbon (OC) and organic matter (OM) which contents were higher in the surface soils (Table 7). Similarly, $Fe_p$ and $Mn_p$ were positively correlated (r = 0.031 – Table 5) implying that they were mutually translocated with depth. This observation buttresses the assertion that they are organic bound. However, means (Table 6) of OM, $Mn_p$ (F = 0.088, p = 0.865) and $Fe_p$ (F = 0.031, p = 0.774) did not vary statistically when compared.

Furthermore, a non-coherence pattern was observed between the $Fe_p$ and OM/OC and $Mn_p$ and OM/OC as they were negatively correlated (r = - 0.062, r = -0.065 and r = - 0.104, r = -0.103 respectively) implying a reduced pedogenic internal transformational process within the surface horizons. Since the content of OM was low due to sparse

Table 1: Soil physical properties of the study area

| Geology | Profile name | Horizon | Depth | Clay | Silt | Fine sand | Coarse sand | Textural class | Bulk density | Total porosity | Hydraulic C | WHC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soils on Mica-Schist | Profile pit 1 | | | | | | Lat. $08^{0}46'41.2''$N Long. $011^{0}$ $16'$ $0.9'$ S | | | | | |
| | BDCP1 | Ap | 0 – 20 | 10 | 9 | 39 | 42 | Loamy sand | 1.82 | 31.32 | 6.83 | 23.1 |
| | BDCP1 | Btv | 20 – 81 | 18 | 7 | 37 | 38 | Sandy loam | 1.53 | 42.26 | 8.08 | 30.57 |
| | BDCP1 | Bt | 81 – 128 | 14 | 7 | 37 | 42 | Sandy loam | 1.85 | 29.81 | 5.05 | 23.5 |
| | BDCP1 | CCv | 128 – 175 | 12 | 7 | 30 | 51 | Sandy loam | 1.74 | 34.34 | 10.1 | 22.21 |
| | Profile pit 2 | | | | | | Lat. $08^{0}46'$ $14.2''$NLong. $011^{0}$ $16'$ $0.9'$ S | | | | | |
| | BDCP2 | Ap | 0 – 35 | 8 | 13 | 41 | 38 | | 1.54 | 41.13 | 10.61 | 26.14 |
| | BDCP2 | Btv | 35 – 106 | 8 | 5 | 40 | 47 | | 1.85 | 30.19 | 14.14 | 19.93 |
| | BDCP2 | CBtv | 106 – 173 | 8 | 19 | 44 | 29 | | 1.84 | 30.57 | 8.92 | 15.1 |
| | Profile pit 3 | | | | | | Lat. $08^{0}46'$ $42.1''$NLong. $011^{0}$ $16'$ $02.5''$S | | | | | |
| | BDUSP1 | Ap | 0 – 12 | 12 | 7 | 37 | 44 | | 1.47 | 44.53 | 3.54 | 24.43 |
| | BDUSP1 | CB | 12 – 62 | 8 | 7 | 30 | 55 | | 1.59 | 40 | 5.05 | 23.47 |
| | BDUSP1 | C | 62 – 126 | 8 | 5 | 35 | 52 | | 1.79 | 32.45 | 4.20 | 19.42 |

Table 2: Soil chemical properties of the study area

| Geology | Profile name | Horizon | Depth | pH_H2O | pH_KCl | EA | $Na^+$ | $K^+$ | $Ca^{2+}$ | $Mg^{2+}$ | TEB |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Soils on Mica-Schist | Profile pit 1 | | | | | Lat. $08^{0}46'$ $41.2''$NLong. $011^{0}$ $16'$ $0.9'$ S | | | | | |
| | BDCP1 | Ap | 0 – 20 | 6.2 | 5.6 | 1.4 | 0.02 | 0.05 | 1.8 | 0.6 | 2.47 |
| | BDCP1 | Btv | 20 – 81 | 5.8 | 4.7 | 2 | 0.02 | 0.05 | 2.2 | 1.0 | 3.27 |
| | BDCP1 | Bt | 81 – 128 | 6.6 | 5.3 | 1.4 | 0.02 | 0.05 | 2 | 0.8 | 2.87 |
| | BDCP1 | CCv | 128 – 175 | 6.7 | 5.4 | 1.2 | 0.01 | 0.005 | 1.8 | 0.8 | 2.615 |
| | Profile pit 2 | | | | | Lat. $08^{0}46'$ $14.2''$NLong. $011^{0}$ $16'$ $0.9'$ S | | | | | |
| | BDCP2 | Ap | 0 – 35 | 6.1 | 5.1 | 2.2 | 0.04 | 0.09 | 1.6 | 1.2 | 2.93 |
| | BDCP2 | Btv | 35 – 106 | 6.9 | 5.7 | 1.2 | 0.006 | 0.01 | 1.6 | 1.8 | 3.416 |
| | BDCP2 | CBtv | 106 – 173 | 7.1 | 6.1 | 1.2 | 0.006 | 0.01 | 0.8 | 1.8 | 2.616 |
| | Profile pit 3 | | | | | Lat. $08^{0}46'$ $42.1''$NLong. $011^{0}$ $16'$ $02.5''$S | | | | | |
| | BDUSP1 | Ap | 0 – 12 | 6.9 | 6.2 | 1 | 0.05 | 0.09 | 4.6 | 0.8 | 5.54 |
| | BDUSP1 | CB | 12 – 62 | 6.5 | 5.3 | 1.4 | 0.008 | 0.01 | 2 | 1.4 | 3.418 |
| | BDUSP1 | C | 62 – 126 | 6.9 | 6.2 | 1.2 | 0.001 | 0.005 | 1.2 | 1.2 | 2.406 |

vegetation that characterized the study area (guinea savanna), it can be surmised that pH (Table 2) cast an immobilization effect on $Mn_p$ co-translocation with OM/OC as the organic bound sesquioxides were positively correlated with pH in water ($r = 0.130$, $p = 0.717$) and KCl ($r = 0.031$, $p = 0.931$) and also contributed to the soil's acidity. The soils varied in their chemical reaction from moderately acidic (5.8) to neutral (7.1) whichpossibly could account for the high content of Mg is the soils. Organic bound manganese ($Mn_p$) correlated positively (Table 5) with the amorphous ($Mn_{ox}$) and free ($Mn_d$) manganese oxides forms indicating an increase in any form will have a concomitant pedogenic effect on the other.

Mean values of $Mn_{ox}$ (94.87 $mgkg^{-1}$) and $Fe_{ox}$ (1267.30 $mgkg^{-1}$) at the surface soils shows that the sequence of their distribution is greater than $Mn_p$ and $Fe_p$ respectively (i.e., $Mn_p < Mn_{ox}$ and $Fe_p < Fe_{ox}$). Generally, the contents of Fe were greater than those of Mn (Table 4) and was attributed to the parent material mineralogical composition which is richer in Fe; especially those contributed by mica. Therefore, it can be opined that Fe is the major contributor of the amorphous form. The $Fe_{ox}$ correlated negatively ($r = -0.444$, $P < 0.5$) with $Fe_p$ implying that there was a shift towards inorganic pedogenic phase, however, a positive correlation obtained between $Mn_{ox}$ and $Mn_p$ is an indication of reciprocal transformational process between the oxide forms at the surface horizons. Also, a strong significant difference ($F = 187.6$, $p = 7.777$***) between their means (Table 6) (i.e., $Mn_{ox}$ and $Mn_p$) buttressed their reciprocal interaction. The high content of Fe in the amorphous form might not have translated to any beneficial pedogenic effect on cation exchange capacity and water holding capacity of the soils as it could not be unconnected to its inverse correlation with clay, water holding capacity and CEC (Table 5). But it perhaps had facilitated the adsorption/retention of N and P.

Contents of $Mn_d$ and $Fe_d$ were higher than those of $Mn_{ox}$ and $Fe_{ox}$ respectively in their corresponding horizons. Mean surface soil content of $Fe_d$ (2459.00 $mgkg^{-1}$) was lower than the computed mean for $Fe_d$ (2543.00 $mgkg^{-1}$) at the subsurface soils. The differential may be attributed to tillage that continually disturb the surface soils and subsequently retard the build up at the surface. This form of Fe is surmised not to be part of the silicate structure but present in soils as discrete bodies. Its distribution pattern shows increase with pedal depth suggesting an illuvial accumulation and at the subsoils, crystallinity might be improved. This phenomenon may not be best for agricultural land-use, because plinthization may be initiated. Again, the high value recorded may account for the soils being highly developed and approaching senility. High iron oxide values may indicate the presence of iron oxide either crystalline such as hematite or amorphous in an appreciable percentage (Sombroek and Zonneveld, 1971).

Thomas *et al*. (2019) submitted that free oxides in soils usually have distinct electrochemical properties that generate CEC as a consequence of the adsorption of proton and hydroxyl ions providing structural cementation in the soil. Only the free iron oxide was observed to contribute to the soils' CEC ($r = 0.1537$, $P < 0.5$) and was not significant ($F = 0.194$, $p = 0.672$); however, this study shows that the free manga-

Table 3 cont.: Soil chemical properties of the study area

| Geology | Profile name | Horizon | Depth | CEC | ECEC | BS | OC | OM | N | P |
|---|---|---|---|---|---|---|---|---|---|---|
| Soils on Mica-Schist | Profile pit 1 | | | | Lat. $08^0$46' 41.2"N | | | Long. $011^0$ 16' 0.9' S | | |
| | BDCP1 | Ap | 0 – 20 | 10 | 3.87 | 24.7 | 0.375 | 0.647 | 0.098 | 0.93 |
| | BDCP1 | Btv | 20 – 81 | 16.8 | 5.27 | 19.46 | 0.375 | 0.647 | 0.056 | 0.92 |
| | BDCP1 | Bt | 81 – 128 | 14 | 4.27 | 18.28 | 0.375 | 0.647 | 0.028 | 0.93 |
| | BDCP1 | CCv | 128 – 175 | 15.2 | 3.815 | 17.14 | 0.075 | 0.129 | 0.056 | 0.98 |
| | Profile pit 2 | | | | Lat. $08^0$46' 14.2"N | | | Long. $011^0$ 16' 0.9' S | | |
| | BDCP2 | Ap | 0 – 35 | 9.2 | 5.13 | 31.85 | 0.781 | 1.346 | 0.308 | 6.53 |
| | BDCP2 | Btv | 35 – 106 | 10 | 4.616 | 34.16 | 0.164 | 0.283 | 0.14 | 1.87 |
| | BDCP2 | CBtv | 106 – 173 | 7.2 | 3.816 | 36.33 | 0.164 | 0.283 | 0.224 | 1.87 |
| | Profile pit 3 | | | | Lat. $08^0$46' 42.1"N | | | Long. $011^0$ 16' 02.5' S | | |
| | BDUSP1 | Ap | 0 – 12 | 16.4 | 6.54 | 33.78 | 1.013 | 1.746 | 0.084 | 0.93 |
| | BDUSP1 | CB | 12 – 62 | 19.6 | 4.818 | 17.44 | 0.263 | 0.463 | 0.084 | 0.94 |
| | BDUSP1 | C | 62 – 126 | 9.6 | 3.606 | 25.06 | 0.075 | 0.129 | 0.07 | 0.93 |

Table 4: Sesquioxide properties of the study area

| Geology | Profile name | Horizon | Depth | Mn_d | Fe_d | Mn_ox | Fe_ox | Mn_p | Fe_p | $Mn_o$/ $Mn_d$ | $Fe_o/Fe_d$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Soils on Mica-Schist | Profile pit 1 | | | | | Lat. $08^0$46' 41.2"N | | | Long. $011^0$ 16' 0.9' S | | |
| | BDCP1 | Ap | 0 – 20 | 237.1 | 2063.55 | 131.1 | 773.6 | 106 | 1290 | 0.55 | 0.37 |
| | BDCP1 | Btv | 20 – 81 | 110.6 | 2793.65 | 66 | 1206.2 | 44.6 | 1587.5 | 0.6 | 0.43 |
| | BDCP1 | Bt | 81 – 128 | 95.15 | 2666.25 | 515 | 1384.7 | 419.8 | 1281.6 | 5.4 | 0.52 |
| | BDCP1 | CCv | 128 – 175 | 131.4 | 3047.7 | 70 | 1543.2 | 61.4 | 1504.5 | 0.53 | 0.51 |
| | Profile pit 2 | | | | | Lat. $08^0$46' 14.2"N | | | Long. $011^0$ 16' 0.9' S | | |
| | BDCP2 | Ap | 0 – 35 | 82.4 | 2266.45 | 83.5 | 1485.2 | 1.1 | 781.3 | 1.01 | 0.66 |
| | BDCP2 | Btv | 35 – 106 | 131.1 | 3089.05 | 62.7 | 2312.7 | 68.4 | 776.4 | 0.48 | 0.75 |
| | BDCP2 | CBtv | 106 – 173 | 52.05 | 2977.2 | 29 | 1981.4 | 23.1 | 995.8 | 0.56 | 0.67 |
| | Profile pit 3 | | | | | Lat. $08^0$46' 42.1"N | | | Long. $011^0$ 16' 02.5' S | | |
| | BDUSP1 | Ap | 0 – 12 | 151.65 | 2473.05 | 76 | 1201 | 75.7 | 1272.1 | 0.5 | 0.49 |
| | BDUSP1 | CB | 12 – 62 | 56.1 | 2377.1 | 22.1 | 683.2 | 34 | 1693.9 | 0.39 | 0.29 |
| | BDUSP1 | C | 62 – 126 | 402.05 | 1421.55 | 231.8 | 481.3 | 170.3 | 940.3 | 0.58 | 0.34 |

nese oxide ($Mn_d$) did not contribute to the soils' CEC as increase in the $Mn_d$ led to decreased CEC (r = -0.2844, p = 0.4258) but CEC was partly contributed by clay (r = 0.5197, $P < 0.5$) and OM (r = 0.1863, $P < 0.5$). The free oxides i.e. $Mn_d$ and $Fe_d$ also did not improve the soils' water holding capacity implying that they were not clay-sized except $Fe_d$ that was somewhat clay-sized. It can also be surmised that the high content of the free oxides was crystallized and therefore inactive.

Contrastively, mean surface soil contents (150.30 $mgkg^{-1}$) of $Mn_d$ was lower than the subsurface soils' average (142.67 $mgkg^{-1}$). This is an indication that Mn-oxide forms minimal fraction of the free forms in the soils formed on the mica-schist therefore, poses less crystallization threat that lowers pedogenesis. The correlation studies show that the fine earth fractions (clay, silt and fine sand) did not influence the formation and distribution of $Mn_d$. Even at lower presence, the $Mn_d$ had resultant inhibitory effect on exchangeable bases i.e. Ca, Mg, K, Na and other macronutrients such as N and P (Table 5). It can be surmised that the content of $Mn_d$ had contributed to the acidity (Table 2) of the soil which could temporarily heighten immobilization at the period field study was carried out (Figure 2).Ratios of oxalate extractable and dithionite extractable were measured to further determine the pedogenic development i.e. recrystallization in soils of the study area. The distribution with depth was irregular for both $Mn_o/Mn_d$ and $Fe_o/Fe_d$ (Table 4). The surface soils recorded mean ratios of 0.70 and 0.51 respectively for $Mn_o/Mn_d$ and $Fe_o/Fe_d$ (Table 7) and the corresponding subsurface mean ratios were 1.22 and 0.50 (Table 8). Increased mean ratio of $Mn_o/Mn_d$ observed in the subsurface soils is suggestive of preponderant recrystallization at the surface soils. However, the similar $Fe_o/Fe_d$ mean ratios observed for both surface and subsurface soils imply similarity in recrystallization process taken place. Maniyunda *et al*. (2014) submitted that values ranging between 0.1 and 0.5 are of moderate pedogenetic development. The mean ratios observed were between 0.5 and 1.06, therefore the soils have weathered appreciably. Sombroek and Zonneveld (1971) associated sesquioxides ratios to possible clay-sized minerals present in soils. They submitted that ratios between 2.0 and 3.0 suggest the presence of both montmorillonite/illite and kaolinite; 1.6 - 2.0 suggest the predominance of kaolinite. Values below 1.6 indicate the presence of considerable percentages of gibbsite or aluminium oxides. However, their analysis was subjected to the clay fraction solely.

## 4.0 Conclusion

It was concluded from the study that free iron oxide was the dominant form of oxide. The forms of oxide increased in the order $Mn_p > Mn_{ox} > Mn_d > Fe_p > Fe_{ox} > Fe_d$ with percentage distribution of 1.86, 2.38, 2.68, 22.41, 24.13 and 46.56 respectively. Generally, the three forms of iron and manganese oxides did not significantly influence the soils' physical and chemical properties as the results revealed non statistically significant interactions between the oxide forms and other soil parameters. The dominant oxide forms (i.e free form) were relatively inactive therefore, did not influence total porosity, hydraulic conductivity and water holding capacity except bulk density. Organic form influenced more to the cation exchange capacity more than the active form (amorphous form). Ratios of oxalate extractable and dithionite extractable indicated that the soils are highly weathered. Because they are highly weathered, the soils might lose much of its nutrients due to excessive leaching (low HD and WHC). Thus, corroborating the soils' general low (exchangeable bases, OC, OM, N and P) fertility status as presented in the study analytical data.

Table 5:Correlation results

| | Clay | Silt | Fine sand | Coarse sand | Bulk density | Total porosity | Hydraulic C | WHC | pH_H2O | pH_KCl | OC | OM | TN | Na | K | Ca | Mg | CEC | TEB | ECEC | BS | EA | AvP | Mn_p | Mn_ox | Mn_d | Fe_p | Fe_ox | Fe_d | Mn-o_Mn-d |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Silt | -0.285 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fine sand | -0.175 | 0.636 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Coarse sand | -0.179 | -0.791 | -0.847 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Bulk density | -0.294 | 0.076 | 0.219 | -0.039 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total porosity | 0.300 | -0.089 | -0.234 | 0.052 | -0.999 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Hydraulic C | -0.191 | 0.194 | 0.344 | -0.221 | 0.247 | -0.256 | | | | | | | | | | | | | | | | | | | | | | | | |
| WHC | 0.685 | -0.368 | -0.254 | 0.050 | -0.705 | 0.697 | -0.123 | | | | | | | | | | | | | | | | | | | | | | | |
| pH_H2O | -0.500 | 0.091 | 0.059 | 0.134 | 0.447 | -0.434 | -0.053 | -0.856 | | | | | | | | | | | | | | | | | | | | | | |
| pH_KCl | -0.533 | 0.116 | 0.204 | 0.052 | 0.314 | -0.299 | -0.268 | -0.760 | 0.854 | | | | | | | | | | | | | | | | | | | | | |
| OC | 0.168 | 0.090 | 0.242 | -0.262 | -0.711 | 0.696 | -0.265 | 0.500 | -0.251 | -0.027 | | | | | | | | | | | | | | | | | | | | |
| OM | 0.167 | 0.089 | 0.239 | -0.259 | -0.712 | 0.698 | -0.267 | 0.501 | -0.252 | -0.028 | | | | | | | | | | | | | | | | | | | | |
| TN | -0.561 | 0.733 | 0.654 | -0.534 | -0.107 | 0.083 | 0.495 | -0.208 | -0.019 | 0.039 | 0.269 | 0.268 | | | | | | | | | | | | | | | | | | |
| Na | 0.266 | 0.079 | 0.207 | -0.278 | -0.687 | 0.671 | -0.210 | 0.551 | -0.306 | -0.098 | 0.980 | 0.980 | 0.230 | | | | | | | | | | | | | | | | | |
| K | 0.306 | 0.105 | 0.326 | -0.378 | -0.611 | 0.590 | -0.202 | 0.610 | -0.452 | -0.205 | 0.946 | 0.946 | 0.263 | 0.962 | | | | | | | | | | | | | | | | |
| Ca | 0.394 | -0.361 | -0.211 | 0.148 | -0.648 | 0.657 | -0.439 | 0.465 | -0.024 | 0.106 | 0.758 | 0.759 | -0.325 | 0.752 | 0.619 | | | | | | | | | | | | | | | |
| Mg | -0.559 | 0.353 | 0.365 | -0.159 | 0.227 | -0.225 | 0.489 | -0.549 | 0.428 | 0.219 | -0.356 | -0.355 | 0.503 | -0.471 | -0.479 | -0.484 | | | | | | | | | | | | | | |
| CEC | 0.520 | -0.517 | -0.758 | 0.493 | -0.573 | 0.588 | -0.406 | 0.586 | -0.273 | -0.406 | 0.183 | 0.186 | -0.615 | 0.185 | 0.080 | 0.587 | -0.363 | | | | | | | | | | | | | |
| TEB | 0.194 | -0.231 | -0.049 | 0.071 | -0.646 | 0.657 | -0.271 | 0.294 | 0.148 | 0.209 | 0.726 | 0.727 | -0.114 | 0.668 | 0.517 | 0.919 | -0.100 | 0.488 | | | | | | | | | | | | |
| ECEC | 0.307 | -0.152 | 0.032 | -0.069 | -0.833 | 0.833 | -0.168 | 0.581 | -0.211 | -0.125 | 0.845 | 0.846 | 0.060 | 0.798 | 0.714 | 0.844 | -0.133 | 0.492 | 0.912 | | | | | | | | | | | |
| BS | -0.487 | 0.491 | 0.786 | -0.508 | 0.024 | -0.028 | 0.318 | -0.438 | 0.431 | 0.572 | 0.346 | 0.344 | 0.689 | 0.273 | 0.243 | 0.052 | 0.513 | -0.643 | 0.307 | 0.246 | | | | | | | | | | |
| EA | 0.263 | 0.195 | 0.195 | -0.334 | -0.425 | 0.398 | 0.252 | 0.673 | -0.856 | -0.798 | 0.260 | 0.261 | 0.418 | 0.289 | 0.450 | -0.204 | -0.074 | -0.006 | -0.238 | 0.181 | -0.154 | | | | | | | | | |
| AvP | -0.364 | 0.458 | 0.446 | -0.349 | -0.266 | 0.230 | 0.453 | 0.135 | -0.275 | -0.247 | 0.399 | 0.398 | 0.879 | 0.399 | 0.458 | -0.217 | 0.236 | -0.431 | -0.107 | 0.168 | 0.425 | 0.655 | | | | | | | | |
| Mn_p | 0.298 | -0.337 | -0.087 | 0.105 | 0.456 | -0.467 | -0.413 | -0.033 | 0.131 | 0.031 | -0.103 | -0.104 | -0.533 | -0.077 | 0.018 | 0.019 | -0.375 | 0.037 | -0.152 | -0.242 | -0.370 | -0.208 | -0.345 | | | | | | | |
| Mn_ox | 0.275 | -0.268 | -0.020 | 0.039 | 0.409 | -0.427 | -0.385 | 0.022 | 0.039 | -0.029 | -0.045 | -0.046 | -0.407 | -0.012 | 0.110 | -0.042 | -0.390 | -0.050 | -0.222 | -0.248 | -0.342 | -0.056 | -0.177 | 0.979 | | | | | | |
| Mn_d | -0.151 | -0.441 | -0.131 | 0.385 | 0.245 | -0.235 | -0.337 | -0.163 | 0.146 | 0.460 | -0.212 | -0.214 | -0.315 | -0.216 | -0.168 | -0.072 | -0.270 | -0.284 | -0.213 | -0.334 | -0.036 | -0.279 | -0.274 | 0.214 | 0.233 | | | | | |
| Fe_p | 0.570 | -0.285 | -0.701 | 0.310 | -0.335 | 0.355 | -0.434 | 0.460 | -0.353 | -0.424 | -0.065 | -0.062 | -0.656 | -0.026 | -0.089 | 0.327 | -0.469 | 0.856 | 0.142 | 0.138 | -0.772 | -0.015 | -0.584 | 0.031 | -0.060 | -0.233 | | | | |
| Fe_ox | -0.060 | 0.351 | 0.511 | -0.461 | 0.268 | -0.276 | 0.786 | -0.296 | 0.302 | -0.001 | -0.065 | -0.067 | 0.417 | -0.029 | -0.075 | -0.165 | 0.525 | -0.353 | 0.056 | 0.037 | 0.514 | -0.047 | 0.289 | -0.156 | -0.175 | -0.552 | -0.444 | | | |
| Fe_d | 0.296 | 0.207 | 0.119 | -0.312 | 0.084 | -0.079 | 0.593 | -0.035 | 0.109 | -0.270 | -0.113 | -0.114 | 0.045 | -0.049 | -0.139 | 0.026 | 0.282 | 0.154 | 0.152 | 0.128 | 0.078 | -0.062 | -0.051 | -0.152 | -0.232 | -0.758 | 0.145 | 0.823 | | |
| Mn-o_Mn-d | 0.342 | -0.088 | 0.047 | -0.128 | 0.313 | -0.336 | -0.242 | 0.091 | -0.022 | -0.216 | 0.054 | 0.053 | -0.274 | 0.090 | 0.194 | -0.007 | -0.289 | 0.054 | -0.132 | -0.108 | -0.318 | 0.062 | -0.055 | 0.902 | 0.917 | -0.173 | 0.020 | 0.060 | 0.079 | |
| Fe-o_Fe-d | -0.197 | 0.426 | 0.659 | -0.527 | 0.222 | -0.240 | 0.759 | -0.296 | 0.278 | 0.069 | 0.092 | 0.089 | 0.616 | 0.117 | 0.102 | -0.183 | 0.511 | -0.540 | 0.038 | 0.067 | 0.668 | 0.067 | 0.529 | -0.149 | -0.113 | -0.434 | -0.678 | 0.943 | 0.612 | 0.078 |

Table 6: Summary of surface/subsurface soils on mica-schist

| **Clay** | **Silt** | **Fine sand** | **CEC** | **ECEC** |
|---|---|---|---|---|
| Min. : 8.0 | Min. : 5.0 | Min. :30.00 | Min. : 7.2 | Min. :3.606 |
| 1st Qu.: 8.0 | 1st Qu.: 7.0 | 1st Qu.:35.50 | 1st Qu.: 9.7 | 1st Qu.:3.829 |
| Median : 9.0 | Median : 7.0 | Median :37.00 | Median :12.0 | Median :4.443 |
| Mean :10.6 | Mean : 8.6 | Mean :37.00 | Mean :12.8 | Mean :4.575 |
| 3rd Qu.:12.0 | 3rd Qu.: 8.5 | 3rd Qu.:39.75 | 3rd Qu.:16.1 | 3rd Qu.:5.052 |
| Max. :18.0 | Max. :19.0 | Max. :44.00 | Max. :19.6 | Max. :6.540 |
| Coarse sand | Bulk density | Total porosity | Hydraulic C | WHC |
| Min. :29.0 | Min. :1.470 | Min. :29.81 | Min. : 3.540 | Min. :15.10 |
| 1st Qu.:39.0 | 1st Qu.:1.552 | 1st Qu.:30.76 | 1st Qu.: 5.050 | 1st Qu.:20.50 |
| Median :43.0 | Median :1.765 | Median :33.40 | Median : 7.455 | Median :23.29 |
| Mean :43.8 | Mean :1.702 | Mean :35.66 | Mean : 7.652 | Mean :22.79 |
| 3rd Qu.:50.0 | 3rd Qu.:1.835 | 3rd Qu.:40.85 | 3rd Qu.: 9.805 | 3rd Qu.:24.20 |
| Max. :55.0 | Max. :1.850 | Max. :44.53 | Max. :14.140 | Max. :30.57 |
| pH_H2O | pH_KCl | OC | OM | TN |
| Min. :5.800 | Min. :4.70 | Min. :0.075 | Min. :0.129 | Min. :0.0280 |
| 1st Qu.:6.275 | 1st Qu.:5.30 | 1st Qu.:0.164 | 1st Qu.:0.283 | 1st Qu.:0.0595 |
| Median :6.650 | Median :5.50 | Median :0.319 | Median :0.555 | Median :0.0840 |
| Mean :6.570 | Mean :5.56 | Mean :0.366 | Mean :0.632 | Mean :0.1148 |
| 3rd Qu.:6.900 | 3rd Qu.:6.00 | 3rd Qu.:0.375 | 3rd Qu.:0.647 | 3rd Qu.:0.1295 |
| Max. :7.100 | Max. :6.20 | Max. :1.013 | Max. :1.746 | Max. :0.3080 |
| Na | K | Ca | Mg | TEB |
| Min. :0.0010 | Min. :0.005 | Min. :0.80 | Min. :0.60 | Min. :2.406 |
| 1st Qu.:0.0065 | 1st Qu.:0.010 | 1st Qu.:1.60 | 1st Qu.:0.80 | 1st Qu.:2.615 |
| Median :0.0150 | Median :0.030 | Median :1.80 | Median :1.10 | Median :2.900 |
| Mean :0.0181 | Mean :0.037 | Mean :1.96 | Mean :1.14 | Mean :3.155 |
| 3rd Qu.:0.0200 | 3rd Qu.:0.050 | 3rd Qu.:2.00 | 3rd Qu.:1.35 | 3rd Qu.:3.380 |
| Max. :0.0500 | Max. :0.090 | Max. :4.60 | Max. :1.80 | Max. :5.540 |
| BS | EA | AvP | Mn_p | Mn_ox |
| Min. :17.14 | Min. :1.00 | Min. :0.920 | Min. : 1.10 | Min. : 22.10 |
| 1st Qu.:18.57 | 1st Qu.:1.20 | 1st Qu.:0.930 | 1st Qu.: 36.65 | 1st Qu.: 63.52 |
| Median :24.88 | Median :1.30 | Median :0.935 | Median : 64.90 | Median : 73.00 |
| Mean :25.82 | Mean :1.42 | Mean :1.683 | Mean :100.44 | Mean :128.72 |
| 3rd Qu.:33.30 | 3rd Qu.:1.40 | 3rd Qu.:1.647 | 3rd Qu.: 98.42 | 3rd Qu.:119.20 |
| Max. :36.33 | Max. :2.20 | Max. :6.530 | Max. :419.80 | Max. :515.00 |
| Mn_d | Fe_p | Fe_ox | Fe_d | Mn-o_Mn-d |
| Min. : 52.05 | Min. : 776.4 | Min. : 481.3 | Min. :1422 | Min. :0.3900 |
| 1st Qu.: 85.59 | 1st Qu.: 954.2 | 1st Qu.: 880.5 | 1st Qu.:2294 | 1st Qu.:0.5075 |
| Median :120.85 | Median :1276.8 | Median :1295.5 | Median :2570 | Median :0.5550 |
| Mean :144.96 | Mean :1212.3 | Mean :1305.2 | Mean :2518 | Mean :1.0600 |
| 3rd Qu.:146.59 | 3rd Qu.:1450.9 | 3rd Qu.:1528.7 | 3rd Qu.:2931 | 3rd Qu.:0.5950 |
| Max. :402.05 | Max. :1693.9 | Max. :2312.7 | Max. :3089 | Max. :5.4000 |
| Fe-o_Fe-d | | | | |
| Min. :0.290 | | | | |
| 1st Qu.:0.385 | | | | |
| Median :0.500 | | | | |
| Mean :0.503 | | | | |
| 3rd Qu.:0.625 | | | | |
| Max. :0.750 | | | | |

Table 7: Summary of surface soils on mica-schist

| **Clay** | **Silt** | **Fine sand** | **Coarse sand** | **Bulk density** | **Total porosity** |
|---|---|---|---|---|---|
| Min. : 8 | Min. : 7.000 | Min. :30.00 | Min. :38.00 | Min. :1.54 | Min. :31.32 |
| 1st Qu.: 9 | 1st Qu.: 8.000 | 1st Qu.:34.50 | 1st Qu.:40.00 | 1st Qu.:1.64 | 1st Qu.:32.83 |
| Median :10 | Median : 9.000 | Median :39.00 | Median :42.00 | Median :1.74 | Median :34.34 |
| Mean :10 | Mean : 9.667 | Mean :36.67 | Mean :43.67 | Mean :1.70 | Mean :35.60 |
| 3rd Qu.:11 | 3rd Qu.:11.000 | 3rd Qu.:40.00 | 3rd Qu.:46.50 | 3rd Qu.:1.78 | 3rd Qu.:37.73 |
| Max. :12 | Max. :13.000 | Max. :41.00 | Max. :51.00 | Max. :1.82 | Max. :41.13 |
| Hydraulic C | WHC | pH_H2O | pH_KCl | OC | OM |
| Min. : 6.830 | Min. :22.21 | Min. :6.100 | Min. :5.100 | Min. :0.0750 | Min. :0.1290 |
| 1st Qu.: 8.465 | 1st Qu.:22.66 | 1st Qu.:6.150 | 1st Qu.:5.250 | 1st Qu.:0.2250 | 1st Qu.:0.3880 |
| Median :10.100 | Median :23.10 | Median :6.200 | Median :5.400 | Median :0.3750 | Median :0.6470 |
| Mean : 9.180 | Mean :23.82 | Mean :6.333 | Mean :5.367 | Mean :0.4103 | Mean :0.7073 |
| 3rd Qu.:10.355 | 3rd Qu.:24.62 | 3rd Qu.:6.450 | 3rd Qu.:5.500 | 3rd Qu.:0.5780 | 3rd Qu.:0.9965 |
| Max. :10.610 | Max. :26.14 | Max. :6.700 | Max. :5.600 | Max. :0.7810 | Max. :1.3460 |
| TN | Na | K | Ca | Mg | CEC |
| Min. :0.056 | Min. :0.01000 | Min. :0.00500 | Min. :1.600 | Min. :0.6000 | Min. : 9.20 |
| 1st Qu.:0.077 | 1st Qu.:0.01500 | 1st Qu.:0.02750 | 1st Qu.:1.700 | 1st Qu.:0.7000 | 1st Qu.: 9.60 |
| Median :0.098 | Median :0.02000 | Median :0.05000 | Median :1.800 | Median :0.8000 | Median :10.00 |
| Mean :0.154 | Mean :0.02333 | Mean :0.04833 | Mean :1.733 | Mean :0.8667 | Mean :11.47 |
| 3rd Qu.:0.203 | 3rd Qu.:0.03000 | 3rd Qu.:0.07000 | 3rd Qu.:1.800 | 3rd Qu.:1.0000 | 3rd Qu.:12.60 |
| Max. :0.308 | Max. :0.04000 | Max. :0.09000 | Max. :1.800 | Max. :1.2000 | Max. :15.20 |
| TEB | ECEC | BS | EA | AvP | Mn_p |
| Min. :2.470 | Min. :3.815 | Min. :17.14 | Min. :1.2 | Min. :0.930 | Min. : 1.10 |
| 1st Qu.:2.542 | 1st Qu.:3.842 | 1st Qu.:20.92 | 1st Qu.:1.3 | 1st Qu.:0.955 | 1st Qu.: 31.25 |
| Median :2.615 | Median :3.870 | Median :24.70 | Median :1.4 | Median :0.980 | Median : 61.40 |
| Mean :2.672 | Mean :4.272 | Mean :24.56 | Mean :1.6 | Mean :2.813 | Mean : 56.17 |
| 3rd Qu.:2.772 | 3rd Qu.:4.500 | 3rd Qu.:28.27 | 3rd Qu.:1.8 | 3rd Qu.:3.755 | 3rd Qu.: 83.70 |
| Max. :2.930 | Max. :5.130 | Max. :31.85 | Max. :2.2 | Max. :6.530 | Max. :106.00 |
| Mn_ox | Mn_d | Fe_p | Fe_ox | Fe_d | Mn-o_Mn-d |
| Min. : 70.00 | Min. : 82.4 | Min. : 781.3 | Min. : 773.6 | Min. :2064 | Min. :0.5300 |
| 1st Qu.: 76.75 | 1st Qu.:106.9 | 1st Qu.:1035.7 | 1st Qu.:1129.4 | 1st Qu.:2165 | 1st Qu.:0.5400 |
| Median : 83.50 | Median :131.4 | Median :1290.0 | Median :1485.2 | Median :2266 | Median :0.5500 |
| Mean : 94.87 | Mean :150.3 | Mean :1191.9 | Mean :1267.3 | Mean :2459 | Mean :0.6967 |
| 3rd Qu.:107.30 | 3rd Qu.:184.2 | 3rd Qu.:1397.2 | 3rd Qu.:1514.2 | 3rd Qu.:2657 | 3rd Qu.:0.7800 |
| Max. :131.10 | Max. :237.1 | Max. :1504.5 | Max. :1543.2 | Max. :3048 | Max. :1.0100 |
| Fe-o_Fe-d | | | | | |
| Min. :0.3700 | | | | | |
| 1st Qu.:0.4400 | | | | | |
| Median :0.5100 | | | | | |
| Mean :0.5133 | | | | | |
| 3rd Qu.:0.5850 | | | | | |
| Max. :0.6600 | | | | | |

Table 8: Summary of subsurface soils on mica-schist

| **Clay** | **Silt** | **Fine sand** | **Coarse sand** | **Bulk density** | **Total porosity** |
|---|---|---|---|---|---|
| Min. : 8.00 | Min. : 5.000 | Min. :30.00 | Min. :29.00 | Min. :1.470 | Min. :29.81 |
| 1st Qu.: 8.00 | 1st Qu.: 6.000 | 1st Qu.:36.00 | 1st Qu.:40.00 | 1st Qu.:1.560 | 1st Qu.:30.38 |
| Median : 8.00 | Median : 7.000 | Median :37.00 | Median :44.00 | Median :1.790 | Median :32.45 |
| Mean :10.86 | Mean : 8.143 | Mean :37.14 | Mean :43.86 | Mean :1.703 | Mean :35.69 |
| 3rd Qu.:13.00 | 3rd Qu.: 7.000 | 3rd Qu.:38.50 | 3rd Qu.:49.50 | 3rd Qu.:1.845 | 3rd Qu.:41.13 |
| Max. :18.00 | Max. :19.000 | Max. :44.00 | Max. :55.00 | Max. :1.850 | Max. :44.53 |
| | | | | | |
| Hydraulic C | WHC | pH_H2O | pH_KCl | OC | OM |
| Min. : 3.540 | Min. :15.10 | Min. :5.800 | Min. :4.700 | Min. :0.075 | Min. :0.1290 |
| 1st Qu.: 4.625 | 1st Qu.:19.68 | 1st Qu.:6.550 | 1st Qu.:5.300 | 1st Qu.:0.164 | 1st Qu.:0.2830 |
| Median : 5.050 | Median :23.47 | Median :6.900 | Median :5.700 | Median :0.263 | Median :0.4630 |
| Mean : 6.997 | Mean :22.35 | Mean :6.671 | Mean :5.643 | Mean :0.347 | Mean :0.5997 |
| 3rd Qu.: 8.500 | 3rd Qu.:23.96 | 3rd Qu.:6.900 | 3rd Qu.:6.150 | 3rd Qu.:0.375 | 3rd Qu.:0.6470 |
| Max. :14.140 | Max. :30.57 | Max. :7.100 | Max. :6.200 | Max. :1.013 | Max. :1.7460 |
| | | | | | |
| TN | Na | K | Ca | Mg | CEC |
| Min. :0.028 | Min. :0.00100 | Min. :0.00500 | Min. :0.800 | Min. :0.800 | Min. : 7.20 |
| 1st Qu.:0.063 | 1st Qu.:0.00600 | 1st Qu.:0.01000 | 1st Qu.:1.400 | 1st Qu.:0.900 | 1st Qu.: 9.80 |
| Median :0.084 | Median :0.00800 | Median :0.01000 | Median :2.000 | Median :1.200 | Median :14.00 |
| Mean :0.098 | Mean :0.01586 | Mean :0.03214 | Mean :2.057 | Mean :1.257 | Mean :13.37 |
| 3rd Qu.:0.112 | 3rd Qu.:0.02000 | 3rd Qu.:0.05000 | 3rd Qu.:2.100 | 3rd Qu.:1.600 | 3rd Qu.:16.60 |
| Max. :0.224 | Max. :0.05000 | Max. :0.09000 | Max. :4.600 | Max. :1.800 | Max. :19.60 |
| | | | | | |
| TEB | ECEC | BS | EA | AvP | Mn_p |
| Min. :2.406 | Min. :3.606 | Min. :17.44 | Min. :1.000 | Min. :0.920 | Min. : 23.1 |
| 1st Qu.:2.743 | 1st Qu.:4.043 | 1st Qu.:18.87 | 1st Qu.:1.200 | 1st Qu.:0.930 | 1st Qu.: 39.3 |
| Median :3.270 | Median :4.616 | Median :25.06 | Median :1.200 | Median :0.930 | Median : 68.4 |
| Mean :3.362 | Mean :4.705 | Mean :26.36 | Mean :1.343 | Mean :1.199 | Mean :119.4 |
| 3rd Qu.:3.417 | 3rd Qu.:5.044 | 3rd Qu.:33.97 | 3rd Qu.:1.400 | 3rd Qu.:1.405 | 3rd Qu.:123.0 |
| Max. :5.540 | Max. :6.540 | Max. :36.33 | Max. :2.000 | Max. :1.870 | Max. :419.8 |
| | | | | | |
| Mn_ox | Mn_d | Fe_p | Fe_ox | Fe_d | Mn-o_Mn-d |
| Min. : 22.10 | Min. : 52.05 | Min. : 776.4 | Min. : 481.3 | Min. :1422 | Min. :0.390 |
| 1st Qu.: 45.85 | 1st Qu.: 75.62 | 1st Qu.: 968.0 | 1st Qu.: 942.1 | 1st Qu.:2425 | 1st Qu.:0.490 |
| Median : 66.00 | Median :110.60 | Median :1272.1 | Median :1206.2 | Median :2666 | Median :0.560 |
| Mean :143.23 | Mean :142.67 | Mean :1221.1 | Mean :1321.5 | Mean :2543 | Mean :1.216 |
| 3rd Qu.:153.90 | 3rd Qu.:141.38 | 3rd Qu.:1434.5 | 3rd Qu.:1683.0 | 3rd Qu.:2885 | 3rd Qu.:0.590 |
| Max. :515.00 | Max. :402.05 | Max. :1693.9 | Max. :2312.7 | Max. :3089 | Max. :5.400 |
| | | | | | |
| Fe-o_Fe-d | | | | | |
| Min. :0.2900 | | | | | |
| 1st Qu.:0.3850 | | | | | |
| Median :0.4900 | | | | | |
| Mean :0.4986 | | | | | |
| 3rd Qu.:0.5950 | | | | | |
| Max. :0.7500 | | | | | |

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