Pedogenesis in the basement complex lithologies of Northeastern Nigeria as defined by its Inherent morpho-physical and chemical properties

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Abstract

*The study focused on secernating the Basement Complex with particular interest on characterizing the soils Northeastern Nigeria in order to examine their genesis. Previous studies focused on soils developed on the Basement Complex as a unit. The present study therefore emphasizes the study of soils over specific lithologies such as Porphyritic granite (PG), granite-gneiss (GG) and pegmatite (PM. Three profile pits were dug in soils overlying each lithology, resulting in a total of nine soil profile pits. Soil samples were collected from genetic horizons and used for the study. Morphological, physical and chemical properties of the soils were examined and analyzed (using R packages) to understand their pedogenic differences. A B and C horizons dominated the soils with pedal depths of greater than 100 cm. Bioturbation was evident in the surface soils and increased lessivationin the B horizons. Clay varied strongly with silt (Pr (>F) 0.003815**) and exchangeable acidity (Pr (>F) 0.01124*) in the soils formed over GG and correlated positively with the silt (r = 0.85***) and exchangeable acidity (r = 0.81***). Observed averages of pH were 6.6, 6.8 and 6.4 for PG, GG and PM, respectively accounting for neutral and slightly acidic soil reactions. Computed means of most soil properties between lithological units were statistically indifferent that the soils are generally similar pedogenically.*

Keywords: Basement complex, granite gneiss, pedogenesis, pegmatite, porphyritic granite

Introduction

Basement complex, granite gneiss, pedogenesis, pegmatite, porphyritic granite organisms, topography and time) which give rise to distinct soil types observed on a landscape (Ojanuga *et al.*, 2003; Esu *et al.*, 2008; Amhakhian and Achimugu, 2011).

Land evaluation (soil survey interpretation) precedes land use planning as the soil resource data provide several information, which may facilitate in predicting soils' behaviour towards different land uses *viz.* crop cultivation, plantation, forest or other usage (Prasad, 2000).

However, utility of the generated data can be significantly enhanced if the taxonomic units are grouped into management units, which can indicate the potential and constraints of an area in terms of its fertility (Akinbola *et al.*, 2009).

Fertility capability classification (FCC) system (a system of land evaluation) has been described as a technical soil classification system that focuses quantitatively on the physical and chemical properties of the soil that are important towards soil fertility management (Sanchez *et al.*, 1982). It is primarily developed for interpreting soil taxonomy and additional soil attributes in a way that is directly relevant to plant growth (Sanchez *et al.*, 2003). Pedological information are very important for general land use planning however, the interest of the farmer lies in the interpretation of the soil surveys, otherwise known as land evaluation (Udoh *et al.*, 2013; Fasina and Adeyanju, 2006). Fertility capability classification identifies the most limiting land qualities and provides a good basis for advising farmers on the appropriate management practice for optimum production in an area. FCC also simplifies information about the profile and analysis of soils for the benefit of those who are not familiar with soil classification system. It appears to be a suitable framework for agronomic soil taxonomy, which is acceptable to both pedologists and agronomists (Udoh *et al.*, 2013).

Little information is currently available to farmers and extension workers with regard to soil fertility management in an agrarian community of Umuahia area of Abia State. In this respect, the research work was carried out to characterize and assess the fertility potentials of soils under selected land use types for sustainable production of different crops.

Materials and methods

Location, geology and climate of the study area

The study was conducted in Bakindutse, Mallum and Kona areas of Taraba State (6°30′ & 9°30′ N; 9°00′ & 12°00′ E), northeastern Nigeria. The geology of the study area is that of an undifferentiated Basement Complex. However, Precambrian granitic and migmatite gneisses with outcrops of the rocks occur at intervals (Ogezi, 2002). The study area is characterized by a tropical climate with distinct wet and dry seasons. The wet and dry seasons last for 7 and 5 months, respectively. Precipitation is lowest in January with an average of 0 mm, while in August, the most precipitation falls with an average of 217 mm (Fig. 1). 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 (Fig. 1). Taraba State is characterized by three dominant vegetational zones. The guinea savannah is found in the southern part of the state and identified by forest and tall grasses, while the Sub Sudan vegetation is characterized by short grasses with a few short trees. The Mambilla Plateau area is uniquely marked by a semi-temperate climate with luxuriant pasture and short trees.

Field and laboratory studies

The sites for the study were identified through reconnaissance visits using the geological map of Taraba State obtained from the Nigerian Geological Survey Agency. Porphyritic granite

(08^{o} 50´32 14.6 N and 011^{o} 17´43.0 E; 247 m), granite gneiss (08^{o}59'10.5 N and 011^{o}19'14.33 E; 268 m) and pegmatite (08^{o}50'14.6''N and 011^{o} 17 '43.0''E; 247 m) were identified and selected amongst other lithological units because of their vast expanse and agricultural value. Three soil profile pits were located on the crests of each of the three lithologies. In all, nine soil profile pits were dug and used for the study, such that: BDCP1+BDCP2+BDCP3 = PG, MCP1+MCP2+MCP3 = GG and KCP1+KCP2+KCP3 = PM. The pedons were described following the procedures in the guidelines for soil profile description as outlined by FAO (2006). Soil samples were collected bottom-top from identified pedogenic horizons. Standard cylindrical cores were used in the collection of soil samples meant for bulk density determination. Soil samples meant for physical and chemical analyses were air-dried and sieved with a 2 mm mesh of a sieve. The fine earth fraction (< 2 mm) was used for laboratory analyses, while the coarse fraction was discarded.

Bulk density was determined by the undisturbed core method (Blake and Hartge 1986), while aggregate stability was determined by the method described by Masri and Ryan (2006).Particle size distribution was determined by the Bouyoucos hydrometer method (Gee and Bauder, 1986), while soil pH was determined in H_2O and KCl in 1:2.5 soil to solution ratio (Udo *et al*., 2009). Organic carbon was determined by the Walkley-Black method modified by Udo *et al*., (2009). The cation exchange capacity (CEC) was determined by the neutral (pH 7.0) NH_4OAc saturation method (Udo *et al*., 2009) and exchangeable Ca, Mg, K and Na were determined by the neutral NH_4OAc displacement method and read through by Atomic Absorption spectrophotometer (Udo *et al*., 2009). Exchangeable acidity was determined by using $BaCl_2$-triethanolamine (TEA) solution buffered at pH 8.2 by back titration procedures of Udo *et al*., (2009). Base saturation was calculated by expressing the sum of exchangeable bases as a percentage of the CEC at pH 7

Statistical analysis

The data generated were analyzed for correlation using R version 4.2.0.

Results and discussion

Data generated from the studied soils are presented in Table 1. All the pedons exhibited distinction in thickness of horizons between the overlying and underlying horizons. A, B and C master horizons dominated the soils. This indicates that the soils are mature. Similarly, pedal depths greater than100 cm for the soils (Table 1 and Fig. 2) are indicative of deep soils which were further evidence that the soils are not only mature but well developed.

Thin surface soil horizons observed in BDCP3, KCP1 and MCP1&2 was attributed to land use as continuous cultivation is a common practice of the farmers in the study area. Bioturbation was evident in the surface soils as the Ap horizons were characterized by fine roots and ant holes which could have contributed to the generally dark colouration (Fig. 2) of the surface soils and subsequent increase in lessivation at the B horizons.

The presence of gravels in BDCP1 (Btv, 20 - 81 cm overlying Bt at 81 - 128 cm) signals botched weathering or might be attributed to the decomposition of clay and formation of sesquioxide concretions between the surface and subsurface transition. Pedons BDCP1, KCP, KCP3 and MCP2 exhibited illuviation of clay implying that the soils have been significantly transformed from the Basement complex. Weathering of the Basement Complex is usually slow because it is mainly of igneous and metamorphic origin, as such, they are high in silica which is known to be highly resistant to weathering.

The weathering depth as indicated by the soil depth presupposes advanced pedogenesis as neither water table nor weathered rock was observed at 2 m depth. Pedons BDCP3 and MCP1 did not show any evidence of clay accumulation hence, the soils were relatively younger. The C horizons in thestudied soils were characterized by ant channels and fine roots implying the supply of soil air and water to facilitate basal weathering of the Basement Complex at extended depth. On the other hand, soil colour and horizonation indicate that the soils are mostly well-drained and formed *in situ*. Therefore, it can be surmised that weathering of the Basement Complex led to the observed variance in the soil colour of the tints of black to brown to gray to yellow and red in the surface soils of BDCP1 (10YR 3/2), BDCP3 (10YR3/1), KCP (10YR3/1), MCP2 (10YR3/2) and MCP3 (5YR4/6)very dark gray – dark gray colours suggesting the presence of glauconite, while organic matter contributed more to the dark soil colour.

The presence of quartz grains may have contributed significantly to the gray colour in the surface soils while the impact of humus produced the observed dark gray. Contrasting soil surface colour matrices were observed in KCP3 (2.5YR6/6 - light red) and MCP1 (10YR2/1 - black) implying the former could be dominated by hematite and the later humus/todorokite (Shobayo, 2019). In the subsurface soils, yellowish/reddish-brown to brown, yellowish red to red imply active braunification and ferritization processes.

Clay content increased significantly in the B horizons of BDCP1 and KCP2exhibiting argilluviation. However, its distribution was inconsistent with depth in BDCP1, MCP1, KCP1 and KCP2 implying that clay translocation was at play and attributed to the alternate wet and dry seasons of the study area. The inconsistency also contributed to the relatively large variation in the soils' texture. Regular decrease in the clay content with depth of BDCP3, MCP2 and MCP3 as well as its regular increase in KCP3) was associated with lessivation (Imadojemu*et al.*, 2018). The implication of the clay distribution pattern and the formation of B horizon soil maturity. Such distribution may also be attributed to more intensive chemical weathering in the subsurface soils. On soils formed over porphyritic granite (PG), clay also varied strongly with silt (Pr (>F) 0.003815) and exchangeable acidity (Pr (>F) 0.01124*) in the soils formed over granite gneiss lithological unit and correlated positively (Fig. 3a&3b) with silt (r = 0.85***) and exchangeable acidity (r = 0.81***).

The distribution pattern of silt in most of the studied soils was inconsistent with pedal depth except in pedons BDCP1, BDCP3 and MCP2 (Table 1).The values of silt for the studied soils were generally lower than those of clay and sand at their corresponding horizons implying that the transformation process was swift in silt during pedogenesis. Soils with high silt content have been reported to account for surface crusting (Lawal and Lawal, 2017). The silt/clay ratio was also used as a measure of soil development (Table 1). Pedons BDCP1, BDCP2, BDCP3, MCP1, MCP2, MCP3, KCP1, KCP2 and KCP3 recorded average silt ratio of 0.59, 1.54, 0.69, 0.95, 1.57, 1.00, 0.70, 0.55 and 0.83 respectively. KCP2 recorded the lowest average (0.55) which is greater than the critical value of 0.15 on the scale of Maniyunda (2012) for highly weathered soils.

The sand fraction was the highest among the fine earth fractions with values ranging from 221 to 630 g kg^{-1}. The dominance of sand in the soils reflect the granitic origin of the geologic materials (Ya'u and Maniyunda, 2018). MCP2 recorded the lowest average of 320 g kg^{-1} while BDCP2 recorded the highest average of 417 g kg^{-1}. The distribution pattern across the pedons was inconsistent with depth and coupled with the high content, contributed to the loamy sand and sandy loam textures of the soils (Table 1). The difference in the textural class is indicative of pedogenic sorting of fine fractions (clay and silt) and eluviation with attendant high precipitation resulting in the higher sand content in the surface soils of BDCP1, BDCP2, BDCP3, MCP2 and KCP2. Conversely, the higher sand content at the lowest horizons might have resulted from the direct decomposition of the underlying bedrock.

High, higher and highest values were recorded for the textural class sandy clay loam, loamy sand and sandy loam, respectively. Soils with the highest values in the surface (BDCP2, BDCP3 and MCP1) would resist erosion and tillage better than those with the highest values at the subsurface soils (KCP1, KCP2, KCP3 and MCP2), which would tolerate the shrinking and swelling of the soil particles more, thereby slowing down weathering. Generally, the soils recorded moderate aggregate stability values implying that they can hold water moderately to facilitate effective pedogenic processes. Lowest average was recorded for KCP2 (17.69) and the highest average of 36.63 was recorded for BDCP2.Therefore, soils of BDCP2 are the most stable as against a weak structural aggregate that can easily be destroyed especially under intensive cultivation.

Bulk density averages are 1.74, 1.74, 1.62, 1.64, 1.78, 1.70, 1.68, 1.67 and 1.67 Mgm^{-3} respectively for Pedons BDCP1, BDCP2, BDCP3, MCP1, MCP2, MCP3, KCP1, KCP2 and KCP3.Soil bulk densityvalues were irregularly distributed down the soil profiles of BDCP1, BDCP2, MCP2, MCP3, KCP1, KCP2, KCP3. Lower bulk density values in the surface soils (Table 1) relative to the underlying horizons is attributed to higher organic matter content in the soil (Odunze*et al.* (2019). Pedons BDCP3 and MCP1 however, increased regularly with depth while MCP2 decreased regularly with depth. The former may be attributed to an increase in clay content and decrease in soil organic matter while the latter presupposes an opposite trend. High bulk density in the surface soils could be attributed to crusting or surface sealing due to high silt content in cultivated areas (Are *et al.*, 2018). Only MCP2 is within the critical limits of 1.75 - 1.80 Mgm^{-3} for the restriction of roots in agricultural soils (FAO, 2006).

Soil reaction in all the pedons shows lower values (falling by at least 0.5 unit) of pH in KCl to pH in water at their corresponding horizons indicating that pH KCl was more acidic. Soil pH varied irregularly with depth in all the pedons. Observed averages of pH (water) were 6.6, 6.8 and 6.4 for PG, GG and PM accounting for neutral and slightly acidic soil reaction. However, averages of 5.6, 5.8 and 5.0 pH (KCl) were recorded for PG (moderately acidic), GG (moderately acidic) and PM (very strongly acidic) respectively. Findings by Odunze *et al*., (2019) show that soil pH conditions required for microbial activity range from 5.5 – 8.8. In soils formed over porphyritic granite (PG), pH H_2O varied significantly with pH KCl (Pr (>F) = 0.001673 **) and exchangeable acidity (Pr (>F) = 0.001596 **).

Similarly, pH H_2O significantly correlated (Fig. 5a&5b) with pH KCl (r = 0.91***) and exchangeable acidity (r = -0.91***). Meanwhile, increase in pH H_2O lead to decrease in the soil exchangeable acidity. In soils formed over granite gneiss (GG), pH H_2O varied significantly with Mg (Pr (>F) = 0.002685**) and correlated very significantly positively (Fig. 3a&3b). This implies that Mg ions reduce soil acidity. Soil pH condition observed for soils formed over pegmatite (PM); showed significant variation in pH (H_2O) over organic carbon content (Pr (>F) = 0.01684*, r = -0.80***), soil K (Pr (>F) = 0.008215**, r = -0.78***Fig. 4a&4b) and soil Na (Pr (>F) = 0.0243*, r = -0.73***).

The soils formed over PG, GG and PM show mean values of exchangeable acidity (EA) in the surface soils to be 1.53, 1.67 and 1.60 cmol(+)kg^{-1} respectively, while the subsurface soils recorded mean values of 1.34, 1.50 and 2.12 cmol(+)kg^{-1}. The surface and subsurface averages indicate that the soils are in medium to high levels since values were greater than 1 cmol (+) kg^{-1} (George, 2009). However, the higher mean values observed in the surface soils of PG and GG, and subsurface soils of PM may be attributed to the loamy nature of the soils as it influences the buildup of exchangeable acidity through reduced leaching of exchangeable aluminium (Al) and hydrogen (H) in the solum (George, 2009).

The exchangeable acidity (EA) of the soils were within limits that may pose threat to crop production. Based on the moderately to strongly acidic soil reaction and medium to a high concentration of exchangeable acidity (> 1 cmol (+) kg^{-1}) in these soils, it is recommended that incorporation of organic materials be adopted.

Soils over PG showed that organic carbon content (OC) was higher at the surface soils of BDCP1 (0.38 g kg^{-1}), BDCP2 (0.78 g kg^{-1}) and BDCP3 (1.01 g kg^{-1}) when compared to their subsurface averages of 0.28, 0.16 and 0.17 g kg^{-1}, respectively. The distribution showed a systematic decrease with pedal depth. Organic carbon content was rated very low (< 10.0 g kg^{-1}) in the studied soils. The low content was attributed to high mineralization rate (Eche *et al*., 2014)and continuous cultivation(Poeplau and Don, 2013) in the study areas. The soils over PG depicted OC had significant variation with soil aggregate stability (Pr (>F) = 0.04771*, r = 0.74***), bulk density (Pr (>F) = 0.02125*, r = -0.74***), Ca (Pr (>F) = 0.01107*, r = 0.76***), soil K (Pr (>F) = 3.3820***, r = 0.95***) and Na (Pr (>F) = 6.4470***, r = 0.98***). A proportional decrease in the soils' OC led to a proportional increase in BD with pedal depth, with a resultant decrease in soil aggregate stability. Since clay did not vary significantly with Ca, K and Na in the soils, it is therefore concluded that OM contributed majorly to the increase of the soils' exchangeable bases.

Organic C in soils formed over GG shows a regular decrease (Table 1) down the studied soil profiles. Sharami *et al.* (2010) attributed low organic carbon content to lower CEC values; however, these soils showed a very strong negative correlation (Fig. 3a&3b) with CEC (r = -0.72***) implying that OC did not contribute appreciably to the soils' CEC. But OC contributed more to soils' K (Pr (>F) = 2.4010***, r = 0.91***) and Na (Pr (>F) = 8.004***, r = 0.97***) for the soils formed over PM as they show very strong positive correlation with OC.

The dominance of exchangeable Ca over exchangeable Mg, K and Na were common in the studied soils (Table 2). The distribution was irregular with pedal depth assuming the distribution of clay content (Table 1) with high Ca affinity. However, a general increase in exchangeable Ca with an increase in soil depth has been reported (John *et al.*, 2018), and was attributed to illuvial accumulation caused by the leaching of nutrient minerals from the surface horizons. Calcium dominance at the exchange site was also attributed to the high affinity of BasementComplex soils for Ca (Fasina*et al.*, 2015; Raji, 2016). Averages of 2.67, 2.20 and 1.47 cmol (+) kg^{-1} were recorded in the surface soils of PG, GG and PM respectively. The values of exchangeable Ca were rated medium (2 – 5 cmol(+)kg^{-1}) for the surface soils of PG and GG but low (< 2 cmol(+)kg^{-1}) for PM. Their subsurface soils averages were also lower for PG (1.6 cmol(+)kg^{-1}) and GG (1.8 cmol(+)kg^{-1}) but medium for PM (2.44 cmol(+)kg^{-1}).

In PG, Ca varied significantly with OC (Pr (>F) = 0.011*, r = 0.76***) suggesting supply through soil organic matter, and BD (Pr (>F) = 0.043*, r = -0.60***) implying negative association with BD. A strong significant relationship, was noted between Ca and Mg, exchangeable acidity and base saturation at a 1 % level of probability in PM.

Distribution of exchangeable Mg, K and Na followed a similar trend as was obtained for Ca in their corresponding genetic horizons; however, the trend was such that the content of Ca > Mg > K > Na. Averages of exchangeable Mg (0.87), K (0.08) and Na (0.04cmol(+)kg^{-1}) in the surface soils of PG (BDCP1+BDCP2+BDCP3) against their subsurface averages Mg (1.32), K (0.02) and Na (0.01cmol(+)kg^{-1}) indicate comparatively higher Mg content in the subsurface soils. Calcium, Mg, K and Na contents in soils formed over PG, GG (MCP1+MCP2+MCP3) and PM (KCP1+KCP2+KCP3) were statistically at par when their means were compared and rated medium, high, and low, respectively. The low level of K could be attributed to low level of mica in Basement Complexes (Shobayo, 2019). Garcia (2003) submitted that high level of Mg in soil may cause deterioration of soil structure, lower water intake rates and affects its chemical and biological properties. Low Na could also buffer the sodicity problems in the soils and promote the balancing of hydrolysable cations.

The CEC (by ammonium acetate) of the studied soils ranged from6 to 12 cmol(+)kg^{-1} (Table 2) across genetic horizons; a range considered medium on the scale of Esu (1987). The distribution with depth was inconsistent in the lithological units. The parent material significantly influenced the CEC of the soils as values were generally low to moderate and was attributed to their granitic origin. Soils formed over PG recorded a range of 9.2 – 16.4 cmol(+)kg^{-1} in the surface soils and 7.2 – 19.6 cmol(+)kg^{-1} in the subsurface soils. The mean average values of 11.87 (surface) and 12.84 cmol(+)kg^{-1} (subsurface) were indications of moderate nutrient retention of the soils as corroborated by Sharami*et al.*, 2010. Cation exchange capacity showed significant variation only with BS (Pr (>F) 0.0448*) plus a strong negative association (Fig. 5a&5b). Similar statistical difference was observed for soil formed over GG.

Similarly, soils formed over GG had CEC ranging from 8.8 – 13.6 cmol(+)kg^{-1} in the surface soils and 8.0 – 20.8 cmol(+)kg^{-1} in the subsurface soils. The surface and subsurface soils had 11.2 and 15.3 cmol(+)kg^{-1} respectively as mean values and were rated medium to high. The higher CEC average recorded in the subsoils could be attributed to its relatively high clay content, which could have improved the cation retention capacity at the exchange site against leaching (Olorunfemi, 2016). Cation exchange capacity ranges of 9.6 – 10.8 (mean, 10.13 cmol(+)kg^{-1}) and 6.0 – 28.0 (mean, 13.23 cmol(+)kg^{-1}) for the surface and subsurface soils, respectively were recorded in soils formed over PM. However, higher mean values recorded in the subsurface soils could be attributed to the active argilluviation process whereas the lower CEC values (of surface soils) is suggestive of low organic matter of Northern Guinea Savanah and dominance of sesquioxides and kaolinite (1:1) clay minerals.

Base saturation (BS) values varied irregularly with soil depth (Table 2) in pedons BDCP3 (PG) and MCP2 (GG).Its distribution was similar to that of clay, organic matter and exchangeable bases. Regular increase with pedal depth in BDCP2 and regular decrease with soil depth in BDCP1, MCP1 and MCP3 were observed. Mean BS in the surface soils (30.11, 32.61 and 24.60 % respectively for PG, GG and PM) over subsurface soils (24.93, 24.41 and 30.48 % respectively for PG, GG and PM) did not vary significantly. The mean BS values across all horizons were rated low (Udo et al., 2009) as values were less than 50 % and considered less favourable(FAO,2006). Effect of crop type and continuous cropping influence may have also contributed to the low

BS. Base saturation varied significantly with CEC in PG (Pr (>F) 0.0448*) and GG (Pr (>F) 0.0205*). However, in PM, statistical difference was observed only between BS and Mg (Pr (>F) 0.0238*) and Ca (Pr (>F) 0.0016*) with a linear association (Fig. 4a&4b) implying that Ca and Mg contributed more to the BS of soils formed over porphyritic granite lithological unit.

Conclusion

The research studied the pedogenesis of soils formed on the Basement with particular interest in characterizing the soils formed over three lithological units viz; porphyritic granite (PG), granite-gneiss (GG) and pegmatite (PM). From the data generated,active pedogenic processes took place within the soils as exemplified by horizon boundary distinction and topography, major A, B, and C horizons. Continuous cultivation in the study areas led to the thin surface soils observed in pedons BDCP3, KCP1 and MCP1&2. The depth analysis classified the soils as mature since soil depths were greater than 1m.However, since pedons BDCP3 and MCP1 did not show any evidence of clay accumulation, they were regarded as comparatively younger. The silt - clay ratio put the soil individuals from PG, GG and PM in the ageing order as: KCP<BDCP1<BDCP3<KCP1<KCP3<MCP1 <MCP3<BDCP2<MCP2. The dominance of sand content in the soils corroborates their generally low fertility status as also reflected in their low exchangeable bases, OC, TN, AP, CEC and BS. The observed averages of 5.6 and 5.8 for soil pH (KCl) in PG and GG contributed to the soil' improved fertility status over PM that was strongly acidic. Computed mean values of parameters of the lithological units were similar It is therefore concluded that the soils are generally similar pedogenically.

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Table 1: Soil morpho-physical properties

Profile	Horizon	Depth (cm)	Clay (g kg^{-1})	Silt (g kg^{-1})	Silt:clay	Sand (g kg^{-1})	Texture	Aggr. Stab. (%)	BD (Mgm^{-3})
BDCP1	Ap	0 – 20	100	90	0.90	390	LS	14.32	1.82
	Btv_1	20 – 81	180	70	0.39	370	SL	33.24	1.53
	B_2	81 – 128	140	70	0.50	370	SL	16.23	1.85
	BCv	128 –175	120	70	0.58	300	SL	31.87	1.74
BDCP2	Ap	0 – 35	80	130	1.63	410	SL	42.91	1.54
	Bv	35 – 106	80	50	0.63	400	LS	35.51	1.85
	CBv	106 – 173	80	190	2.38	440	SL	31.46	1.84
BDCP3	Ap	0 – 12	120	70	0.58	370	SL	52.91	1.47
	CB	12 – 62	80	70	0.88	300	LS	27.45	1.59
	C	62 – 126	80	50	0.63	350	LS	21.25	1.79
MCP1	Ap	0 – 12	100	90	0.90	320	LS	53.85	1.61
	B	12 – 36	80	50	0.63	340	LS	28.13	1.66
	BC	36 – 200	220	290	1.32	410	SCL	18.55	1.66
MCP2	Ap	0 – 12	180	210	1.17	420	LS	19.89	1.79
	B	12 – 38	120	210	1.75	320	LS	25.27	1.78
	CB	38 – 200	119	215	1.81	221	SCL	25.23	1.77
MCP3	A	0 – 30	100	50	0.50	320	LS	26.88	1.78
	B	30 – 80	80	110	1.38	440	LS	37.08	1.61
	C	80 – 155	80	90	1.13	630	LS	14.97	1.7
KCP1	Ap	0 – 12	80	70	0.88	300	LS	15.24	1.72
	AB	12 – 38	120	90	0.75	340	LS	13.85	1.58
	B	38 – 63	80	30	0.38	270	SCL	31.41	1.69
	CB	63 – 123	220	250	1.14	610	SL	30.3	1.68
	C_1	123 – 159	80	30	0.38	180	SL	20.13	1.74
	C_2	159 – 176	100	70	0.70	430	SL	38.52	1.65
KCP2	Ap	0 – 20	120	90	0.75	360	LS	19.76	1.64
	Bt	20 – 62	220	70	0.32	320	LS	19.76	1.66
	B_1	62 – 126	100	70	0.70	330	LS	14.57	1.51
	B_2	126 – 168	120	70	0.58	330	LS	13.11	1.73
	CB	168 – 200	220	90	0.41	530	SL	21.24	1.82
KCP3	Ap	0 – 46	80	70	0.88	360	LS	16.53	1.66
	B	46 – 97	100	90	0.90	360	SCL	17.24	1.69
	C	97 – 145	100	70	0.70	360	LS	20.91	1.65

Table 2: Soil chemical properties

Profile	Horizon	Depth	pH		OC	Ca	Mg	K	Na	CEC	EA	BS
		cm	H_2O	KCl	g kg^{-1}	←		cmol(+)kg^{-1}			→	%
BDCP1	Ap	0 – 20	6.2	5.6	0.375	1.8	0.6	0.05	0.02	10	1.4	24.7
	Btv	20 – 81	5.8	4.7	0.375	2.2	1	0.05	0.02	16.8	2	19.46
	Bt	81 – 128	6.6	5.3	0.375	2	0.8	0.05	0.02	14	1.4	18.28
	CCv	128 – 175	6.7	5.4	0.075	1.8	0.8	0.005	0.01	15.2	1.2	17.14
BDCP2	Ap	0 – 35	6.1	5.1	0.781	1.6	1.2	0.09	0.04	9.2	2.2	31.85
	Btv	35 – 106	6.9	5.7	0.164	1.6	1.8	0.01	0.006	10	1.2	34.16
	CBtv	106 – 173	7.1	6.1	0.164	0.8	1.8	0.01	0.006	7.2	1.2	36.33
BDCP3	Ap	0 – 12	6.9	6.2	1.013	4.6	0.8	0.09	0.05	16.4	1	33.78
	CB	12 – 62	6.5	5.3	0.263	2	1.4	0.01	0.008	19.6	1.4	17.44
	C	62 – 126	6.9	6.2	0.075	1.2	1.2	0.005	0.001	9.6	1.2	25.06
MCP1	Ap	0 – 12	6.7	5.9	1.676	2.6	1	0.09	0.05	11.2	1.6	33.39
	B	12 – 36	6.4	5.5	0.479	1.8	0.6	0.05	0.02	14	1.4	17.64
	C	36 – 200	6.6	5.7	0.439	2.4	1	0.05	0.02	20.8	2.2	16.68
MCP2	Ap	0 – 12	6.7	5.6	0.838	1.2	1	0.104	0.06	13.6	2.2	17.38
	Bt	12 – 38	6.7	5.5	0.798	2	0.4	0.101	0.06	8	2	32.01
	C	38 – 200	6.5	5.4	0.082	2.2	1.2	0.09	0.05	17.6	1	22.03
MCP3	A	0 – 30	7.1	6.3	1.058	2.8	1.2	0.09	0.05	8.8	1.2	47.05
	B	30 – 80	7.5	6.1	0.326	1.2	3.6	0.05	0.02	12.4	1.2	39.27
	C	80 – 155	7.4	6.3	0.285	1.2	2.4	0.011	0.008	19.2	1.2	18.85
KCP1	Ap	0 – 12	6.6	5.4	1.439	1.6	1.4	0.09	0.05	10.8	1.8	29.07
	AB	12 – 38	6.3	4.8	0.37	0.8	1.2	0.05	0.02	9.2	1	22.5
	Bt	38 – 63	6.3	4.6	0.37	2	1	0.05	0.02	12.4	2.2	24.76
	CB	63 – 123	6.4	4.1	0.247	1.6	0.4	0.009	0.007	8	2	25.2
	C	123 – 159	7.3	6.6	0.123	1	1.6	0.01	0.008	8	1.8	32.73
		159 – 176	7.2	6.2	0.041	1	0.8	0.009	0.008	6.4	1	27.12
KCP2	Ap	0 – 20	5.4	4.1	1.726	1.2	1	0.103	0.06	9.6	1.8	24.61
	Bt1	20 – 62	5.9	4.1	1.069	2.4	1.4	0.09	0.05	28	1.6	14.07
	Bt2	62 – 126	6.4	4.4	0.411	2.2	2.4	0.05	0.02	16	1.8	29.19
	BC	126 – 168	6.6	5.1	0.164	1.2	1.8	0.009	0.007	9.6	0.8	31.42
	C	168 – 200	6.6	5	0.123	1.2	0.8	0.009	0.005	6	1.6	33.57
KCP3	Ap	0 – 46	6.5	5.6	0.244	1.6	0.4	0.009	0.004	10	1.2	20.13
	Bt	46 – 97	5.8	4.3	0.529	7.4	2.6	0.06	0.02	16.8	3.6	60
	C	97 – 145	6.3	5.1	0.081	1.2	1.2	0.005	0.001	15.2	3	15.83

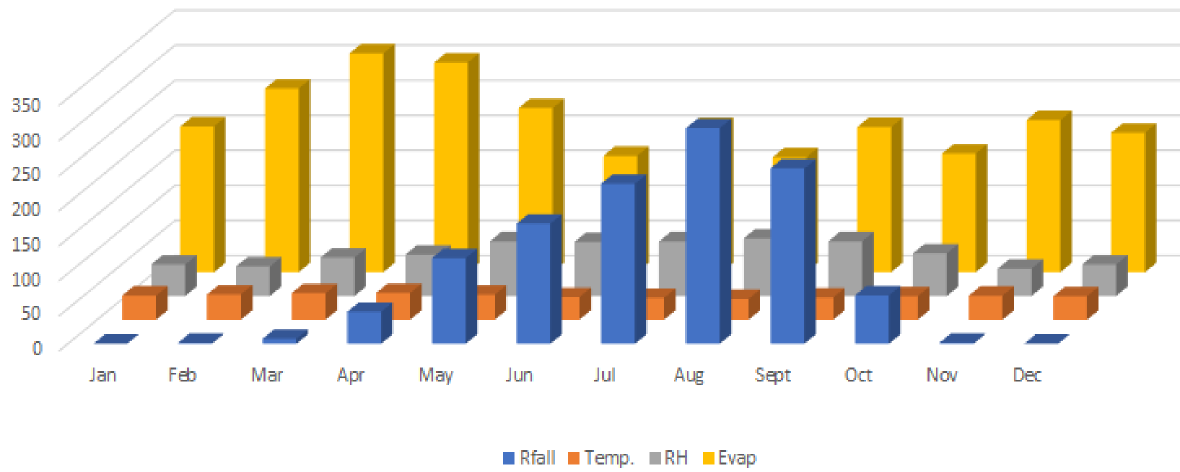

Fig. 1 Climatic data of the study area (*Source: Taraba State Water Board,2018*)

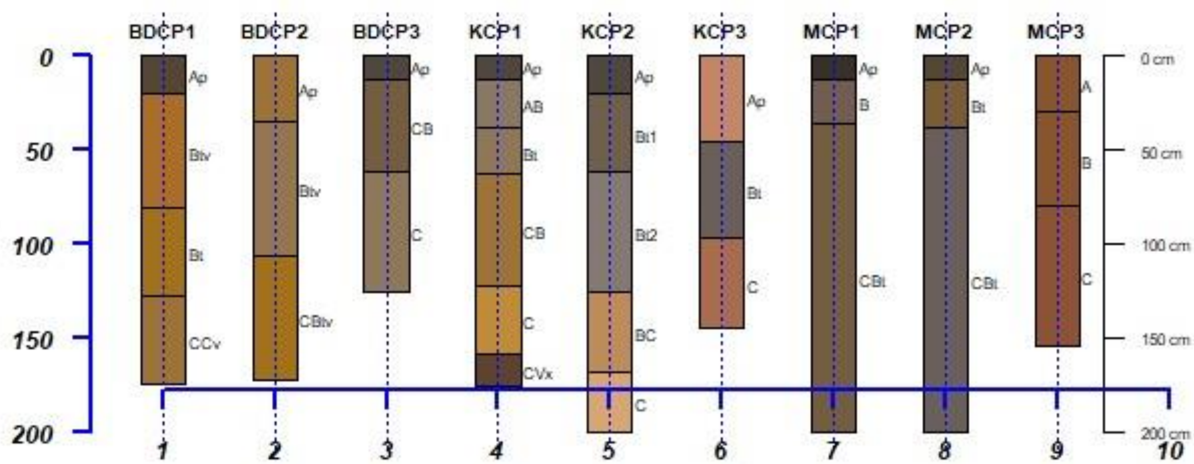

Fig. 2 Depth function of soil colour matrices of the study areas

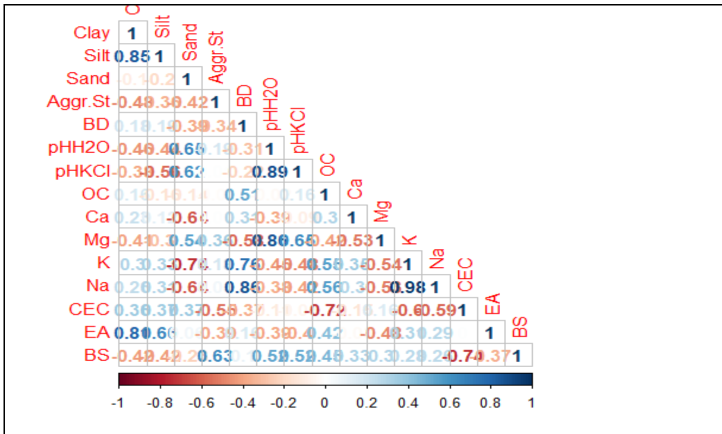

Fig. 3a Correlogram of granite gneiss (GG) chemical and physical properties

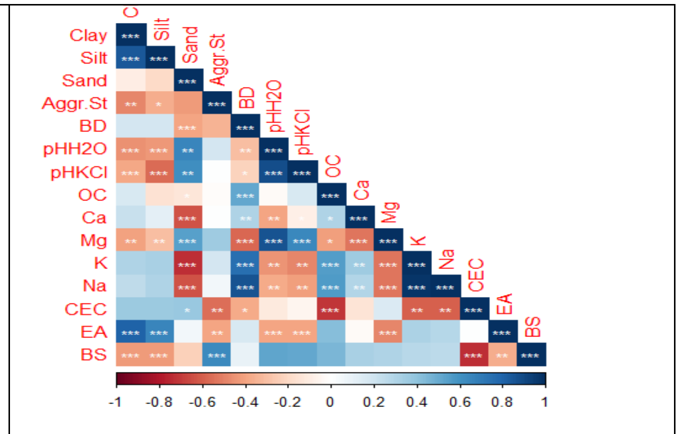

Fig. 3b Correlogram of granite gneiss (GG) chemical and physical properties

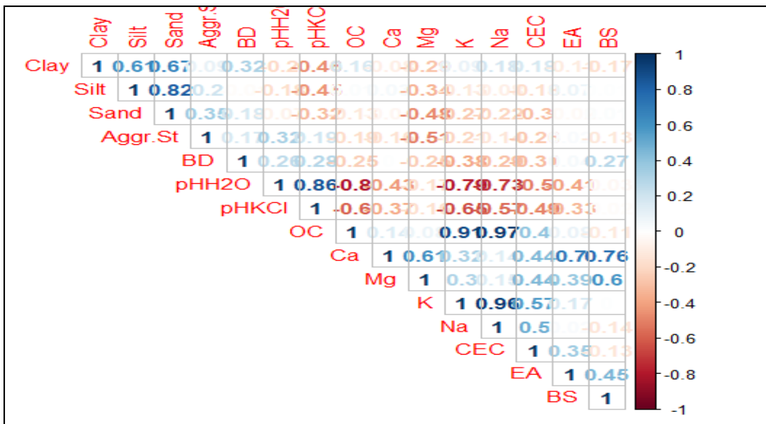

Fig. 4a Correlogram of pegmatite (PM) physical and chemical properties

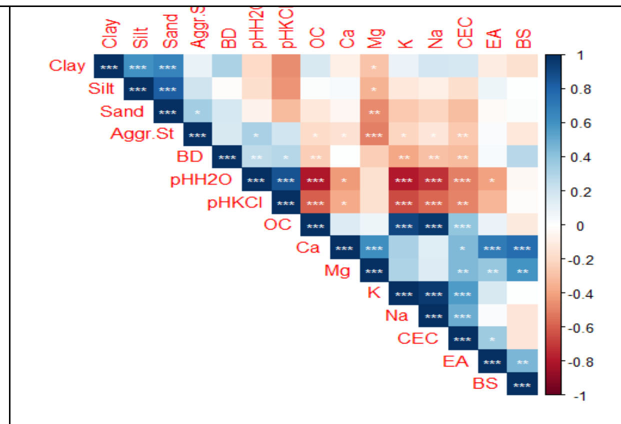

Fig. 4b Correlogram of pegmatite (PM) physical and chemical properties

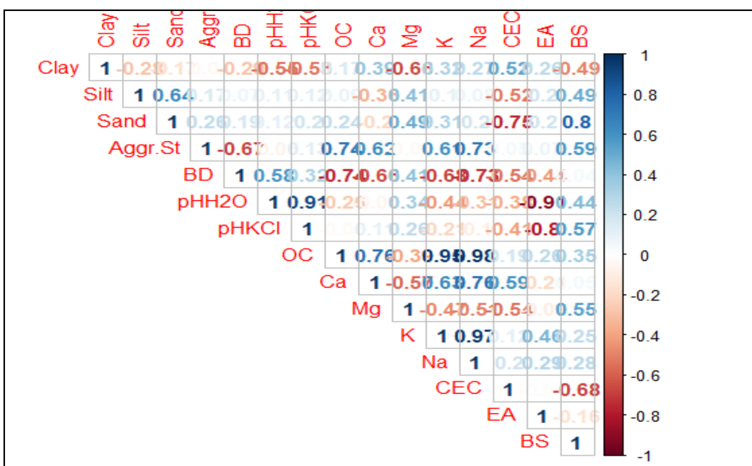

Fig. 5a Correlogram of porphyritic granite (PG) physical and chemical properties

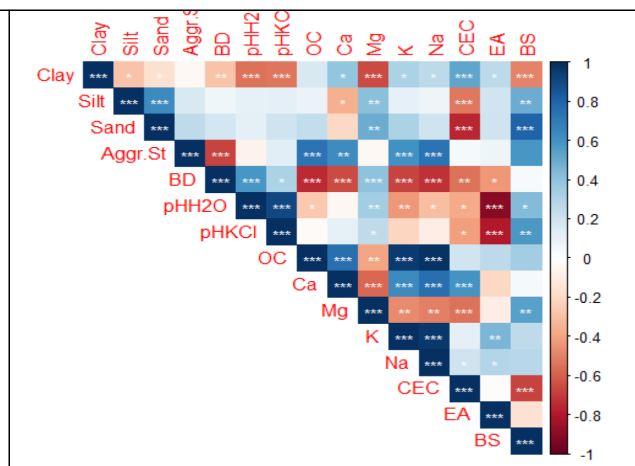

Fig. 5b Correlogram of porphyritic granite (PG) physical and chemical properties