



Impact of Iron and Aluminum on the Aggregate Stability of Some Latosols in Central and Southern Liberia (West Africa)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Problem: Latosols of Liberia are marked by intense surface leaching, strong acidity, low soil organic matter (SOM) content, and low nutrients status, caused by low aggregate stability, which are limiting factors to crop production.

Aim: to evaluate the effect of soil organic carbon (SOC) different forms of Fe and Al on the aggregate stability of latosols.

Methodology: Composite surface (0-20 cm depth) samples of four latosols at different localities in Liberia (Lat1, Phebe; Lat2, Felela; Lat3, Salala; Lat4, Todee) were collected and analyzed for aggregate stability parameters and factors by standard laboratory methods.

Results: the studied soils are sandy clayey, very acidic and poor in SOC. The cation exchange capacity (CEC) ranges from 10.28 to 14.80 mmol.kg⁻¹. Dominant forms of Al and Fe are free Fe (Fed) and Al [1], followed by amorphous Fe (Feo) and Al (Alo) and chelated Fe (Fep) and Al (Alp). The highest levels of water dispersible clay (WDC) and clay dispersible index (CDI) in Lat1 and Lat2 implied that these two soils are less stable compared to Lat3 and Lat4. The Fe and Al in all forms seem to contribute to soil aggregate stability. The SOC, although very low, also contributes to soil aggregate stability. SOC correlated positively with WDC, CDI and ASC, indicating the impact of SOC both as an aggregating agent and as a dispersing agent, in contrast to previous studies.

Conclusion: The study reveals that Fe, Al and SOC are cementing materials which impact the aggregate stability in Latosols.

Keywords: Latosol; Aggregate stability; soil organic carbon; erosion; iron; aluminum, Liberia.

1. INTRODUCTION

Soil aggregation contributes to soil quality improvement as it promotes root penetration, plant growth, soil erosion prevention, soil nutrient recycling and soil compaction reduction [1-4]. Moreover, soil aggregation can increase SOC sequestration by protecting carbon from decomposition [5]. Soil aggregate stability is commonly used as an indicator of soil structure [6], because better soil structure and higher aggregate stability are key factors to soil fertility improvement, sustainability and productivity [7].

Soil aggregate stability is estimated by investigating the process of aggregate fragmentation or the factors that stabilize aggregates. Soil stabilizing factors are principally linked to soil mineralogy and organic matter, which may be influenced by agricultural practices [8]. Indeed, SOM, Al or Fe oxides and colloidal silica or calcium carbonate are cementing substances that control aggregate formation [9]. The importance of these cementing substances is relative and depends on their abundance and associations, as well as on the environmental conditions under which soil aggregates are formed [10]. In highly weathered, humid tropical soils, Fe and Al oxides bind with soil particles to form stable structural units, promoting the stability of soil aggregates and therefore reducing soil erosion [11]. In kaolinitic soils with low clay

and organic carbon, Fe-oxides may form granular soils, enhance the strength of soil aggregates and improve soil aggregate stability [12]. Fe oxides interact with positively charged oxides and negatively charged clay minerals to form organo-mineral complexes [13]. Fe oxides associated to organic and inorganic compounds, or aggregates via cation bridges, are the greatest dynamic components in soils to improve soil structure [14]. Al oxides improve the stability of aggregates by acting as flocculants, binding fine particles to organic molecules and precipitating as gels on clay surfaces [15,16]. Previous studies have identified amorphous aluminous compounds [17] as binding substances of silt size particles [18]. At low clay content, Alo controls the formation of large and resistant aggregates, maintaining the resistance of soil to wind erosion [19].

In addition to the aggregates stability, soil dispersion is among the main factors controlling the stability of soil structure in topsoil [20]. The soil dispersion index such as WDC, dispersion ratio [21] and CDI, clay-flocculation index (CFI) and silt + clay aggregate are widely used to estimate microaggregate stability [22,23]. Previous studies report the strong correlation between aggregate stability and WDC, which indicates that the variations affect mainly flocculation and aggregation in microaggregates [24]. Moreover, there is significant correlation between WDC contents and wetting and drying

cycles, indicating that WDC is influenced by wetting and drying cycles [25]. The relationship between Fe and Al sesquioxides content and the stability index of micro-aggregates, such as the DR and ASC, are extensively documented [22,26]. Soils with high microaggregate indices (CFI and ASC) have greater structural stability than those with low indices [22,26].

There are three dominant soil classes in Liberia, namely laterites (latosols), sandy (Regosols) and alluvial (Fluvisols) soils [27]. Latosols are widely distributed and cover about 75% of land surface in Liberia where they are very acidic (pH 3-5) and contain abundant Al and Fe oxides [28]. Mining extraction (iron, gold and diamond) and deforestation remove vegetation and expose the soil to erosion. As the Fe and Al are abundant in the latosols, different forms of these oxides and their effects on aggregates stability need to be elucidated in order to secure the soils from erosion and enhance soil fertility. Consequently, the objective of this paper was to evaluate the effect of different forms of Fe and Al on the aggregate stability in the latosols. The results obtained will serve as baseline data for designing strategies to protect and evaluate latosols in Liberia for more efficient crop production.

2. MATERIALS AND METHODS

2.1 Study Site Description and Fieldwork

The studied soils were collected from Phebe, (Lat1) at N07°02.55' W9°32.56'; Felela, (Lat2) at N06°45.18' W10°01.23'; Salala, (Lat3) at N06°44.53' W10°7.35' from Suakoko district in Bong County, and Todee, (Lat4) at N06°18.17' W10°42.22', in Montserrado County (Table 1). Ten topsoil samples were collected per locality and mixed to form a composite sample. Overall, the climate of studied sites is tropical, and the details are summarized in Table 1. The parent material of the studied soils is Gneiss. The studied soils were classified as Latosol (Soil taxonomy, Brazil) and were collected at the topsoil (0-20 cm depth).

2.2 Laboratory Procedures

In the laboratory, soil samples were air-dried, crushed, and passed through a 2 mm sieve to remove extraneous material such as root, plant, and others. The particle size distribution was determined by the Robinson's pipette method. The soil particle size distribution of < 2 mm fractions was collected using the pipette method

[29], after H₂O₂ pre-treatment using the methods described previously by [30]. The results obtained were thereafter used to determine the total clay content. Water-dispersible clay (WDC) and silt (WDSi) were determined using the particle size distribution analysis method reported above [29], with the exception that no chemical dispersant was applied on the samples. Nonetheless, only mechanical agitation with an end-over-end shaker was employed after soaking the samples for 16 h. The indices of microaggregate stability were determined using the relationships explained below [11,22] :

$$\text{ASC (aggregated silt+clay)} = (\text{TS} + \text{TC}) - (\text{WDSi} + \text{WDC}) \quad (1)$$

$$\text{CFI (clay-flocculation index)} = (\text{TC} - \text{WDC}) / \text{TC} \quad (2)$$

$$\text{DR (dispersion ratio)} = (\text{WDSi} + \text{WDC}) / (\text{TC} + \text{TS}) \quad (3)$$

$$\text{CDI (clay dispersion index)} = \text{WDC} \times 100 / \text{TC} \quad (4)$$

Where:

TS: the total silt content or the one from chemically dispersed soil,

TC: the total clay content or the one from chemically dispersed soil,

WDSi: the water-dispersible silt content,

WDC: the water-dispersible clay content.

The pH of the bulk soil before fractionation was determined in distilled water by 1:2.5 soil: water ratio. The CEC was measured using the ammonium acetate (1 M and pH 7.0) method. SOM was determined by the K₂Cr₂O₇ wet oxidation method. The Fe_o and Fe_d were determined by ammonium oxalate, Fe_d and Al_d were determined by dithionite-citrate-bicarbonate (DCB) method, and the Fe_p and Al_p were extracted by sodium pyrophosphate method [31].

Data analysis of the stability indices and the Fe- and Al-oxide contents of soils and aggregates were performed using SPSS17.0 and origin 9 pro.

3. RESULTS

3.1 Soil Chemical and Physical Properties

The physico-chemical properties of studied soils are shown in Table 2. All the studied soils are acidic, with pH varying from 3 to 4. The studied soils are poor in organic carbon, their values decrease from 10.23 g.kg⁻¹ to 4.50 g.kg⁻¹, with the lowest value attributed to Lat3 and the highest value to Lat1 (Table 2). The Cation

Exchange Capacity (CEC) was 14.80 mmol.kg⁻¹ in Lat1, 12.45 mmol.kg⁻¹ in Lat2, 10.28 mmol.kg⁻¹ in Lat3, and 11.98 mmol.kg⁻¹ in Lat4. The sand and clay fractions are dominant particle size fractions in Lat1, Lat2, Lat3, and Lat4. These studied soils belong to sandy clay textural class (Table 2).

3.2 Distribution of Iron and Aluminum Oxides in the Studied Soils

The distribution of Feo and Feo, Fed and Fed, and Fep and Alp were compiled in Table 3. The Feo and Feo extracted forms are the most dominant, followed by amorphous and chelated extracted forms (Table 3). The Fed ranges from 78.25- 87.4 g.kg⁻¹ with the lowest value in Lat2 and the highest value in Lat1 while the Ald ranges from 15.72- 20.23 g.kg⁻¹ with the lowest value in Lat3 and the highest value in Lat4. In the

studied soils, the levels of Feo vary from 1.01 g.kg⁻¹ in Lat1 to 4.24 g.kg⁻¹ in Lat3, while those of amorphous Al change from 2.34 g.kg⁻¹ to 4.70 in Lat3. The chelated extracted forms are very low in all the studied soils and their values were less than 1 g.kg⁻¹ (Table 3).

3.3 Aggregate Stability Indices of Studied Soils

The aggregate stability indices of the studied soils are compiled in Table 4. The WDSi, which is used to estimate the instability, ranges from 313 to 343 g.kg⁻¹, with lowest value in Lat1 and the highest one in Lat4. The water-dispersible clay and the instability indices range from 50 g.kg⁻¹ in Lat3 to 77 g.kg⁻¹ in Lat1. The dispersion ratio changes from 0.7 in Lat1 to 0.9 in Lat3. Their values are 0.8 and 0.7 in Lat2 and Lat4,

Table 1. Characteristics of the studied sites

Sample	Site	Location	Soil Type	Land use	Temperature	Precipitation (mm/year)	Parent material
Lat1	Phebe	N07°02.55' W9°32.56'	Latosol	Cacao	29 °C	2000	Gneiss
Lat2	Felela	N06°45.18' W10°01.23'	Latosol	Rubber	28 °C	2200	Gneiss
Lat3	Salala	N06°44.53' W10°07.35'	Latosol	oil-palm	25 °C	2400	Gneiss
Lat4	Todee	N06°18.17'W10°42.22'	Latosol	pineapple	26 °C	2300	Gneiss

Table 2. Main properties of the studied Latosols

Soil Type	pH	SOC (g kg ⁻¹)	CEC (mmolkg ⁻¹)	Sand (g kg ⁻¹)	Silt (g kg ⁻¹)	Clay (g kg ⁻¹)	Texture
Lat1	4.00	10.23	14.80	440.23	89.77	470.00	SC
Lat2	4.20	8.70	12.45	468.39	90.75	440.86	SC
Lat3	3.40	4.50	10.28	572.14	77.49	350.37	SC
Lat4	3.55	5.20	11.98	337.97	81.82	580.21	SC

SOC: soil organic carbon; CEC: Cation exchange capacity; SC: Sandy clay

Table 3. Quantities (g kg⁻¹) of different forms of iron (Fe) and aluminium (Al) oxides in the studied soils

Soil type	Al-oxide			Fe-oxide		
	Ald	Alo	Alp	Fed	Feo	Fep
Lat1	16.25	2.34	0.9	87.4	1.01	0.3
Lat2	19.1	3.26	0.6	78.25	1.98	0.1
Lat3	15.72	4.70	0.8	82.54	4.24	0.2
Lat4	20.23	5.12	0.9	86.98	2.9	0.2

Ald: free Al- oxides; Fed: free Fe-oxides; Alo: amorphous Al- oxides. Feo: amorphous Fe- oxides; Alp: organic complexes of Al-; Fep: amorphous Fe- oxides

Table 4. Aggregate stability indices of the studied Latosols

Sample	WDSi (gkg ⁻¹)	WDC (gkg ⁻¹)	DR	CDI	CFI	ASC (gkg ⁻¹)
Lat1	316	77	0.7	16.4	0.8	167
Lat2	341	85	0.8	19.3	0.8	106
Lat3	323	50	0.9	14.3	0.9	55
Lat4	343	68	0.7	14.2	0.9	151

WDSi: water-dispersible silt; WDC: water-dispersible clay; DR: dispersion ratio; CDI:clay dispersion index; CFI: clay-flocculation index; ASC: aggregate silt+clay

Table 5. Correlation coefficient between Latosol stability indices and aggregating agents

Parameters	WDC	DR	CDI	CFI	ASC
Soc	0.8	-0.6	0.7	-0.7	0.6
Fed	-0.2	-0.7	0.7	0.7	0.7
Feo	-0.9	0.8	-0.6	0.6	-0.8
Fep	-0.2	-0.5	-0.5	0.5	0.5
Ald	0.5	-0.3	0.2	-0.2	0.4
Alo	-0.7	0.4	-0.7	0.7	-0.4
Alp	-0.4	-0.5	-0.8	0.8	0.5

WDC: water-dispersible clay; DR: dispersion ratio; CDI: clay dispersion index; CFI: clay-flocculation index; ASC: aggregate silt+clay

respectively. The clay-flocculation index (CFI) is less than 1 in all the studied soils. Their values range from 0.8 in Lat1 and Lat2, to 0.9 in Lat3 and Lat4. The values of aggregated silt+clay range from 55 g.kg⁻¹ in Lat3 to 167 g.kg⁻¹ in Lat1. The ASC is 106 g.kg⁻¹ in Lat2 and 151 g.kg⁻¹ in Lat4.

3.4 Relationships between Aggregate Indices and Aggregating Agents (SOC, Fe and Al)

The correlation matrix between the aggregate indices and the aggregating agents (SOC, Fe and Al) is shown in Table 5. WDC is only positively correlated with SOC and Ald. The DR correlates positively with Feo and Alo. Also, there is a positive correlation between CDI and SOC, Fed and Ald. In addition, CFI correlates positively with different forms of Fe and Al, except for Ald.

For ASC, there is a positive correlation with SOC, Fed and Fep. In the studied soils, ASC is an important aggregate stability index. A regression analysis was performed between ASC, clay, Feo, and Alo. The best regression equations were (Fig 1):

$$ASC = -15.73 + 180.21, R^2 = 0.16$$

$$ASC = -28.74(Feo) + 192.36, R^2 = 0.62$$

$$ASC = 10.29(SOC) + 45.87, R^2 = 0.32$$

$$ASC = 0.81(Tclay) - 232.75, R^2 = 0.90$$

Fig. 1 shows that silt+clay aggregates have an inverse correlation with amorphous Alo and Feo, whereas ASC correlated positively with SOC and total clay (Fig.1).

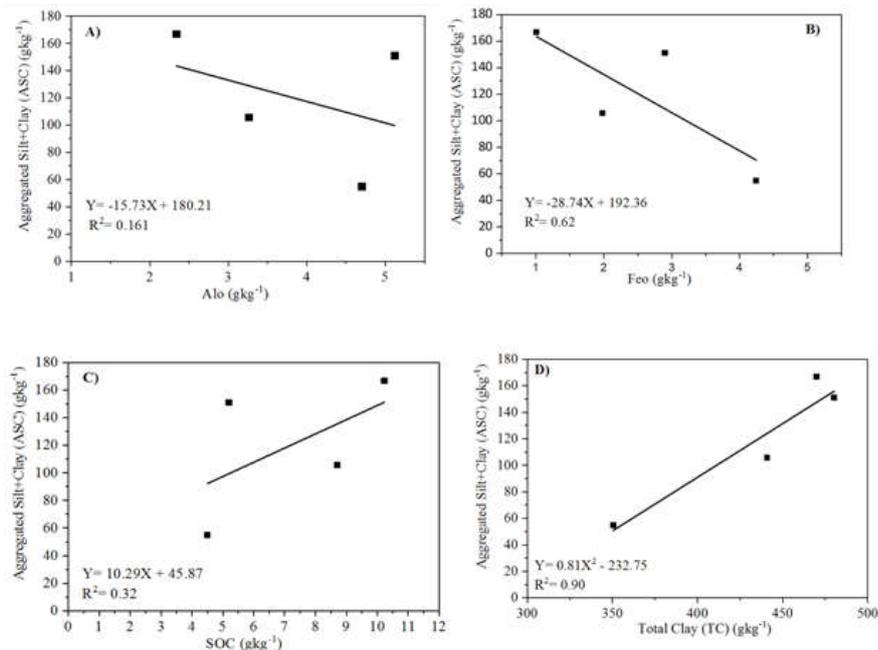


Fig. 1. Relationship between ASC and Alo, SOC, Feo and TC in the studied soils

4. DISCUSSION

4.1 Aggregate Stability of the Latosols

The WDC, DR, and WDSi are all indicators of the rate of soil dispersion. It has been reported that soils with low WDC, WDSi and low to moderate DR are stable and less erodible [22]. In this study, the variability of WDSi values is not considerable among the studied soils. To distinguish between the stability between the study soils, the WDC and CDI will be considerate. As previously reported, high WDC and dispersion indices have negative consequences on soils and the entire environment in terms of water and wind erosion [32]. In the present study, the WDC is high in Lat1 and Lat2. Moreover, the CDI is high in Lat1 (16.4 g.kg⁻¹) and Lat2 showing that Lat1 and Lat2 are less stable compared to Lat3 and Lat4. Lat3 and Lat4 appear to be more stable but in the field, there are several degradation indices which contrast with the results obtained in the laboratory. Previous studies indicate that there are external factors that can impact on the aggregate stability such as climate, pedogenic processes, land use, deforestation and biological factors [14,22]. In these studied sites, the annual precipitation attains 2500 mm and could cause the degradation observed in the field. Findings proof that rainfall breaks main structural units and causes the rapid formation of crust resulting in depositional seals [33]. According to the author, the consequence of this categorization of events is that soil aggregate breakdown is the prime regulation in the erosional system.

4.2 Role of SOC, Fe and Al Oxides in Aggregate Stability

In this study, SOC correlated positively with WDC, CDI and ASC, indicating the positive impact of SOC both as an aggregating agent and as a dispersing agent. This finding contrast with works of [22]. However, the present finding agrees with those on the key role of SOC in soil aggregation [34-36]. Previous studies reveal that the role of SOC as aggregation or dispersing agent is strongly linked to the soil quality and the quantity of SOC [22]. The quantity of SOC is low in the studied latosols, varying from 4.50 gkg⁻¹ in Lat3 to 10.23 g.kg⁻¹ in Lat1, indicating that the SOC might act as aggregating agent independently of its quantity in soil, but the significance of this action will increase with increasing SOC contents.

The present study reveals that WDC positively correlates with Ald, DR positively correlates with Feo and Alo. In addition, CDI positively correlates with Fed and Ald, CFI correlates positively with different forms of Fe and Al except for Ald, while ASC positively correlates with Alp and Fed. Such results unfold the significant role of the different forms of Fe and Al on the aggregate stability in the soils. There is ongoing debate on the forms of Al and Fe that may be responsible for aggregate stability in soils of tropical regions. For instance, some studies support the oxalate-extractable forms of Fe oxide might be responsible for the aggregation of some subtropical and tropical soils [21,35,37]. Other works argue that Al oxides are better aggregating agents than Fe oxides in some tropical soils [38]. The present study confirms that Al and Fe oxides, independent of their forms, contribute to the soil aggregate stability.

5. CONCLUSION

The present work investigated the role of Fe and Al oxides on the aggregate stability of some Liberian Latosols. Thus, all four studied Latosols were acidic, with low SOC. The dominant forms of Al and Fe were free Fe and Al, followed by amorphous Fe and Al, as well as chelated Fe and Al. The high values of water dispersible clay and clay dispersible index in some of the studied Latosols might imply a less stable aggregate stability. The Fe and Al in all their different forms seem to contribute to the soil aggregate stability. The SOC, although very low, contributes to soil aggregate stability. The present study suggests that Fe and Al as well as SOC are cementing materials which impact aggregate stability in the four Latosols. However, further studies are required to investigate the relationship between these cementing agents and the mechanisms accompanying the aggregate stability of these West African Latosols.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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