Morphological characteristics and classification of soils formed from acidic sedimentary rocks in North Kalimantan

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Abstract. The morphology of acidic mineral soils explains the evolution that occurs in the soil body during the process of soil formation, which is predominantly influenced by the parent material and climate. Determination of epipedon and endopedon of diagnostic horizons through description and interpretation of soil profile properties is the basis of land classification, as the knowledge of soil properties, capabilities, and utilization. This research was a descriptive study, carried out in North Kalimantan using a survey method at two different locations based on the rock types, namely Location 1 (clay sand sedimentation) and Location 2 (sandstone). The description and interpretation of soil morphology were carried out by observing the nature of the soil profile, then determining the diagnostic horizon and soil classification referring to the Field Observation Guidelines in the Field and Key to Soil Taxonomy. The results of the study found that, based on its morphological characteristics, the soil in Location 1 had brighter colors, lower OC, higher Al solubility, and a thicker horizon compared to the soil in Location 2. Meanwhile, the texture, structure, pH, and consistency were the same. In both soil profiles, umbric epipedon and cambic endopedon were found. Therefore, the soil was classified as Inceptisols. At the sub-order level, Location 1 was classified as Udepts, and Location 2 as Aquepts. At the great group level, the soil in Location 1 was classified as Hapludepts, and the soil in Location 2 as Endoaquepts. This type of soil had low natural fertility therefore the efforts are needed to improve its ability and utilization through amelioration and fertilization technology.

Keywords: Acidic Sediments, Soil Morphology, Hapludepts, Cambic

1. Introduction

Dryland in Kalimantan region is dominated by mineral soils formed from acidic sedimentary rocks. The spread is estimated reach an area of 30.15 million ha or 57.22% of the total area of Kalimantan Island (Puslittanak, 2000; Suharta, 2010). The characteristics of acidic sedimentary rocks vary due to their formation process, which depends on the characteristics of the component materials, the process or model of the deposition, and the environmental conditions of the deposition area. Physio-graphically, mineral soils from acidic sedimentary rocks spread...
to tectonic landforms, which are formed as a result of geomorphic processes from inside (endogenous/hypogenous) or from outside (exogenous/epigenous), like in forming of forces, folds, faults, and/or a combination thereof (Marsoedi et al., 1997). The relief or slope formed in this landform is closely related to geomorphic processes and its lithological (structural) properties.

Soil morphology is the presence of the soil properties observed and studied in the field (Hardjowigeno, 1993). Study on the soil morphology is very important to get a picture of changes, or evolution, that occur in the soil body through the description and interpretation of soil profile properties in the form of diagnostic epipedon and endopedon, which will be the initial information in soil classification activities. Soil classification is important to have the information of soils properties of the soil and theirs productivities. Land use that based on soils characteristics and capability will be more productive and can minimize the threat of wasteful land use, leads to in decreasing the sustainability of land resources.

The natural fertility of acidic mineral soils is very dependent on the mineral composition of the parent material or soil nutrient reserves. The higher the soil nutrient reserves, the higher the level of soil fertility. Nutrients in the soil are very dependent on the composition, amount, and type of minerals. Marginal soils from acidic sedimentary rocks had low mineral reserves or nutrient reserves. Marginal soils in Kalimantan are characterized by various soil textures from sand to clay due to acidic sedimentary rocks formed from two types of soil parent material, namely coarse-textured sandstone and fine-textured claystone or siltstone (Suharta, 2010). The characteristics of acidic sedimentary rocks vary due to their formation process, which depends on the nature of the component material, the process or model of the deposition, and the environmental conditions of the deposition area.

Each soil has unique characteristics, consequently, the data on the morphology and diagnostics of epipedon and endopedon are needed to determine the overall development of the soil in balance with the environment. This study aimed to determine the morphological characteristics and classification of the soil formed from acidic sedimentary rocks in North Kalimantan.

2. Materials and Method

2.1. The condition of soil and environment
This research was a descriptive exploratory study, carried out using a survey method in the field and supported with data from laboratory analysis. This research was conducted in two locations classified based on the differences in soil parent material. The first location was East Tarakan District located at 3°23’28” E and 117°32’56” N with soils composed of clay sand sedimentation. Meanwhile, the second location was West Tarakan District located at3°19’4” Eand 117°37’45” N with soils composed of sandstones (Figure 1). Some variables of soil and environments conditions observed were the average annual rainfall, average monthly evapotranspiration, dominant vegetation, altitude (asl), slope, and soil moisture regime.

2.2. Soil morphology observation
Observation of soil morphology in each profile was made based on the reference book for Field Observation Guidelines and Key to Soil Taxonomy 1999. Profiles were made perpendicular to the soil body measuring 1.5 m x 1.5 m to a depth of groundwater and parent material. Observation of soil morphological characteristics in each profile on each layer/horizon included solum thickness, layer boundary, color, texture, structure, consistency, and roots. The data were used to determine the diagnostic horizon (epipedon and endopedon) as the basis for land classification. Soil classification referred to Key to Soil Taxonomy 1999 –to the great group level category.
2.3. *Laboratory analysis*

Soil samples were taken at each horizon from the two soil profiles to analyze the soil chemical and physical properties. Soil samples were dried and sieved with a 2 mm diameter sieve. Texture was measured by using pipette method (Black et al., 1965), bulk density was measured by using Wax method (Blake and Hartge, 1986), density was measured by using pycnometer method (Blake and Hartge, 1986), pH H$_2$O (1: 2.5 ) was measured by using a pH meter (McLean, 1982), organic C was determined by using Walkley-Black method (Nelson and Sommers, 1982), cation exchange capacity (CEC) and available K, Ca, Mg, Na were determined by using NH$_4$Cl Extract (Hanudin, 2000), Total N was determined by using Kjeldahl/Titration method (Balittanah, 2009), and total P and K content were determined by using HCl 25% (Balittanah, 2009).

3. Results and Discussion

3.1. Environmental condition of the research site

The average of rainfall and evapotranspiration are 3900 mm yr$^{-1}$ and 41.65 mm month$^{-1}$, respectively. The soil moisture categorized into udic, where rainfall exceeds evapotranspiration. The soils in the study site are formed from different parent materials, namely clay sand and sandstone sediments, classified as acidic sedimentary rocks (Table 1). The region of the research site is wavy to hilly. The effective depth of the soil is shallow to deep. The depth of the soil in lowland areas is generally thick, while in slopy areas is thin. High rainfall caused the movement of water on high slope areas and leaching of soil particles, including organic matter, nutrients, and other soil components (Arsyad, 2000).

| Environment                  | Location 1 | Location 2 |
|------------------------------|------------|------------|
| Elevation (m dpl)            | 59         | 37         |
| Slope                        | 8-15       | 3-8        |
| Soil moisture regime         | Udik       | Udik       |
| Soil temperature regime      | termal     | termal     |
| Parents materials            | clay sand deposits | sandstone |

3.2. *Soil morphology*

The morphological characteristics of the two soil profiles are presented in Table 2. The thickness of the soil in the two profiles was different. The profile thickness of Profile 1 was more than 112 cm. In this depth the parent material was found. The thickness of Profile 2 was more than 59 cm, and the water table was found at this depth. There were no organic horizon in both profiles.

Horizon A tended to be dark (dull yellowish-brown, 10YR 4/3 and brownish-black, 10YR 3/2). In moist conditions, the color of the soil from the BW horizon was dull yellowish-brown (10YR 6/4) and yellowish-brown (10YR 6/4), gradually turned into brighter following the depth (Figure 1 and 2). The texture of the soil was dominated by sand in top soil. In BW1 horizon was silt loam and became coarser in C horizon (loamy sand). The dominance of the sand fraction was caused by leaching that occurred intensively, which was driven by a high amount of annual rainfall of around 3900 mm. Although there was an increase in clay on the BW horizon, it did not indicate the presence of argillic horizon, due to did not meet the requirement of an argillic horizon. Suharta (2010) stated that rough soil texture (sand dominance) leads to the low ability of the soil to retain water and nutrients, and the soil becomes prone to drought and sensitive to erosion.
In general, soil structure on the A-BW horizon (BW1 and BW2) was crumbs, and on the B/C and C horizon were granular. The soil consistency in moist conditions was loose in BW1, BW2 and B/C horizon, while in C horizon was loose. The roots in the two profiles were few and even did not found in the deeper horizon. The limitation of root indicated that the population of shrubs vegetation above the ground were rare.

Table 2. Morphological characteristics of soil in the research site

| Horizon | Depth (cm) | Munsell color | Texturea | Structure | Consistence | Rootsb | Boundaryc |
|---------|------------|---------------|-----------|-----------|-------------|--------|-----------|
| Location 1, Elevation 59 m | | | | | | | |
| A | 0-19 | 10 YR 4/3 | SiL | massive | gembur | mf | cs |
| BW1 | 20-41 | 10 YR 6/4 | SiL | massive | gembur | sf | ds |
| BW2 | 42-81 | 10 YR 7/8 | SL | massive | gembur | - | ds |
| B/C | 82-112 | 10 YR 7/8 | SL | massive | gembur | - | ds |
| C | >112 | 10 YR 7/6 | LS | granular | friable | - | - |
| Location 2, Elevation 47 m | | | | | | | |
| A | 0-20 | 10 YR 3/2 | SiL | massive | gembur | mc | cw |
| BW | 21-32 | 10 YR 5/6 | SiL | massive | gembur | ff | dw |
| B/C | 33-59 | 10 YR 6/4 | LS | granular | friable | fvf | dw |
| C | >59 | 10 YR 7/2 | LS | granular | friable | - | - |

a SiL: silt loam, LS: loamy sand, SL: sandy loam, L: loam
b c: common, m: many, s: some, f: few, c: coarse, m: medium, f: fine, vf: very fine
c a: abrupt, c: clear, s: smooth, g: gradual, d: diffuse, w: wavy, i: irregular, b: broken

3.3. Chemical and physical properties of the soil

The chemical and physical properties of the soil are presented in Table 3 and 4. The soil reactions were acid to very acid. The content of P and K nutrient was low to very low, while saturation of Al were high to very high. The available Fe were high to very high. The low soil pH was caused by the acidic sedimentary parent materials. The acidity of the soil caused the very high content of Al-dd and Fe-dd that affected the P content in the soil. Suharta (2010) stated that mineral soils formed from acidic sedimentary rocks in the Kalimantan region had acid to very acid reaction, contributed to high Al content and reduced the available P (Yatno et al., 2000). The level of soil salinity or was low to moderate, therefore salinity was not a problem.

The total N and organic C in were varied in these two sites from low to very low The N and organic C content tended to decrease with depth. This was the common situation, where the organic C content in the upper layer was higher than in the lower layer (Suharta, 2010). Soil nitrogen content was in line with the content of soil organic C due to some of soil nitrogen derived from organic matter. The presence of organic matter in acidic mineral soils was largely determined by the level of soil weathering and organic matter content and the types of minerals in the soil. Very low organic C content was caused by a very high decomposition process and the dominance of quartz mineral (about 98%). This was also stated by Suharta & Prasetyo (2008) on acidic mineral soils in Riau which were dominated by kaolinite, goethite, and quartz.

Coarse soil texture in the two research sites will cause the low soil ability in retain water nutrients that prone to be drought and to erosion. There was a close relationship between coarse soil texture and soil chemical fertility. The higher the content of sand fraction in acidic rock mineral soils in Kalimantan, the lower the content of organic C, N, P, and K, meanwhile the Al was higher (Suharta, 2007). Conversely, the higher the content of the clay fraction, the higher the content of P and K, exchangeable bases (Ca, Mg, and Na), soil CEC, and base saturation. Low organic matter content in the tropics was common due to the high mineralization process.

The exchangeable bases of soil in both locations were low to very low, the cation exchange capacity (CEC) was low, and the base saturation was very low. According to Suharta (2010), the exchangeable bases (Ca, Mg, K, and Na) in acidic minerals is classified as low to very low,
due to the excessive leaching and/or the parent materials had poor basic cation content. The exchangeable bases at the upper horizon was higher than the lower horizon, indicated the occurrence of plants residues in the upper (Suharta and Prasetyo, 2008), which were decomposed as organic matter (Quideau et al., 1999).

The CEC value is was influenced by the types of minerals and organic matter in the soil. Prasetyo et al. (2001) stated that soil developed from acidic sedimentary rocks was dominated by kaolinite, that naturally had a low CEC value. The presence of organic matter was very important in increasing the CEC value. The base saturation of acidic mineral soils in Kalimantan was relatively low to very low, whereas the saturation of Al was classified as very high, which increased with the increase of the solum depth (Suharta, 2010).
| Horizon | Depth (cm) | pH H₂O | N-tot (g kg⁻¹) | C-org (cmol⁺kg⁻¹) | P-tot (g kg⁻¹) | K-tot (mg kg⁻¹) | Al-sat (dSm⁻¹) | Fe-exch (mg kg⁻¹) | DHL (dSm⁻¹) | Soil fraction (g kg⁻¹) | Texture | BD (mg m⁻³) |
|---------|------------|--------|----------------|-------------------|----------------|----------------|----------------|-----------------|--------------|------------------------|----------|-------------|
| Location 1, Elevation 59 m |
| A       | 0-19       | 4,3    | 1,6            | 11,0              | 81             | 92,4           | 430            | 28,90           | 2,3          | 450                    | SiL      | 1,19        |
| BW1     | 19-41      | 4,9    | 1,0            | 9,5               | 70             | 121,5          | 490            | 11,63           | 2,19         | 430                    | SiL      | 1,21        |
| BW2     | 41-81      | 4,3    | 0,90           | 7,2               | 40             | 100,1          | 620            | 25,43           | 3,11         | 650                    | 220      | 130         |
| B/C     | 81-112     | 4,3    | 0,70           | 5,7               | 44             | 65,4           | 660            | 24,85           | 1,15         | 680                    | 180      | 140         |
| C       | >112       | 4,7    | 0,60           | 3,2               | 21             | 49,4           | 690            | 22,78           | 1,74         | 730                    | 150      | 120         |
| Location 2, Elevation 47 m |
| A       | 0-20       | 4,1    | 1,9            | 12,4              | 76             | 46,6           | 400            | 21,80           | 1,25         | 420                    | SiL      | 1,21        |
| BW      | 20-32      | 4,9    | 1,9            | 12,7              | 53             | 64,2           | 450            | 41,30           | 2,05         | 400                    | SiL      | 1,22        |
| B/C     | 32-59      | 4,4    | 1,2            | 11,2              | 33             | 32,9           | 580            | 31,70           | 0,67         | 790                    | 120      | 90          |
| C       | >59        | 4,1    | 0,80           | 0,80              | 20             | 108,2          | 630            | 46,73           | 1,11         | 660                    | 240      | 100         |

* BD: bulk density
| Table 4. Content of exchangeable bases, CEC and base saturation of soil in the research site |
|-------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Horizon   | Depth (cm) | Exchangable cations (cmol(+) kg⁻¹) | CECa (cmol(+) kg⁻¹) | BSb (g kg⁻¹) |
| Location 1, Elevation 59 m |
| A  | 0-19  | 0.75 | 0.28 | 0.18 | 0.17 | 10.0 | 140 |
| BW1  | 19-41  | 0.72 | 0.27 | 0.11 | 0.18 | 9.7 | 110 |
| BW2  | 41-81  | 0.32 | 0.11 | 0.10 | 0.08 | 7.0 | 90 |
| B/C  | 81-112 | 0.37 | 0.12 | 0.06 | 0.07 | 7.4 | 80 |
| C  | >112  | 0.17 | 0.08 | 0.09 | 0.03 | 5.1 | 70 |
| Location 2, Elevation 47 m |
| A  | 0-20  | 0.92 | 0.27 | 0.15 | 0.05 | 11.2 | 140 |
| BW  | 20-32  | 0.87 | 0.22 | 0.19 | 0.05 | 10.1 | 130 |
| B/C  | 32-59  | 0.36 | 0.20 | 0.16 | 0.05 | 7.1 | 110 |
| C  | >59  | 0.28 | 0.14 | 0.10 | 0.09 | 7.2 | 90 |

a CEC: cation exchange capacity; b BS: base saturation

3.4. Soil classification

Referring to the soil classification system of Soil Taxonomy (USDA, 1999), soil classification was carried out based on the diagnostic epipedon and endopedon. Based on the interpretation of environmental conditions, soil morphology, and supported by the results of laboratory analysis, the upper diagnostic horizon (epipedon) of the two soil profiles was classified as umbric epipedon, with the following characteristics:

a. Color values was 3 or less in moist condition and 5 or less in dry condition; and

b. Color chroma was 3 or less;

c. Chroma in the C horizon was least 1 unit lower, or a minimum chroma of 2 units lower than the umbric horizon

d. Base saturation was less than 50% in part or all parts of epipedone

e. Soil organic carbon content was 0.6% higher than in the C horizon.

The diagnostic horizon in the subsurface (endopedon) was classified as cambic horizon, with the characteristics following characteristics:

a. Aquatic conditions at a depth of 50 cm from the ground, or drained, with properties of having a soil structure, colors that do not change when open in the air, the dominant color, moist on the surface of the ped or in the matrix, value color of 4 or more, and chroma of 1 or less

b. Not having aquatic combinations in 50 cm from the ground or drained and having a soil structure, higher chroma, higher color values, and higher clay content compared to the upper horizon

c. Having properties that do not meet the requirements for other epipedons.

Based on the diagnostic horizon in the surface (epipedon) and subsurface (endopedon), the soil in both locations was classified as Inceptisols. At the sub-order level, the soil in Location 1 was classified as Udepts due to had udic soil moisture regime. Meanwhile, the soil in Location 2 was classified as Aquepts because, at a depth of 50 cm from the surface, the mineral soil had aquatic conditions during the time of normal years (or drained). At the great group level, the soil in Location 1 was classified as Hapludepts because of the limited development of the
horizon, while the soil in Location 2 was classified as Endoaquepts because of the presence of water table in the solum.

4. Conclusion
The factor of soil formation greatly influences the type of soil formed. The acidic sediments and high rainfall of around 3900 mm\(^{-1}\) were the dominant factors affecting the formation of acidic Inceptisol in Kalimantan, based on the umbric diagnostic epipedon and cambic endopedon. Chemical characteristics and soil morphology showed that the pH and the level of natural fertility were very low, the soil color of the surface was dark and being lighter in the deeper soil depth, the texture of the soil was dominated by fine sand, and the C horizon was dominated by coarse sand. Soil structure on the A horizon to BW (BW1 and BW2) were crumbs, with loose soil consistency. Since the vegetation on the upper layer was dominated by shrubs, the fine roots were only reaching the depth of 40-50cm. The border of the upper horizon was clear, while the border of the lower horizon was unclear.

Soil classification at the sub-order level showed that the soil at Location 1 was classified as Uddepts, and the soil in Location 2 was classified as Aquepts. At the great group level, Location 1 was classified as Hapludepts, and Location 2 was classified as Endoaquepts. Acidic Inceptisol soil is very potential to be used for the agricultural sector. Therefore, amelioration technology and fertilization technology can be carried out as an effort to improve chemical properties and low soil fertility of the soil.

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