Physical and chemical characteristics in peat lands of Aceh Jaya District, Indonesia

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Abstract. This study aims to determine the physical and chemical characteristics of the peat lands (Histosols) in Aceh Jaya District using descriptive method. The results showed that some physical characteristics such as: water saturation in drilling-M1 (fibric soil materials) was 786.06% higher than drilling-M2 (hemic soil materials) and drilling-M3 (sapric soil materials) were 568.01% and 549.97%, respectively. Bulk density (BD) of drilling-M1, drilling-M2 and drilling-M3 are very low (0.08 - 0.12 g cm⁻³). Porosity in drilling-M1, drilling-M2 and drilling-M3 are classified as very porous at 95.00%, 93.00% and 90.54%. Some chemical characteristics show as follows: pH in drilling-M1, drilling-M2, and drilling-M3 categorized acid (4.52 - 5.16). Organic-C in drilling-M1, drilling-M2, and drilling-M3 ranges of 20.75 - 55.62% (very high). Exchangeable bases for calcium (3.6 - 23.9 cmol.kg⁻¹), Mg (0.6 - 18.1 cmol.kg⁻¹), and K (0.18 - 1.22 cmol.kg⁻¹) are classified as low - very high. Exchangeable acidity for H (1.2 - 6.1 cmol.kg⁻¹) higher than Al measured only in the drilling of M3 layers of Oa3 (2.3 cmol.kg⁻¹). The CEC in drilling-M1, drilling-M2 and drilling-M3 ranges from 35.28 - 204.48 cmol.kg⁻¹ (high - very high). Bases saturation (BS) ranges from very low - high (11.73 - 73.27%). Soil EC ranges 0.48 - 0.92 dS cm⁻¹ (very low).

1. Introduction

Peat swamp lands is one of the natural resources that has a hydrological and environmental function for human life and livelihood. Therefore, it must be protected and preserved, its function and utilization improved. In the utilization of natural resources such as peat swamp lands, it requires appropriate technology so that the preservation of natural resources and the environment can be maintained to be sustainable. Development and use of peat soils requires careful planning, application of appropriate technology and proper management.

The physical characteristics of peat lands are determined by the decomposition of the material itself. Peat bulk density generally ranges from 0.05 to 0.40 g cm⁻³. The value of bulk density is largely determined by the degree of decomposition of organic matter, and mineral content [1]. Reference [1] examined the peat porosity calculated based on bulk density ranging from 75 - 95%. According to the Soil Taxonomy [2], peat soils or Histosols are classified into four sub-orders based on the degree of decomposition, namely: Folists - organic matter not decomposed, Fibrists - fibric organic matter (BD < 0.1 g cm⁻³), Hemists - hemic organic matter (BD 0.1 - 0.2 g cm⁻³), and Saprists - sapric organic material (BD > 0.2 g cm⁻³).
Aceh Jaya District has a large area of peat lands, mainly in Panga Sub District, covering an area of 13,022.35 ha. Until now, only part of the peat lands has just been used by the community for agricultural lands, and the rest cannot be utilized by the community in the local area, because the suitability of the peat lands is unknown. Through this peat soils characteristics research, it is expected that in the future the land can be utilized for agricultural cultivation, especially for plantations and food crops, as well as knowing inhibiting factors in its management.

2. Materials and methods

2.1. Location of research
This research was carried out in Tuwi Eumpeuk Village, Panga Sub District, Aceh Jaya District, Aceh Province, Indonesia.

2.2. Materials and tools
The materials used in this study were administrative map, soil type map, land use map, and geological map of Panga Sub District, Aceh Jaya District, soil samples, chemicals for soil identification in the field, namely: HCl 10% for lime test, H$_2$O$_2$ 30% for testing organic matter, clean water and other materials needed for soil characteristics analysis in the laboratory. The tools used in this research were peat drill, GPS (global positioning system), ring samples, meters, digital cameras, ground knives, plastic bags, stationery, drilling description cards, Munsell soil colour chart, shovels and hoes.

2.3. Research implementation methods
The research method used was descriptive-quantitative survey method, namely by comparing data between pedons and horizons on the same pedon. Soil samples were taken on representative pedon included: (1) undisturbed soil samples (ring samples) for determination of physical characteristics, namely: water content in field capacity, bulk density, porosity of soil, and (2) soil samples disturbed for the analysis of chemical characteristics of the soil. Methods of soil analysis in the laboratory is presented in Table 1.

| Components of soil analysis | Methods/tools/formulas |
|-----------------------------|-------------------------|
| Maximum water content when saturated | Ring sampel |
| Moisture content in the field capacity | Ring sampel |
| Bulk density | Ring sampel |
| Porosity | Ring sampel |
| pH H$_2$O (1:2.5) and pH-peat water | pH meter |
| Organic carbon | Walkley & Black |
| Acid clays (1:3) | pH H$_2$O$_2$ 30% |
| Exchangeable bases (Ca, Mg, K, Na) | $1 \ N \text{NH}_4\text{OAc}$ pH 7 |
| Exchangeable acidity (H & Al) | $1 \ N \text{KCl}$ |
| Cation exchangeable capacity (CEC) | $1 \ N \text{NH}_4\text{OAc}$ pH 7 |
| Base saturation (BS) | $\sum$ Exchangeable bases x 100% |
| Base saturation of (EC) soil & water of peat | $\text{CEC} \ 1\text{N \ NH}_4\text{OAc} \ \text{pH7}$ |
| Electrical conductivity (EC) soil & water of peat | Conductivity meter |

Table 1: Methods of analysis of physical and chemical characteristics of soils.
3. Results and discussion

3.1. Physical characteristics of peat lands

Peat physical characteristics are very closely related to peat water management. The constituent of peat consists of four components, namely organic matter, minerals, water and air. Changes in water contents due to peat reclamation will also change other physical characteristics [3]. Because the physical characteristics of peat lands are related to other physical properties of peats, the discussion of the physical characteristics of peat lands cannot be done separately. An understanding of physical characteristics will be very useful in determining peat utilization strategies.

Important physical characteristics of peat soil are: the degree of peat decomposition, bulk density, irreversible drying and subsidence [4]. Peat thickness and peat moisture content are physical characteristics that need attention in peat utilization [5].

The degree of peat decomposition are divided into: (1) coarse peat (fibrist), namely peat which has more than 2/3 of the coarse material; (2) medium peat (hemists) has 1/3 - 2/3 of coarse organic material; and (3) fine peat (saprists) if the raw organic material is less than 1/3. Coarse peat has high porosity (95%), high water-holding ability (786.06%), but nutrients are still in organic (20.75 - 54.20%) form and are difficult to provide for plants. Coarse peat easily shrinks if the land is reclaimed. Refined peat has higher nutrient availability and has larger bulk density (0.12 g cm\(^{-3}\)) than coarse peat (0.08 g cm\(^{-3}\)) [4]. The physical characteristics of peat soils in the study area are presented in Table 2.

| No. drilling (soil materials) | Water content when saturated (%) | Moisture content in the field capacity (%) | Bulk density (g cm\(^{-3}\)) | Porosity (%) |
|-------------------------------|----------------------------------|------------------------------------------|-----------------------------|--------------|
| M1 (fibric-soil materials)    | 786.06                           | 90.44                                    | 0.08                        | 95.00        |
| M2 (hemic-soil materials)     | 568.01                           | 82.01                                    | 0.10                        | 93.00        |
| M3 (sapric-soil materials)    | 549.97                           | 78.33                                    | 0.12                        | 90.54        |

Table 2: Physical characteristics of peat soils in the study area.

3.1.1. Water content when saturated. The results of the analysis of measurements of water content at the time of water saturation based on the data in Table 2, showed that the M1 drilling had higher water content at the time of water saturation (786.06%) than that of M2-drilling (568.01%), while water content at water saturation in drilling-M3 was lower (549.97%) compared to M2 and M1 drilling. Those because the fibric peat has higher ability to hold water than hemic and sapric peats.

Peat has a very large water holding capacity, which in a saturated condition peat water content can reach 4.5 - 30% of the dry weight of peat. Therefore, peat dome in the tidal area will be a very efficient reservoir. Fibric peat has a water content of 850 - 3000% for each oven dry material, hemic peat for 450 - 850%, and sapric peat for less than 450% [6].

3.1.2. Moisture content in the field capacity. The results of the analysis of measurement of water content in the field capacity based on the data in Table 2, M1 drilling water content at the field capacity was 90.44% higher than M2 drilling (82.01%), while in M3 drilling the water content was lower (78.33%) compared to M2 drilling (82.01%) and M1 drilling (90.44%). This result is consistent with the previous study stated that fibric peat has the ability to hold water higher than hemic and sapric...
of peats. Water contained in peat soils can reach 300-3,000% dry weight, far higher than mineral soils whose ability to absorb water is only around 20 - 35% dry weight [7]. The peat water content in the lower range, which is 100 - 1,300% [8]. The high ability of peat to store water is determined by, among others, peat porosity which can reach 95% [9].

The amount of water retained by the ground is a function of groundwater height. The capacity to hold water from peat soils can be expressed in terms of water weight per unit dry weight of material. The capacity to hold peat soil water varies depending on the degree of peat decomposition. The weight of the water retained by the fibric material is about two times that of the hemic and sapric material. Peat water content varies according to the degree of decomposition and type of peat material [10].

### 3.1.3. Bulk density

Based on the results of soil analysis, the average bulk density (BD) in the study area at drilling M1, M2, and M3 ranged from 0.08 to 0.12 g cm\(^{-3}\) (very low). The study area in M1 fulfills the requirements of fibric soil material with BD 0.08 g cm\(^{-3}\) because the requirements for fibric material are below 0.10 g cm\(^{-3}\) (0.08 g cm\(^{-3}\)), while M2 drilling which has BD 0.10 g cm\(^{-3}\) including hemic soil material. Furthermore, drilling M3 with BD of 0.12 g cm\(^{-3}\) does not meet the definition of sapric soil material which has BD > 0.20 g cm\(^{-3}\) (Table 2). But in terms of color and degree of maturity, including sapric soil materials.

Bulk density is an important characteristic, because many other physical characteristics are related to bulk density. Peat soils have very low BD, which is less than 0.10 g cm\(^{-3}\) for fibric peat, hemic 0.10 - 0.20 g cm\(^{-3}\) and 0.20 g cm\(^{-3}\) for sapric peat. Reference [11] determined BD for several peat sequences with different regional conditions in the Sebangau and Durian Rasau areas, West Kalimantan with BD variations between 0.09 - 0.23 g cm\(^{-3}\).

### 3.1.4. Porosity

Soil porosity at M1 drilling was 95.00% higher than M2 and M3 drilling which had values of 93.00% and 90.54%, respectively (Table 2). Porosity of peat soils determines ground water movement. Generally tropical peat has porosity between 75 - 95% [12].

Fibric peat has a high rate of groundwater movement because it has large pores. According of Ref. [8] calculated the total porosity of peat in Indonesia, using parameters for peat, and concluded that the total porosity was determined by bulk density.

### 3.2. Soil chemical characteristics of peat lands

The chemical component of the soil has a major role in determining the nature and characteristics of the soil in general and soil fertility in particular. The thickness of the organic horizon, the subsoil nature and the frequency of river flooding affect the chemical composition of peat. Peat soils that often get flooded, the more mineral content of the soil so that it is relatively more fertile. Soil fertility is closely related to plant nutrients and soil conditions. The results of the analysis of the chemical characteristics of peat soils carried out in the laboratory are presented in Table 3 and Table 4.

| No. drilling | Layer symbol/ depth (cm) | Degree of acidity pH of soil (1:2.5) | pH of peat water (pH H\(_2\)O\(_2\)) 1:3 | Acid clay Organic C (%) | Exchangeable bases and acidity Ca Mg K Na H Al (cmol.kg\(^{-1}\)) |
|--------------|-------------------------|-------------------------------------|-------------------------------------|--------------------------|---------------------------------------------------------------|
| M1           | Oi\(_1\) (0-75)          | 4.69                                | 1.33                                | 54.20 23.9, 06 0.28 1.54 4.6 -                                  |
| (fibric-soil materials) | Oi\(_2\) (75-150)    | 5.00                                | 2.13                                | 20.75 14.1 11.2 0.18 0.37 1.5 -                                |
| M2           | Oe\(_1\) (0-75)          | 5.07                                | 1.07                                | 48.32 9.4 12.8 0.62 1.15 2.1 -                                 |
| (hemic-soil materials) | Oe\(_2\) (75-150)    | 5.16                                | 1.71                                | 52.34 11.3 8.4 1.11 1.43 1.2 -                                 |
| M3           | Oa\(_1\) (0-75)          | 4.79                                | 1.57                                | 55.62 3.6 14.9 1.10 2.65 2.3 -                                 |
| (sapric-soil materials) | Oa\(_2\) (75-150)    | 4.78                                | 1.41                                | 55.02 13.1 14.2 0.78 1.04 2.7 -                                 |
|              | Oa\(_3\) (150-225)      | 4.52                                | 1.34                                | 48.34 5.4 18.1 1.22 1.62 2.7 -                                 |
|              | Oa\(_4\) (150-225)      | 4.64                                | 1.18                                | 54.92 7.7 10.6 1.12 1.55 6.1 -                                 |

Table 3: pH, acid clay, organic C, exchangeable bases and acidity peats in the study area.
3.2.1. Reaction of peat soils. Table 3 showed the reaction of peat (pH H$_2$O 1: 2.5) in the study area, namely: the M1 drilling ranged from 4.69 to 5.07 and the pH of peat water was 6.46, while the M2 drilling ranged between 5.16 and 4.78 and the pH of peat water was 6.18. Furthermore, pH of M3 drilling ranged from 4.52 to 4.75 and the pH of peat water was 5.37. pH of peat water, which ranged from 5.37 to 6.46 (acid to slightly acid), was higher than the peat pH from 4.52 to 5.16 (acid).

Peat lands generally have a relatively high acidity degree with a pH range of 3 - 5. Oligotrophic peat which has a quartz sand substratum in Berengbengkel, Kalimantan Tengah has a pH range of 3.25 - 3.75 [13] [14]. On the other hand, peat around Air Sugihan Kiri, Sumatera Selatan has a higher pH range of 4.1 to 4.3 [15].

The function of soil pH is very important in terms of: (1) determining whether nutrients are easily absorbed by plants, (2) indicating the possibility of toxic elements, in acidic soils the Al ions are found and also in swamp soils there is sulfate content that is high to be toxic to plants, and (3) affect the development of microorganisms [4].

The thickness of the organic horizon, subsoil properties and frequency of flooding affect the chemical composition of peat. In peat soils that often get overflowing, the more mineral content of the soil so that it is relatively more fertile. Tropical peat soils have low mineral content with organic matter content of more than 90%. Chemically peat reacts acidy (pH < 4) [3]. Shallow peat has a higher pH (4.0 - 5.1), compared to deep peat (3.1 - 3.9).

In Malaysia, the pH of peat ranges from 3.2 to 4.9 while on the east coast of Sumatra it ranges from 3.42 to 4.3. Peat developed along the east coast of Sumatra has the following characteristics: deep peat (more than 4 m) with nutrient status N, P, K, Mg, Ca, Zn and B are in sufficient condition, while the main limiting factor in peat lands is unavailability of element Cu for plants [16].

3.2.2. Acid clays. If the pH-H$_2$O value of the soil is higher than the pH of the H$_2$O$_2$ soil, the soil is stated to have a high acid content [17]. This test is usually carried out in tidal regions [18]. Example on M1/Oi1, 4.69 - 1.33 = 3.36 (> 2) as shown in Table 3. This shows that the topsoil (M1/Oi1) fibric materials have a pyrite (FeS) layer. If the pyrite layer (sulfidic materials) is oxidized due to drainage channel construction it will turn into FeSO$_4$ in the form of jarosite mineral (sulfuric horizon) which has a pH ≤ 3.5 and is highly toxic to plants [2] [19] [20].

3.2.3. Organic C. Organic C of peat soils showed that M1 drilling ranged from 20.75 - 54.20%, while M2 drilling ranged from 52.34 - 55.62% and M3 drilling ranged from 48.34 - 54.92%, these values based on the reference [21] are classified as very high (Table 3). The high contents of organic C in the peats is probably caused by the source of its original materials (litter of plants), in which the most of the dry matter of plants consisted of organic matter. The contents of organic C in M1-Oi2 layer was lower than other layers, mostly due to this layer containing sand materials.

The results of research conducted by the Bogor Agricultural University (IPB) in several locations in Sumatra, showed that the BD of peat soil varies according to the degree of decomposition of organic matter and mineral content [22]. Peat soils with a content of more than 65% organic material (> 38% C-organic) have BD for fibric types 0.11 - 0.14 g cm$^{-3}$, for hemic 0.14 - 0.16 g cm$^{-3}$, and for sapric 0.18 - 0.21 g cm$^{-3}$. If the content of organic matter is 30 - 60%, BD for hemic type is 0.21 - 0.29 g cm$^{-3}$ and for sapric 0.30 - 0.37 g cm$^{-3}$.

3.2.4. Exchangeable bases (macro nutrient availability). Total base cations are influenced by rainfall and the nature of the parent material. The availability of K, Ca, and Mg in peat soils is generally low [8]. In accordance with this study, for the cation K and Mg in the top soil layer fibric soil material (M1-Oi1) is low (0.2 and 0.6 cmol kg$^{-1}$). Average for Ca cations in sapric (M3 drilling) soil material with moderate value (6.6 cmol kg$^{-1}$) (Table 3).
3.2.5. Exchangeable acidity. The highest value for H\(^+\) was in the top soil layer of fibric (M1-Oi1) soil material, which was 6.1 cmol.kg\(^{-1}\). In the study area, exchangeable H more dominant than exchangeable Al. In sapric soil material (M3 drilling) in the Oa3 layer the Al\(^{3+}\) value was 2.3 cmol.kg\(^{-1}\) or the Al saturation was 3.39% (very low), whereas in other layers the Al was not measured (Table 3).

3.2.6. Cation exchangeable capacity. Cation exchangeable capacity (CEC) is important for soil fertility and soil genesis [22]. CEC value in drilling M1, M2 and M3 ranged from 35.80 - 204.48 cmol.kg\(^{-1}\) categorized high to very high (Table 4). The high CEC value is due to the negative charge depending on the pH which is mostly from the carboxylate and phenolate groups and also the derivatives of the lignin fraction [23].

| No. drilling | Layer symbol/depth (cm) | CEC (cmol.kg\(^{-1}\)) | BS (%) | EC peat soil (dS cm\(^{-1}\)) | EC peat water (dS cm\(^{-1}\)) |
|--------------|-------------------------|-------------------------|--------|-------------------------------|-------------------------------|
| M1           | Oi1 (0-75)              | 134.64                  | 19.84  | 0.48                          | 0.63                          |
| (fibric-soil materials) | Oi2 (75-150)           | 35.80                   | 73.27  | 0.76                          | 0.64                          |
| M2           | Oe1 (0-75)              | 186.96                  | 11.91  | 0.64                          | 0.64                          |
| (hemic-soil materials) | Oe2 (75-150)           | 171.00                  | 13.01  | 0.92                          | 0.24                          |
| M3           | Oa1 (0-75)              | 148.42                  | 17.77  | 0.66                          | 0.30                          |
| (sapric-soil materials) | Oa2 (75-150)           | 159.72                  | 13.13  | 0.85                          | 0.84                          |
|              | Oa3 (150-225)           | 67.80                   | 31.78  | 0.30                          | 0.30                          |

Table 4. Cation exchangeable capacity (CEC), base saturation (BS) and electrical conductivity (EC) of peat soils in the study area.

3.2.7. Base saturation. Base saturation (BS) in all three drilling (M1, M2, and M3) top soil layers were low (11.91 - 19.84%) (Table 4). BS value was closely related to pH and soil fertility [24]. In general a good BS for plant growth was 30% [25]. Even though peat lands have very high CEC, low BS results in low K, Ca and Mg nutrient availability [26].

3.2.8. Electrical conductivity. Salinity is shown by the electrical conductivity (EC) value of saturated peat extract in dS cm\(^{-1}\). The results of the analysis of peat soils showed EC-soil of 0.48 - 0.92 dS cm\(^{-1}\) and EC-water of 0.24 - 0.63 dS cm\(^{-1}\) (very low) (Table 4). Soil salinity in tidal land is indicated by the high condition of Na, as a result of sea water (intrusion). High salinity in the root zone will inhibit the absorption of water and nutrients dissolved in it. The higher the value of EC, the more inhibiting plant growth. The content of dissolved salt is strongly influenced by the neutralizing factor of sea water, namely fresh water [24].

4. Conclusion

1. Physical characteristics in all three soil materials (fibric, hemic, and sapric) at the study site have a very large water content when saturated, which is 5.5 - 8% of the peat dry weight; while the water content at the field capacity the higher the decomposition degree the lower the percentage (90-80%). The weight of the contents of the three soil materials is very low (0.08 - 0.12 g cm\(^{-3}\)) compared to mineral soil. The porosity of the three is classified as very porous 90 - 95%.

2. Chemical characteristics in peat soils at the study area that are classified as specific include having acidic pH (4.5 - 5), very high C-organic (20 - 55%), low K and Mg nutrients in fibric soil materials (0.18 and 0.6 cmol kg\(^{-1}\)), the highest exchangeable acids (H\(^+\)) in top soil fibric soil materials (4.6 cmol kg\(^{-1}\)), high to very high CEC (35 - 200 cmol kg\(^{-1}\)), with low base saturation at top soil layers (10 - 20%). EC Soil and peat water were low (0.24 - 0.92 dS cm\(^{-1}\)).

3. There are inhibiting factors in soil management, namely water saturation, organic-C and very high acidity, and low degree of maturity in fibric and hemic soil materials.
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