Variations in peat soil properties at the west coast of Sumatra Island

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Abstract. Peat in coastal areas has different characteristics compared to peat in inland areas because coastal peat usually has high DHL, pyrite, marine sandy substratum, and maturity which is generally classified as hemic to sapric. These variants in soil characteristics drive peculiarity in its management. For this reason, a more detailed information about the characteristics is needed to allow sustainable management and utilization. A total of 78 peat soil samples from 20 peat soil profiles taken over west coast of Sumatra was studied and analyzed for their physical and chemical properties. Field observations were made using a peat auger to determine thickness and maturity, substratum, presence of pyrite, and others. Results showed that peat thickness varied from shallow (50-100 cm), medium (100-200 cm), to very deep (>700 cm); peat situated closer to the coast generally has shallow peat depth. Peat soil in coastal areas contained a mineral soil substrate with a sand content of >70%. It was found that soil had a hemic maturity level and a very acidic to acidic pH value (pH 2.5-5.4). The P2O5 content extracted by 25% HCl varied from low to moderate, while K2O content of 25% HCl extraction was very low. Cations K, Na, and Ca were very low to very high, while Mg spanned from very low to high. Based on its thickness, 25% of peatland were not suitable (Nrc) for general agriculture uses because of >300 cm thickness. Therefore, it is necessary to improve soil fertility and water management in several places.

1. Introduction

Indonesia possesses 13.43 M ha peatlands spread over four major islands; Sumatra Island occupies the largest, i.e. 5.85 M ha or 43.6% of Indonesia's total peatlands [1]. On this island, peatlands are found along the west coast, and east into the interior [2]. Driessen and Sudjadi [3] suggested that according to the formation, peat soils can be divided into (i) ombrogenous peat, which is peat formed in an environment that was only affected by rainwater, not by tides, and (b) topogenous peat, i.e. peat formed at the back of the coastal plain/river, influenced by tidal/flood runoff. Therefore, topogenous peat contains many minerals, so it is arguably more fertile (eutrophic).

Indonesia is the largest archipelagic country in the world with a coastline length of around 95,181 km [4]. This condition causes Indonesia to have a very wide coastal area. Data shows that around 60% of Indonesia's population lives and makes a living in coastal areas. This shows that coastal areas play an important and strategic role in the economy of Indonesian people.

On the island of Sumatra, west coast stretches from Aceh Province to Lampung Province. In general, the use of coastal resources is still focused on marine resources, while land resources have not received a full attention, indicated by limited publications, especially those that inform about
characteristics and potentials of land/soil, including peat areas. With this regard, this paper presents information about characteristics and potential/suitability of peatlands for agriculture, their coverage, and distribution along west coast of Sumatra Island. This information can be used as a reference in peatland management of the region.

2. Materials and methods

2.1. Research area

Peatlands in the West Coast of Sumatra Island covered over 16 regencies, with a total area of 353,395 ha (Table 1). Their distribution is presented in Figure 1.

| Province          | Regency             | Area of peat |
|-------------------|---------------------|--------------|
| Aceh              | Aceh Barat, Aceh Barat Daya, Aceh Jaya, Aceh Selatan, Aceh Singkil, Nagan Raya, Subulussalam | 150,485      |
| Sumatera Utara    | Mandailing Natal, Nias, Nias Utara, Tapanuli Selatan, Tapanuli Tengah | 71,305       |
| Sumatera Barat    | Agam, Pasaman Barat, Pesisir Selatan | 125,340      |
| Bengkulu          | Mukomuko            | 6,265        |
| **Total**         |                     | **353,395**  |

Source: BBSDLP (2019)

Figure 1. Distribution of peatlands on the West Coast of Sumatra.

2.1.1. Field research and soil sampling

Twenty peat soil representative pedons were described in-situ, and eight of them were evaluated in this research (PN1152, HK17, SP09, GB33, GB25, PS14, PS13, GB20). Observed parameters included morphological properties, namely: depth/thickness and maturity level of peat (fibric, hemic, and sapric), color, sulfidic/pyrite material, soil/water pH, tidal/flood effects, mineral insertion. To determine physical and chemical properties of the soil, 78 samples derived from representative pedons have been analyzed in the laboratory.

Peat depth/thickness is divided into: shallow (50-<100 cm), medium (100-<200 cm), deep (200-<300 cm), very deep (300-< 700 cm) and very deep (>700 cm). Based on its maturity, peat is categorized into fibric, i.e. peat that has >75% fiber (raw) by volume, hemic peat (half-cooked), has fiber between 15-75%, and sapric peat has <15% fiber (ripe) [3]. In-situ soil observation refers to the Technical Instructions for Survey and Mapping for Semi Detailed Level 1:50,000 Scale [5] and SNI 8473:2018 [6]. Soils were classified according to the National Soil
Classification [7] to type level, with their general equivalency degree to the Keys to Soil Taxonomy [8] of Subgroup level.

2.1.2. Laboratory research
Analysis of peat soil samples was carried out at the Laboratory of Soil Research Institute, Bogor, including determining physical and chemical properties of the soil. Physical properties included bulk density (BD), ash content, and fiber content. Chemical properties covered organic C and N content (Walkley and Black), soil pH (extraction 1:5), potential P$_{2}$O$_{5}$ and K$_{2}$O content (25% HCl extraction), available P$_{2}$O$_{5}$ (Bray 1), exchangeable bases (Ca, Mg, K, Na) and cation exchange capacity (CEC) (NH$_{4}$OAc 1N pH 7), base saturation (KB), sulfidic/pyrite materials. Procedures for analyzing soil samples followed the Technical Instructions for Analysis of Soil, Water, Plants, and Fertilizers [9].

3. Results and discussion
3.1. Peat thickness and maturity level
Peatlands on west coast of Sumatra were found at a distance of 1.30 km to 19.13 km from the coastline. Peat thickness varied, ranging from very shallow (50-<100 cm) to very deep (>700 cm), loamy sand substratum, sandy loam to loam. Peatland was dominated by medium peat (115,853 ha), followed by deep peat (94,849 ha), very deep peat (71,965 ha), and shallow peat (53,637 ha). Meanwhile, extreme deep peat covered around 16,207 ha, while extreme deep peat was 883 ha. Area and distribution of peatlands by thickness class on the West Coast of Sumatra are presented in Table 2.

| No | Province         | Area (ha)     | Total       |
|----|-----------------|---------------|-------------|
|    |                 | D1    | D2    | D3    | D4    | D5    | D6    |
| 1. | Aceh            | 19,298 | 57,543 | 30,636 | 43,007 | -     | -     | 150,485 |
| 2. | Sumatera Utara  | 20,248 | 26,097 | 16,941 | 4,631  | 3,389 | -     | 71,305  |
| 3. | Sumatera Barat  | 13,754 | 28,357 | 45,754 | 23,774 | 12,818 | 883   | 125,340 |
| 4. | Bengkulu        | 337   | 3,855 | 1,518 | 554    | -     | -     | 6,265   |
|    | Grand Total     | 53,637 | 115,853 | 94,849 | 71,965 | 16,207 | 883   | 353,395 |

Table 2. Area and distribution of peat thickness classes

Note: D1 = shallow peat (50-<100 cm), D2 = medium peat (100-<200 cm), D3 = deep peat (200-<300 cm), D4 = very deep (300-<500 cm), D5 = extreme deep (500-<700 cm), and D6 = extreme very deep (>700 cm).

Based on Landform Classification Guidelines for Soil Mapping in Indonesia [10], peat soils on the research area were found in the Peat Dome (G.1) landform, both on its edge (G.1.1) and in the center (G.1.2); Topogenous peat (G.2), formed in freshwater swamp areas (G.2.1) and salt/brackish swamp areas (G.2.2); some were found in tidal back swamps (M.2.5).

Landform Classification Guidelines for Soil Mapping in Indonesia [10] defines the Peat Dome as peat that is formed in a large back swamp, located between two rivers or between mainland and coast. Its formation is influenced by rainwater puddles to form thick peat. This peat is also known as Ombrogen peat, which has negligible fertility (oligotrophic). Peat dome is distinguished by the edge of the dome, having a thickness of <300 cm, while the peat dome having a thickness of >300 cm. Topogenous peat is peat that is formed in a sunken topographic area, in the form of swamps and is relatively shallow. This peat is influenced by mineral enrichment from tidal/flood runoff; hence, it has a relatively high fertility level (eutrophic). Topogenous peat is distinguished into topogenous peat that is formed in freshwater swamp areas, and topogenous peat that is formed in saltwater/brackish swamp areas. Swamps are low areas behind coastal embankment that is influenced by tides.

Peat thickness is positively proportional to its age. The thickness also determines peat fertility; thick peat makes difficult for plants to absorb nutrients from soil substratum. Therefore, very little biomass is returned to the soil; as a result, peat tends to be less fertile [11].

Topogenous peats or peats formed in back-tidal swamps are thinner/shallower than ombrogenous peats. Tidal/floodwater runoff which carries minerals enriches peats; hence, more fertile. This resulted
in layer stratification which was visible in SP09 and PS13 pedons (Table 3). Field observation suggested that SP09 pedon was formed in freshwater swamp basins, while the latter was formed in tidal swamps. SP09 thickness was considerably shallow (50-<100 cm), while SP13 depth was categorized in 200-<300 cm level. Topogenous peats formed in other freshwater swamp basins (HK17, GB25, and GB20) possessed medium (100-<200 cm) to deep (200-<300 cm) thickness.

Peat thickness found over peat dome landform was varied depending on its position. Thickness over outer dome areas (PN 1152 and GB33) ranged from shallow (50-<100 cm) to deep (200-<300 cm). Moving inwards, thickness was very deep (300-<500 cm) with some cases >700 cm. Currently, those peatlands have been used for agriculture, especially oil palm plantations, both managed by local communities or private/large companies. For this reason, peat thickness/depth is a crucial information for peatland management, alongside with carbon stock estimation [12].

Peat maturity describes the level of weathering of organic matters as the main component of peat soil. It determines peat soil productivity because it’s relationship to fertility and nutrient availability [13]. Maturity of top peat layer was classified as sapric (fiber content <15% by volume), while bottom layer was hemic (fiber content 15-75% by volume). National Soil Classification System [7] classifies the peat as Hemic Organosols and their equivalents according to Keys to Soil Taxonomy [8] are Sapric Haplohemists and Typic Haplohemists, Observed peats had coarse to medium textured (loamy sand to loam) mineral soil substratum. Sandy substrate is a characteristic of peat formed in coastal areas [2].

3.2. Chemical properties
Peat soils generally have a high level of acidity. Laboratory analysis showed that pH ranged from acidic to very acidic (pH 2.5-5.4) (Table 4). High peat acidity is due to high organic acids, especially humic and fulvic acids produced during decomposition. Hartatik et al. [14] found that about 85-95% of peat soil acidity is caused by these two acids. Further analysis showed that there was a correlation between peat thickness and pH H$_2$O, i.e. shallow peat (50-<100 cm) had a higher average H$_2$O pH value than the ones observed over medium peat (100-<200 cm), deep (200-<300 cm), and very deep (300-<500 cm). Averaged pH H$_2$O values, respectively, from shallow peat (D1) to very deep peat (D4), were 4.8, 4.2, 3.9, and 3.8 (Figure 2), similar to findings in a previous report [13].

C-organic content was very high ranging from 14.76 to 66.85%. This is understood because peat soil is formed from accumulation of plant remains that have not decomposed. Peat soils with 50 cm thick or more contain at least 12% C-organic by dry weight [7]. Meanwhile, total N ranged from moderate to very high (0.33-1.65%). P$_2$O$_5$ potential (25% HCl extraction) was generally low to moderate; top layer had a higher P$_2$O$_5$ potential. Available P$_2$O$_5$ (Bray 1 extraction) was in agreement with potential P$_2$O$_5$. High amount of P$_2$O$_5$ in top layer was possibly due to overland nutrient management. Results of the analysis showed that most peatlands in the research site were utilized for oil palm plantations, both managed by the locals or large/private companies (Table 3). Potential K$_2$O (25% HCl extraction) was generally very low.

Exchangeable bases generally ranged from very low to moderate, with an average of 4.62 cmolc kg$^{-1}$ for Ca and very low to high with an average of 2.28 cmolc kg$^{-1}$ for Mg. Some pedons indicated a rise in Ca and Mg with increasing peat depth. This was due to the application of dolomite which was then washed down as soil weakly absorbs nutrients. In addition to reducing soil acidity, the application of dolomite also increased Ca and Mg in the soil. Levels of K and Na were generally low to very low, averaging 0.28 cmolc kg$^{-1}$ and 0.30 cmolc kg$^{-1}$ (Table 5). The content of bases was generally low, causing base saturation of peat soils to be low to very low. This research found that Ca was the basic cation that gave the highest contribution to the base saturation, followed by Mg and Na. Meanwhile, K delivered the smallest contribution to the base saturation (Ca>Mg>Na>K).
Table 3. Thickness, degree of decomposition, and soil classification.

| Pedon | Depth (cm) | Horizon | Degree of Decomposition | Substratum Texture | Peat depth (cm) | Depth Class | Distance from the coastline (km) | Existing land use |
|-------|------------|---------|-------------------------|--------------------|-----------------|-------------|---------------------------------|------------------|
| Hemic Organosols/Typic Haplohemists: South Aceh, Edge of the Peat Dome, Coordinate: 2°56’7” N; 97°27’7” E | 0-15 | Oa | Sapric | 70 | D1 | 1.30 | Oil Palm |
|      | 15-70 | Oe | Hemic |                |                 |             |                                 |                  |
|      | 70-100 | Cg | - | Sandy loam | | | | |
| PN1152 | 0-30 | Oa | Sapric | 120 | D2 | 3.50 | Mixed garden |
|      | 30-120 | Oe | Hemic | | | | |
|      | 120-150 | Cg | - | Loamy Sand | | | | |
| HK17 | 0-5 | Oa | Sapric | 88 | D1 | 9.76 | Oil Palm |
|      | 5-61 | Oa | Sapric | | | | |
|      | 61-70 | C | Loam | | | | |
|      | 70-102 | Oa | Sapric | | | | |
|      | 102-114 | 2C | Sandy Loam | | | | |
| Organosol Sapric/Typic Haplosaprists: West Pasaman, Freshwater Topogenous Peat, Coordinate: 0° 9’ 17,2” N; 99° 37’ 50” E | 0-50 | Oa | Sapric | 290 | D3 | 5.73 | Oil Palm |
|      | 50-150 | Oa | Sapric | | | | |
|      | 150-290 | Oe | Hemik | | | | |
|      | >290 | C | Sandy Loam | | | | |
| SP09 | 0-5 | Oa | Sapric | 196 | D2 | 11.81 | Oil Palm |
|      | 5-55 | Oa | Sapric | | | | |
|      | 55-100 | Oe | Hemik | | | | |
|      | 100-196 | Oe | Hemik | | | | |
|      | >196 | C | Sandy Loam | | | | |
| GB33 | 0-30 | Oe1 | Hemic | 446 | D4 | 19.13 | Oil Palm |
|      | 30-110 | Oe2 | Hemic | | | | |
|      | 110-210 | Oe3 | Hemic | | | | |
|      | 210-323 | Oe4 | Hemic | | | | |
|      | 323-446 | Oe5 | Hemic | | | | |
| Organosol Hemik/Typic Haplohemists: South Pesisir, Edge of the Peat Dome, Coordinate: 2° 11’ 8,117” S; 100° 53’ 31,463” E | 0-18 | Oa | Sapric | 251 | D3 | 1.75 | Oil Palm |
|      | 18-100 | Oe | Hemic | | | | |
|      | 100-115 | C | Loam | | | | |
|      | 115-155 | Oe | Hemic | | | | |
|      | 155-225 | Oa1 | Sapric | | | | |
|      | 225-266 | Oa2 | Sapric | | | | |
| Organosol Hemik/Typic Haplohemists: Seluma, Tidal Swamp Back, Coordinate: 1° 45’ 48,4” S; 100° 46’ 21,5” E | 0-55 | Oe | Hemic | 200 | D3 | 5.01 | Oil Palm |
|      | 55-160 | Oe1 | Hemic | | | | |
|      | 160-200 | Oe2 | Hemic | | | | |
|      | >200 | C | Sandy Loam | | | | |

Note: D1 = shallow peat (50-<100 cm), D2 = medium peat (100-<200 cm), D3 = deep peat (200-<300 cm), D4 = very deep (300-<500 cm), D5 = extreme deep (500-<700 cm), and D6 = extreme very deep (>700 cm).
Figure 2. Relationship between pH value of H₂O and peat thickness.

Table 4. pH (H₂O dan KCl), Organic matter, Potential (P₂O₅ and K₂O), Available (P₂O₅).

| Pedon | Depth | Horizon | Extract 1:5 | Organic Matter | Potential (HCl 25%) | Available (Bray 1) |
|-------|-------|---------|-------------|----------------|--------------------|-------------------|
|       |       |         | pH          | Walkley & Black | Kjeldahl           | H₂O   | KCl | C | N | P₂O₅ | K₂O | P₂O₅ | ppm-- | mg 100 g⁻¹-- |
| PN1152| 0-15  | Oa      | 4.9         | 3.9           | 50.24              | 1.65              | 48    | 6  | - | -   | -    | -     | 28.8   |
|       | 15-70 | Oe      | 5.0         | 4.0           | 54.28              | 1.63              | 27    | 6  | - | -   | -    | -     | 19.6   |
|       | 70-100| Cg      | 5.3         | 4.2           | 1.45               | 0.07              | 18    | 6  | - | -   | -    | -     | 2.4    |
| HK17  | 0-30  | Oa      | 3.7         | 2.8           | 57.89              | 1.16              | 39    | 7  | - | -   | -    | -     | -      |
|       | 30-120| Oe      | 4.5         | 3.5           | 56.16              | 1.13              | 8     | 2  | - | -   | -    | -     | -      |
|       | 120-150| Cg     | 5.1         | 4.1           | 7.63               | 0.26              | 28    | 2  | - | -   | -    | -     | -      |
| SP09  | 0-5   | Oa      | 4.9         | 4.1           | 17.33              | 0.46              | 358   | 38 | - | -   | -    | -     | 30.2   |
|       | 5-61  | Oa      | 4.8         | 4.1           | 26.82              | 0.68              | 249   | 33 | - | -   | -    | -     | -      |
|       | 61-70 | C       | 5.4         | 4.4           | 15.81              | 0.43              | 121   | 30 | - | -   | -    | -     | 2.4    |
|       | 70-102| 2Oa     | 5.3         | 4.4           | 22.68              | 0.59              | 123   | 45 | - | -   | -    | -     | 4.1    |
|       | 102-114| 2C     | 5.3         | 4.4           | 16.16              | 0.39              | 75    | 42 | - | -   | -    | -     | 22.2   |
| GB33  | 0-50  | Oa      | 3.7         | 2.4           | 63.52              | 1.25              | 19    | 84 | - | -   | -    | -     | 36.7   |
|       | 50-150| Oa      | 3.8         | 2.5           | 61.46              | 1.16              | 23    | 50 | - | -   | -    | -     | 69.1   |
|       | 150-290| Oe     | 4.7         | 3.3           | 55.12              | 0.97              | 43    | 29 | - | -   | -    | -     | 32.9   |
|       | >290  | C       | -           | -             | -                  | -                 | -     | -  | - | -   | -    | -     | 5.3    |
| GB25  | 0-55  | Oa      | 3.5         | 3.0           | 41.11              | 0.82              | 23    | 3  | - | -   | -    | -     | 3.1    |
|       | 55-100| Oe      | 3.5         | 3.0           | 49.94              | 0.93              | 27    | 8  | - | -   | -    | -     | 36.7   |
|       | 100-196| Oe     | 3.3         | 3.0           | 48.20              | 0.87              | 36    | 10 | - | -   | -    | -     | 6.7    |
|       | >196  | C       | -           | -             | -                  | -                 | -     | -  | - | -   | -    | -     | 9.3    |
| PS14  | 0-30  | Oe1     | 3.4         | 2.7           | 45.31              | 0.92              | 21    | 5  | - | -   | -    | -     | 13.8   |
|       | 30-110| Oe2     | 3.8         | 3.0           | 66.77              | 1.17              | 3     | 3  | - | -   | -    | -     | 5.3    |
|       | 110-210| Oe3    | 4.0         | 3.1           | 47.57              | 0.83              | 3     | 1  | - | -   | -    | -     | 3.1    |
|       | 210-323| Oe4    | 4.1         | 3.3           | 46.54              | 0.79              | 8     | 4  | - | -   | -    | -     | 10.9   |
|       | 323-446| Oe5    | 4.2         | 3.4           | 59.99              | 0.96              | 6     | 7  | - | -   | -    | -     | 9.3    |
| PS13  | 0-18  | Oa      | 3.4         | 2.8           | 48.90              | 0.99              | 29    | 0  | - | -   | -    | -     | 29.2   |
|       | 18-100| Oe      | 4.1         | 3.2           | 41.77              | 0.86              | 14    | 0  | - | -   | -    | -     | 12.7   |
|       | 100-115| C      | 4.8         | 3.9           | 44.24              | 0.87              | 17    | 5  | - | -   | -    | -     | 16.5   |
|       | 115-155| 2Oe    | 3.8         | 3.2           | 43.55              | 0.84              | 12    | 4  | - | -   | -    | -     | 9.1    |
|       | 155-225| 3Oa1   | 2.8         | 2.6           | 49.26              | 0.89              | 11    | 1  | - | -   | -    | -     | 1.7    |
|       | 225-266| 3Oa2   | 2.5         | 2.4           | 40.80              | 0.74              | 10    | 1  | - | -   | -    | -     | 1.9    |
| GB20  | 0-55  | Oe      | 3.6         | 2.9           | 51.99              | 1.02              | 21    | 3  | - | -   | -    | -     | 34.8   |
|       | 55-160| Oe1     | 3.4         | 2.7           | 51.40              | 0.97              | 6     | 1  | - | -   | -    | -     | 12.2   |
|       | 160-200| Oe2    | 2.9         | 2.5           | 49.38              | 0.93              | 5     | 2  | - | -   | -    | -     | 9.8    |
|       | >200  | C       | -           | -             | -                  | -                 | -     | -  | - | -   | -    | -     | -      |

Note: - = not analyzed.
Ash content is one of differentiating factors for peat soil fertility. Based on fertility levels, peat soils are distinguished as: (a) eutrophic peats, i.e. peats with a high fertility level as characterized by >10% ash content, (b) oligotrophic peats, i.e. peats with low fertility with <5% ash content, and (c) mesotrophic peats, i.e. peats having a medium-fertility level, usually with ash content ranges 5-10%. Results of the analysis showed that ash content was generally >10%, indicating eutrophic category.

### Table 5. Interchangeable bases, CEC, BS, ash content, and fiber content.

| Pedon  | Dept | Horizon | Cation exchange rate (NH₄Acetate 1N, pH7) | Cs (cmolc kg⁻¹) | Mg (cmolc kg⁻¹) | K (cmolc kg⁻¹) | Na (cmolc kg⁻¹) | Total CEC (%) | BS (%) | Ash content (%) | Fiber content (%) |
|--------|------|---------|----------------------------------------|----------------|----------------|----------------|----------------|---------------|--------|----------------|-------------------|
| PN1152 | Oa   | 0-15    | Ca                                      | 13.44          | 2.02           | 0.11           | 0.48           | 16.05         | 80.02 | 20             | 11.93             | 62.50             |
|        |      | 15-70   | Mg                                      | 15.84          | 2.70           | 0.12           | 0.63           | 19.29         | 89.49 | 22             | 10.20             | 62.50             |
|        |      | 70-100  | K                                        | 1.31           | 0.36           | 0.02           | 0.07           | 1.76          | 5.41  | 30             | -                 | -                 |
| HK17   | Oa   | 0-30    | Ca                                      | 2.55           | 1.68           | 0.12           | 0.22           | 4.57          | 89.98 | 5              | 8.69              | 50.00             |
|        |      | 30-120  | Mg                                      | 2.85           | 2.92           | 0.03           | 0.15           | 5.95          | 87.28 | 7              | 8.96              | 77.78             |
|        |      | 120-150 | K                                        | 2.34           | 2.33           | 0.03           | 0.02           | 4.72          | 15.36 | 31             | -                 | -                 |
| SP09   | Oa   | 0-5     | Ca                                      | 1.88           | 0.35           | 0.70           | 0.06           | 2.99          | 27.42 | 11             | -                 | -                 |
|        |      | 5-61    | Mg                                      | 2.17           | 0.40           | 0.63           | 0.09           | 3.29          | 40.16 | 8              | 44.87             | 86.67             |
|        |      | 61-70   | K                                        | 2.07           | 0.56           | 0.56           | 0.14           | 6.33          | 29.65 | 21             | -                 | -                 |
|        |      | 70-102  | Ca                                      | 8.04           | 0.82           | 0.86           | 0.13           | 9.85          | 42.49 | 23             | 53.13             | 80.00             |
|        |      | 102-114 | Mg                                      | 5.98           | 0.58           | 0.76           | 0.18           | 7.50          | 24.34 | 31             | -                 | -                 |
| GB33   | Oa   | 0-50    | Ca                                      | 3.49           | 1.12           | 1.52           | 0.80           | 5.95          | 46.61 | 10             | 1.89              | 80.0              |
|        |      | 50-150  | Mg                                      | 4.19           | 2.08           | 0.98           | 0.84           | 5.09          | 63.20 | 13             | 2.30              | 81.25             |
|        |      | 150-290 | K                                        | 5.88           | 2.26           | 0.51           | 0.64           | 9.29          | 54.50 | 17             | 5.86              | 73.33             |
|        |      | >290    | Ca                                      | -              | -              | -              | -              | -             | -                | -                 | -                 |
| GB25   | Oa   | 0-55    | Ca                                      | 0.92           | 0.44           | 0.04           | 0.07           | 1.47          | 37.30 | 4              | 24.40             | -                 |
|        |      | 55-100  | Mg                                      | 1.26           | 0.57           | 0.14           | 0.16           | 2.13          | 44.52 | 5              | 8.24              | -                 |
|        |      | 100-196 | K                                        | 7.25           | 3.74           | 0.19           | 0.60           | 11.78         | 40.39 | 29             | 10.42             | 86.67             |
|        |      | >196    | Ca                                      | -              | -              | -              | -              | -             | -                | -                 | -                 |
| PS14   | Oe1  | 0-30    | Ca                                      | 0.47           | 0.17           | 0.09           | 0.18           | 0.91          | 50.40 | 2              | 80.0              | 60.00             |
|        | Oe2  | 30-110  | Mg                                      | 3.89           | 1.24           | 0.05           | 0.33           | 5.51          | 58.08 | 9              | 80.00             | 66.67             |
|        | Oe3  | 110-210 | K                                        | 3.18           | 1.07           | 0.02           | 0.29           | 4.56          | 45.23 | 10             | -                 | -                 |
|        | Oe4  | 210-323 | Ca                                      | 3.99           | 1.27           | 0.07           | 0.33           | 5.66          | 42.83 | 13             | -                 | -                 |
|        | Oe5  | 323-446 | Mg                                      | 4.03           | 1.39           | 0.12           | 0.50           | 6.04          | 46.79 | 13             | 78.57             | 64.28             |
| PS13   | Oa   | 0-18    | Ca                                      | -              | -              | -              | -              | -             | -                | 10.79             | 80.00             |
|        | Oe1  | 18-100  | Mg                                      | -              | -              | -              | -              | -             | -                | 25.17             | -                 |
|        | Oe2  | 100-115 | K                                        | 0.92           | 0.48           | 0.07           | 0.24           | 1.71          | 40.46 | 4              | -                 | -                 |
|        | Oe3  | 115-155 | Ca                                      | 1.12           | 0.74           | 0.05           | 0.15           | 2.06          | 39.70 | 5              | 23.19             | -                 |
|        | Oa1  | 155-225 | Mg                                      | 4.49           | 3.30           | 0.01           | 0.14           | 7.94          | 42.28 | 19             | 9.73              | 86.67             |
|        | Oa2  | 225-266 | K                                        | 5.19           | 6.47           | 0.01           | 0.05           | 11.72         | 38.65 | 30             | 26.22             | 86.67             |
| GB20   | Oe   | 0-55    | Ca                                      | 2.79           | 0.35           | 0.06           | 0.07           | 3.27          | 42.27 | 8              | 6.80              | -                 |
|        | Oe1  | 55-160  | Mg                                      | -              | -              | -              | -              | -             | -                | 7.72              | -                 |
|        | Oe2  | 160-200 | K                                        | 1.70           | 0.62           | 0.04           | 0.18           | 2.54          | 35.01 | 7              | 8.74              | 80.00             |
|        | Oe3  | >200    | Ca                                      | -              | -              | -              | -              | -             | -                | -                 | -                 |

Note: -= not analyzed.
There is a relationship between peat maturity and ash content, where peats with sapric maturity has a higher ash content than hemic weathered peats. This was in line with previous finding [15] on freshwater peat soils in Riau Province, Sumatra. Inversed association between organic C and ash content is presented in Figure 3.

![Figure 3. Relationship between organic C and ash content.](image)

3.3. Land suitability and existing land use

Despite possessing low nutrients and base, acid pH, and poor drainage, peatlands have potentials for agricultural development if fertilization, dolomite provision, water management are properly managed. Based on soil depth (Table 2), about 25% of studied peatlands were not suitable (Nrc) for agriculture because they were >300 cm thick.

BPS data [18-23] indicated a sharp increase in oil palm plantations over the last 10 years (2009-2019) (Figure 4). Increasing plantations certainly results in land clearing, in which agricultural development over peatlands needs to pay attention to maturity levels (sapric-hemic maturity), the thickness of peat <100 cm, water content, bulk density, peatland subsidence, and irreversible drying of the peat [13, 24].

![Figure 4. Oil palm plantation coverage, 2009-2019.](image)

3.4. Management recommendations

Cultivating oil palm on peatlands requires water management, soil compaction, and fertilization [25]. Water management is a necessity for favorable growth and yield [26]. Excessive drainage causes
truncated water level, thus increasing the rate of subsidence and risk of peat fire [27]. Poor drainage causes irreversible dry conditions [25]. Water management attempts to regulate drainage/water table and to remove hazardous organic acids to plants [28]. It is, therefore, expected that groundwater levels in oil palm plantations can be maintained at a depth of 40-60 cm [29].

The presence of toxic organic acids and acid soil reactions can be overcome by adding ameliorants in the forms of lime, mineral soils, manure, and ash from combustion. Adding ameliorants can increase soil pH and bases [30].

Fertilization is needed to increase nutrient content in peat soils. A complete fertilizer is required, especially ones containing N, P, K, Ca, Mg, and microelements Cu, Zn, and B. Fertilization are gradually carried out at a low dose because of low nutrient sorption power to avoid leaching [30].

4. Conclusions

Peatlands on the West Coast of Sumatra covered 353,395 ha over 16 regencies in 4 provinces. They consisted of medium peat 115,853 ha, followed by deep peat 94,849 ha, very deep peat 71,965 ha, and shallow peat 53,637 ha. Meanwhile, extreme deep peat spreaded around 16,207 ha and extreme deep peat 883 ha. Peat maturity was classified as hemic to sapric (classified as Hemic Organosol and Sapric Organosol). Peat soil was found in the Peat Dome (G.1) landform, both on the edge of the dome (G.1.1) and in the middle of the peat dome (G.1.2); Topogenous peat (G.2), formed in freshwater swamp areas (G.2.1) and salt/brackish swamp areas (G.2.2); and some were found in tidal back swamps (M.2.5). The substrate was loamy sand, sandy loam to clay.

Topogenous peats and peats formed in back-tidal marshes are thinner/shallower. Tidal/flood runoff that carries minerals causes peat enrichment and be more fertile. Peats occupying peat dome landform had varying thickness depending on its position; at the edges of the dome, peat thickness was shallow (50-<100 cm) to deep (200-<300 cm), while in the middle, the thickness was very deep (300-<500 cm) and even very deep (>700 cm).

Results of laboratory analysis showed that peat soil pH ranged from very acidic to acidic (pH 2.5-5.4), and shallow peat (50-<100 cm) had a higher average H$_2$O pH value than medium peat (100-<200 cm), deep (200-<300 cm), and very deep (300-<500 cm). Averaged H$_2$O pH are successive as follows: D1>D2>D3>D4. Potential P$_2$O$_5$ (25% HCl extraction) was generally low to moderate, with top layer had a higher potential P$_2$O$_5$ probably due to nutrient management on peatlands. Meanwhile, K$_2$O potential (25% HCl extraction) was generally very low.

Ash content differentiates peat soil fertility. Results suggested that ash content was generally >10%, indicating that peat soil was eutrophic. In addition, peat depth/thickness is a requirement for exploiting peatlands for agriculture. Based on soil depth, about 25% of peatlands were not suitable (Nrc) for agriculture because they had >300 cm thickness. Therefore, apart from increasing soil fertility, water management is also very necessary to reduce subsidence on peatlands.

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