Degree of peatland maturity over different types of land use in Kinali, West Sumatra Indonesia

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Abstract. Different types of land management determine groundwater level of peatlands, which affects the degree of its maturity. A research conducted in Kinali, West Sumatra Indonesia was aimed to identify the degree of peat maturity over five land use types (oil palm plantation, mixed garden, bush land, seasonal crop land, and open land). Soil characteristics, i.e. BD, OM, fiber, ash content, soil color, and degree of maturity, were analyzed. This research showed that BD was 0.31-0.64 g/cm$^3$, SOM content was 26.77-65.84%, fiber content was 3.33-40.67%, ash content was 17.21-70.73%, and the peat was classified into saprist with the color was 7.5 YR 2/2-10YR 3/2 (Brownish Black). It was concluded that the peatland was quite mature (saprist). Mixed garden hosted the highest degree of peat maturity as indicated by the lowest value of SOM content (26.77%), the highest BD (0.64 g/cm$^3$) and ash content (70.73%), the lowest fiber content (3.33%), and the deepest water table (65-67 cm) among other types of peatland.

1. Introduction

Peatlands in Indonesia cover approximately 13.43 M ha, which are mostly found in four islands: Sumatera (43.56%) > Kalimantan (33.80%) > Papua (22.41%) > Sulawesi (0.18%) [1]. Based on BBSDLP (Indonesian Research & Development for Natural Resource) data in 2011, the total peatland found in West Sumatera was 101,000 ha and about 12,045 ha (11.93%) was found in Kinali, West Pasaman Regency, West Sumatra [2].

Land use change over peatlands, especially from forest into agriculture, would change soil properties, in particular, bulk density, ash content, fiber content, and SOM content. This alteration consequently affects the degree of peat maturity. Critical degree of peat could be determined by the C/N ratio, the dynamics of soil water table, and the degree of soil acidity [3].

Forested peatlands to farming lands in Indonesia has been changed during last four decades. It was reported that about 63,824 ha (13.6%) peatlands were converted into agricultural lands during 22 years (1986-2008) in Districts of Kubu Raya and Pontianak in West Kalimantan, Indonesia [4]. Peatland conversion in Indonesia reached 1.7 M ha in 2009 (12.66% of total peatlands); of this figure, 1.4 M ha was in Sumatra island and 307,000 ha in Borneo island for oil palm plantation [5]. It is expected that the converted areas would continuously increase into 60% by 2030, with approximately 40% managed by small holders [6].

Peatland conversion from forest into farming lands also happens in Kinali, West Sumatra. Based on soil and land use maps, peatland was mostly converted into oil palm plantations (about 11.9 thousands ha), followed by mixed gardens (2.4 thousands ha), bush lands (0.7 thousands ha), seasonal
crop lands (0.3 thousands ha), barren (0.1 thousand ha) and others. Peatland areas in Kinali were higher than the one reported [2, 7]. Kinali is a watershed of many rivers, notably Batang Masang, Batang Kinali, Batang Mandiangin. Therefore, the peatland was much affected by materials brought by rivers. Conversion has long been done; this is the reason that some areas appear like mineral soils.

Peatland conversion affects land characteristics, mainly due to changing water table. The depth of water table would determine oxidation process of peatland, soil physical and chemical properties, and finally subsidence rate of soil surface. The latter tends to decrease by time if farming activities do not maintain the conservation rules.

Based on the above information, it was interesting to know characteristics and maturity of peatlands after being converted into agriculture in Kinali, West Pasaman Regency, West Sumatra, Indonesia.

2. Methodology

This research was conducted in Kinali, West Pasaman Regency, West Sumatra Indonesia (Figure 1). It is located between 00° 03’ N and 00° 11’ S; between 99° 45’ and 99° 03’ E [8]. Kinali covers about 482.64 km², having two subdistricts (Kinali dan Katiagan), which is mostly found in flat area next to the beach. It is about 30 km from the capital of West Pasaman and 160 km from Padang city, the capital of West Sumatra.

The research area was situated in a part of Kinali, neighboring the beach. The area was utilized for rice agriculture (about 2.59%) and upland fields (90.94%), while the rests were villages, rivers, and forest [8]. Total forested area was 356,786 Ha in 2014. Of the total 482.64 km² (about 48,264 ha), 15,351.67 ha was covered by peatlands [8].

This research employed data collection and analysis based on soil surveys, in which soil samples were purposively collected according to existing land use types. Five types of land use were considered, i.e. oil palm plantations, bush lands, mixed gardens, seasonal crops, and barren. At each land use type, three disturbed and undisturbed soil samples were randomly taken. Soil characteristics were analyzed at the Soil Laboratory, Andalas University, Padang Indonesia, specifically for soil BD, OM, fiber and ash content, as well as soil color. Soil depth, color, and water table depth were measured in-situ. Peat maturity was analyzed both in the field and in the laboratory (using Syringe method). All datasets were analyzed using JMP statistical software and Excel.
3. Results and discussion

3.1. General characteristics of surveyed area
Data from Sicincin Climate Station, Padang Pariaman Region, showed that the annual rainfall in Kinali was around 3535 mm/y in average for the last 7 years (2013-2019). Monthly rainfall varied, with the lowest rainfall was 155 mm in July and the highest was 527 mm in October. Therefore, climate type in Kinali is A or very wet (Q value = 0.013) [9].

Histosols cover almost a half (47.5%) of existing soil resources in Kinali District [2], being utilized for palm oil plantations (11,886.52 ha), seasonal crops (281.20 ha), barren (111.97 ha), mixed gardens (2,377.84 ha) and bush lands (694.14 ha) (see Figure 1). This soil order was categorized into 2 Great Groups, i.e. Troposaprist having soil depth < 2 m (6,507.32 ha) and > 2 m (8,844.39 ha). Saprist type was found having completely decomposed OM, fiber content was <1/6 part, BD > 0.2 g/cm³ [10]. Further, Troposaprist type has deep effective depth, low fiber content and a high degree of peat maturity [11].

3.2. History of peatland uses
Based on discussion with local farmers, peatlands in Kinali were firstly converted into oil palm plantations because it could increase land productivity. Some areas, however, further altered into mixed gardens and drylands for seasonal crop farming, especially corn (Zea mays L.). Few areas remained barren and abandoned. Canal drainage systems, in forms of middle canal or secondary canal, covered the whole area of interest.

3.2.1. Oil palm plantations
Oil palm is considered as the highest contributor from plantation commodity in Pasaman Barat economy. Oil palm plantation covered about 121.800 ha with productivity around 15.32 ton/ha/y in 2019 [8]. Plantation was traditionally managed by local farmers. Water table was usually shallow (37-39 cm), and peat depth was approximately 3 m.

3.2.2. Mixed gardens
This land use was originally oil palm plantation. Some oil palm areas were converted into banana and Arenga catechu L. trees since the last 11 years. The farmers did not apply fertilizer to the crops. This land had about 67 cm water table with 1.43 - 2.56 m of peat depth.

3.2.3. Bushes
Bush lands were formed from forested lands after clearance. This land cover type was dominated by Cyclophorus aridus (paku kadal or gulma pakis to locals). This weed can grow up to 2 m height with dense roots. Water table in this area was 42-59 cm with approximately 0.6 m of peat depth.

3.2.4. Seasonal crops
This land was planted with corn (Zea mays L.) since 2019, developed from oil palm plantations. In 2019, corn was cultivated in about 50.936 ha with yield approached 95,820 ton [8]. This peatland had about 3.4 m depth with 35-50 cm water table.

3.2.5. Barren
This open land was derived from oil palm plantation, left open before replanted. There was a drainage canal in this area, especially vermicanal functioning for letting the water in and out. Water table was observed in between 41 and 47 cm with ca. 2 m peat depth.
3.3. Soil physical characteristics

Figure 3 suggests that there was a significant difference in soil organic matter (SOM) content of peatland at different land use. The highest SOM content (16.17%) was found in oil palm plantation while the lowest was in barren and mixed gardens (15.53%). We observed that this was possibly related to different water table depth or due to land management.

The deepest water table (± 66.3 cm) among the peatland was observed in mixed gardens. This suggests that the depth of peat materials being oxidized was the highest, which lowered SOM content. Low SOM content in barren surface was due to substantially deep water table (± 44.0 cm). The absence of vegetation over soil surface caused low SOM, since it was continuously oxidized. Low SOM content (±28.05%) in the average was also reported in Mappy Regency, especially in Bangge River Watershed, Papua [12].

Figure 3. SOM content over different land use

Total-N in Kinali peatlands was considerably high, as depicted in Figure 4. Total-N increased in line with SOM content ($R^2=0.94$); details are presented in Figure 5. This is understood since OM contains nitrogen. The highest N content (1.56%) was found in oil palm plantation; this followed the highest SOM content of this land use type (Figure 4). The lowest total-N (0.41%) was found in mixed gardens, accounting only one-fourth of total-N in oil palm plantations.

Unlike total-N, C/N ratio inversely correspond to SOM (Figure 6). The highest C/N ratio (38.53%) was found in mixed gardens, while the lowest (23.78%) was in barren surface. This could be understood since the amount of total-N in a soil conversely correlates to the amount of OM as a source of N and C. When OM is oxidized, C content decreases (emitted as CO$_2$), therefore, total-N increases. This findings complemented the outcome of Tanjung et al. [12]. They found that Papuan peat soil contained a moderate C-organic (16.31%), high nitrogen (1.09%) and moderate C/N ratio (15.01).
Observed soil BD varied with examined land use types (Figure 7). The highest soil BD reached 0.64 g/cm$^3$ (in mixed gardens), while the lowest was 0.31 g/cm$^3$ (in oil palm plantations). This value was considered high in peatlands; much higher than the one usually observed ($\leq$ 0.2 g/cm$^3$). As stated by Agus et al. [13], BD of saprist was the highest among three classes of peat soils. High BD was due to peatland management and the location of the peatland. Peatlands in Kinali is close to the sea and impacted by several through flooding, which deposits some minerals over land. In that sense, high deposited materials lead to high BD values.

Land use change on peatlands had increased SOM decomposition. Drainage lowers water table and cultivation increases SOM oxidation and solidification of peat soils. This process resulted in high BD of peat soils, confirming Tie and Lim [14], which found BD $> 0.2$ g/cm$^3$ along rivers and close to beach. River could highly contribute on the development and peat characteristics, similar to the findings of this research. It was reported that the area next (50-200 m) to a drainage channel had a higher soil BD [15], again, in line with the outcome of this research. We note that BD was higher than those reported in Riau and Jambi Provinces [16].

Bulk density of peat soil was negatively and weakly correlated with fiber content ($R^2=0.45; r=-0.67$). It indicates that fiber content was not the only factor affecting soil BD (Figure 8a). However, soil BD was positively and highly in agreement with ash content ($R^2=0.81; r=0.90$) (Figure 8b). This was due to the fact that ash is mostly derived from mineral materials. Further, soil BD negatively and highly corresponded to SOM content ($R^2=0.81; r=-0.90$) (Figure 8c).
Figure 8. Correlation between fiber content (a), ash content (b), SOM content (c) and BD of peat soil in Kinali West Sumatra Indonesia.

Fiber content of peat soil was significantly different among land uses (Figure 9). The highest fiber content (27.33%) was found in seasonal crop lands, while the lowest (2.33%) was in mixed gardens. Extremely low ash content of mixed gardens suggests that the degree of SOM degradation was very high, and minerals from flood deposit was also very high. This was also supported by deep (the deepest=66.3 cm) water table of this land use type. Mixed gardens had been cultivated for quite a while, therefore, OM oxidation has decreased fiber content.

Figure 9. Fiber content of peat soil at different land use

Figure 10. Ash content of peat soil at different land use

Ash content of Kinali peat soil was significantly different among land use types (Figure 10). It was inversely related to fiber content [17]. They found that ash content of Tanjung Soar, Kalimantan, peat soil (20 - >400 cm depth) was 1.13-43.88%. The highest ash content in our research site was discovered in mixed garden (73.23%), while the lowest (34.16%) was found in oil palm plantations.

Water table, irrespective to land use type, was < 1.0 m depth. The deepest water table (66.7 cm below soil surface) was found in mixed gardens. This land had been cultivated for a long time with variety of crops, mainly oil palm, banana, and Areca catechu. Water table continues to lowering, since it was not well-managed.

Table 1 indicates that peatland depth varied. Two land use types had peat depth > 3 m; hence, it does not suit farming. Water table over all land use types was < 1.0 m and peat maturity was in saprist, because retained fibers after being squeezed was < one third. Soil color was classified as brownish black because fiber was indiscernible.

3.4. Degrees of peat maturity

The degree of peat maturity was affected by land use altering the nature of peat soil (Table 1). Based on field observation, the depth of water table varied from 37 to 67 cm. The deepest was in mixed
gardens and the lowest was in oil palm plantations, which seemed to be associated to different management. Mixed gardens were mainly abandoned oil palm plantations. Environment in oil palm plantations was well maintained, including depth of water table.

Table 1. Some characteristics of Kinali peat soils

| No | Land Use       | Soil Depth (cm) | Depth of Water Table (cm) | BD (g/cm³) | SOM (%) | Ash Content (%) | Fiber Content (%) | Soil Color |
|----|----------------|-----------------|---------------------------|------------|---------|----------------|-------------------|------------|
| 1  | Oil Palm Plantation | 0 – 30          | 37-39                     | 0.31       | 65.84   | 34.16          | 22.67 sp          | 10 YR 2/2  |
| 2  | Mixed Garden       | 0 – 30          | 65-67                     | 0.64       | 26.77   | 73.23          | 2.33 sp           | 10 YR 2/3  |
| 3  | Bush Land          | 0 – 30          | 42-59                     | 0.52       | 39.07   | 60.93          | 7.67 sp           | 10 YR 2/3  |
| 4  | Seasonal Crop land | 0 – 30          | 35-50                     | 0.45       | 44.01   | 55.99          | 13.33 sp          | 10 YR 2/3  |
| 5  | Open Land          | 0 – 30          | 41-47                     | 0.54       | 27.88   | 72.12          | 4.00 sp           | 10 YR 2/3  |
|    | 30 – 60           |                 |                           | 0.52       | 50.40   | 49.60          | 10.00 sp          | 7.5 YR 2/2  |

Note: sp = saprist, hm = hemist, BB = Brownish Black

Low SOM, combined with high soil BD, indicated that the peat soil had been degraded. Ash content tended to increase, while fiber content decreasing, as peat soil develops its maturity. Laboratory analyses showed that peat soil had high ash content, indicating that maturity level has been advancing. We found that similar result was shown either from field measurement or from laboratory. Brownish black color was also an indicator that soil had been degraded

4. Conclusion

This research summarized that Kinali peatland was in Saprist. The degree of peat maturity was affected by land management, in particular, controlling the depth of water table as well as the location of the area. Based on fiber and ash content, supported by BD values, high level of peatland maturity in Kinali, West Sumatra, Indonesia, was in mixed gardens, followed in descending order by bushes, barren, dry lands and oil palm plantations.

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