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Soil organic carbon of grassland and bush forest on dryland in Aceh Besar District, Indonesia

UMAR H. ABDULLAH[1,♥], SUFARDI SUFARDI[2], SYAFRUDDIN SYAFRUDDIN[3], TETI ARABIA[2]
[1]Doctoral Program in Agricultural Sciences, Graduate Program, Universitas Syiah Kuala. Jl. Tgk. Chik Pante Kulu No. 5, Banda Aceh 23111, Aceh, Indonesia. Tel./fax.: +62-651-7551002. ♥email: umarah_1977@yahoo.co.id
[2]Department of Soil Science, Faculty of Agricultural Science, Universitas Syiah Kuala. Jl. Tgk. Hasan Krueng Kale No. 3 Kopelma Darussalam, Banda Aceh 23111, Aceh, Indonesia
[3]Department of Agrotechnology, Faculty of Agricultural Science, Universitas Syiah Kuala. Jl. Tgk. Hasan Krueng Kale No. 3 Kopelma Darussalam, Banda Aceh 23111, Aceh, Indonesia

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Abstract. *Abdullah UH, Sufardi S, Syafruddin S, Arabia T. 2022. Soil organic carbon of grassland and bush forest on dryland in Aceh Besar District, Indonesia. Biodiversitas 23: 2594-2600.* Soil organic carbon (SOC) is one of the important components that can improve soil conditions and maintain agriculture sustainability. This study was conducted to determine the potential of soil organic carbon in grassland and bush forest in Aceh Besar District. We used purposive random sampling by taking soil samples at various depths with five samples for each land type. The parameters of soil bulk density, % carbon soil, the potential of carbon and carbon stock were analyzed. Soil organic carbon (SOC) analysis followed the Walkley and Black method using analytical guidelines from the Indonesian Soil Research Institute. The results showed that land type and soil depth affected bulk density, % carbon soil, the potential of carbon and carbon stock. Land type affected soil organic carbon in which grasslands had a higher soil carbon than bush forests. In total, total soil carbon stock in the bush forest of Aceh Besar District was higher than that in grassland due to the much larger extent of bush forest in the district. Land use management efforts to improve soil SOC need to be carried out and in collaboration with various parties. Thus, it is necessary to maintain the availability of soil carbon stock for sustainable land management, including agriculture.

Keywords: Bush forest, dryland, grassland, soil carbon, soil quality

INTRODUCTION

Despite the decreasing trends, deforestation in Indonesia is still occurring at an alarming rate (Wahyuni and Suranto 2021). Deforestation in the country is driven by various factors, a including land conversion for infrastructure, settlement, agriculture, mining and plantations (Yakin 2011). Based on data by Global Forest Watch, Indonesia had 93.8 Mha primary forest in 2001. However, 9.75 Mha of the primary forest had been lost during the period 2002-2020 (Global Forest Watch 2022). The high rate of deforestation not only cause damage to the environment but also impacts the social conditions of the forest-based community (Wahyuni and Suranto 2021). In terms of climate change, deforestation has a great contribution to the amount of carbon released into the atmosphere due to the reduced number of trees.

Optimizing the potential for carbon sequestration in the soil can be used to mitigate climate change. Soil carbon can be a significant source or sink of greenhouse gases, depending on how land is used and managed, and whether the soil carbon is organic or inorganic (Monger et al. 2015; Sanderman 2012). Soil could serve as important storage of C because it is able to store about 81% of C in terrestrial ecosystems (Laganiere et al. 2010; World Bank 2012). The carbon contained in the soil, often so-called soil organic carbon (SOC), plays an essential role in the global carbon cycle that involves cycling through the soil, vegetation, oceans, and atmosphere (Clara et al. 2017). During the cycle, carbon is pooled in above-ground biomass, below-ground biomass, organic matter, and soil organic carbon (SOC), which altogether are taken into account in the carbon inventory (Sutaryo 2009).

SOC plays a role in increasing soil aggregation, pore space and connectivity, increasing air and water infiltration, reducing soil erodibility, and soil fertility preservation (Njoroge et al. 2018; Victoria et al. 2012). A decrease in SOC will cause a decrease in aggregate stability, total porosity, and water retention, as well as an increase in bulk density. This will reduce soil infiltration rate, hydraulic conductivity, and water availability (Ghorbani-Dashtaki et al. 2016; Toohey et al. 2018). Cultivation practices can affect the stability of soil aggregates which eventually changes SOC (Franzluebbers et al. 1997; Liu et al. 2019; Six et al. 2000). Soils become more susceptible to erosion when macroaggregates are disturbed. On the other hand, livestock farming and tillage can have a seven-fold and twenty-one-fold impact on surface runoff and soil erosion (Aweto 2013). These various activities are able to affect soil organic carbon conditions in terrestrial areas such as dryland.

Monitoring and determining SOC content is very important to assess the spatial and temporal variations in SOC pools and fluxes. Estimated SOC stock is also crucial for global climate change prediction (Adhikari et al. 2019). The availability of SOC in various types of land use needs to be studied to support sustainable agricultural activities and environmental conservation actions of land resources as optimally as possible. The results of the study by Han et al. (2015) showed that land-use changes could affect soil carbon storage in terrestrial ecosystems by changing biotic or abiotic processes involved in the carbon cycle, such as carbon adsorption in soil minerals. The results also showed that plant functional type was important for controlling depth-related changes in SOC content. Loss of soil organic C and C emissions from degraded drylands can be reduced by implementing restorative measures that can improve soil quality, soil organic carbon content, and biomass productivity (Arshad et al. 2016).

Mineral-related organic carbon is a valuable indicator of soil degradation resulting from land-use change. The research by Davari et al. (2020) showed that organic carbon content in the primary particles decreased significantly after forest conversion and cultivation. Land-use changes and cultivation practices can result in soil organic carbon de-protection, and consequently microbial degradation might occur rapidly. Deforestation and land-use change significantly affect the organic carbon content in various aggregates size classes. Sand-sized particles have a higher organic carbon content compared to clay and silt-size particles. Therefore, although coarse aggregate of organic carbon content in dry agricultural soils is less than in forest soils, they hold a higher organic carbon content in micro aggregates. Yet, forest land protects the SOC and reduces CO emissions and land degradation. Thus, improper land management in forest ecosystems can lead to land degradation and a significant reduction in soil quality and health. As a result, effective strategies should be adopted to promote sustainable land management and policies to mitigate the adverse effects of cultivating native soils. Cultivation in standing forests (e.g., agroforestry) can maintain land productivity to fulfill human needs, yet it still inhibits further land degradation. As a result, is highly recommended to plant among forest trees to preserve nature resources such as forest trees and soil.

One of the largest drylands in Indonesia is Aceh Besar District, Aceh Province, Indonesia. A previous study conducted by Sufardi et al. (2020) determined the distribution of soil carbon content in the drylands of Aceh Besar District depending on the type of soil (or soil order). Sufardi et al. (2020) reported that organic C content on the soil surface of entisols, inceptisols, mollisols, oxisols, and ultisols is generally low (less than 2%), and only andisols have a high organic C content (3.95%). To expand such research, this study aimed to investigate soil organic carbon on two land types (i.e., grassland and bush forest) in Aceh Besar District. We expect the result of this study can provide insights regarding the potential of soil carbon that exists in various types of land-use as well as future treatments that will be carried out, both reforestation and soil management to increase soil carbon stock.

MATERIALS AND METHODS

Study site

This study was conducted in Aceh Besar District, Aceh, Indonesia (Figure 1). This district is administratively divided into 23 sub-districts. Aceh Besar District is dominated by areas with an altitude of 200-400 meters above sea level. This shows that almost 70% of the dry land area in Aceh Besar District is located in a lowland area, so it is more suitable for developing lowland plants.

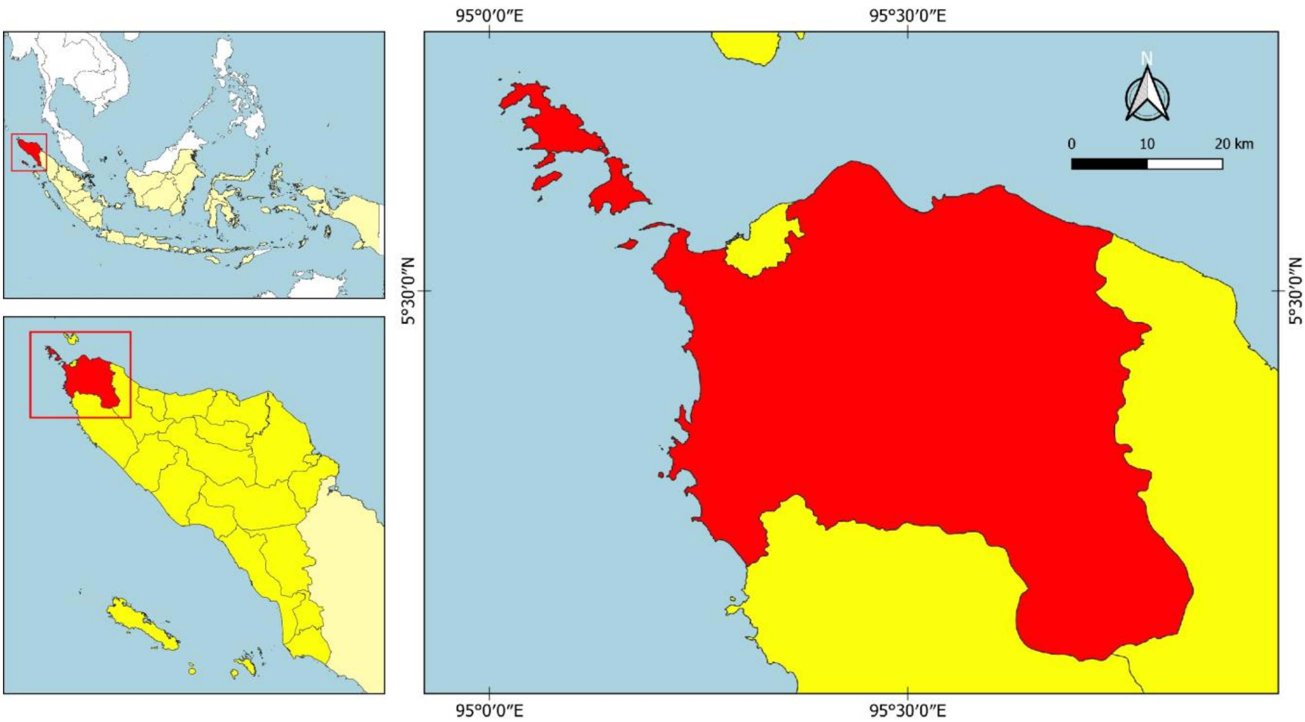

Figure 1. Map of study site in Aceh Besar District, Aceh Province, Indonesia

In terms of terrain, Aceh Besar District is dominated by small hilly reliefs and hilly to mountainous with slopes > 15% covering an area of 175,787 ha or 60.34%, while the rest includes flat to wavy reliefs with slopes <15% covering an area of 111,364 ha or 38.23% of the total district area. The distribution of areas with flat to slightly flat relief covers 18.02%, wavy relief 10.55%, and wavy relief 9.65% of the total district area. Based on the slope, the areas in Aceh Besar District have the potential for agricultural development, both annual and perennial crops with the assumption that other limiting factors for plant growth, such as high acidity and low soil fertility can be overcome. In this study, we evaluated the soil in grassland and bush forest that has different vegetation. Bush forest is mixed vegetation of trees and bushes. Some notable plant species in the bush forest included *Syzygium cumini*, *Eucalyptus* spp., *Acacia mangium, Morus alba, Acacia leucophloea*, and *Swietenia mahagoni, Lannea coromandelica, Syzygium aromatium, Cyperus rotundus, Urena lobata, Piper aduncum, Leucaena leucocephala, Moringa oleifera, Calontropis gigantea, Ficus benjamina, Jatropha curcas, Lantana camara, Eusideroxylon zwagery*. Grassland was dominated by low layer vegetation including *Imperata cylindrica*, *Cyperus rotundus*, *Paspalum conjugatum, Paspalum commersonii*, *Bidens pilosa, Panicum repens, Cyathula prostata, Axonopus compressus, Euleusine indica*, *Physalis angulata, Abrus precatorius, Borreria laevis, Hedyotis diffusa, Portulaca grandiflora,* and *Pennisetum purpureum*.

The research was carried out from July to December 2020. Purposive sampling was employed in grassland and bush forest located in dryland areas with 5 sample points in grasslands and 5 sample points in the bush forest. Sampling was based on digital maps obtained from overlaying several types of maps such as land-use maps, slopes, soil types and the administration of Aceh Besar (Table 1). Soil analysis was carried out at the Soil and Plant Research Laboratory, Faculty of Agriculture, Syiah Kuala University, Banda Aceh, Indonesia.

Materials

Soil samples were composite soil samples taken at a depth of 0-5, >5-10, >10-20, >20-30, >30-70, and >70-100 cm and were limited to a 25% slope representing entisol and inceptisol soil types. This is because the slope is still usable and feasible for cultivation and environmental conservation. For the purposes of taking soil samples, a profile with a length and width of 100 cm x 100 cm was made with a depth of 125 cm. There were two kinds of soil samples taken, namely disturbed soil samples and intact soil samples. Disturbed soil samples were used to analyze the chemical properties of the soil, including organic C content. A sampling of disturbed soil was carried out using a soil drill at the respective depths: 0-5 cm, 5-10 cm, 10-20 cm, 20-30 cm, 30-50 cm, 50-70 cm, and 70-100 cm. Whole soil samples were used to analyze the physical properties of the soil, such as soil bulk density (BD) and soil texture. Sampling of intact soil was carried out using a sample ring (size 7.4 x 4 cm) at the respective depths: 0-5 cm, 5-10 cm, 10-20 cm and 20-30 cm, 30-50 cm, 50-70 cm and 70-100 cm (Davari et al. 2020; Donovan 2013; Purwanto et al. 2014; Sutaryo 2009).

Determination of soil bulk density used gravimetric method. The weight of the soil sample at each depth was dried at 105ºC until a constant weight was achieved, resulting in a dry weight of the soil. The soil bulk density was determined by dividing the dry weight of the soil material (W_d) by the volume of soil (V) (Rai et al. 2017).

SOC analysis

Soil organic carbon analysis was carried out using the Walkley and Black method as explained by Global Soil Laboratory Network (2019). A total of 0.5 grams of soil sample (<0.5 mm) was dissolved with 5 ml of $K_2Cr_2O_7$ solution and 10 ml of H_2SO_4 on a hotplate. After the solution had cooled, 5 ml of H_3PO_4 and 50 ml of distilled water were added. Next, it was titrated with 0.025 $FeSO_4$ solution M using a burette until the color changed into a clear green. After that, the volume of the $FeSO_4$ solution used was recorded. The organic carbon content of the soil was calculated as the difference between the volume of the $FeSO_4$ solution used in the sample and that used for the blank (without soil). Criteria for the C-Organic score of the soil were as follow: very low (<1.00), low (1.00-2.00), moderate (2.00-3.00), high (3.00-5.00), and very high (>5.00) (Sukarman et al. 2017).

Table 1. Soil carbon sample point on grassland and bush forest in Aceh Besar District, Aceh, Indonesia.

Land type	Sample points	X	Y	Area (ha)	Location
Grassland	5	95.492339	5.538698	80.50	Eumpe Awee 1
		95.492244	5.539973		Eumpe Awee 2
		95.490307	5.535439		Eumpe Awee 3
		95.569250	5.306556		Jantho 1
		95.595111	5.293056		Jantho 2
Bush forest	5	95.417849	5.645336	6,513.47	Neuheun
		95.417816	5.646102		Neuheun
		95.496851	5.547359		Uteun Sira
		95.494559	5.549042		Uteun Sira
		95.493367	5.551604		Uteun Sira

The amount of carbon in the soil was obtained by multiplying the observed parameters. The formula for soil carbon density was as follows (SNI 2011):

$$Ct = Depth \times \rho \times \% C\ organic \quad [1]$$

Where: Ct = soil carbon content (g cm^{-2}), Depth = the depth of soil sample (cm), ρ = bulk density (g cm^{-3}), % C organic = the percentage of carbon content as much as 0.47 or using the carbon percentage obtained from the measurements in the laboratory.

Then, the soil carbon content obtained was converted to ton per hectare with the following equation (SNI 2011):

$$C_{soil} = Ct \times 100\ (ton\ ha^{-1}) \quad [2]$$

Where: C_{soil} = Soil organic content per hectare, expressed in tonnes per hectare (ton.ha^{-1}), Ct = Soil carbon content (g cm^{-2}), 100 = Conversion factor of g cm^{-2} to ton ha^{-1}.

Data analysis

The data from field measurements and laboratory analysis were presented in the form of C distribution in the soil, which was then converted into acreage (hectares). Carbon stocks in the soil on each land type were expressed in ton ha^{-1}. Furthermore, it was processed using the soil carbon formula descriptively to compare the carbon stocks with the existing carbon content.

RESULTS AND DISCUSSION

Bulk density, soil carbon, and potential of carbon in two different land types

The results show that soil density, % soil carbon, and potential of carbon of grasslands were higher than in the bush forest. Grasslands provide more C input from plants, especially underground plants, due to the continued influence of roots and ground cover. Continuous soil cover and the absence of tillage help curb soil C output due to reduced soil erosion and increased protection of soil physical properties. This suggests that reduced tillage does not necessarily increase SOC stock, but a redistribution of SOC may occur so that it is closer to the soil surface (Haddaway et al. 2017; Powlson et al. 2014). Differences in land use between grasslands and bush forests, the intensity of cultivation, and fertilization are factors that cause changes in soil conditions (Abera and Maskel 2013). It can also be seen in the study area that the grassland vegetation is tightly covered hence erosion did not occur easily. On the other hand, many open lands were not flat in the bush forest vegetation, so erosion was easy to occur. The topography of the grassland vegetation was flatter than that of the bush forest, which also caused erosion and nutrient leaching. The result of this study is in line with Li et al. (2019) that studied the effect of soil erosion on soil organic carbon content that observed the increase of soil erosion led to the decrease of SOC.

Table 2 shows that the overall average soil density in grasslands and bush forests at a depth of 0-100 cm was 1.48 g cm^{-3} and 1.38 g cm^{-3}, respectively. Both land types showed the same results at a depth of 0-5, >5-10, >10-20 with a bulk density of 1.43 g cm^{-3} (grasslands) and 1.28 g cm^{-3} (bush forest). Meanwhile, at depths >20-100, it was 1.54 g cm^{-3} (grasslands) and 1.48 g cm^{-3} (bush forest). The same result was obtained by Siringoringo (2014) who found that bulk density in *Acacia mangium* plantation increased significantly with increasing soil depth. Soil density conditions can be influenced by several factors, one of which is the number of roots. The soil layer 0-20 cm has more accumulation and number of plant roots compared to the soil layer >20 cm. Low bulk density in the upper layer is closely related to the increase in the number of roots while high bulk density is caused by low root volume (Hunke et al. 2014). In addition, the lower layer has less organic matter, resulting in the soil becoming denser (Eluozo 2013). The density of the soil surface causes less pore space and it affects soil aggregation and root growth.

Other results showed that soil organic carbon content was inversely proportional to soil depth. Based on the results of the analysis, it can be seen that the soil carbon content in grassland at a soil depth of 0-5 cm was 2.12%, and 0.15% at a depth of 70-100 cm. The same results also happened in the bush area. The soil carbon content at a depth of 0-5 cm was 1.52%, while at a depth of 30-70 cm and 70-100 cm were 0.93% and 0.76% respectively. The highest soil organic carbon content in dryland in Aceh Besar District was at a soil depth of 0-5 cm (top surface), while the lowest soil organic carbon content was found in layers >70-100 cm (grasslands) and >30-70 cm (bush forest).

Table 2. Comparison of bulk density, soil carbon and potential of carbon in grassland and bush in Aceh Besar

No.	Depth (cm)	Bulk density (g cm^{-1})		% Carbon in soil		Potential of carbon (ton ha^{-1})	
		Grassland	Bush forest	Grassland	Bush forest	Grassland	Bush forest
1	0-5	1.43	1.28	2.12	1.52	15.16	9.73
2	>5-10	1.43	1.28	1.91	1.32	13.66	8.45
3	>10-20	1.43	1.28	1.72	0.86	18.20	11.01
4	>20-30	1.54	1.48	1.26	0.92	19.40	13.62
5	>30-70	1.54	1.48	0.83	0.93	51.13	55.06
6	>70-100	1.54	1.48	0.15	0.76	6.93	33.74
	Total					124.48	131.61
	Average	1.48	1.38	1.33	1.05	20.75	21.94

A similar result was obtained by Wei et al. (2012), that conducted a comparative study on SOC sequestration and distribution in the Chinese Loess Plateau. Their study also showed that SOC content was the highest in the topsoil layer. The SOC decreased significantly at a depth of 30 cm and had an almost constant value at a depth of 40-50 cm. The results are due to the limited ability of the forest to increase SOC content in deep soil (Wei et al. 2012). Dorji et al. (2014) also conducted a study of SOC vertical distribution in the Eastern Himalayas. The study determined the SOC in the depths of 0-20 cm to 80-100 cm. The SOC value relatively decreased along with the soil depths. SOC value was significantly different across the depth of 0-20 cm compared to the depth of 20-40 cm, 40-60 cm, 60-80 cm, and 80-100. However, at the depths of 20-40 cm, the value was not significantly different from the last three depth ranges in the study (Dorji et al. 2014). The accumulation of organic matter from litter decomposition tends to be high in the topsoil layer, so soil organic carbon in the topsoil layer tends to be higher. This also causes the soil carbon value of grassland to be higher than that of bush forests (Elliott 1986). The high soil carbon is also strongly influenced by the density of the soil and the formed pore space. Almost all of the organic carbon in the soil is located in the pores between the soil particles, so the size of the large soil pore space will be directly proportional to the organic carbon content of the soil (Davy and Koen 2013).

Our study found that the potential carbon value of grasslands and bush forests was linear with the increasing soil depth. The highest value of the potential of carbon at a depth of 30-70 cm reached 51.13 tons ha^{-1} (grasslands) and 55.06 tons ha^{-1} (bush forests). The potential of carbon is strongly influenced by vegetation that grows above the soil surface. Furthermore, the vegetation is influenced by the environment where it grows, such as humidity, temperature, and land cover type (Tuah et al. 2017). Sugirahayu and Rusdiana (2011) stated that land cover has an influence on the amount of carbon stored. For example, the amount of carbon sequestration in mangrove forests is greater than in oil palm plantations, so carbon storage in mangrove forests is also greater than in oil palm plantations (Sugirahayu and Rusdiana 2011). The amount of carbon stored is influenced by density, species, age of trees, and environmental factors. The level of soil carbon storage can also be determined from interrelated variables such as organic carbon concentration, soil density, and soil depth (Siringo 2013).

Soil carbon stock in two different land types in Aceh Besar

The total area of grassland and bush forest in Aceh Besar were 80.50 hectares and 6,513.47 hectares, respectively (Table 2, Figure 2).

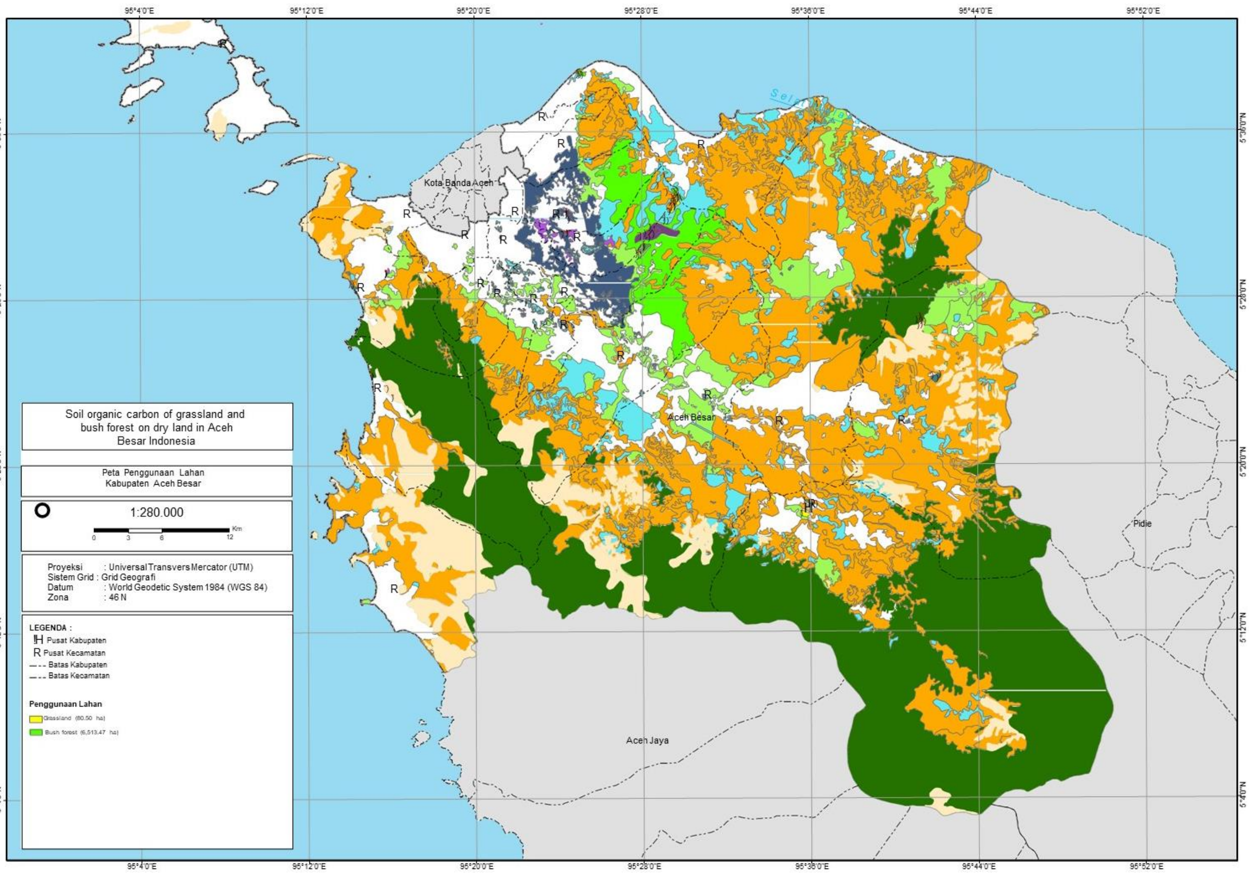

Figure 2. The spatial distribution of soil carbon in grassland and bush forest in Aceh Besar, Indonesia

Table 3. Soil carbon stock in grassland and bush forest vegetation in Aceh Besar, Indonesia

Land type	Potential of carbon (ton ha^{-1})	Area (ha)	Total carbon (ton)
Grassland	124.48	80.50	10,020.64
Bush forest	131.61	6,513.47	857,237.79

Table 2 shows that the potential of carbon in grasslands had a smaller value than bush forests which had a wider area. Grasslands had a potential carbon of 124.48 tons ha^{-1}, while bush forests had a potential carbon of 131.61 tons ha^{-1}. The potential for carbon storage was quite low in grasslands, so conservation efforts need to be done by increasing plant density, one of which is by planting woody plants. This is because the difference in carbon storage in each land cover is influenced by the number and density of trees, tree species, and environmental factors, including sunlight, water content, temperature, and soil fertility that affect the rate of photosynthesis (Sugirahayu and Rusdiana 2011).

The result of the analysis showed that the total soil carbon stock in grassland vegetation in Aceh Besar was 10,020.64 tons, while that in bush forest reached 857,237.79 tons (Table 3). This is because the bush area was wider than the grassland in Aceh Besar. Although the amount of soil carbon in grasslands horizontally was lower compared to that in the bush forest, the soil carbon content in grasslands vertically was relatively high compared to the bush area. This could be affected by the diversity of plants found in the bush forest. Soils that are formed under grassy vegetation have organic matter levels at least twice that of forest soils due to organic matter added to the top layer of above-ground growth and dead roots. In general, soil organic matter will increase with high biomass production (USDA-NRCS 2014). Wei et al. (2012) also found that SOC in the grassland was higher than in the forest. They stated that grass cover was more effective for carbon sequestration (Wei et al. 2012). This is similar to Dorji et al. (2014) that found the SOC density in grasslands was higher than in bush forestlands at any depths. That results are possibly caused by shallow vertical root distribution in the grassland (Dorji et al. 2014).

In conclusion, land type and soil depth affected bulk density, % carbon soil, the potential of carbon and carbon stock. Land type influenced the SOC in which grasslands had a higher soil carbon than bush forests. In total, total soil carbon stock in the bush forest of Aceh Besar District was higher than that in grassland due to the much larger extent of bush forest in the district. Land-use management efforts to improve soil SOC need to be carried out and in collaboration with various parties. Dryland management efforts in Aceh Besar also function to preserve the environment and maintain the carbon cycle to be in good condition. Therefore, it is necessary to maintain the availability of soil carbon stock for sustainable land management, including agriculture.

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