Comparison of Carbon Content in Soil and Biomass in Various Types of Sub-Optimal Dryland Use in Aceh Besar, Indonesia

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Abstract. This study was conducted to compare the content of carbon in soil and in biomass vegetation in various type of sub-optimal dryland in Aceh Besar district, Indonesia. Soil samples were collected from seven soil depth from 0 to 100 cm under 12 land uses including primary forest, secondary forest, pine forest, *Eucalyptus* forests, teak forest, forest shrubs, shrublands, grasslands, mixed gardens, moorlands, rainfed rice fields, and bare lands. The measurement of plant biomass is differentiated according to the type of vegetation based on the BSN (2020) procedure [1]. The biomass of vegetations were used allometric equations. The results of the study showed that the C content of the soil at a depth of 0-30 cm was higher than the C content at 30-100 cm. Carbon soil potential at the depth of 0-100 cm and biomass carbon contents in the sub-optimal dryland of Aceh Besar varies greatly between land use types. Primary forest has the highest potential for soil carbon and biomass carbon compared to other land use types. Soil and biomass C potentials in primary forest were 332.28 ± 28.75 t ha^{-1} and 241.71 ± 24.46 t ha^{-1} (70.4%), respectively, with soil C stock of 25,103.68 Gg. The lowest soil C potential was found in bare land, namely 57.54±5.87 t ha^{-1} with a biomass C potential of 0.53 ±0.06 t ha^{-1}, while the lowest soil C stock was found in teak forest, which was 4.83 Gg. There is a positive correlation between soil C stock and biomass C content. The ratio of soil C and biomass C in sub-optimal dryland of Aceh Besar varied from 0.01 to 1.57.

1. Introduction

Climate change, which has recently become a global issue, is associated with high level of carbon emissions in terrestrial systems. The changes in land use pattern and land cover are two of the factors making carbon emissions go up either due to legal and illegal deforestation. Deforestation alone accounts for around 12% of the world's anthropogenic greenhouse gas emissions, while another 6% comes from other sources [2]. Deforestation has led to an increase in abandoned vacant land and humans are responsible for this to take place [3] [4].

The conversion of forests to agricultural land and other uses is common in Indonesia done by communities and by plantation companies [5]. Indonesia's forest monitoring in 2020 showed that the total forested land area in Indonesia was 95.6 million hectare or 50.9% of the total land area of the country. 88.4 million hectare belongs to forest area and net deforestation in 2019-2020 both within and outside Indonesia's forest area is 115.5 thousand hectares [6]. The highest area of deforestation occurred in the secondary forest class at 104.4 thousand hectares, 58.1% of which or 60.64 thousand hectares were inside the forest area and the remaining 43.7 thousand hectare were outside the forest area. This forest conversion leaves lands unproductive (sub-optimal) because the community tends to abandon some of these areas as in sub-optimal dryland in Aceh Besar [7].

The conversion of forest into cultivated land or abandoned land can have an unfavorable impact on the environment as it can reduce ecological functions and expedite climate change since forests function as carbon recycler from the atmosphere to the terrestrial biosphere that mainly take place in forests [8] [9]. Forests are complex ecological systems dominated by various types of dense trees that play an important role for human life and other living things. They are the most efficient natural ecosystems with high photosynthetic rates, carbon dioxide reservoir, animal habitats, and carbon storage as well as a provider of nutrients for plants [10]. Forests are also the largest supplier of oxygen on Earth which is very beneficial for living creatures and is considered the lungs of the world [11] [12]. Forest vegetation and other plants on the earth's surface can play a role in fertilizing the soil through the process of recycling carbon into the soil and as a source of soil organic matter. Soil organic content reflects a higher level of soil fertility because soil organic matter can act to improve physical, chemical and biological properties of soil [13] [14] [15].

This organic matter is the most important component of soil. It is formed predominately by a mixture of the decomposition of plant material that falls to the surface of the soil, the decaying parts of the rooting systems of plants within the soil, and the remains of any of the huge population of organisms on the soil once they die [16]. Soil organic carbon (SOC) is the largest carbon stock in terrestrial ecosystems and plays a key role in biosphere feedback for an increase in atmospheric carbon dioxide in the world, so that the earth's atmosphere will be warmer [17]. Soil contains approximately 2,344 Gt (1 gigaton = 1 billion tons) of organic carbon, which is globally the largest terrestrial organic carbon stock [18]. Small changes in soil organic carbon stocks can have a significant impact on atmospheric carbon concentrations [19]. Soil carbon stock decreases due to forest degradation and deforestation [20] [21], but overall soil carbon stock does not decrease due to forest degradation and even increases at each layer during forest conversion to grassland [22].

The effect of forest conversion on soil quality and the relationship between vegetation type and soil carbon storage are very important information in the management of sustainable agricultural land. This is required to find out whether the conversion of forestland into various cultivation or agricultural lands can reduce organic soil carbon stocks. The research findings in East Kalimantan, Indonesia, showed that soil carbon stocks subsoil at a depth of 40 cm at 36.2 t ha^{-1} in cogon grass land and at 38.9 t ha^{-1} in secondary forest and then at 33.2 t ha^{-1} in primary forest, which is much lower than in Sumatra [12]. Therefore, knowing carbon stocks in various types of land is very essential because carbon stocks can be used to estimate the amount of carbon dioxide (CO_2) absorption by plants, including in soil. This information is very important because the conversion of forest land to cultivation areas can have a negative impact on the quality of the environment and soil. This study aims to examine the relationship between biomass carbon potential and soil carbon content and stock in various types of sub-optimal dryland use in Aceh Besar.

2. Materials and Methods

2.1. Site description

The study was conducted at sub-optimal dryland in Aceh Besar Regency, Indonesia and based on map analysis, the area was around 239.484,63 hectares. The twelve land use types are primary forest, secondary forest, pine forest, Eucalyptus forests, teak forest, forest bush, shrubs, grasslands, mixed garden, moor, rainfed fields, and bare land and they were the sites for taking the soil samples and for measuring the biomass of vegetation.

2.2. Soil sampling and measurements

Carbon stored in soil is varied by soil layer, and based on Indonesian National Standard or SNI [1], we took the soil samples from seven soil layers. They are at 0–5 cm, 5-10 cm, 10-20 cm, 20-30 cm, 30-50 cm, 50-70 cm, and 70-100 cm. They all represent the 12 land use types (LUT) in sub-optimal dryland in Aceh Besar. Of each LUT, five to eight random locations (sites) were selected for soil sampling using plot sample of 20 m x 20 m, thus there were 75 sites to be evaluated. For soil carbon analysis, the samples of soil in each site were taken using soil auger. For soil bulk density, the samples of soil were taken using the soil cores or ring sample at a height and diameter of 10 cm and 7.4 cm, respectively. The samples of soil organic carbon in each depth were collected and put in plastic bags and then taken to the laboratory to be air-dried. Afterwards, all plant materials and root biomass were removed for fresh soil samples, and the soil was passed through a 0.5-mm sieve. The soil bulk density of soil layers (0 to 100 cm) in the ring sample were measured using gravimetric method. After drying in the oven at a temperature of 105^0C for 4 hours, it was weighed again and separated according to the volume of the soil cores. SOC was determined from air-dried soil samples using Walkley and Black method [23]. The calculation of the carbon density in the soil (profile) was carried out using the Donavan formula, 2012, namely the content of carbon (percentage) multiplied by the bulk density at each layer. The carbon potential at each LUT location is calculated by adding up the carbon density at each soil layer from 0-100 cm with the soil volume per hectare. The carbon stock is calculated from the potential carbon times the total area of each LUT.

2.3. Analysis of biomass Carbon

Biomass carbon was analyzed using the dry ashing method (proximate analysis). Samples of biomass in the form of wood, twigs, and branches were put into the moving chamber (furnace) at a temperature of 700 ^{0}C. The percentage of carbon was calculated using the gravimetric method. The carbon content on leaves and litter were calculated using the same procedure as for soil carbon determination using the Walkley and Black method [24]. Carbon density in plant biomass (living plants, litter, dead plants/branches) in each LUT were calculated by multiplying the percentage of carbon in biomass with wood density and volume of biomass.

2.4. Statistical analysis

The research data were processed statistically using descriptive statistics, Cluster analysis, least significant difference (LSD) test at P 0.05, and Spearman correlation and regression analysis.

3. Results and Discussions

3.1. Soil carbon content

Table 1 shows that the percentage of soil carbon content on the top layer (0-30 cm) of each type of suboptimal dryland use in Aceh Besar varies greatly with an average range at 0.87-5.91% meaning they are in the criteria of very low to very high [25]. The proportion of soil carbon content in the subsoil (30-100 cm) does not differ much between types of land use, ranging from 0.27-1.19% (very low to low). These data indicate that the accumulation of soil organic matter is in the upper layers and decreases in the deeper layers. The result of this study is in accordance with the result of research by [26] which also shows that the carbon content decreases with deeper soil layers.

Furthermore, looking at the criteria of soil carbon content, the soil carbon content in the sub-optimal dryland in Aceh Besar falls into four categories, namely very low, low, medium, and very high [25]. The highest soil carbon content is in primary forest vegetation, while those with moderate soil carbon content is in secondary forest and mixed garden. Very low soil carbon content is in shrubs and the high and low carbon content is influenced by the amount of accumulation of organic matter on the soil surface [27]. Sources of organic matter can derive from the supply of material from vegetation and accumulation of organic matter from the addition of organic fertilizers [28]. Primary forest is a mixed vegetation type with high density of trees and has high biomass [29]. Therefore, the role of forest vegetation is very important for the storage of carbon into the subsoil. On the other hand, in bushland and bare land as well as dryland, the organic carbon content in the soil is relatively low because the vegetation biomass here is lesser because it has sparse grass area and tree vegetation.

Table 1. The average of soil carbon content and carbon stock in the soil profile in sub-optimal dryland in Aceh Besar at various land use type

No.	Land use type (LUT)	C content in soil (%)		Soil Carbon	Land area	Soil C Stock
		0-30 cm	30-100 cm	(t/ha)	(ha)	(Gg)
1	Primary forest	5.91±0.21	1.19±0.19	332.28±28.75 c	77,894.98	25,103.68
2	Secondary forest	2.23±0.13	0.52±0.10	123.50±14.01 b	23,558.37	2,909.55
3	Pine forests	1.67±0.09	1.15±0.21	111.50±12.11 ab	53.85	6.00
4	Eucalyptus forest	1.80±0.31	0.68±0.01	105.90±10.69 ab	307.14	32.52
5	Teak forest	1.45±0.01	0.43±0.24	82.58±8.54 a	58.50	4.83
6	Forest bush	1.16±0.01	0.85±0.06	78.24±7.42 a	6,513.47	509.64
7	Shrubs	0.87±0.11	0.73±0.01	61.13±6.51 a	96,962.20	5,927.49
8	Grasslands	1.75±0.06	0.49±0.13	99.08±11.08 ab	80.50	7.98
9	Mixed garden	2.00±0.08	0.67±0.02	115.82±5.31 b	15,052.09	1,743.27
10	Moor	1.05±0.01	0.27±0.07	58.90±2.47 a	313.03	18.44
11	Rainfed fields	1.07±0.01	0.94±0.11	76.38±2.38 a	4,478.57	342.09
12	Bare land	1.01±0.21	0.30±0.02	57.54±5.87 a	14,211.93	817.70
					239,484.63	37,423.20

Numbers in the fifth row followed by the same letter, they are not significantly different according to the BNT test (0.05)

Table 1 also shows that the percentage of soil carbon content is closely related to the potential for soil carbon storage. The potential soil carbon varies greatly between land use types with the potential carbon ranging from 57.54 to 332.28 t ha^{-1}. The highest soil carbon potential is in primary forest vegetation and the lowest is in shrubs, dryland, and open land or bare land. This carbon potential is an illustration of the ability of soil to maintain carbon reserves in the soil. The result of this study indicate that forest vegetation types, especially primary forest is a better land for maintaining soil carbon and sequestration compared to other lands as reported by previous researchers [30] [31]. The result of this study indicate that the higher the carbon potential, the higher the capacity of soil carbon storage. The result of the calculation of soil carbon reserve in the sub-optimal dryland in Aceh Besar showed the total carbon reserve at 37,423.20 Gg. If the area of primary forest in sub-optimal dryland in Aceh Besar is still above 75%, then certainly the soil carbon reserve will be much higher. Therefore, to anticipate greater loss of carbon due to land conversion, any land that has experienced forest loss and land degradation require conservation actions, such as reforestation or land management through agroforestry systems [32], because both lands are considered essential in increasing soil carbon.

3.2. Biomass carbon (vegetation)

Table 2 shows that the potential for biomass carbon in each land use type is highly diverse and the biomass weight ranges from 0.53 to 241.71 t C ha^{-1}. Primary forest is a vegetation type that has the highest biomass carbon potential compared to other vegetation types. The lowest biomass carbon content is on land with little vegetation such as open land. The result of cluster analysis based on data on biomass carbon content from the 12 types of land use in sub-optimal dryland fall into three groups, namely: (a) those with carbon biomass content above 200 t C ha^{-1} belong to primary forest (b) biomass carbon content at 100 to 200 t C ha^{-1} exists in secondary forest, pine forest, Eucalyptus forest, and teak forest, and (c) biomass carbon content below 100 t C ha^{-1} exist in forest shrubs, scrublands, grasslands, mixed gardens, dry fields, rainfed rice fields, and open land or bare land.

Table 2. Biomass carbon potential and percentage of carbon loss from biomass in various types of dryland use in Aceh Besar

No.	Land Utility Type (LUT)	C Potential in Biomass	Land area	Total of Biomass C	
		(t C ha^{-1})	(ha)	(Gg C)	(%)
1	Primary forest	241.71 ±24.46 d	77,894.98	18,817.44	70.40
2	Secondary forest	152.05 ±14.43 c	23,558.37	3,582.14	13.40
3	Pine forests	173.69 ±23.78 c	53.85	9.35	0.03
4	Eucalyptus forest	150.03 ±33.74 c	307.14	46.08	0.17
5	Teak forest	107.81 ±18.35 c	58.50	6.31	0.02
6	Forest bush	69.92 ±10.21 b	6,513.47	455.45	1.70
7	Shrubs	24.50 ±3.66 a	96,962.20	2,375.37	8.89
8	Grasslands	15.15 ±2.21 a	80.50	0.44	0.00
9	Mixed garden	92.69 ±9.10 b	15,052.09	1,395.11	5.22
10	Moor	35.42 ±2.66 a	313.03	11.09	0.04
11	Rainfed fields	4.79 ±0.37 a	4,478.57	21.43	0.08
12	Bare land	0.53 ±0.06 a	14,211.93	7.47	0.03
	Total		239,484.63	26,727,68	100.00

The numbers in the third row followed by the same letter are not significantly different according to the BNT test (0.05)

Table 2 shows the total biomass carbon as a whole at 26,727,68 Gg. The largest contribution of carbon comes from primary forest vegetation biomass at 70.4% with a total area of 77,894.98 hectare. The second contributor to biomass carbon comes from secondary forest at 13.4% with an area of 23,558.37 hectare. The third is shrubs at 8.89% with an area of 96,962.20 ha. The contribution of biomass carbon from other land use types is relatively low at below 6%. The other finding also show that despite bushland having the largest area, its contribution of biomass carbon is still far lower than that of the primary forest. This is because the total biomass in primary forest is much higher than that of vegetation in secondary forest. Grassland is the type with the lowest contribution to biomass carbon due to its small area at 80.5 ha and the potential for biomass carbon is at 15.15 t C ha^{-1}. Natural forest act as the highest carbon storage compared to agricultural land use systems [33]. Measuring the amount of carbon stored in living plant bodies (biomass) in a field can describe the amount of CO_2 in the atmosphere that is absorbed by plants. Measuring carbon that is stored in dead plant parts (necro-mass) indirectly describes CO_2 that is not released into the atmosphere [34] [35].

3.3. The comparison of soil carbon and biomass carbon

Figure 1 shows the comparison of the carbon content of vegetation biomass with soil carbon of the 12 types of land use. Subsoil carbon content is much higher in primary forests, shrubs, grasslands, mixed gardens, moorland, rainfed rice field, and open land than biomass potential carbon aboveground. This indicates that the storage of carbon in the subsoil in these LUTs has occurred for a long time, thus forgoing dependence on the amount of the vegetation above them. The soil carbon content in primary forest is the highest compared to other lands owing to the abundant vegetation biomass supplying organic matter into the soil for a long time hence the soil carbon content is almost equal to the carbon potential of the above biomass [30] [33] [36]. Furthermore, in shrubs, grasslands, moorland, rainfed rice fields, and open land, the biomass content is low due to reduced vegetation biomass after these areas are converted from primary forest into cultivated land or other uses. Therefore, the soil carbon content does not balance any more with the carbon content in the soil vegetation biomass on it. In addition, soil characteristics also affect the capacity of soil carbon storage [26] [37]. In contrast, secondary forest, pine forest, Eucalyptus forests, teak forest, and forest shrubs have higher carbon biomass content than soil carbon content (Figure 1) thanks to it having more vegetation thus the biomass can be maintained even though the amount of biomass is still lower than primary forest. The result of field observation shows that shrubs and cultivated forests such as pine forest, teak forest, and

Eucalyptus forests have trees that are more than 20 years old and the plants density is high to produce a potential carbon biomass at 100 - 200 t ha^{-1} (Table 2).

Figure 1 (right) shows a large variation in total biomass carbon and soil carbon reserve between land use types. This is due to the different potential carbon and dependency on the area. The result of the study shows that the highest soil carbon reserve is on primary forest vegetation at 25,103.68 Gg. This high soil carbon reserve is related to the highest biomass carbon content at 18,817.44 Gg. The soil carbon reserve (underground carbon) is higher than the aboveground carbon biomass. This is in accordance with the statement of researchers who often find that the capacity of soil carbon storage is higher than that of carbon storage in biomass [27]. Furthermore, when compared with the soil carbon storage in other land use types, it is very small at below 10,000 Gg. If the comparison between soil carbon reserve in primary forest and other LUTs is calculated, it turns out that the ratio can reach between 1:5 and 1:5000. Based on the result of this study, to maintain the carbon content in the soil, land use patterns need to be taken into account. If this sub-optimal dryland area is used as a place to grow crops (cultivated land), then it is necessary to choose types of plants that produce high biomass, for example by implementing conservation farming systems such as agroforestry as part of continuous efforts to return the carbon cycle to the soil [38]. Neglected lands, such as shrubs, grasslands, and forest shrubs, should be managed for conservation areas by planting forest vegetation or reforestation because these lands are more effective in preserving the nature, especially in maintaining the balance of soil carbon [39].

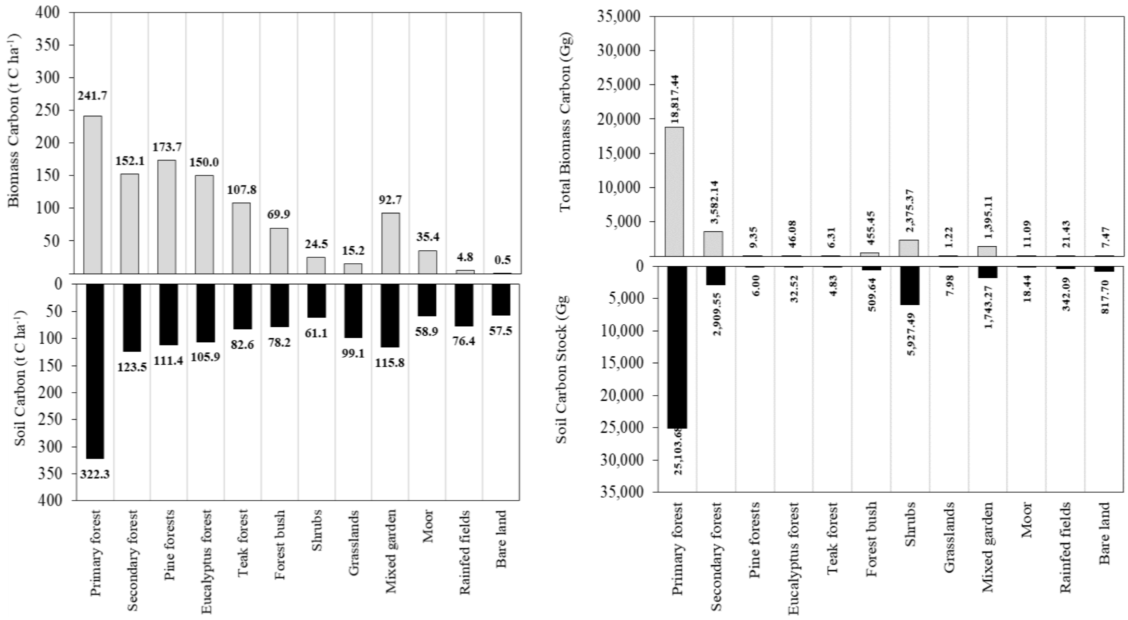

Figure 1. Comparison of potential carbon in subsoil and biomass for each sub-optimal dryland use in Aceh Besar

Figure 2 shows that the ratio of the content of biomass carbon and soil carbon also varies greatly amongst vegetation types or land use types. The ratio varies from 0.01 to 1.56. This diversity shows that the ability of the soil to store carbon is not the same. One of the factors determining the ability to store carbon are soil texture, solum depth, and other soil physical properties such as porosity, bulk density and the presence or absence of layers that curb the penetration of plant root. Although the main source of soil organic matter is the vegetation atop it, the type of vegetation and soil conditions have an effect as well [40]. The lowest ratio of biomass carbon and soil carbon is in LUT without vegetation or open land at 0.01 and the highest is in teak forest at 1.56 while in primary forest at 0.75. Ideally, the biomass carbon/ soil carbon ratio is around 1.00 meaning the carbon content of the biomass is equal to the carbon content of the soil. Therefore, lands with biomass carbon/ soil carbon ratio above 1.00 such as secondary forest, teak forest, pine forest, and Eucalyptus forest have problems with the penetration of biomass into the subsoil. On the other hand, if the biomass carbon/ soil carbon ratio is below 0.5, then this kind of land needs planting with vegetation or reforestation.

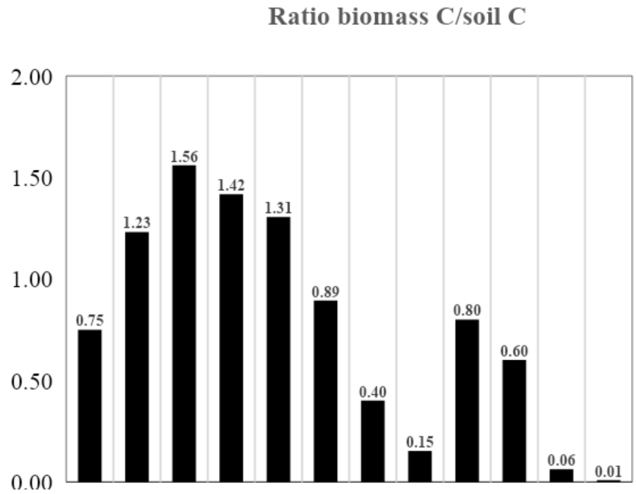

Figure 2. The ratio of biomass carbon content and soil carbon for each type of sub-optimal dryland use in Aceh Besar

3.4. Correlation between carbon biomass and soil carbon

The result of the Spearman correlation analysis (Table 3) shows that there is a strong and significant correlation ($r > 0.75$) between soil carbon potential and biomass potential, soil carbon reserve, and total carbon biomass. Likewise, there is a strong and significant correlation between soil carbon reserve and total biomass carbon. There is only a significant correlation ($r < 0.75$) between potential biomass carbon and soil carbon reserve and total biomass carbon hence the correlation is positive. This indicates that there is a close relationship between the biomass aboveground and carbon content of vegetation biomass and carbon content and storage in the soil. Organic biomass contains about 56-58% of carbon so that this vegetation biomass contributes greatly to be a carbon sink into the soil [27] [30] [41] [42]. Based on this study result, to increase the amount of soil organic matter on a land, it is necessary to maintain vegetation atop it and prevent processes that can reduce soil carbon content such as erosion, burning, overgrazing, and excessive tillage [43] [44] [45].

Table 3. Correlation matrix (r) between soil carbon stock and potential and biomass carbon in sub-optimal dryland in Aceh Besar

Indicators or Parameters	X_1	X_2	X_3	X_4
X_1 - Soil carbon potential (t ha^{-1})	1			
X_2 - Biomass carbon potential (t ha^{-1})	0.7780**	1		
X_3 - Soil carbon stock (Gg)	0.9101**	0.5787*	1	
X_4 - Total biomass carbon (Gg)	0.9472**	0.6436*	0.9896**	1

Figure 3 shows the regression relationship models between soil carbon potential and reserve and biomass carbon potential. The top left image shows that the vegetation biomass carbon potential found in the sub-optimal dryland in Aceh Besar is exponentially and significantly related to the soil carbon potential ($R^2 = 0.715$**) whereas the top right image shows that between the soil carbon potential and carbon reserves are linearly related and also highly significant ($R^2 = 0.8284$**).

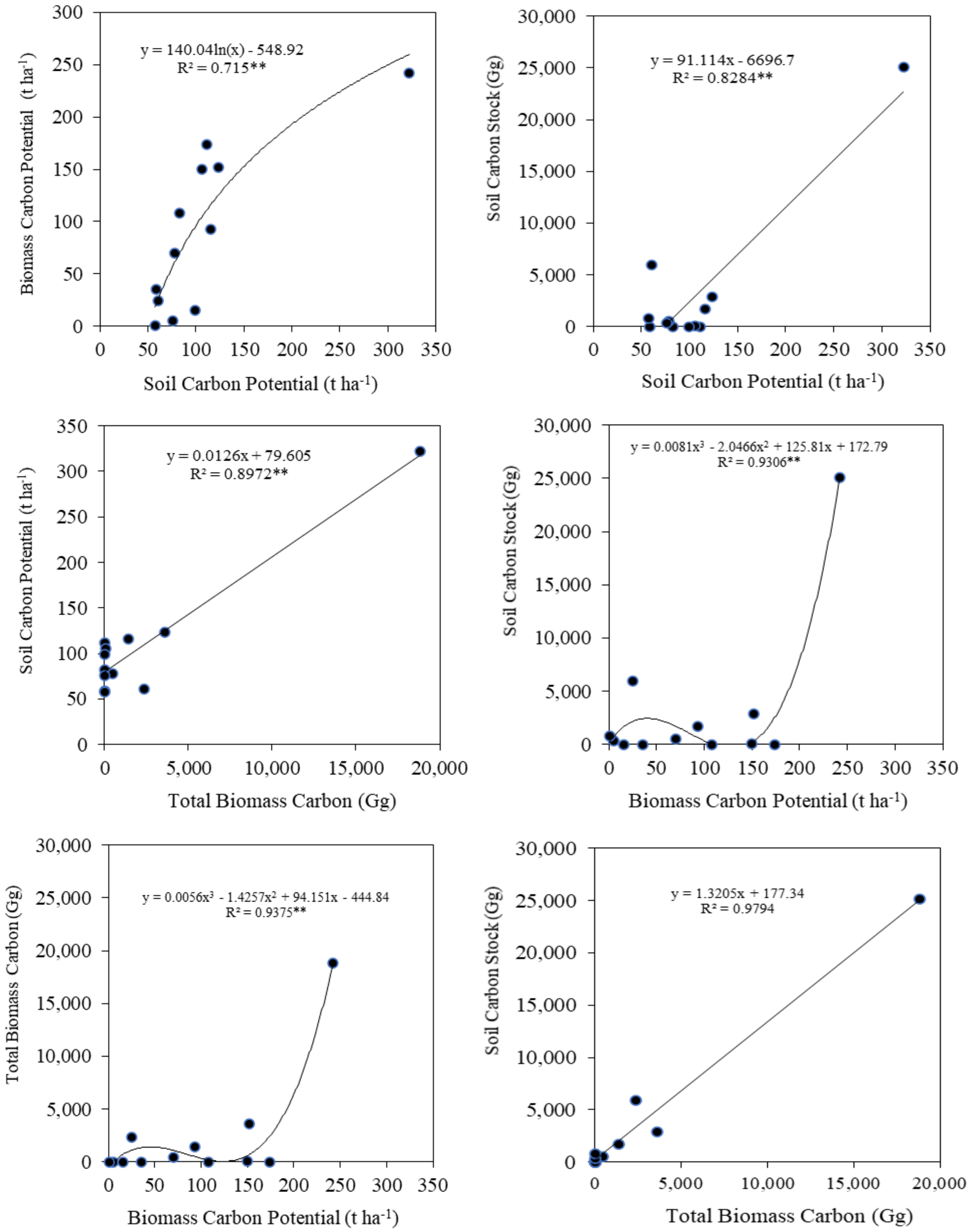

Figure 3. Comparison of carbon stock in subsoil and total biomass carbon for each type of sub-optimal dryland use in Aceh Besar

This proves that the higher the amount of vegetation biomass aboveground, the greater the amount and carbon reserve that can be stored in the soil. The middle-left image also shows that the total biomass carbon is linearly and significantly related to soil carbon potential (R^2 = 0.8972**) whereas the middle right image shows that the biomass carbon potential is positively related to soil carbon reserve yet the relationship is non-linear or follows a cubic polynomial model (R^2 = 0.9306**). This means that lands with little vegetation, the soil carbon reserve is not significantly and directly dependent on the biomass content whereas in areas with dense vegetation and high biomass content, soil C storage tends to increase. This cubic polynomial model is explicable in terms of the relationship between potential biomass carbon and total biomass carbon contained in the sub-optimal dryland. This non-linear model occurs because the total carbon biomass does not only depend on the potential carbon of the biomass but also depends on the area. The relationship between total biomass carbon and soil carbon stock is linear and highly significant (R^2 = 9794**) as shown in the image on the bottom-right.

These relationship models put emphasis on land management patterns and vegetation types that make a significant contribution to soil carbon content and reserve. Therefore, in order to increase and maintain carbon reserve in the soil or prevent carbon emissions and global warming, it is necessary to develop land use models that are more oriented towards environmental sustainability, for example by implementing a forest farming system (agroforestry), planting intercropping plants, returning plants residues, and recycling of organic matter [46] (Smith et al., 2016). In addition, the presence of organic matter or carbon in each sub-optimal dryland needs to be maintained and increased, especially in open land, moorland, grasslands, rainfed rice fields, forest bushes, and shrubs due to their little vegetation. In primary forest, pine forest, eucalyptus forest, teak forest, and mixed gardens, this management model is worth maintaining and needs to be expanded to neglected areas so that with the increasing amount of biomass produced in an area, the better it is in maintaining environment quality [47] [48].

It is imperative to maintain and increase the carbon content and soil organic matter because the role of soil organic matter is not only to store soil carbon (carbon sequestration) but also to maintain better soil quality [30]. This becomes very important, especially in the sub-optimal dryland in Aceh Besar because the soils here are physically and chemically somewhat infertile and there are many obstacles [49] [50] [51]. Soil organic matter is a binding agent or core in aggregate formation that can increase the stability of soil aggregates because there is a close relationship between organic matter and mineral surfaces [27]. The protection of SOM by clay minerals can largely change the amount of processing SOM in the soil [52], in particular, the contribution of fine mineral particles to the conservation of soil organic carbon [53]. The distribution of soil organic matter in clay-sized organo-mineral particles is about 50%-75% of the total soil organic matter through various binding patterns [54]. The topsoil, which is rich in SOC, plays an important role in agricultural productivity and other soil functions as the supporter of nature conservation. This loss of organic matter and soil degradation will lead to the loss of irreplaceable resources in the long term, because humus contains mostly organic carbon and most of the biological community which are responsible for nutrient cycling and maintaining soil structure [55]. The process of soil aggregation, nutrient supply, macro-aggregate stabilization can control carbon enrichment from loss of soil mass due to erosion and transformation. The input of organic matter through the return of organic biomass can quickly stimulate the formation of soil humus colloidal particles that can protect physically, chemically, and biologically faster decomposition rate for better the soil quality [56].

4. Conclusions

The potential for soil carbon and biomass carbon in the sub-optimal drylands in Aceh Besar varies greatly among land use types. Primary forest has the highest potential for soil carbon and biomass carbon compared to other lands. Soil carbon potential and biomass carbon potential in primary forest are at 332.28 ± 28.75 t ha-1 and 241.71 ± 24.46 t ha-1, respectively, with soil carbon reserve at 25,103.68 Gg. The lowest soil carbon potential was found in open land at 57.54±5.87 t ha-1 with biomass carbon potential at 0.53 ±0.06 t ha-1, while the lowest soil carbon reserve was found in teak forest at 4.83 Gg. The total carbon content of biomass in primary forest reaches 70.4% of the sub-optimal dryland area in Aceh Besar. Total soil carbon reserve in this moorland was at 37,423.20 Gg, while biomass carbon at 26,727.68 Gg. The carbon content of the soil and its reserve was positively correlated with the carbon content of the biomass. In general, the ratio of soil carbon content to biomass carbon is relatively balanced but varies among land use types with a ratio of 0.01-1.57.

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