The potentials of biomass carbon and CO_2 absorption in various land uses of dryland in Aceh Besar Regency, Indonesia

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Abstract. This study aims to determine the contents of biomass, C content of biomass, loss of biomass and carbon, and absorption of CO_2 by vegetation in various types of sub-optimal dryland use in Aceh Besar. The study was conducted on 12 land utility types (LUTs For each LUT, 5-6 sites were selected, and each location was repeated three times so that a total of 300 sample points were observed. The plant biomass measurement and calculation were differentiated according to the vegetation type. The biomass retrieval was based on The Indonesian National Standard Agency (BSN) procedure No. SNI 7724:2011. The primary forest was a land utilization type with the highest biomass contents, total C biomass, and CO_2 absorption compared to other land utility types. The lowest was on bare land. The contents for biomass in the primary forest was 501.54±73.27 Mg ha^{-1}, while in bare land, it was only 1.03±0.12 Mg ha^{-1} with C biomass content of 241.71 ±34.46 Mg ha^{-1} and 0.53 ±0.06 Mg ha^{-1}, respectively. Total C biomass on sub-optimal dryland with an area of 239,387.91 ha was 26,728,46 Gg and could absorb CO_2 of 202,735.14 Gg. Conversion of primary forest to open land can result in loss of C biomass from 37.1% to 99.8%.

1 Introduction

Indonesia has a tropical climate and rainforests are important to maintaining and preventing global warming due to climate change. Indonesia's forest area reaches 187 million ha consisting of various forest and land cover types [1]. However, the continuous increase in population each year drives the growing demand for agricultural land. The rate of deforestation for conversion to agricultural and non-agricultural land also increases. Data from the evaluation show that mainland Indonesia has a land cover consisting of various forest types and land cover, and around 95.6 million hectares of land are still in the form of forest in 2020, equivalent to 50.9% of Indonesia's total land area [2]. Of that amount, 46.9

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million ha is primary forest (25%), 43.1 million ha (23%) is secondary forest, and 5.4 million ha (2.9%) is plantation forest or conversion forest. Meanwhile, the area of non-forest land was recorded at 92.1 million ha (49.1%). The distribution patterns of forests and non-forests play an important role in reducing greenhouse gas emissions and the impacts of climate change [3].

Forest vegetation and other plants on the Earth's surface contribute to soil fertilization by serving as a source of organic matter, recycling carbon back into the soil. Soil organic matter reflects soil fertility levels, enhancing the soil's physical, chemical, and biological properties [4]. Organic matter is the most important component of soil, and it comes from plant litter and organic remains resulting from decomposition that enters the soil as part of the plant root system [5]. Therefore, the role of vegetation is vital to maintaining environmental sustainability and the life cycle of plant nutrients.

Indonesia has also experienced a decrease in forest area due to deforestation, estimated to reach 119,091 ha in the 2019-2020 period. It is also accompanied by the reforestation of 3,631 ha [1]. Thus, the total deforestation in Indonesia in that period was 115,460 ha. Logging or land conversion from forest to agricultural land is one of the leading causes of land degradation, leaving unproductive lands. In addition to accelerating the land and environmental degradation rate, this action can also affect ecosystem damage, impacting both local and global climate conditions [3]. Deforestation of forests and land can also accelerate the loss of carbon stocks from vegetation biomass and carbon stocks in the soil [4].

In addition to reducing forest area, this deforestation shrinks vegetation biomass and C biomass and hurts land degradation. Land degradation due to deforestation can result in the opening of the land surface, which can cause erosion and impact reducing the carbon content above and below the ground surface [6]. C loss due to erosion is one of several pathways of carbon loss from agricultural systems. The specific process of C loss, especially through terrestrial hydrological pathways at the agricultural scale, is still not widely disclosed. Therefore, forest management will greatly determine whether land can function well as a carbon sink or as a carbon producer [3]. It is imperative to have precise information regarding the carbon content of a vegetation type that is stored in biomass to accurately characterize the state of a vegetation ecosystem in the context of sustainable land resource management, ensuring that it is both economically and ecologically profitable. Furthermore, this information is indispensable as a fundamental element in the calculation and monitoring of national carbon, which serves as the primary input for the formulation of a strategy to reduce greenhouse gas (GHG) emissions, particularly CO_2 from the land sector. As a result, the amount of biomass that emerges from plants needs to be matched with the amount of biomass that is added to the forest [7].

This study was intended to assess the effect of different land utility types on the contents and total biomass, total C content of biomass, and CO_2 absorption capacity and analysis of C loss from biomass in sub-optimal dryland in Aceh Besar, Indonesia.

2 Materials and Methods

2.1. Description of Study Area

This study was conducted on 12 land use types (LUTs) in Aceh Besar Regency, Aceh Province, Indonesia, which was limited to sub-optimal dryland with an area of 239,387.91 hectares. The study area does not include irrigated rice fields, fishpond areas, and island areas. Primary, secondary, pine, *Eucalyptus*, teak, forest shrubs, shrubland, *Imperata* grassland, mixed gardens, moors, rainfed rice fields, and barren land are among the twelve LUTs. Table 1 describes each land use (LUT) unit under study.

Table 1. Description and area of each land-use type in the study area

No	Land utility type (LUT)	Land Area		Description of the area
		(ha)	(%)	
1.	Primary forest	77,849.98	32.52	Areas with native tropical forest vegetation
2.	Secondary forest	23,558.37	9.84	Forest area where secondary vegetation grows
3.	Pine forest	53.85	0.02	Area planted with Pinus *merkusii* for >50 years
4.	*Eucalyptus* forest	307.14	0.13	Area planted with Eucalyptus for 25-30 years
5.	Teak forest	58.50	0.02	Area planted with teak for >25 years
6.	Forest shrubs	6,513.47	2.72	Former forest area where trees grow
7.	Shrubland	96,962.20	40.50	area of former forest vegetation of reeds and bushes
8.	*Imperata* grassland	80.50	0.03	Areas overgrown with dry grass/reeds
9.	Mixed garden	15,052.09	6.28	Land planted with various perennials and seasonal crops
10.	Moor	313.03	0.13	Dryland planted with seasonal crops
11.	Rainfed rice field	4,478.57	1.86	Rice fields are managed as dryland
12.	Bare land	14,211.93	5.94	Land that has no vegetation or damaged land.
Total		239,387.91	100.00	

Source: Map analysis (2023)

2.2. Sampling Methods and Biomass Measurement

Determination of observation points for measuring vegetation and biomass in each LUT was conducted using the purposive sampling technique, which refers to the map created as a sampling point representing the 12 land utility types in sub-optimal dryland in Aceh Besar Regency. For each LUT, 5 to 6 sites were selected, and each location was repeated three times so that the total observation points (N) were 300 sample points. Plant biomass samples were differentiated according to the type of vegetation. The Indonesian National Standard Agency (BSN) guided the biomass sampling method for tree-dominated vegetation types [8]. According to this standard, the biomass was collected using stratified sampling and a simple random sampling technique with a maximum sampling error of 20%. Stratification aimed to classify sites based on land cover maps obtained from the interpretation of satellite imagery with a resolution of at least 30 m.

The samples that were measured and observed were samples contained in a plot made in the form of a square with an area of 20 m x 20 m or 400 m^2 which was further divided into 4 (four) subplots according to vegetation growth levels: (a) subplot A (2 m x 2 m or 4 m^2) for observation and sampling of biomass of small plants 1.5 cm in diameter and leaf litter samples; (b) subplot B (5 m x 5 m or 25 m^2) for observation and collection and measurement of plant biomass weights with stem diameters of 2-10 cm; (c) subplot C (10 m x 10 m or 100 m^2) for biomass with a stem diameter of 10-20 cm; (d) subplot D (20 m x 20 m or 400 m^2) for measuring and estimating plant/ vegetation biomass in the form of trees >20 cm in diameter. An allometric equation model adapted to the type of vegetation found in the field was used to estimate plant biomass in the form of trees [9]. The allometric equation used in general was the model equation: y = a x b, where y is the weight of the biomass; x is the diameter (tree, trunk, or twig) depending on the vegetation type, while a and b are constants [10]. Calculating tree biomass for certain plants uses allometric equations according to [11].

Total tree biomass was calculated from the sum of each part of the plant [10] with the formula:

$$\text{Total biomass (Wt)} = Ws + Wb + Wl + Wr \quad (1)$$

Wt is the total biomass (t), while Ws, Wb, Wl, and Wr are stem, branch/twig, leaf, and root biomass (kg or t). The wood density was calculated as follows:

$$\text{Wood density (Wd)} = (\text{dry weight of disc/disc volume}) \quad (2)$$

2.3. Carbon Density Analysis and Calculation

Carbon in forest and plant biomass from various LUTs was analyzed using the dry ashing method (proximate analysis) using the CHONS elemental analyzer. Samples of various biomass components were heated to a temperature of 700 ^{0}C. The C content in leaves and leaf litter was calculated using the Walkley and Black method. The C content in each LUT was calculated using the following formula:

$$TCp = FCp \times Dp \times Vp \quad (3)$$

TCp is the total carbon (C) for each plant part/tree, or biomass (t), while FCp is the percentage of C in each plant part (%C/100); Dp is wood density (kg dm^{-3} ~ t/m^3), and Vp is wood volume or biomass share (m^3). The absorption of CO_2 by vegetation was calculated as follows [10]:

$$WCO_2 = Wtc \times 3.67 \quad (4)$$

WCO_2 is the amount of CO_2 absorbed (t/ha), Wtc is the total weight of a particular stand (t/ha), and 3.67 is the equivalent number (conversion) of the element carbon C to CO_2. All data were examined using descriptive statistics, regression, and Spearman correlation analysis.

3 Results and Discussion

3.1. Contents of Biomass

The biomass content is the average weight of vegetation representing each land-use type (LUT) above the soil surface. It includes leaf litter, deadwood, stems, branches, twigs, leaves, other plant parts, and vegetation contained in the soil in the form of plant roots/plants expressed in Mg (t) per hectare. The results of the estimation and calculation of biomass contents and the percentage of contents loss of biomass and total biomass in each LUT can be seen in Table 2.

Table 2. Average contents and biomass loss in each land-use type in dryland in Aceh Besar Regency

No	Land utility type (LUT)	Biomass Contents	Loss of Biomass Contents		Total Biomass of LUT area
		(Mg ha^{-1})	(Mg ha^{-1})	(%)	(Gg)
1	Primary forest	501.54±73.27 i	0.00	0.00	39,044.55
2	Secondary forest	315.41±134.32 g	-186.12	37.11	7,430.64
3	Pine forests	361.27±112.50 h	-140.27	27.97	19.45
4	*Eucalyptus* forest	310.17±68.65 g	-191.37	38.16	95.27
5	Teak forest	225.52±145.00 f	-276.02	55.03	13.19
6	Forest shrubs	146.55±43.01 d	-354.99	70.78	954.55
7	Shrubland	48.21±7.20 c	-453.33	90.39	4,674.39
8	*Imperata* grassland	29.71±4.34 b	-471.83	94.08	2.39
9	Mixed garden	195.18±124.77 e	-306.36	61.08	2,937.79
10	Moor	74.18±42.53 e	-427.35	85.21	23.22
11	Rainfed rice field	9.38±0.72 a	-492.15	98.13	42.02
12	Bare land	1.03±0.12 a	-500.51	99.79	14.64
Total					55,252.10

Table 2 shows that the highest vegetation biomass contents are found in the LUT of primary forest. Here, the primary forest is a rainforest or tropical forest with dense vegetation of various types and high density and diversity. The biomass produced in the unit area becomes higher [12]. This study shows that the contents for vegetation biomass in this primary forest LUT reaches 501.54±73.27 Mg ha^{-1}. Statistical analysis shows that the average value of the biomass contents in this LUT is significantly different from those in other LUTs. The lowest contents of vegetation biomass are found in bare land LUT, which is 1.03±0.12 Mg ha^{-1} or ton ha^{-1} on average. This indicates that converting forests into agricultural land and other use areas significantly contributes to biomass content loss.

Table 2 also shows that when compared to primary forest, changes in land-utility type from primary forest to agricultural land or non-agricultural land contributed significantly to the amount and percentage of biomass loss. Furthermore, suppose the LUTs used for agriculture (mixed garden, moor, and rainfed rice field) and LUTs designated for cultivation forest planting areas (pine forest, *Eucalyptus* Forest, and teak forest) are compared. In that case, it turns out that the biomass contents in cultivated forest areas is higher. The contents for biomass loss will be even more significant on abandoned land such as bare land, *Imperata* grassland, shrubland, and forest shrubs. The highest biomass loss was found in the bare land because the bare land contained very little vegetation.

Figure 1 shows the difference in plant biomass contents with the inversely related percentage of biomass loss. If seen in more detail in Figure 1 on the left, it appears that the vegetation biomass production of the 12 LUTs can be divided into four clusters, namely: (a) those with high biomass contents >500 Mg ha^{-1} found in primary forest; (b) medium biomass contents of 300-500 Mg ha^{-1} found in the pine forest, secondary forest, and *Eucalyptus* forest; (c) low biomass contents of 100-300 Mg ha^{-1} found in teak forests, mixed gardens, and forest shrubs; and (d) very low biomass contents of <100 Mg ha^{-1} found in a moor, shrubland, *Imperata* grassland, rainfed rice field, and open forests. Furthermore, the highest total vegetation biomass was found in primary forest types, namely 39,044.55 Gg or 39.04 Tg in all primary forest areas. The highest total biomass is in the primary forest since, apart from having the highest biomass contents, the area is also significant (77,849.98 ha). However, it is not as large as the secondary forest area. The lowest total biomass is found in the *Imperata* grassland because, in addition to the low biomass contents, this area is not large, which is only 80.5 hectares. From Table 2, only the primary forest has the highest total biomass compared to the total biomass in other LUTs. Therefore, deforestation activities need to be

avoided because forest conversion to other use areas will reduce vegetation biomass, affecting climate change [13].

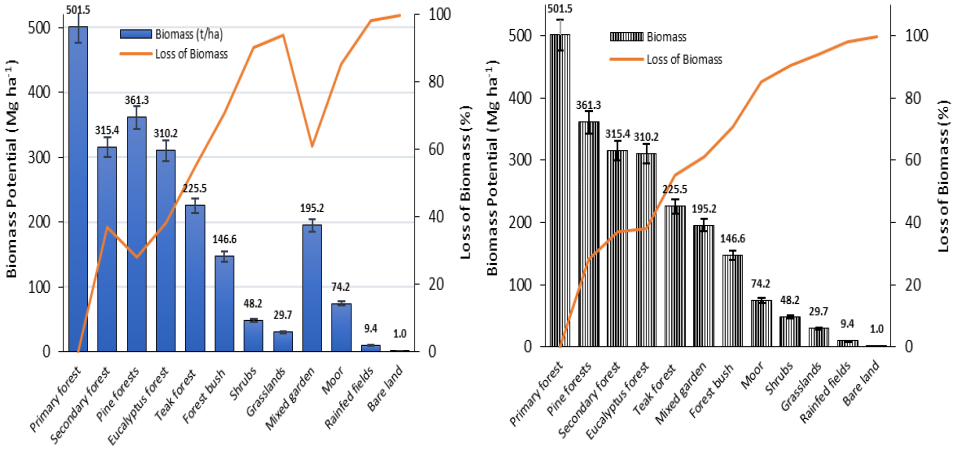

Fig 1. Comparison of the contents and percentage of biomass loss for each type of dryland use in Aceh Besar

Plants absorb C from the atmosphere through photosynthesis and store it in the form of plant biomass. Many factors affect carbon absorption by plants such as climate, topography, land characteristics, plant age, and vegetation density, as well as species composition and quality of the growing habitat [14]. The main place of carbon storage in biomass from the upper part of the vegetation is the stem, branches, twigs, leaves, flowers, and fruit, while at the bottom are the roots, dead organic matter, soil, and wood products which can later be emitted for long-term products [7, 15]. The variations in biomass allocation in trees can be caused by differences in plant age, density, and quality of the place to grow [13]. Diameter size affects the distribution of tree biomass. Biomass in tree stands affects the contents of stored carbon. Individual density, stem diameter, tree species diversity, and soil conditions are all elements that will have an indirect effect on the ecosystem's biomass and carbon storage. Increased tree density in a given area can also have an impact on carbon stores [1]. Forest stand growth plays an important role in forest structure, biomass, and soil nutrient content [15].

3.2. Carbon Contents in Biomass

The carbon analysis results of the biomass in each LUT in the sub-optimal dryland of Aceh Besar can be seen in Table 3. Table 3 showed that the average biomass carbon content among Land Use Types (LUTs) in the drylands of Aceh Besar varied significantly. This is in line with the diversity of biomass from the vegetation. Contents C in biomass varied from 0.53 ±0.06 Mg C ha^{-1} to 241.71 ±34.46 Mg C ha^{-1}. The highest biomass C contents are found in primary forests, and the lowest is bare land. The sequence of LUTs that have biomass C contents from the highest to the lowest can be seen in Figure 2. Based on the data on the contents of C biomass from the highest to the lowest, it can be said that the loss of C biomass and the percentage loss is inversely proportional to the amount of biomass and the ratio between the lowest and highest contents of C biomass is around 1:600. This means that if the land cover in the form of primary forest (tropical forest) is converted to non-forest uses such as cultivated land (moor, rainfed rice field) and grazing land (*Imperata* grassland, shrubland), then the percentage loss of biomass and loss of C is very high.

Table 3. Biomass carbon contents and percentage of carbon loss from biomass in various types of drylands use in Aceh Besar

No.	Land Utility Type (LUT)	Carbon Contents in Biomass	Carbon loss from Biomass*)		Total C Biomass of LUT area
		(Mg C ha^{-1})	(Mg C ha^{-1})	(%)	(Gg C)
1	Primary forest	241.71 ±34.46	0.00	0.00	18,817.44
2	Secondary forest	152.05 ±64.43	-89.66	37.09	3,582.14
3	Pine forest	173.69 ±53.78	-68.02	28.14	9.35
4	Eucalyptus forest	150.03 ±33.74	-91.69	37.93	46.08
5	Teak forest	107.81 ±68.35	-133.90	55.40	6.31
6	Forest shrubs	69.92 ±20.21	-171.79	71.07	455.45
7	Shrubland	24.50 ±3.66	-217.22	89.86	2,375.37
8	*Imperata* grassland	15.15 ±2.21	-226.56	93.73	1.22
9	Mixed garden	92.69 ±59.10	-149.03	61.65	1,395.11
10	Moor	35.42 ±20.66	-206.29	85.34	11.09
11	Rainfed rice field	4.79 ±0.37	-236.93	98.02	21.43
12	Bare land	0.53 ±0.06	-241.19	99.78	7.47
				Total	26,728,46

*) compared with primary forest

Table 3 further shows that the total carbon biomass in all suboptimal dry lands was 26,728.46 Gg. The highest total C biomass was also found in primary forest (18,817.44 Gg) and the lowest in *Imperata* grasslands (1.22 Gg). The low contents and loss of C biomass in bare land are due to this type of land having little vegetation, while in the primary forest, there are a lot of large and long-lived plants/vegetation [6]. As the amount of biomass increases, carbon storage will also increase [7]. This is because carbon and biomass have a positive correlation, so if biomass increases, the carbon content also increases. This follows [11] research, which states that long-lived plants that grow in forests are a place for storing C, much larger than seasonal plants and land without vegetation. Various types of long-lived trees and leaf litter are the highest C storage warehouses [16-18]. Figure 2 and Figure 3 show that when the contents biomass and total C biomass in the primary forest are compared, they are very different from the contents and total C biomass in other LUTs. The order of biomass contents from highest to lowest is primary forest> pine forest >secondary forest > *Eucalyptus* forest > teak forest > mixed garden > forest shrubs > moor> shrubland > *Imperata* field > rainfed rice field > bare land. As the biomass decreases, the biomass loss also increases. This will also have an impact on the total amount of biomass contained. With biomass loss due to forest conversion to other areas, the loss of C in the biomass will also increase.

Compared to other natural ecosystems and atmospheres, primary forests contain more carbon in biomass and soil [19]. The ecosystems of forests play a critical role in global biogeochemical cycles and climate change mitigation [20]. The primary forests are global biodiversity hotspots that play an important role in the global and regional management of the C cycle [21]. Tropical forests have more biomass than other forest types and serve as major carbon sinks due to their species variety and strong net primary output over time [22, 23]. The magnitude of the density value at the growth rate of trees and poles can substantially contribute to the contents of bound carbon, which is closely related to the amount of biomass of a tree [24].

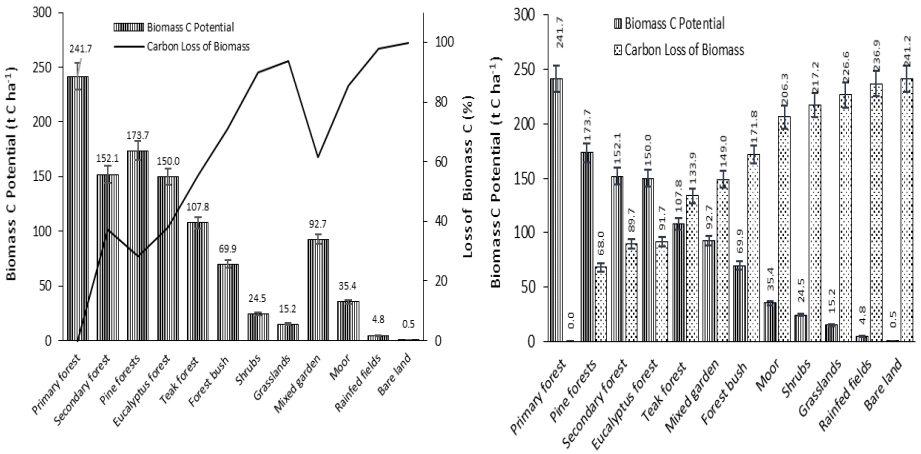

Fig 2. Comparison of contents and percentage of biomass loss for each type of dryland use in Aceh Besar

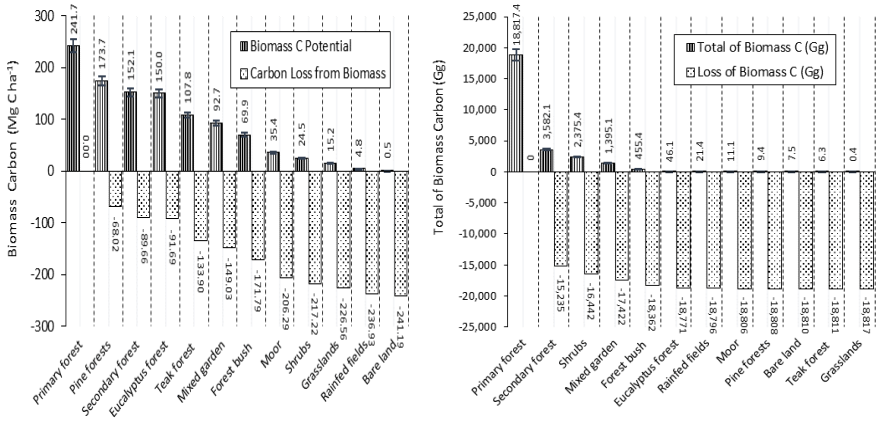

Fig 3. Comparison of contents and total biomass carbon with biomass carbon loss for each dryland-use type in Aceh Besar

3.3. CO_2 Absorption

The results of the calculation of CO_2 absorption content by various types of plant vegetation can be seen in Table 4. Table 4 shows that the contents for CO_2 absorption by plant vegetation for each land use type vary widely. The highest contents for CO_2 absorption are found in primary forest vegetation, namely 1,840.64 Mg ha^{-1}, and the lowest is in bare land, namely 1.03 Mg ha^{-1}. The highest total CO_2 absorption is also found in the primary forest. This shows that forests, especially tropical forests, are very important as the largest CO_2 absorbers in the air. This CO_2 absorption is one of the functions of plant vegetation (biomass) because CO_2 and water are raw materials for the photosynthesis process [12]. Therefore, maintaining areas with forest types is very important in land management. The original type of primary forest should not be converted to other forms of use. Climate change is a global concern, and

Primary forests play a crucial role in climate change control and mitigation by lowering the amount of carbon dioxide in the atmosphere [24]. Carbon stock estimation for main and secondary forests will aid in making sound carbon management decisions. This information helps to meet the international commitment to reduce atmospheric carbon emissions [12]. The total amount of biomass stored in a forest indicates how much carbon (C) may be absorbed to fulfill emission targets [22]. Natural forests have the largest carbon storage [1]. To mitigate the effects of climate change, efforts are made to either boost carbon absorption or reduce carbon emissions.

Table 4. Total CO_2 absorption in various types of drylands use in Aceh Besar

No	Land Utility Type (LUT)	CO_2 Absorption Contents (ton ha^{-1})	Total CO_2 Absorption	
			(ton/LUT)	(Gg/LUT)
1	Primary forest	1,840.64	143,293,787.19	143,293.79
2	Secondary forest	1,157.57	27,270,462.36	27,270.46
3	Pine forest	1,325.86	71,397.56	71.40
4	*Eucalyptus* forest	1,138.33	349,626.68	349.63
5	Teak forest	827.66	48,418.11	48.42
6	Forest shrubs	537.84	3,503,204.70	3,503.20
7	Shrubland	176.92	17,154,552.42	17,154.55
8	*Imperata* grassland	109.03	8,876.92	8,876.14
9	Mixed garden	716.29	10,781,661.55	10,781.66
10	Moor	272.25	85,222.42	85.22
11	Rainfed rice field	34.44	154,241.95	154.24
12	Bare land	1.03	14,638.29	14.64
Total			202,735,990.14	202,735.14

4 Conclusions

The primary forest has a high biomass carbon content, making it an excellent biomass producer and the largest CO_2 absorber compared to other vegetation types, while bare land has the lowest levels for both parameters. The total vegetation biomass on the entire land is 55,252.10 Gg with a total C biomass of 26,728.46 Gg. The highest content for biomass loss is bare land because it has very little vegetation. The highest CO_2 absorption was also found in the primary forest with an absorption content of 1,840.64 Mg ha^{-1}, and the total CO_2 absorption in the sub-optimal dryland of Aceh Besar reached 202,735.14 Gg. The contents for biomass in the primary forest is 501.54±73.27 Mg ha^{-1}, while in bare land, it is only 1.03±0.12 Mg ha^{-1} with C biomass content of 241.71 ±34.46 Mg ha^{-1} and 0.53 ±0.06 Mg ha^{-1}, respectively. The total absorption of CO_2 is 202,735.14 Gg. Conversion of primary forest to open land can result in loss of C biomass from 37.1% to 99.8%.

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