Estimation of Carbon Stocks on Difference Land Use and Slopes in The Central of Horticultural Production Banuhampu Agam, West Sumatra Indonesia

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***Abstract*—Soil Organic Carbon (SOC) has an important role in soil fertility, so it becomes one of the soil properties as an indicator in determining soil health and quality. The amount of carbon stock in the soil can change due to land use and erosion that occurs at different slope levels and the transformation process from soil to air in the form of CO_2, which can cause global warming. This study aims to study soil carbon stocks in various types of land use and slope levels at The Central of Horticultural Production, Banuhampu Agam West Sumatra. Soil sampling from various types of land use (forest, paddy fields, and fields) and slope (0–8; 8–15; 15–25, and 25–45%) at a depth of 0–20 cm. The results showed that the average value of BD and SOC at The Central of Horticultural Production, Banuhampu Agam West Sumatra, was 0.93 g cm^{-3} and 0.22% C with a carbon potential of 4.04^{E2} Mg ha^{-1}. The highest estimation of soil carbon stocks on land use and slopes in The Central of Horticultural Production of 296338.76 [paddy (0–8%)]; 118778.52 [fields (15–25%)]; and 55367.64 [forest (25–45%)] Mg. The Correlation of soil carbon stock in The Central of Horticultural Production, Banuhampu Agam West Sumatra, is positively related to carbon potential = carbon density > bulk density > SOC (*r* = 0.111 = 0.111 > 0.094 > 0.048).**

***Keywords*—carbon stocks, land use, slopes, horticultural production**

I. Introduction

Climate change is an issue that is currently happening, not only in Indonesia but throughout the world. The increase in greenhouse gas emissions in the atmosphere is the main cause of this climate change. Global warming is caused by an increase in the amount of greenhouse gases such nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2) [1]. Increases in air temperature of 0.1 to 0.3 °C per decade and an increase in rainfall for almost all of Indonesia's islands are brought on by global warming. Specifically, in Sumatra and Kalimantan, it is forecasted to be 10–30% wetter by 2080, except for Java and the islands to the south, where rainfall decreases to 15% [2]. Burning fossil fuels such as coal, oil, and natural gas, as well as disturbing the soil, are two processes that release greenhouse gas emissions into the atmosphere. The latter has an important role in determining changes in the global carbon cycle because the soil is the connector between vegetation, oceans, and the atmosphere [3]. The transfer of CO_2 to the soil occurs due to plant growth and some of the other carbon will enter the soil as Soil Organic Carbon (SOC).

The biggest carbon store in the terrestrial ecosystem is found in soil, which is also essential to biosphere feedback, which raises global atmospheric carbon dioxide levels and warms the earth's atmosphere. The soil is the greatest terrestrial organic carbon pool in the world, with an estimated 2,344 Gt (1 Gigaton = 1 billion tons) of organic carbon. The amount of carbon in the atmosphere can be significantly impacted by changes in the soil's organic carbon pool [4]. As SOC lowers the amount of carbon in the atmosphere, more carbon is deposited in the soil, assisting in the mitigation of climate change and global warming. The act of storing carbon in the soil is known as "soil carbon sequestration". Increasing SOC helps to prevent climate change while also improving soil health. Land use and management are two variables that determine the quantity of SOC [5]. There is mounting evidence that changes in land use and agricultural techniques can influence the quantity of carbon emitted into the atmosphere by Soil Organic Matter (SOM). Indonesia has a diverse spectrum of land uses, from the vastest, such as sophisticated agroforestry systems that resemble forests, to the most intense, such as monoculture and polyculture seasonal agricultural systems [6]. The amount of SOC for each land use varies according to the diversity and density of existing plants, soil type, and management. Changes in land use, cropping patterns, and slope levels can all have an impact on the quantity of carbon in the soil. The quantity of SOC in the soil decreases as forest area is converted to agricultural land.

Changes in the quantity of SOC in the soil can be caused by monoculture or polyculture and rotating cropping systems. The quantity of carbon stored in a land increases if the soil fertility conditions are favorable, or the amount of carbon stored above the soil (plant biomass) is governed by the amount of carbon stored in the SOC [7]. Variations in land function and the diversity of cropping patterns, land use, and the degree of slope of the projected soil carbon store are fascinating to research, particularly in the horticultural

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production of Banuhampu Agam, West Sumatra Indonesia. The carbon store of forest soil and agricultural land must be explored further with climate change mitigation measures since this is critical for sustainable agricultural management and environmental protection. The purpose of this research is to examine and estimate soil carbon stocks in types of land use and slopes in the horticultural production of Banuhampu Agam, West Sumatra Indonesia.

II. Materials and Methods

This research was carried out from June to September 2022 and focused on several field observation points on several types of land use and slopes in the horticultural production of Banuhampu Agam, West Sumatra Indonesia, and also conducted on a sample test at the Laboratory of the Department of Soil, Faculty of Agriculture, Anadalas University.

Soil sampling includes: (a) Observing the physical condition of the land, where observations will be made in the form of physiographic observations around the research location, and (b) Soil sampling, where the research sample will be in the form of soil samples. Determination of soil samples will be carried out by purposive random sampling. Soil samples to be taken are disturbed soil samples with composites and undisturbed soil samples with rings at a depth of 0–20 cm. Sampling was based on land use (3 levels: Forest, Paddy, and Fields) and slope level (4 levels: 0–8%; 8–15%; 15–25% and 25–45%) at a depth of 0–20 cm with each −3 replicates each so that 36 soil samples were obtained. Survey activities are guided by the Technical Guidelines for Field Observations by the Soil Research Centers. The process of analyzing soil samples focused on bulk density and SOC [8] as well as data analysis through GIS (Geography Information System) in Figs. 1, 2, and 4:

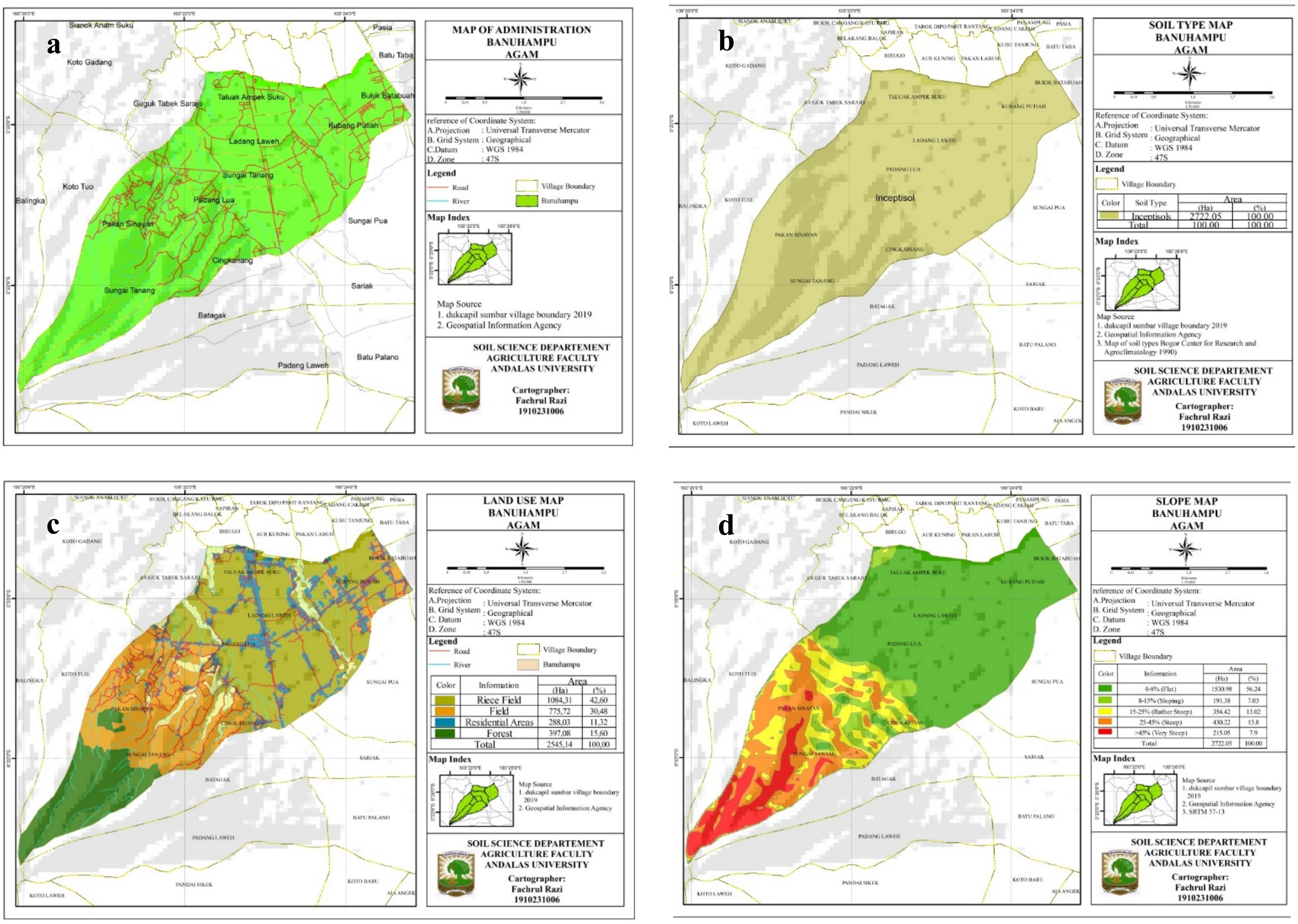

Fig. 1. Map of administration (a), soil type (b), land use and (c) and slope (d) in the central of horticultural production, Banuhampu Agam West Sumatra.

A. Bulk Density

Bulk Density (BD) analysis using soil samples in the sample ring. The sample was weighed by the wet weight of the soil sample along with the ring, then put into the oven at a temperature of 105 °C for at least 2 × 24 h, after drying, the soil was taken with the ring from the oven and cooled in a desiccator after it was cold, it was weighed as the weight of the oven-dry sample, the sample ring is soiled and cleaned, then the ring is weighed as the weight of the sample ring, then the weight of the oven-dry soil without the ring is determined, and the bulk density value is obtained by dividing the value of the oven dry soil by the volume of the sample ring.

B. Soil Organic Carbon

Samples were weighed 0.5 g of soil samples measuring <0.5 mm and put into a 100 mL volumetric flask. Added 5 ml of $K_2Cr_2O_7$ 1 N, then shake. Added 7.5 ml of concentrated H_2SO_4, shake, and let stand for 30 min. Diluted with ionized water, allow to cool and squeeze. The next day the absorbance of the clear solution was measured using a spectrophotometer at a wavelength of 561 nm. As a comparison, 0 and 250 ppm standards were made, by pipetting 0 and 5 ml of a 5,000 ppm standard solution into a

100 mL volumetric flask with the same treatment as the sample. Note: If the sample reading exceeds the highest standard, repeat the determination by weighing fewer samples. Change the factor in the calculation according to the weight of the sample being weighed by the Eq. (1).

$$Organic\ C\ (\%) = ppm\ C \times \frac{10}{500} \times KKA \quad (1)$$

Remarks: ppm *C* = sample content obtained from the curve of the relationship between the levels of the standard series, and *KKA* = correction of sample moisture content.

$$KKA = 1 + KA \quad (2)$$

Remarks: *KA* = sample moisture content.

C. Carbon Density

The amount of carbon contained in the soil is by multiplying several observed parameters. Calculation of soil carbon density is carried out using the following Eq. (2).

$$Cd\ (g\ cm^{-2}) = Kd \times \rho \times \%\ Organic\ C \quad (3)$$

Remarks: C_d: soil carbon density, expressed in grams (g cm^{-2}); *Kd*: the depth of the soil sample, expressed in centimeters (cm); ρ (bulk density) = expressed in grams cubic per centimeter (g cm^{-3}), and % organic C: using the percent carbon value obtained from the results of measurements in the laboratory.

D. Carbon Potential and Stock

The potential of soil C on dry land use in Blang Bintang District needs to be searched to find out more about the value of C reserves contained in each land use (Eqs. (3) and (4)).

$$Cp\ (t\ ha^{-1}) = Cd \times 100 \quad (4)$$

$$Cs\ (ton) = Cp \times area \quad (5)$$

Remarks: C_p: C content per hectare in each land use is stated in (after all ha^{-1}); C_d: density C of soil, expressed in grams (g cm^{-2}); 100: conversion factor from g cm^{-2} to anyway ha^{-1}, and C_s = carbon stock.

III. Result and Discussion

The average value of BD and SOC of soil in the central horticulture production Banuhampu Agam West Sumatra is 0.93 g cm^{-3} and 0.22% C (Table 1). The type of soil found in the central land of West Sumatran horticultural production, namely Inceptisols (Fig. 1(b)), where the BD of Inceptisols ranges from 0.85–0.96 g cm^{-3} [9] and the SOC of Inceptisols ranges from 0.15–1.25% C [10] and 2.19% C [11]. The BD of soil is largely determined by naturally formed pores. If the soil pores are large and well-developed, it can be ascertained that the value of the density of the soil is low. If the BD value is close to 1, and if you get additional organic matter, the BD tends to decrease.

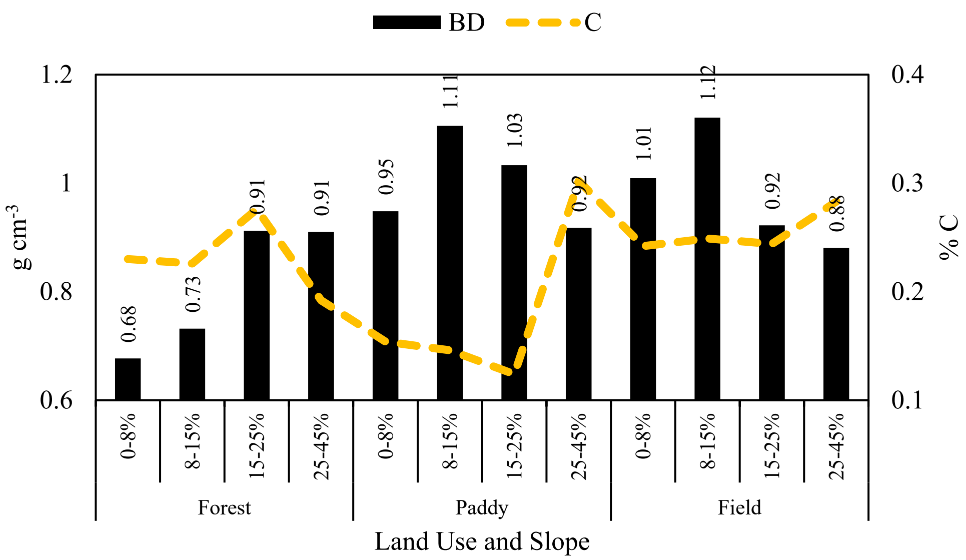

Fig. 2. Bulk density and SOC in the center of horticultural production, Banuhampu Agam West Sumatra Indonesia.

The identification of BD on differences in land use and slope in the central horticulture production Banuhampu Agam West Sumatra looks different due to processing factors, cropping patterns, and the level of the slope of each region. It is also seen that the highest BD of the three land uses and slopes is fielded at 1.12 g cm^{-3} followed by rice fields (1.11 g cm^{-3}) on the same 8–15% slope, in contrast to the forest (0.91 g cm^{-3}) at slopes of 15–25% and 25–45% (Figs. 2 and 3(c)). The increase in BD on land use changes is due to intensive processing for maximum. Continuous land cultivation causes soil compaction to occur. The use of forest land has a low BD value due to the absence of agricultural activities because it is used as conservation land which is slightly used as productive land for agriculture, especially for horticulture. The higher the weight of the soil volume causes the soil density to increase, and aeration and drainage are disturbed, so that root development becomes abnormal [12].

The weight of the soil volume can be used to define multiple elements of the soil, such as the presence of layers, tillage, organic matter content, minerals, porosity, drainage capabilities, and the ease with which roots can penetrate the soil. As the pore space and structure change, the bulk density of the soil can vary over time and from layer to layer. The BD of the soil with different slope positions shows a significant difference [13], the higher the slope position, the greater the value of the bulk density of the soil. The occurrence of soil erosion in the top layer causes the topsoil layer of soil and soil Harrison A to tend to be thin and some places have lost topsoil. This erosion will separate the horizon below which tends to be denser due to the accumulation of the horizon above it. The amount of Bulk Density will be inversely proportional to the porosity of the soil. the lower the slope position, the greater the porosity of the soil because the value of the bulk density of the soil is getting smaller. As a result of the accumulation of the above slope position, the lower slope tends to develop new soil, and this new soil creation tends to have quite a few soil cavities.

Table 1. Descriptive statistics of soil carbon stock in the central of horticultural production, Banuhampu Agam West Sumatra Indonesia

Analysis	Min	Max	Mean	Std. Error	Std. Deviation
Bulk Density (g cm^{-3})	0.56	1.37	**0.93**	0.03	0.17
SOC	0.07	0.44	**0.22**	0.02	0.09
Carbon Density (g cm^{-2})	1.62	8.66	**4.04**	0.29	1.77
Carbon Potential (t ha^{-1})	162.26	865.71	**4.04^{E2}**	29.43	176.58
Carbon Stock (ton)	53.99	3.46^{E5}	**6.21^{E4}**	1.46^{E4}	87545.05

Remarks: BD = Bulk density; SOC = Soil organic carbon; and *n* = 36.

Changes in carbon values due to changes in land use from forests to rice fields and fields are seen to fluctuate due to the identification of the influence of land use and slope in the center of horticulture production Banuhampu Agam West Sumatra. The highest carbon values from land use and slope are in paddy (0.302%) on a slope of 25–45%, fields (0.283%) on a slope of 25–45%, and forests (0.276%) on a slope of 15 −25% (Figs. 2 and 3(d)). The difference in organic C values due to differences in stands and processing on each land resulted in different inputs of organic matter. The diversity of values for organic matter content is caused by the influence of the diversity of plant species that make up the stand and high plant crown density, thus contributing to the formation of soil organic matter [14]. The organic C value in coffee pine is high because at the observation location, the plant density is very close and in the cultivation system in fields and paddy fields there is the addition of manure and crop residues on plants such as crops and straw. Soil organic carbon may be increased in situ by adding local organic matter.

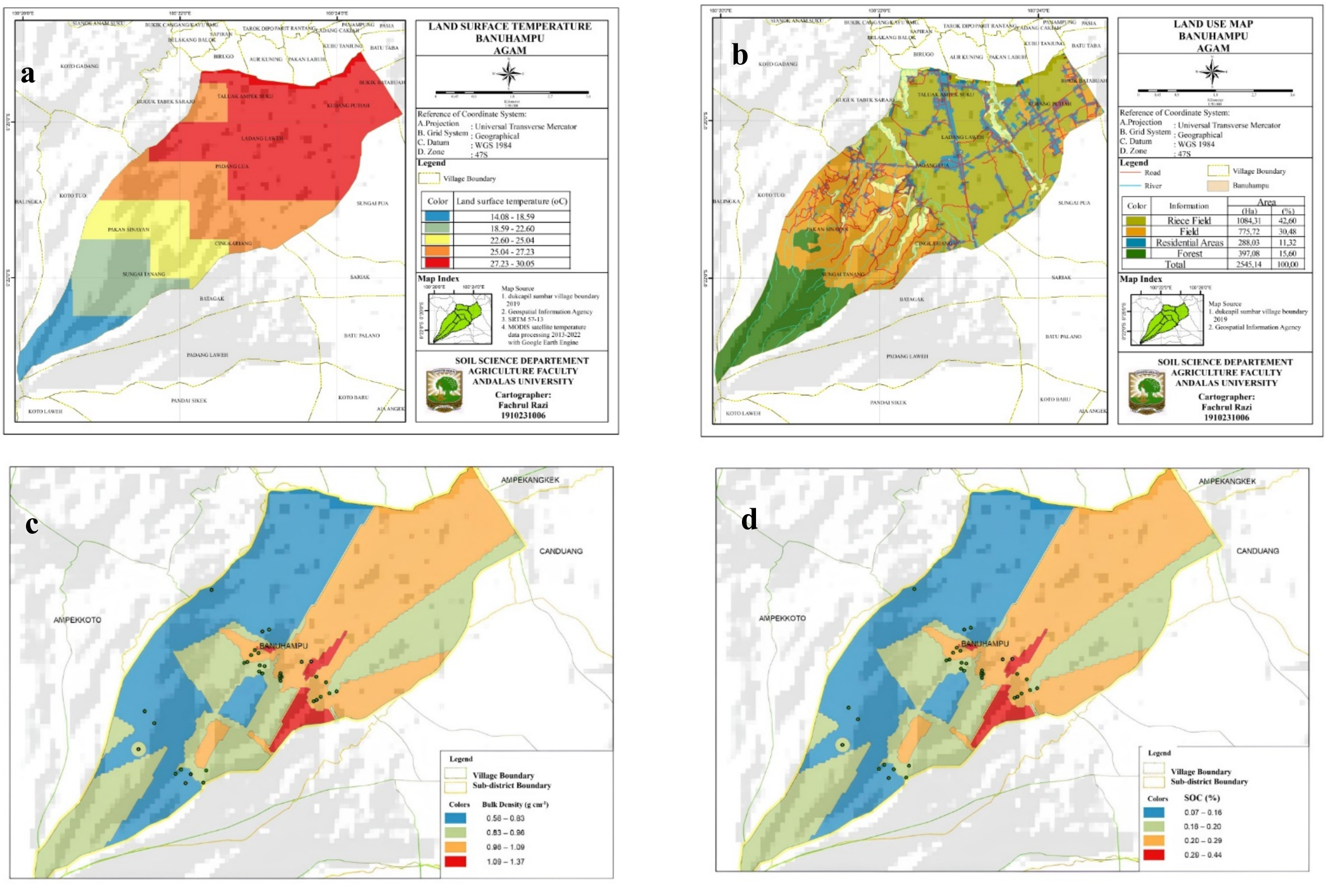

Fig. 3. Map of (a) temperature, (b) area, (c) BD, and (d) SOC in the central of horticultural production, Banuhampu Agam West Sumatra.

The addition of organic matter into the soil increases the amount of organic C value of the soil because it provides microorganisms with a source of nutrition and energy. In forest land use, the organic C content is only affected by litter yields and the absence of land management that reduces soil fertility and undergrowth in pine forests which are slow to decompose, so it also plays a role in increasing organic C content [15]. The high content of C in land use in fields with slopes at 0–8% causes the kinetic energy of surface runoff to be small so that the energy to release and transport layers because the topsoil rich in organic matter is not washed away by surface runoff. When surface flow occurs, a relatively open agricultural system allows for significant erosion, which takes most of the carbon-organic matter away [16, 17]. However, forest land has a greater organic C content. This is because there is a lot of vegetation from annual plant species that can reduce surface runoff on the soil, accumulating organic matter on the forest floor on slopes of 15–25%. This also looks different in the use of rice fields that are at a slope level of 25–45% which has a high organic C value compared to other slope levels. This is because the accumulation of organic matter from biomass can increase the organic C content of the soil.

The amount of soil organic C may be utilized for estimating how much carbon may be retained in the soil, which will have an impact on future soil fertility and climate change. Based on the results, the average value of carbon density and potential of each land use and slope in the center of horticulture production Banuhampu Agam West Sumatra is 4.04 g cm^2 and 4.04^{E2} Mg. This can explain why the potential for soil carbon in each land use and the slope has different values, this is caused by several factors such as soil type, land use type, nutrient content, organic matter content, soil texture, and others. An important factor in determining the carbon potential is the depth of the soil which is used to determine the carbon potential for each land use and slope. The value of potential C is obtained by converting the value of density C into units of weight (tons) and area (hectare) and the potential value of C is obtained in units of tons ha^{-1} for each land use and slope (Table 2 and Fig. 4(a)).

Table 2. Carbon density, potential, and stocks on land use and slope in the central of horticultural production, Banuhampu Agam West Sumatra Indonesia

Land Use	Slope	Carbon Density	Carbon Potential	Area	Carbon Stock[s]
	%	g cm^{-2}	t ha^{-1}	ha	ton
Forest	0–8	3.03	302.89	0.18	54.52
	8–15	3.20	319.99	2.87	918.36
	15–25	**5.12**	**511.65**	37.16	19013.03
	25–45	3.32	331.76	**166.89**	**55367.64**
Paddy	0–8	2.91	290.88	**1018.77**	**296338.76**
	8–15	3.22	322.02	37.23	11988.77
	15–25	2.52	252.38	3.06	772.29
	25–45	**5.56**	**556.08**	0.67	372.57
Field	0–8	4.84	484.38	104.36	50549.70
	8–15	**5.35**	**535.40**	138.95	74394.32
	15–25	4.35	434.98	**266.95**	116117.51
	25–45	5.03	502.89	236.19	**118778.52**

Remaks: a = dept (e.g., 0–20 cm) × BD × % C; b = a × 100 (100 = conversion factor from g cm^{-2} to Mg ha^{-1}); c = b × broad land use

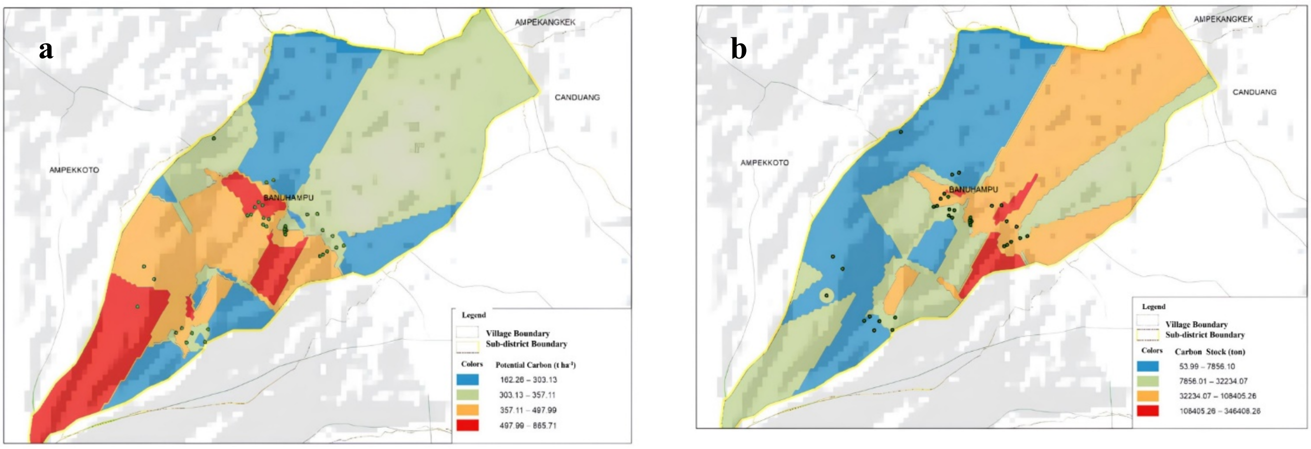

Fig. 4. Map of carbon potential (a) and stock (b), in the central of horticultural production, Banuhampu Agam West Sumatra Indonesia.

The potential C value of the soil has a fluctuating value for each type of use and slope. The highest potential yield of soil carbon is found in land use in paddy fields (556.08 Mg ha^{-1}) with a slope of 25–45%%, followed by paddy fields (535.40 Mg ha^{-1}) with a slope of 8–15% and forest (511.65 Mg ha^{-1}) with a slope of 15–25%. This appears to be the same as the soil organic C content for each land use and slope. This potential C value can estimate soil C reserves in the center of horticultural production, Banuhampu Agam West Sumatra Indonesia by multiplying the potential value of soil carbon (Mg ha^{-1}) by area (ha). The results of soil C reserves are presented in Table 2 and Fig. 4(b). Based on the area, paddy is the largest land use compared to other land uses (fields and forests) with an area of 1018.77 ha with a C stock value of 296338.76 tons at a slope of 0–8%, compared to the use of fields and forests. In field use, it has an area of 266.95 ha on a slope of 15–25%, but the highest C stock is found on a slope of 25–45% of 118778.52 tons. While the forest occurs on a slope of 25–45%, with an area of 166.89 ha and carbon reserves of 55367.64 tons. The percentage of land use change that is assumed to grow and has the potential to reduce the value of carbon stock, while the percentage of land use change that is assumed to decrease is forest plantations, rice fields, and swamps [18]. It is proven that the forest in the center of horticulture production Banuhampu Agam West Sumatra Indonesia has the lowest carbon stock value compared to rice fields and fields. The slope does not affect tree biomass and stored carbon. It is suspected that the spacing of the three land slope classes is relatively the same, where the level of the slope is a topographical element that affects runoff and erosion. The steeper the slope, the greater the erosion and runoff that occurs. As a result of the steep slope's increased flow and speed, more materials will be carried and dissolved, which will hasten erosion. Steeper slope will enhance the flow resulting a bigger power and amount of water to transport the soil [19]. Likewise with the content of organic matter. The steeper the slope, the lower the organic matter content. However, the presence of vegetation density/planting distance which is relatively the same on each slope will minimize runoff and erosion hazards so that on steep slopes the organic matter content can be maintained so that each slope with relatively the same spacing has the same organic matter content [20].

Correlation results between components of carbon stock show that carbon stock has a positive correlation with soil carbon potential and density of r = 0.111, while for BD (r = 0.094), SOC (r = 0.048) which does not provide a significant relationship to soil carbon stock based on types of land use and slope in the horticultural production center of Banuhampu Agam, West Sumatra (Table 3). Land use and the slope are influenced by the type of vegetation and the level of erosion that occurs due to the decrease and increase in soil organic carbon. Factors that cause differences in carbon stocks in each type of land use and slope are caused by differences in human activities [21], that occur in the center of horticultural production, Banuhampu Agam West Sumatra. This proves that the potential soil carbon stock is dominated by external factors that cause soil carbon stock to vary. So there are efforts that can be made to increase the content and potential of C in the horticultural production center of Banuhampu Agam, West Sumatra, namely conservative soil management, integrated nutrient management, agroforestry, and application of organic fertilizers.

Table 3. Correlation of carbon stock with bulk density, SOC, carbon density, and potential in the central of horticultural production, Banuhampu Agam West Sumatra Indonesia

Analysis	BD	SOC	Carbon Density	Carbon Potential	Carbon Stock
BD (g cm^{-3})	1	−0.312	0.092	0.092	0.094
SOC (%)		1	**0.906****	**0.906****	0.048
Carbon Density (g cm^{-2})			1	**1.000****	0.111
Carbon Potential (t ha^{-1})				1	0.111
Carbon Stock (ton)					1

Remarks: BD = Bulk density; SOC = Soil organic carbon; **. Correlation is significant at the 0.01 level (2-tailed), and n = 36.

IV. Conclusion

The average value of BD and SOC at The Central of Horticultural Production, Banuhampu Agam West Sumatra, was 0.93 g cm^{-3} and 0.22% C with a carbon potential of 4.04^{E2} Mg ha^{-1}. The highest estimation of soil carbon stocks on land use and slopes in The Central of Horticultural Production of 296338.76 [paddy (0–8%)]; 118778.52 [fields (15–25%)]; and 55367.64 [forest (25–45%)] tons. The Correlation of soil carbon stock in The Central of Horticultural Production, Banuhampu Agam West Sumatra, is positively related to carbon potential = carbon density > bulk density > SOC (r = 0.111 = 0.111 > 0.094 > 0.048). Estimation of carbon stocks in the Horticultural Production Center, Banuhampu Agam, West Sumatra, Indonesia, can provide an overview of the initial conditions regarding the intensity of land management and the level of land degradation, so further research on the impact of climate change on the land is needed.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Amsar Maulana SP., MP, Fachrul Razi, Ellsya Tatalia Augustin Putri Tanjung, Tasya Rahmatul Zalfi, and Yesma Melly Mailiza conducted the entire research, data analysis, and writing process. Prof. Syafrimen Yasin, Prof. Herviyanti, Ir. Irwan Darfis, MP, and Dewi Rezki, SP., MP facilitated the research, validated the data; all authors had approved the final version.

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