IOP Conf. Series: Earth and Environmental Science **129** (2018) 012021 doi:10.1088/1755-1315/129/1/012021

Organic carbon sequestration under selected land use in Padang city, West Sumatra, Indonesia

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Abstract. Organic carbon is a potential element to build biomass as well as emitting CO_2 to the atmosphere and promotes global warming. This research was aimed to calculate the sequestered Carbon (C) within a 1-m soil depth under selected land use from 6 different sites in Padang city, Indonesia. Disturbed and undisturbed soil samples were taken from several horizons until 100 cm depth at each location. Soil parameters observed were organic carbon (OC), bulk density (BD), and soil texture. The result showed that soil OC content tended to decrease by the depth at all land use types, except under rice field in Kurao-Nanggalo which extremely increased at >65 cm soil depth with the highest carbon stock. The soil organic carbon sequestration from the highest to the lowest according to land use and the location is in the following order mix garden- Kayu Aro > mix garden- Aie Pacah > Rangeland- Parak Laweh >seasonal farming- Teluk Sirih > rice field- Kampuang Jua.

1. Introduction

Carbon (C) is considered to be one of the elements contained in the greenhouse gases (CO_2, CH_4, CFCs, HCFCs and HFCs). Therefore, an effort to sequester C becomes one among the answers for climate change control. As stated by Lal [1] that C-sequestration was the net rate of atmospheric CO_2 reduction by transferring into other long-lived global pools involving oceanic, pedologic, biotic, and geological strata. The C-sequestration is a method that might help to limit emissions and have potential to alleviate the risks of climate change [1,2].

A carbon sink is defined as storing CO_2 removed from the atmosphere or captured from emissions in other forms. Carbon is stored within terrestrial ecosystems for about 2110 Pg, almost three times the amount in the atmospheric CO_2, with 74% is stored by soils [1]. Soil organic carbon is estimated to be 684–724 Pg of C in the upper 30 cm, 1462–1548 Pg of C in the upper 100 cm soil profile [3].

The quantity of carbon sink in soil is determined by the types of land use and the management applied in each location. As found by Liu *et al.* [4] that the amount of biomass input into the soil was strongly affected by land-use. Plants capture CO_2 from and release O_2 to the atmosphere during photosynthesis process. Therefore, the more vegetation growing on a land more carbon is sequestered or removed from the atmosphere. Carbon stocks in soil decreased by 0.39 Mg/ha/y due to land conversion [5]. Moreno *et al* [6] found that the highest SOC stocks within a 4-m depth in tropical Colombia were found under primary forest (227.9 Mg ha^{-1}) > secondary forest (192.5 Mg ha^{-1}) > pasture (171.2 Mg ha^{-1}). Soil OC and easily decomposed OC in aggregates under grassland and forestland were higher than those under farmland.

Johnson *et al* [7] stated that agriculture can be a source of greenhouse gases and it can also be a sink for CO_2 through C sequestration into biomass products and soil organic matter (SOM). SOM can be found intra or inter soil aggregates protects from microbial attacks and known as physically protected OM. On the other hand, it is exposed and easily attacked by degrading microorganisms. Liu [4] found that soil OC and easily decomposed OC under farmland in the Loess Plateau of China concentrated in < 1 mm macro-aggregates, in others in > 1 mm. Soil OC and easily decomposed OC within aggregates in grassland and forestland were higher than in farmland.

Land use change is considered as the primary sector that contributes to greenhouse gas emissions. The CO_2-eq emissions increased about six times in 2005-2009 compared to that in 2000-2005 (681 006.94 tons of CO_2-eq per year) as agricultural land conversed to settlement for approximately 11.12% in Bogor, Indonesia from 2000-2009 [8]. Novara *et al*. [9] in Mediterranean areas found that land use conversion, vegetation type, and management practices, which control biogeochemical and physical soil properties, affected CO_2 emissions and SOC sequestration. Chen *et al* ([10] found that suburban and rural areas in Southern China had higher soil C content than that in an urban area.

The number of OC sequestered in soil is also affected by the soil properties, besides the types and density of plants. Yulnafatmawita [11] and Yulnafatmawita *et al* [12] found that types of soil texture affected SOM content. Clay content was found to be positive-linearly correlated with SOM content. The higher the clay particle percentage in a soil the more the SOM content. It was found that there was 18.8 g SOM/kg soil having 82% clay [13] and 12.3 g SOM/kg soil having 67% clay [12] on the surface of 20 cm soil depth in Ultisols Limau Manis Padang.

Furthermore, the amount of SOM is also determined by the management applied to the land. Cultivated soil used to contain 50-75% of the original SOC pool [1]. Under clay textured soil being intensively cultivated, for example, the percentage of SOM could be lower than that under the loamy textured soil in a forest. A forest with plenty of woods is potential to catch carbon (in form of CO_2) from the atmosphere, as well as at land which is never cultivated accumulates carbon (in form of SOM) in the soil.

Land use in a city is dominated by building either for private or public facilities. In Padang City, a capital of West Sumatra Province, some land has been uncovering, especially the area close to the coastline, and some is still being covered by primary forest (±51%) based on statistical data [14]. The rest was for agriculture (rice field, mix garden, bush, seasonal farming), rangeland, animal husbandry and fishery, then for housing and other buildings, infrastructure, and other facilities. How much carbon was sequestered in different types of land use in an urban area under wet tropical climate is interesting to study. This research was aimed to identify the carbon sequestration under different types of land use in Padang city, Indonesia.

2. Material and methods

2.1. Research site

Our study was focused in Padang, a mid-sized city in Indonesia, covering an area approximately 694.96 km^2, having population 902,413 with the density was 1,299 people/km^2 [14]. It is located on the West Coast of Sumatra, Indonesia (0°44′-1^{o}08’ S, 100°05’-100^{o}34’E) (Fig. 1) with the altitude 0-1853 m *asl*. The region has a wet-humid tropical climate, receiving 3,552 mm of precipitation in 2016 and average annual daily minimum and maximum temperatures of 26.10°C and 31.30 °C, as well as 73% and 95% relative humidity, respectively. The climate of the city belongs to wet tropics, classified as *Af* (very wet) class according to Smith and Ferguson [15].

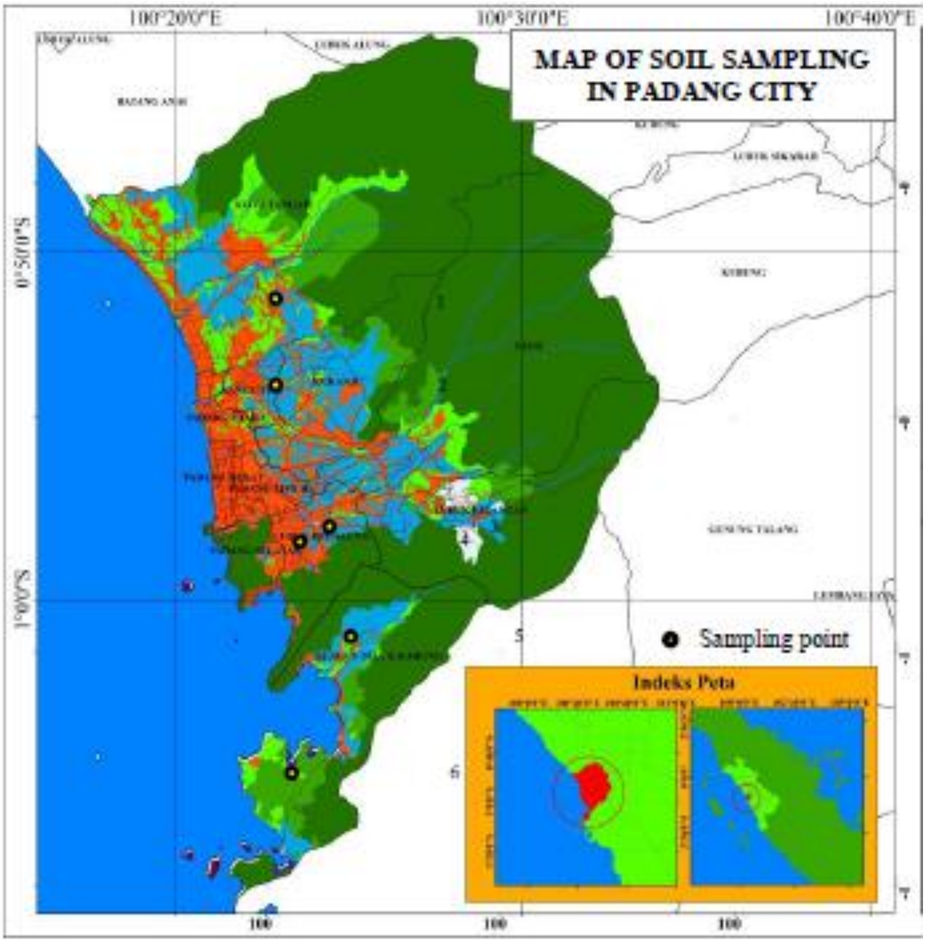

Figure 1. Map of research site and soil sampling points

2.2. Soil sampling

Soil sampling was taken from 4 different types of land use, rice field (Kurao Nanggalo and Kampuang Jua), mix garden (in Kayu Aro and Aie Pacah), seasonal farming (in Teluk Sirih), and rangeland (in Parak Laweh) in June 2016.

Disturbed (using mineral soil bore) and undisturbed (using 4 cm x 7 cm core) soil samples were taken from each sampling location from the topsoil until 100 cm soil depth. There were 6 sites being sampled, those were listed in Table 1. Soil bulk density (ρ_b) was measured by using the gravimetric method, and the data was calculated using the following formula:

$$\rho_b \,(Kg\ m^{-3}) = \frac{Dry\ Weight}{Total\ Volume} \quad (1)$$

Table 1. Types of land use selected in Padang City.

No	Land Use	Location	Code	Geographical Position
1	Mix Garden-AP	Aie Pacah	AP	S: 00°51'25.6” E: 100°22'54.4"
2	Rice field-KN	Kurao Nanggalo	KN	S: 00°53'55.2" E: 100°22'56.7"
3	Rice field-KJ	Kampuang Jua	KJ	S: 00°57'53.5" E: 100°24'30.6"
4	Rangeland-PL	Parak Laweh	PL	S: 00°58'16.2" E: 100°23'30.3"
6	Mix Garden-KA	Kayu Aro	KA	S: 01°01'1.5" E: 100°25'2.0"
5	Seasonal Farming-TS	Teluk Sirih	TL	S: 01°05'1.2" E: 100°23'22.3"

2.3. Soil preparation and analysis
Core soil samples were dried at 105 °C for 48 h and subsequently weighed for soil bulk density determination. The bulk soil sample was air dried under laboratory, then homogenized into a fine powder in an agate ball-mill. The ball-milled sample was then passed through a 2-mm sieve [16]. This was used for particle size distribution analyses. Then the 2 mm soil samples were further milled, sieved using 0.5 mm sieve for soil OC analyses. Soil OC content of the samples was determined using wet oxidation method [17]. Amount of OC sequestered in soil was employed the following formula:

$$Organic - C\ \left(\frac{kg}{ha}\right) = (\%\ Org - C)x\ BD\ x\ soil\ volume\ in\ 1\ ha \quad (2)$$

3. Results and discussion

3.1. Research sites

3.1.1. Aie Pacah. Land use in Aie Pacah was in form of mix garden having some trees, such as jackfruit, bananas, petai, durian, mango, coconut trees, and some other tropical trees with quite low density. The land was not tilled for crop cultivation, therefore, the soil surface was covered by grass. According to the land owner, the area was less productive.

3.1.2. Kurao Nanggalo. Sampling area in Kurao Nanggalo was under rice field. The area was continuously used for rice cultivation all year long or without rotation. The rice biomass used to be burnt by farmers after harvest time. They used to cultivate the land 3 times a year for rice cultivation. Rice crops were fertilized using synthetic fertilization as recommended.

3.1.3. Kampung Jua. Sampling area in Kampung Jua was under rice field. The rice field culture was also without rotationFarmers here also used to burn rice biomass after being harvested.

3.1.4. Parak Laweh. Sampling area in Parak Laweh was under rangeland or open land, without any cash crops. Types of vegetation growing on the land were grass, imperata, melastoma, mimosa, etc. The short cycle life of the plants contributes the residue to be SOM after being degraded. This cycle run fast without any disruption to the soil.

3.1.5. Kayu Aro. Sampling area in Kayu Aro was under mix garden. The area of the land was cultivated for some tree crops. The area was not intensively cultivated like for vegetable crop farming.

3.1.6. Teluk Sirih. Sampling area in Teluk Sirih was under seasonal (annual crop) farming. The area of the land was cultivated for annual crops, or it was a rotation among seasonal crops especially food crops, such as chili, corn, etc.

3.2. Soil organic carbon concentration
Soil OC concentration at 6 different locations in Padang city is presented in Figure 2 a-f. In general, SOC concentration in Padang city was affected by the types of land use as well as the management applied to the land. The cultivated area including seasonal farming and rice field had the lowest amount of OC concentration. Tillage in seasonal cop farming causes SOM oxidation and CO_2 release into the atmosphere. As reported by Yulnafatmawita [18] the CO_2 emissions from ORP land use under rainforest in a temperate climate in Australia increased by the increasing of energy applied in cultivating the soil. Rice field had low SOM content due to farmer habit in burning biomass, returning it to the soil. Farmers just applied synthetic fertilizer as the nutrient sources for the rice.

Figure 2 presents soil OC concentration at each location. It can be seen that the percentage of OC concentration in soil profile tended to decrease by deeper soil depth from the soil surface, except under rice field in Kurao Nanggalo (Figure 2-a). Higher OC content on soil surface was found to be true since the source of soil OC was mainly derived from the soil surface, plant litters, waste of agriculture product, and animal decay. Yulnafatmawita and Hermansah [19] reported that lowering soil depth from surface soil decreased the soil organic C concentration in Ultisol Limau Manis under wet tropical area.

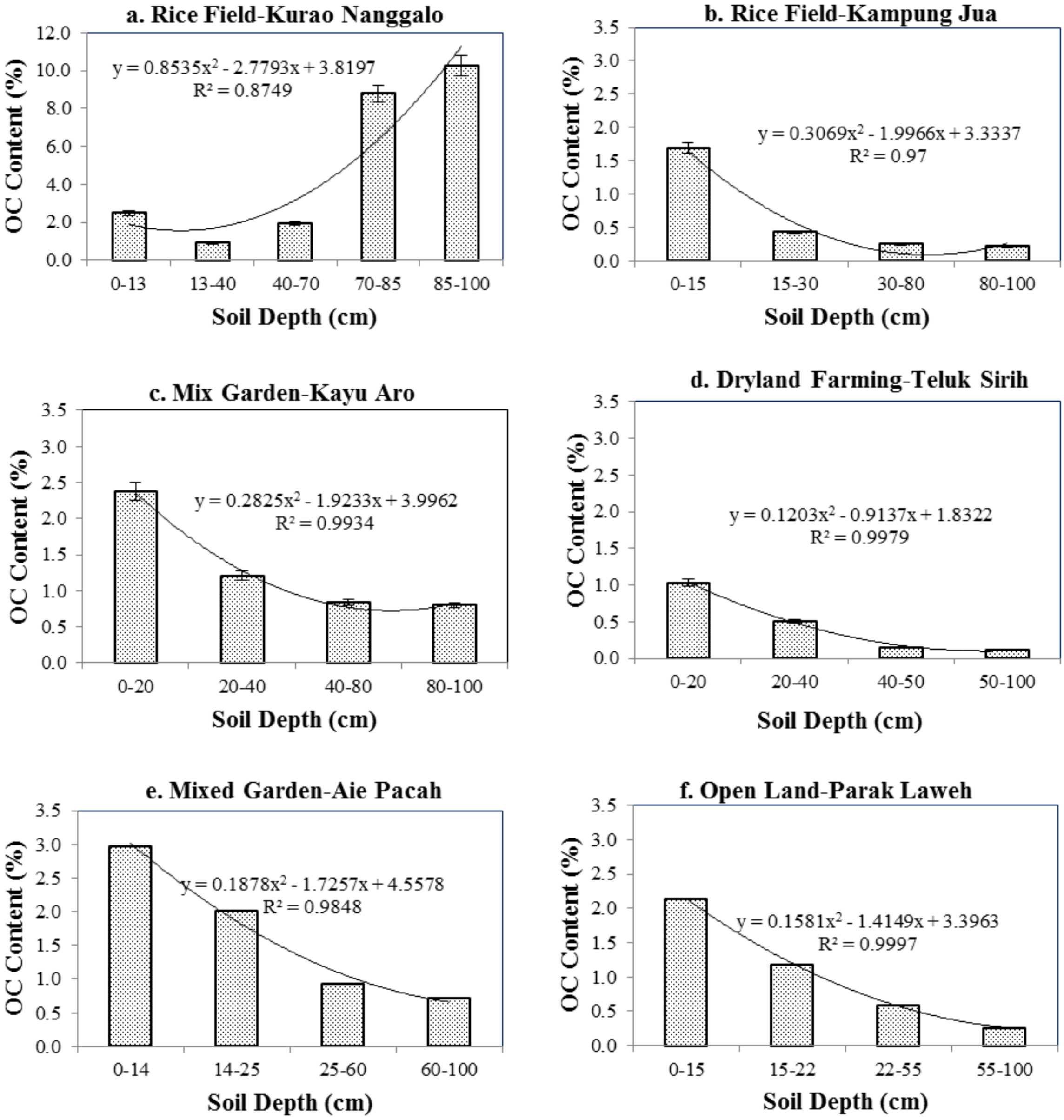

Figure 2. a-f. Soil Organic C percentage within a-100 cm soil profile under several types of land use in Padang City.

The OC found in lower depth within soil profile could be derived from soil microorganisms, root exudates and root senescent, and some are OM leached from the soil surface, even though there was only a little amount of SOM leached from the topsoil. The movement of the SOM was affected by the soil texture type, besides the amount of rainfall received in the area. Based on Yulnafatmawita *et al* [20] vertical movement of OC at coarser soil texture was higher than that at finer soil texture under super wet (annual rainfall reached 6,500 mm) tropical area in Bukit Pinang-Pinang West Sumatra, Indonesia.

Unlike common trend, organic C percentage under rice field in Kurao Nanggalo (Figure 2-a) extremely increased at depth >70 cm. The percentage of SOM at soil depth 85-100 was about 4.12 times higher than that at the top 13 cm soil surface. The OC form in the deeper soil profile was almost in pure OM. It seems that the area was previously a depression land and then filled with mineral matter due to flood routinely happened in that location. Since the rice field was not cultivated until 70 cm depth, the OC on that depth was sequestered. Nahlik and Fennessy [21] found that in the conterminous US wetland could store 11.52 PgC, which was mostly found in > 30 cm soil depth.

At the soil surface, OM content on the top 13 cm soil depth under rice field in Kurao Nanggalo was 2.49%. This is higher than the OC content under the same land use in Kampung Jua (1.69%) (Figure 2-b), which almost reached 1.5 times. The same tendency was also found under the second horizon of rice field, the OC content at a rice field in Kurao Nanggalo was approximately 2.07 times higher than that in Kampung Jua. This could be due to the higher sand percentage in Kampung Jua (20.1%) than that in Kurao Nanggalo (7.9%). The higher the sand particle percentage in a soil texture is the less the OM possibly bound by the mineral matters and the easier the OM degraded during good soil aeration, such as after rice harvesting. Besides that, finer particle soils have more micropores in which the OM contained in it was hard to be accessed by degrading organisms. Yulnafatmawita [18] reported that SOM content positively correlated to the finer soil particles.

Among the types of land use being study, mix garden-AP (Figure 2-e) contributed more percentage of OC (2.97%) at the top (0-14 cm) soil profile in Aie Pacah. This was 1.2 -2.9 times higher than OC contents at the topsoil profile in Kurao Nanggalo (Figure 2-a), Teluk Sirih (Figure 2-d), Parak Laweh (Figure 2-f), Kampung Jua (Figure 2-b), and Kayu Aro (Figure 2-c). Higher OC percentage under mix garden (Figure 2-c dan 2-e) was due to soil surface was covered by grass. The residue of grass contributed to high SOC by time. Since grass has a short life cycle, it could produce more biomass per year compared to perennial plants. Faster decomposition rate under seasonal and full sunlight received by the soil causes the grass residue decomposed and transform into SOC in relatively short time. As reported by Yulnafatmawita and Hermansah [19] that the more the grass covering soil surface was the higher the soil OC content under wet tropical area.

Organic C percentage under rangeland in Parak Laweh (Figure 2-f) was still higher than that in a rice field in Kampung Jua, seasonal farming in Teluk Sirih, and mix garden in Kayu Aro. Since the land was abandoned for the last few years, and it was just grown by bushes like *imperata*, *mimosa*, *melastoma*, as well as without any cultivation or soil disruption, the percentage of SOM in the rangeland increased by time.

3.3. Soil organic carbon sequestration

Soil OC sequestration at 6 different locations in Padang city is presented in Figure 3. Among the locations, OC sequestered under rice field in Kurao Naggalo was found to be very high. It was much higher than that under rice field in Kampung Jua, due to extremely high OC at depth ≥70 cm. This high OC content at lower soil depth was probably due to OM accumulation long time ago, much far beyond the rice field created. Therefore, the OC sequestration in Kurao Nanggalo is incomparable to other types of land use in Padang city to the depth of 100 cm soil profile.

Mix garden such as in Kayu Aro and Aie Pacah could sequester more OC. It was much higher than that under rice field in Kampung Jua, under dryland (seasonal crop) farming in Teluk Sirih, and under rangeland (open land) in Parak Laweh. Higher SOM sequestration in Aie Pacah was due to the short cycle of grass as well as management was given to the land. The area was not tilled because the crops being grown was perennial trees, as well as bananas which do not need soil tillage. Since the plants were not closely planted each other, the open land becomes covered by grass (*Axonopus campestris*) permanently causing high OM contribution to the soil. As reported by Deng et al [5] that change of land use types from farmland and forest into grassland increased soil C stocks 0.30 Mg/ha/y and 0.68 Mg/ha/y, respectively. Zhang *et al* [22] found that SOC stocks increase as cultivated land is conversed to grassland and therefore improve the potential for SOC sequestration in the surface soil over a decade period of time.

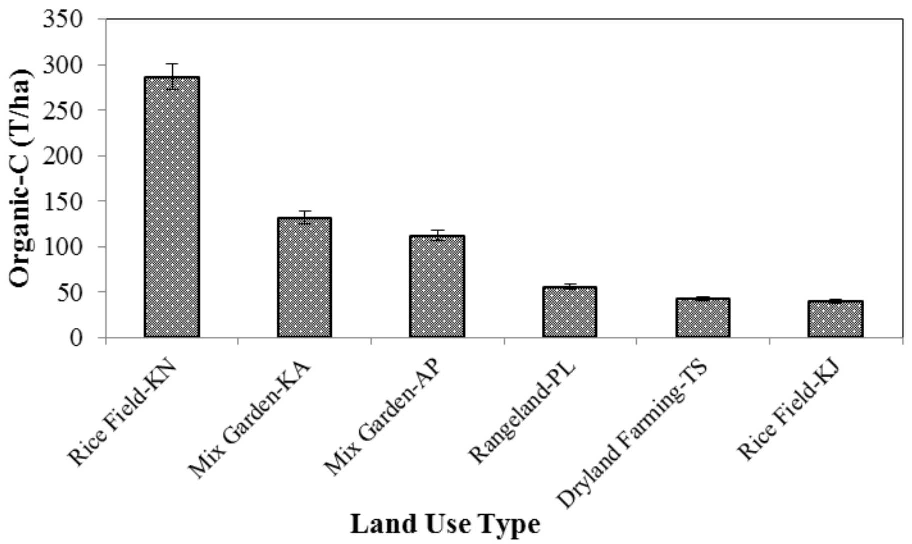

Figure 3. Organic-C sequestered within a-100 cm soil profile under several types of land use in Padang City.

Seasonal farming in Teluk Sirih sequestered low OC due to the types of crops being planted as well as the management given to the soils. Even though the seasonal crops can yield more SOM/year, less crop residue was left on the soil surface, and then the residue was degraded fast since the soil was tilled seasonally. Deng *et al* [5] found that soil C stocks significantly decreased (0.68 Mg/ha/y and 0.89 Mg/ha/y), respectively as grassland and forest conversed to farmland. Additionally, compared to Kayu Aro, Teluk Sirih had coarser soil texture on the top 20 cm soil. Coarse-textured soil means the soil has a large proportion of macropores causing good soil aeration. This condition increases decomposing organism activity in degrading and even oxidizing SOM, consequently, the percentage of SOM decreases.

3.4. Soil properties

Soil properties especially soil OC content, particle size distribution, bulk density, and texture at 6 different sampling locations were presented in Table 2. On the top 20 cm soil profile, soil bulk density was found to be in the medium criteria (> 600-<1140 Kg m^{-3}), it is not too soft and too hard to till or cultivate. It means that the soil could be used or continued for crop production. The value of soil bulk density determines the amount of OC sequestered within the soil profile. Ahukaemere [23] found that the average amount of C and N sequestered in the soil varied (from 3142.60-6139,74 g.m^{-2} to 101.33-388.6 g Nm^{-2}), it was affected by the soil bulk density besides the thickness of the soil horizon.

Table 2. Some soil properties at the top 20 cm soil profile.

Code	Land use	Location	BD	OC	Sand	Silt	Clay	Texture Class
			Kg m^{-3}	%				
AP	Mix Garden-AP	Aie Pacah	910	2.68	3.80	41.60	54.60	Silt Clay
KN	Rice Field-KN	Kurao Nanggalo	720	1.93	7.90	71.10	21.00	Silt Loam
KJ	Rice Field-KJ	Kampuang Jua	820	1.38	20.10	39.00	40.90	Clay
PL	Rangeland-PL	Parak Laweh	770	1.90	9.30	70.80	19.90	Silt Loam
TS	Mix Garden-KA	Kayu Aro	1090	2.38	9.60	39.10	51.30	Clay
KA	Seasonal farming-TS	Teluk Sirih	1130	1.03	16.60	71.60	11.80	Silt Loam

Soil OC also correlates with soil texture. The relationship between sand as well as clay and OC content is presented in Figure 4. Figure 4 showed that OC content was a negatively linear correlation with sand (R^2=0.7582) (Figure 4-a), and positively linear correlation with clay (R^2=0.5171) (Figure 4-

b) content of the soil tested. Lower OC content under highly sand containing soil (coarse texture) was due to good aeration in the soil, enough O_2 available, causing degrading microorganism activities become intensive. Therefore, plant residue cannot be accumulated in the coarse soil.

Higher OC content at clay dominated textured soil was due to the high specific surface area of the clay particles causing a large amount of OC could be adsorbed and protected from the degrading microorganisms. As found by Yulnafatmawita [11] that there was a positive linear relationship (R^2=0.8633) between clay and SOM content of a soil. Clay materials adsorb and occlude carbon in soil pores, and are not accessible to the main decomposing organisms, leading to stable complexes between Al-sites and organic compounds [24].

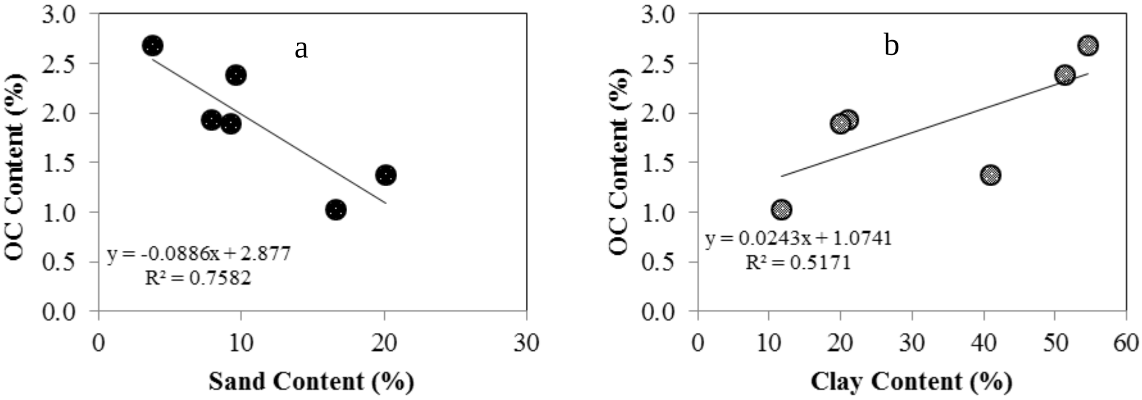

Figure 4. The relationship between soil particles ((a) sand and (b) clay) and OC content of the soil.

4. Conclusion

Different types of land use lead to different OC sequestered, which is also affected by was a land cover, land management, and the soil characteristics. Other than special case under rice field in Kurao Nanggalo, amount of OC sequestered was the highest under mix garden in Kayu Aro (132.11 t/ha/m depth) and Aie Pacah (112.54 t/ha/m depth). Then, it was followed by rangeland in Parak Laweh (55.30 t/ha/m depth). While the lowest OC sequestration was found under seasonal farming in Teluk Sirih (42.78 t/ha/m depth) and rice field in Kampung Jua (39.74 t/ha/m depth). In order to mitigate CO_2 emission to the atmosphere as a control for climate change, mix garden with grass covering the soil surface could be suggested to practice in a city. Then, OC sequestration in farmland could be increased if the farmers would like to improve their style in managing the soil.

Acknowledgements

Authors wishing to acknowledge Seprianto, Youngky Kurniawan, Farras Fadilla, Zaki Jumaika, Ultari Wahyuni for field soil sampling and to Desni Asrita as well as Erlinda for soil analyses in the laboratory.

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