Organic matter sequestration under sugarcane cultivation in Nagari Lawang, a wet tropical region, West Sumatra Indonesia

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Abstract. Organic matter sequestration in soil is important not only to improve soil properties but also to avoid environmental problems such as global warming due to high carbonic gases in the atmosphere. This research was aimed to calculate the amount and rate of OM sequestration under sugarcane cultivation. The soil was sampled at 4 ages of sugarcane cultivation (±15, ±50, ±80, and ±100 Y) from a 1-m soil profile and from forest as a comparison. The results showed that the SOM was higher by longer cultivation of the sugarcane. Compared to the forest nearby, the amount of SOM stock under sugarcane reached 0.88, 0.77, 0.95, and 0.99 respectively, for the sugarcane 15, 50, 80, and 100 years' old. Within 1-m soil profile, the SOM stock under forest (412.68 T/Ha) was >100 years (409.28 T/Ha) >80 years (390.02 T/Ha) >15 years (361.45T/Ha) >50 years (319.55 T/Ha) of sugarcane cultivation. The OM sequestration rate for the 1-m soil profile under sugarcane cultivation was -0.40 T/Ha/Y (between 15-50 Y), 0.78 T/Ha/Y (between 50-80 Y) and 0.32 T/Ha/Y (between 80-100 Y). This implies that traditional sugarcane cultivation can avoid soil degradation as well as decrease the CO_2 emission to the atmosphere causing global warming.

1 Introduction

Land use change from forest to agriculture land is used to decrease the soil OM content or stock [1,2] as well as increase CO_2 emission to the atmosphere. This is due to the different vegetation, environment, and management given to the soil after being farmed. Therefore, it will contribute different amount to soil OM. Unlike to perennial crops, land use change from forest into seasonal crops is used to open or no heavy canopy covering the soil surface, to loose the soils in order the plant roots can grow well. Therefore, the soil OM will decrease faster than that under perennial crops.

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However, some farming types could accumulate OM in the soil, mostly from plantation. Increasing soil OM stock after land use change from forest to farming land was reported at tea cultivation in mount Talang, Solok Regency, under wet tropical area. The OM stock reached 166.52 Mg/Ha after 36 years old tea cultivation [3]. Increasing soil OM was also reported under coffee plantation in Sibarasok Maninjau, Agam Regency [4]. Therefore, land use for perennial crops tends to accumulate than degrade OM in the soil.

Sugarcane (*Saccharum officinarum* L.) is a type of plantation crop having long age or it is considered as a perennial crop. Harvesting can be carried out after the crop reaches maturity without uprooting the plants, as only the mature stalks are cut while the young plants are left to regrow through the ratoon system. Therefore, the litter from the leaf senescence will accumulate on the soil surface and contribute to soil OM since the land was not cultivated except at the first time of planting. However, some the sugarcane people practiced different methods.

The amount of OM sequestration or degradation is mainly affected by the management given. It is reported that burnt management of sugarcane field tended to decrease SOM while green field method increased soil OM content [5]. It is reported that sugarcane cultivation after 30 years decreased the total OC especially in soil macro aggregates compared to the adjacent native forest in South Africa [6]. Furthermore, cultivated soils promoted OC loss from soil [7]. Conversion of coffee and citrus ecosystems to intensive till sugarcane decreased soil C stock in Southern Brazil [8].

However, some reported that sugarcane cultivation can improve soil OM stock. Soil management such as permanent pasture, no tillage, and direct sowing contribute to high OM accumulation in soil [9]. There was a potency of accumulating OC in raw sugarcane fields [10]. Natural, organic farming, or traditional practices of sugarcane was found to increase soil OM stock [11]. Different areas apply different management practices in sugarcane cultivation, resulting in dynamic soil OM accumulation.

Nagari Lawang is one of the primary sugarcane production centers in West Sumatra. In this region, sugarcane has been cultivated using traditional methods by the local community for more than a century, predating Indonesia's independence. The forest at the study site was initially cleared, after which sugarcane was planted and continuously cultivated without crop rotation. Soil tillage was performed only during the first planting, and in subsequent years the soil was left untilled. Leaf litter and post-harvest crop residues were retained on the soil surface; however, bagasse was not returned to the fields. Accordingly, this study was aimed to assess whether organic matter (OM) can accumulate under traditional sugarcane cultivation and to quantify the rate of OM sequestration in Nagari Lawang.

2 Materials and methods

2.1 Research site

This research was conducted under sugarcane cultivation in Nagari Lawang, Matur Sub-District, Agam Regency, West Sumatra Province Indonesia. Nagari Lawang in Agam regency is located at the upper part of Maninjau lake (a volcano lake) having altitude 850 - 1450 m *asl*. It has low temperature (15.3°– 24.4°C) in tropical area [12]. The soil in the research site is classified into Inceptisol with the area approximately 1,323.15 ha. This area is known as agricultural region, with the main commodity is sugarcane.

The research site was located between 0°14'44,52" – 0°17'3,51" S and 100°13'54,53"–100°16'54,40" E, with the total area 1,323.15 ha, and receives approximately 2,866.5 mm annual rainfall [12]. The area is considered as a wet tropical region. The soil in the research area is derived from materials erupted by Mount Tinjau approximately 52 thousand years

ago [13]. The area is located in the upper part of Maninjau lake, a volcanic lake. It has undulating topography, but soil samples for this research were taken at 0-8% slope level at each sampling point. The area has been cultivated for sugarcane since long time before the independence day of Indonesia, it has been more than 100 years ago. Then, the local society always enlarge the area up to now.

2.2 Soil sampling

This research employed survey methods, soil was sampled by purposive sampling based on land usage for sugarcane cultivation. There were four different ages of sugarcane land use (15, 50, 80, and 100 years old) and secondary forest as a comparison, with three replicates for each land use. The geographical position of each sample is provided in Table 1. Soil was sampled for a 1-m depth, with three consecutive depths (0-30, 30-60, and 60-100 cm depth). Disturbed and undisturbed soil samples were taken from each sampling point. Disturbed soil samples were collected using a mineral soil auger, while undisturbed soil samples were obtained using a metal ring. Then, soil samples were processed at Soil Laboratory Universitas Andalas before being analyzed.

Tabel 1. Sampling point position

Land Use	Age (y)	Land Use code	Geographical Position	
			East	South
Sugarcane	15	SC-15	100º16'25.66"E	0º16'3.15"S
			100º16'26.73"E	0º16'1.03"S
			100º16'28.06"E	0º16'3.06"S
	50	SC-50	100º16'08.67"E	0º16'33.62"S
			100º16'10.86"E	0º16'32.09"S
			100º16'08.56"E	0º16'31.03"S
	80	SC-80	100º14'53.31"E	0º16'22.96"S
			100º14'54.89"E	0º16'21.11"S
			100º14'52.42"E	0º16'20.73"S
	100	SC-100	100º15'36.37"E	0º16'28.21"S
			100º15'34.05"E	0º16'27.61"S
			100º15'34.60"E	0º16'29.90"S
Forest	>100	Forest	100º15'26.17"E	0º15'30.95"S
			100º15'28.62"E	0º15'31.11"S
			100º15'27.10"E	0º15'32.99"S

2.3 Parameter

Some parameters analyzed were soil texture, soil bulk density (BD), total soil porosity (TSP), hydraulic conductivity (HC) besides soil organic carbon (OC). Soil OC was analyzed by using wet oxidation method, soil texture by using sieve and pipet method, soil BD and TSP using gravimetric method, and soil hydraulic conductivity using constant head permeameter. Soil OM content of the soil was calculated by using equation 1. Then, the calculation of SOM Stock is presented in equation 2 [6], and OM sequestration in equation 3.

$$SOM\ content\ (\%) = \%\ OC * 1.724 \quad \ldots\ldots(1)$$

$$SOM\ stock\ (T/Ha) = \%SOM * volume * \rho b \quad \ldots\ldots(2)$$

$$OM\ Sequestration\ rate\ (T/Ha/Y) = \frac{OM\ stock\ at\ (latest\ one - previos\ one)T/Ha}{Total\ year\ (latest\ one - previous\ one)Y} \quad \ldots\ldots\ldots(3)$$

2.4 Data analyses

Data collected from analyses at laboratory were calculated the mean and the standard deviation. Then, the data were compared to the forest land use. The data are presented in Graphs.

3 Results and discussion

3.1 Research location

The research site received quite high rainfall (170-369 mm) per month (Fig.1). The area was classified as A type climate (very wet region) [28], because the comparison between the total of dry month (rainfall<60 mm/month) and the total of wet month (rainfall>100 mm/month) is <2.22%. In average for the last 10 years (2014-2023), the site belonged to wet area because rainfall received was >100 mm/month. Therefore, the area is quite prone to erosion, especially at steep slopes. The wettest month was at the end of each year (November and December).

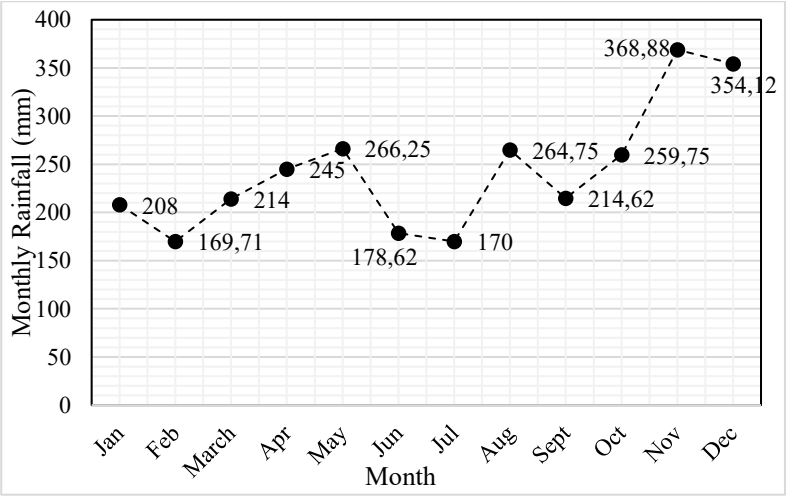

Fig. 1. Mean monthly rainfall in Nagari Lawang from 2014-2023

Sugarcane cultivation in Nagari Lawang was conducted by local society through traditional methods. The crops were planted at the first, and then kept the sapling growth all time long. So, the crops do not have to be replanted, but just maintained the saplings. This is beneficial for the land itself, because the organic matter from the leaf litter can be accumulated, as presented in Fig. 2a. Since the soil was not cultivated for a long time, the OM was not easily decomposed which can control CO_2 emission to the atmosphere. Therefore, the amount of CO_2 emission from the sugarcane cultivated land can be controlled.

Fig. 2. Sugarcane cultivation (3a) and the bagasse (3b) in Nagari Lawang, Agam Regency

Local communities have cultivated sugarcane continuously for more than a century, dating back to the pre-independence period and persisting until today. Then, after being harvested, the sugarcane was processed traditionally to produce brown sugar called "*saka*". The bagasse produced after extracting the sugar (Fig. 2b) was not returned to the field, but it was used as an energy source in producing "*saka*".

3.2 Soil physical properties

Physical properties of soil under sugarcane and forest land use were described in Fig. 3 and 4. Soil particle size analyses at three different depths in each land use were provided in Fig 3.

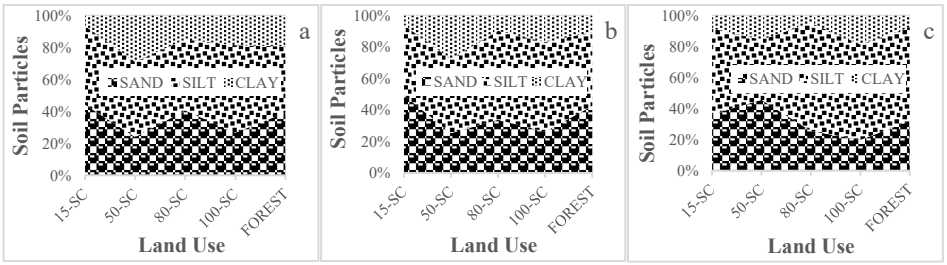

Fig. 3. Soil particle distribution at sugarcane cultivation and forest in Nagari Lawang Agam Regency, at 0-30 (a), 30-60 (b), and 60-100 (c) cm soil depth

Based on the data in Fig. 3, the soil texture in the research sites was classified into loamy soil. It was indicated by high course (sand and silt) particles. The total of sand and silt particles composing the soil was quite high, the lowest was 71% and the highest was 95%, with the average was 85,81% of the total soil particles. High course and less fine mineral particles composing soils will cause the soil to be porous, having high macro pores, meaning less water retention, especially at low OM soil content.

High course soil particles in the research site are much affected by mount Tinjau eruption which is considered relatively new or about 52 thousand years ago [13]. The research site is at the upper part of the mount Tinjau caldera. Since the location is relatively near to the crater, the soil particles accumulated was quite course. Course soil texture were also reported under coffee cultivation in Simarasok [4] which were also affected by mount Tinjau eruption.

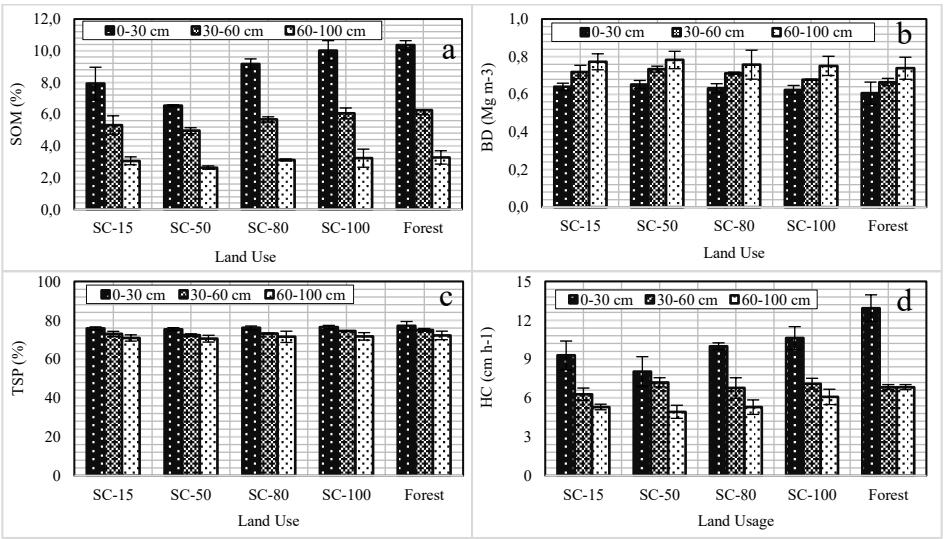

Fig. 4. Soil OM content (a), BD (b), TSP (c), and HC (d) of soils under sugarcane cultivation and forest in Nagari Lawang, Agam Regency, West Sumatra Indonesia

Fig 4. showed that the soil OM content (4a) decreased by depth at each land use. This is due to the fact that main source of OM comes from above soil surface, especially plant litter. The amount of the litter is much higher than that of OM derived from root exudates or root senescence. This is not comparable between above and below ground total biomass. Therefore, the soil OM is higher on the top than on the deeper layer. This is in line with some results reported [3]. They found that the SOM sharply decreased as the soil layer deeper under tea cultivation in Batang Barus, Solok Regency.

Compared to the soil OM content at the forest land use, increasing land usage under sugarcane cultivation from 15 to 100 years old, the soil OM content tended to reach the OM content of the soil under forest. Higher soil OM under forest than that under sugarcane land use is due to the fact that forest has many types of and dense vegetation which will accumulate the litter on the soil surface. Since the soil is never disturbed or tilled, the accumulated OM will contribute to soil OM.

Soil OM content, in general, increased by age of land use for sugarcane, except between 15 and 50 years old land usage. At 15 years old, the soil OM content was higher that that under 50 years old land usage. This might be due to soil OM from the forest has been accumulated for a long time without any disturbance. After the land was converted to sugarcane cultivation, soil OM showed a tendency to oxidize. Until 50 years old sugarcane cultivation, it seems that the rate of OM oxidation was higher than the OM accumulation. Then, by time the amount of OM accumulated was higher than the oxidation. This agreed with the result reported [4] under coffee plantation in Sibarasok, Maninjau. The soil OM content under 3 years old coffee plantation was higher than that under 84 years old at 15-25% slope, since the soil OM content at the 3 years old coffee cultivation was still the residue of soil OM from the forest.

It takes time to decompose the fresh OM under forest land use, due to its micro climate. As the forest was cleared for farming activities, the OM becomes decomposed and oxidized faster, therefore, the content decreased by time until 50 years old. This agreed with the result reported in central-south Brazil after > 20 years as pasture was converted to sugarcane decreased the soil C-stock by 40% [14]. Then, as sugarcane was continuously cultivated, the litter from the crops was accumulated by time. Then, after 100 years, the SOM content of the land under sugarcane almost reached that under secondary forest land use. The soil OM

content under 15, 50, 80, and 100 years old sugarcane cultivation reached 0.81, 0.77, 0.90, and 0.97 of that under forest.

High soil OM content on the soil surface decreased the soil BD (4b) and increased the TSP (4c). Unlike the OM content, the soil BD increased by the soil depth at each land use. This was due to the effect of OM in the soil. Since the OM has lower mass than mineral matter per the unit volume, the higher the OM causes the lower the soil BD. In general, soil BD was less than 0.9 Mg m^{-3}, even though the texture was dominated by course particles. This indicated that the soil was quite loose, meaning good for root development.

Soil BD is inversely correlated with TSP. Therefore, the lower the BD is the higher the TSP. Indirectly, soil OM helps to increase space in the soil through creating soil aggregates which soil porosity. There was a tendency of decreasing soil BD and increasing of STP by longer the land usage for sugarcane cultivation. At approximately 100 years old sugarcane cultivation, the soil BD and TSP almost equal to those of natural forest. The highest soil BD was found under 50 and the lowest was under 100 years old sugarcane cultivation. Lower soil BD and higher TSP due to soil OM was also reported under tea cultivation [3].

Fig. 4 also performs that the soil HC (4d) under sugarcane land usage decreased by depth at all ages. This was due to the fact that the TSP of the soil also decreased by depth. Among the age of the land use for sugarcane, the HC increased by increasing land usage for sugarcane, except under 50 years old land usage since the soil OM content and the TSP was the lowest. The value of HC followed the SOM pattern, it decreased by soil depth at each type of land use, and increased by increasing land usage for sugarcane. The highest soil HC was found under forest land use, since the forest had the highest TSP and soil OM which can stabilize the soil aggregates affecting the HC of the soil.

3.3 SOM stock and the sequestration rate

The soil OM stocks increased by time of sugarcane land usage and decreased by depth at each land usage (Fig. 5a). This was due to litter accumulation, especially old leaves during the growth as well as after being harvested were left on the soil surface. Then, it was continuously accumulated since the soil was not cultivated since the first time of sugarcane planting. Compared to the forest nearby, the amount of SOM stock under sugarcane cultivation reached 0.87, 0.77, 0.95, 0.99 respectively for the land usage 15, 50, 80, and 100 y. This seemed to be due to no soil disturbance during sugarcane cultivation besides litter accumulation. Since the environment under sugarcane was warmer than that under forest, the litter accumulation would be degraded faster and contributed to soil OM. The stock increased by age of land usage. Increasing SOM stock by time was also reported under perennial energy crops [15], such as under tea in Solok Regency [5], and gambier cultivation in Pesisir Selatan Regency [7].

The total amount of OM sequestered within 1-m soil profile under forest (412.68 T/Ha) >sugarcane 100 Y (409.28T/Ha) >sugarcane 80 y (390.02 T/Ha) > sugarcane 15 y (361.45 T/Ha)> sugarcane 50 Y (319.55 T/Ha). The OM sequestration rate was quite low, and became lower as the land age increased. The OM sequestered within 30 cm top soil much higher than those under 60-80 and 80-100 y. It reached 17-53% higher soil OM stock at the 0-30 cm than at the 30-60 cm soil layer, and between 55-91% at the 60-100 cm depths. This results agreed with the result of SOM stock under tea cultivation [3].

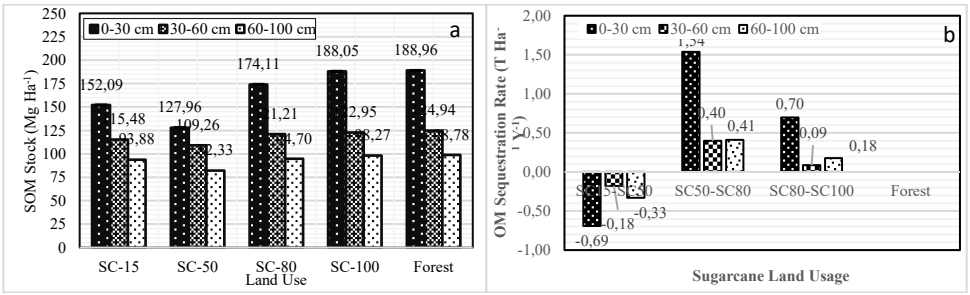

Fig. 5. Soil OM stock (a) and soil OM sequestration rate (b) under sugarcane land usage and forest land use in Nagari Lawang, Agam Regency.

The OM sequestration rate was negative from sugarcane 15 to 50 years land usage with the rate -0.69, -0.18, and -0.33 T/Ha/Y respectively for soil depths 0-30 cm, 30-60 cm, and 60-100 cm. Then, the sequestration increased up to 1.54 T/Ha/Y for 0-30 cm depth as the sugarcane land usage increased from 50 to 80 years. By time the OM sequestration rate decreased into 0.70 T/Ha/Y as the sugarcane land usage increased from 80 to 100 years. At the 30-60 cm soil depth, the SOM sequestration rate was found the lowest among the three soil depths.

The average OM sequestration rate for a 1-m soil profile was -0.40 T/Ha/Y (between 15 and 50 Y), 0.78 T/Ha/Y (between 50-80 Y), and 0.32 T/Ha/Y (between 80-100 Y) of sugarcane Land Use. This was in line with result reported under perennial energy crops [15] on which the SOC sequestration rate was 0.21 Mg Ha^{-1} y^{-1}. The sequestration rate decreased by time. It was reported that land use conversion from coffee to sugarcane decrease the soil OC for years from 124.5-99.8 Mg C Ha^{-1} for a 1-m soil profile [8]. The OM sequestration rate under sugarcane was lower than that under tea plantation. It was reported that OM sequestration rate under tea was 1.67 Mg Ha^{-1} y^{-1} (between 9-21 years old) and 0.49 Mg Ha^{-1} y^{-1} (between 21-36 years old) due to more litter was produced and was often pruned [3].

3.4 Correlation between SOM Stock and soil physical properties

The correlation between soil OM stock and soil physical properties, especially soil BD, TSP and HC under sugarcane cultivation in Nagari Lawang Agam Regency is presented in Fig. 6. Fig. 6a showed that there was a strong negative correlation between soil OM stock and the soil BD (r=-0.94). The higher the soil OM stock was the lower the soil BD, meaning that the looser the soil was the easier the crop roots to penetrate the soil. This is in line with the research reported [3] that the higher the SOM stock was the lower the soil BD. Since the soil BD is inversely proportional to TSP, the higher the soil OM stock is the higher the TSP. It means that the soil OM stock has positively correlation to the TSP. Fig. 6b showed a high positive correlation (r=0.93) between soil OM stock and TSP.

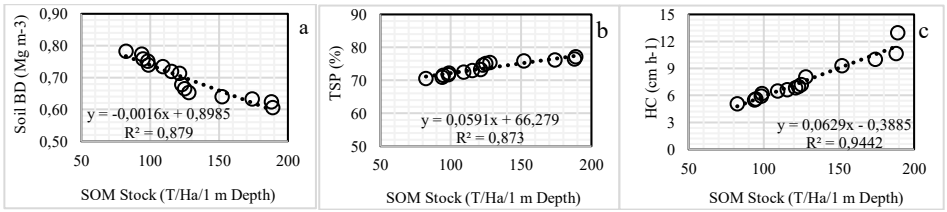

Fig. 6. Correlation between SOM stock and (a) soil B, (b) TSP, (c) soil HC rate under sugarcane land usage and forest land use in Nagari Lawang, Agam Regency.

Soil OM stock also affected soil HC (Fig. 6c). It shows a strong positive correlation (r=0.97) between soil OM stock and soil HC rate in sugarcane land usage and forest land use in Nagari Lawang, Agam Regency. Besides OM stock, coarse texture of the soil also helped to increase the soil HC rate. High sand or low clay particles in a soil will cause the soil to have a large percentage of macropores which cause to be easier in transmit water. It was reported that higher soil OM stock improved the soil HC rate [3].

4 Conclusion

Based on the laboratory data, it can be concluded that traditional sugarcane cultivation is generally capable of sequestering soil organic matter (OM). The total OM stock within the 1-m soil depth of a 100-year-old sugarcane field reached 409.28 Mg ha^{-1}, equivalent to 99% of the stock found under secondary forest. The soil OM sequestration rates were −0.40, 0.78, and 0.32 Mg ha^{-1} yr^{-1} for the periods of 15–50 years, 50–80 years, and 80–100 years, respectively. The accumulated OM substantially improved key soil physical properties particularly bulk density (BD), total soil porosity (TSP), and hydraulic conductivity (HC) all of which contribute to long-term soil sustainability. Therefore, high OM sequestration not only reduces carbon emissions to the atmosphere but also enhances overall environmental quality.

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