Organic matter stock at suboptimal soils under forest and corn cultivation in wet tropical region

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Abstract. The primary constraint of suboptimal soils under wet tropical regions, besides their low pH, is their low soil organic matter (SOM) content. This research was aimed to determine SOM stock of suboptimal soil orders (Ultisol, Oxisol, and Inceptisol) under corn (Zea mays) cultivation. This research was conducted using survey method, and soil samples were taken from 0-20 cm soil depth from each soil order under two types of land use (LU), corn cultivation and forest, in Lima Puluh Kota Regency, West Sumatra, Indonesia. The soil samples were analyzed at the soil laboratory at Andalas University, Padang. Parameters analyzed were soil bulk density (BD), texture, SOC, total-N. Data resulted showed that the soil texture from the three soil orders was classified as clay loam to clay, with the sand size particle was Inceptisol > Oxisol > Ultisol. Then, soil BD was categorized as medium. The highest SOM stock was at Oxisol under forest LU, then Ultisol and Inceptisol. Generally, SOM stock under forest was higher than under corn LU except at Ultisol, which the SOM stock was comparable. SOM stock under corn cultivation reached 43.7%, 87.7%, and 102.8% of that under forest, respectively, for Inceptisol, Oxisol, and Ultisol. Approximately 52-89% of the SOM was in the form of particulate organic matter (POM). The percentage of POM was generally higher under corn cultivation than that under forest LU. Stock soil total-N under corn cultivation compared to under forest was 37.7%, 68.7%, and 90.9% for Inceptisol, Oxisol, and Ultisol, respectively. The C/N ratio value of the SOM was considered medium.

1. Introduction

Most soils in the wet tropical region are classified as acid soils due to its high rainfall, which causes the basic cations leached. Some of the soils dominant in the wet tropical region are Inceptisol, Oxisol, and Ultisol. In general, the soils had low pH-H₂O, such as 4.9 for Ultisol Limau Manis [1], 5.0 [2] for Oxisol, and ≤5.1 [3] or 5.3 [2] for Inceptisol. However, under calcareous soil, the pH of Inceptisol reached 7.2-8.0 [4]. Based on Yulnafatmawita et al. [1,5] that Ultisol Limau Manis had high clay content (>70%), high water retention (>40% at field capacity). Those three soil orders are potential for farming development, especially for dryland farming, because they had a wide area.
Dryland farming for annual crops needs intensive soil tillage. Intensive cultivation does not only decrease SOM content but also easily degrade soil physical characteristics. Rezapour and Samadi [4] found that forest clearance and cultivation significantly decreased SOC and total N. However, under more intensive farming but best management practices such as no-tillage and another best-recommended practice system, they could decrease SOC loss as the land converted from monoculture and conventional tillage-based system at the top 30 cm soil [6].

The OM content indicates the soil quality for farming land. Organic matter in soil plays an essential role in improving soil fertility, either soil physical, chemical, and biological properties. Physically, SOM is able to create and stabilize soil aggregates, increase soil water retention, decrease soil bulk density, increase total soil pore. Based on Yulnafatmawita et al. [1] that Ultisol Limau Manis had very low (1.23%) SOM and less (0.47) aggregate stability index. If the soil is cultivated for seasonal crops, the soil will be easily degraded.

Soil OM is important to improve the soil medium for plant growth. It creates and stabilizes soil aggregates, produces crumb type aggregates having balance macropores and micropores, decreases bulk density allowing well root development, retains enough amount of water and provides enough air for root breath and microbial activities. Moreover, SOM also provides nutrients for plant growth after being decomposed, increases cation exchange capacity (CEC) as well as buffer capacity of soils. Furthermore, SOM functions as an energy source for microorganisms.

Apart from that, increasing aggregate stability using OM controls soil degradation as well as soil erosion. Stable aggregate is able to keep the soil pore distribution, either macropore for aeration and drainage or micropore to retain water for plant growth. Macropores can infiltrate more water during irrigation or rainfall; therefore, runoff could be reduced, and soil erosion can be avoided. Thus, OM can reach sustainable agriculture. Due to the important role of OM, research on suboptimal soil was conducted to determine the concentration and stock of OM found under corn cultivation and forest types of land use as a comparison.

2. Materials and Methods

The research was conducted in Taeh Bukik and in Lubuak Batingkok with the geographical position is between 100° 35’ 31.345” - 100° 38’ 33.804” E and between 0° 6’ 46.683”–0° 9’ 24.223” S) Lima Puluh Kota Regency, West Sumatra, Indonesia. Based on the data from the closest climatic station, the areas had an average of 3004 mm annual rainfall and > 20°C air temperature.

This research was conducted using a survey method. Soil samples were taken from three different soil orders (Inceptisol, Oxisol, and Ultisol) under corn cultivation and secondary forest having the same range of slope (15-25%). Disturbed and undisturbed soil samples were taken from 0-20 cm soil depth. The samples were analyzed for the OC (wet oxidation method) and then multiplied by 1.74 for SOM, total-N (digestion method), texture (sieve and pipette method), BD, and TP (gravimetric method). Then, SOM was fractionated into particulate and mineral associated one. Particulate OM was determined by the method introduced by Cambardella and Elliott (1992). Mineral associated OM was calculated by subtraction of POM from total SOM.

\[ \text{MOM} = \text{total OM} - \text{particulate OM} \]

Stock SOM was calculated using the following formula [8]:

\[ \text{SOM stock} = \%\text{SOM} \times \rho_b \times \text{soil volume/ha (T/ha)} \]

3. Results and Discussion
Particle size distribution among the three soil orders was presented in Table 1. Based on data presented in Table 1, it was found that there was no significant difference among the soil texture. However, there was a tendency of increasing finer size particle from order Inceptisol, to Oxisol, and to Ultisol for both land use, corn cultivation, and forest. On the other hand, the sand content decreased from order Inceptisol to Oxisol, and to Ultisol. The soil texture class ranged from clay loam to clay. Clay will affect the soil OM content. The higher the clay content in a soil, the more the OM can be stabilized or protected. As reported by Yulnafatmawita [9], that there was a linearly positive correlation between clay content and SOM content. She further explained that the finer particle of the soils have higher micropores in which SOM can be protected from organism attack. It cannot be easily degraded; otherwise, the soils are tilled. Singh et al. [10] also explained the role of clay type in retaining and stabilizing SOM.

Organic matter in soil affects the soil BD value, which is used as an indicator of porous soil. Based on Table 1, soil bulk density (BD) of all three soil orders under both types of land use was categorized into medium class for all soil orders and types of soil management. It means that physically the soil was good for plant growth. It could support root growth and root development. The total pore also followed the trend of soil BD. The total pore was classified into medium class. However, the amount of air and water in the soil was determined by the pore size distribution. The void ratio, the comparison between pore space with solid-phase in soil, was higher in the forest than in corn cultivation type of land use. This was due to the effect of management given to the land. Since the forest was not cultivated or disturbed, the rate of SOM degradation was lower than that at annual land cultivation for corn. However, the void ratio was comparable between forest and corn cultivation types of land use under Ultisol.

| Land Use       | Sand % | Silt % | Clay % | Texture Class | BD (Mg m⁻³) | TP % | Void Ratio |
|----------------|--------|--------|--------|---------------|-------------|------|------------|
| Incept-Forest  | 22.96  | 38.56  | 38.48  | Clay Loam     | 1.02        | 69.03| 2.23       |
| Incept-Corn    | 30.12  | 34.34  | 35.54  | Clay Loam     | 1.00        | 61.67| 1.61       |
| Oxisol-Forest  | 22.82  | 32.53  | 44.65  | Clay          | 1.04        | 70.67| 2.41       |
| Oxisol-Corn    | 26.03  | 36.63  | 37.34  | Clay Loam     | 1.07        | 61.00| 1.56       |
| Ultisol-Forest | 17.57  | 35.56  | 46.97  | Clay          | 1.00        | 69.33| 2.26       |
| Ultisol-Corn   | 15.43  | 46.01  | 38.54  | Silt Clay Loam| 1.04        | 70.33| 2.37       |

Total SOM content and stock, as well as the fractionation, were presented in Table 2. The total SOM at these three soil orders was considered low (<5%) for both types of land use. In general, SOM content under forest was higher than that under corn cultivation types of land use. This was due to the effect of management given to the land. The soil in the forest was not cultivated; in other words, the SOM at the forest stays without any disruption. Bonfatti et al. [11] found that SOC was accumulated more at the top 30 cm soil than that under pasture. However, the SOM under corn cultivation was always disturbed regularly during soil preparation for corn growth. Therefore, the SOM was easily attacked by microorganisms due to the good balance between air and water available in the soils. As reported by Zinn et al. [12] that about 6.74 Mg/ha (10.3%) SOC was lost from the top 0-20 cm soil depth under intensive farming systems. Then, the amount of OM sequestered on the topsoil under secondary forest was not
significantly higher than that under the plantation area in the tropics [13]. Even under good management, the farming practice can be the potential for net C sequestration [14].

Among the 3 soil orders, Inceptisol had the lowest SOM content from both types of land use. This was mainly due to the effect of different soil texture of the soil. As presented in Table 2 that Inceptisol seemed to have coarser soil texture than those other soil order. Soils having coarser texture will have better aeration; therefore, the decomposing microorganisms can be more intensive because the oxygen is needed can be fulfilled. Then, the management was given to corn (seasonal crop) in which the soil is tilled every cropping season. Tillage activity causes that the soil becomes more porous; oxygen will be more available for root breath and microorganism activity in decomposing OM, besides it provides enough available water. The same result was also found that SOC loss was higher under coarse soils [12].

Generally, SOC content and stock under forest were higher than those under corn cultivation. Most (>50%) of the soil OC was in the form of particulate OC. It means that the OC was easily degraded, depending upon the management given to the land. Lower SOC content under corn cultivation was due to the effect of tillage. In this region, farmers were used to tilling soil several times before planting. Tillage causes soils to be friable, high oxygen contained for microorganism activity. Therefore, the SOM was oxidized, and the CO2 produced was emitted to the atmosphere. As found by Tornquist et al. [15] that 44-50% SOM stock decreased as woodland was changed in to intensive annual crop farming. Rezapour and Samadi [4] also reported that SOC and total N decreased as the Inceptisol, especially typic calcixerept, was degraded. Maia et al. [16] reported that soil OC stock decreased by a factor of 0.91±0.14 at degraded grassland compared to native vegetation in Brazilia.

If it was compared to forest land use, SOM stock at the forest was 228%, 114%, and 97% of that under corn cultivation at soil order Inceptisol, Oxisol, and Ultisol, respectively (Figure 1-a).

| Land Use          | TOC | Tot-N | C/N Ratio | TOM | POM | MO M | POM / MO M | MO M / TOM | TOM Stock | Total N-Stock | SOM Stock | N-Stock |
|-------------------|-----|-------|-----------|------|-----|------|------------|------------|------------|-------------|-----------|---------|
| Inceptisol-Forest | 1.95 | 0.13  | 15.03     | 3.39 | 1.77| 1.62 | 0.52       | 0.48       | 69,22      | 2.65        | 2.28      | 2.65    |
| Inceptisol-Corn   | 0.87 | 0.05  | 17.46     | 1.51 | 1.04| 0.47 | 0.69       | 0.31       | 30,28      | 1.00        |           |         |
| Oxisol-Forest     | 2.64 | 0.18  | 14.68     | 4.59 | 2.56| 2.03 | 0.56       | 0.44       | 95,55      | 3.74        | 1.14      | 1.46    |
| Oxisol-Corn       | 2.26 | 0.12  | 18.83     | 3.93 | 2.35| 1.58 | 0.60       | 0.40       | 84,15      | 2.57        |           |         |
| Ultisol-Forest    | 2.30 | 0.16  | 14.38     | 4.00 | 3.57| 0.43 | 0.89       | 0.11       | 80,04      | 3.20        | 0.97      | 1.10    |
| Ultisol-Corn      | 2.27 | 0.14  | 16.23     | 3.95 | 3.29| 0.66 | 0.83       | 0.17       | 82,16      | 2.91        |           |         |

Highly different amount of SOM at Inceptisol was mainly affected by the difference of soil texture on the top soil to the two other soil orders. Among the three soil order, the amount of clay particles in the soil Inceptisol>Oxisol<Ultisol. The texture of Inceptisol on the top 0-20 cm soil depth was dominated by coarse particles (61.52%), especially sand and silt. While at ordo Ultisol, on the other hand, the SOM stock on the top 0-20 cm soil was comparable between under forest and corn types of land use. Martinez
et al. [17] explained that acid soils, especially Oxisols and Ultisols, have higher activity of enzymes than Inceptisols as a consequence of higher clay and SOM of the soils.

Figure 1. SOM stock comparison between forest and corn type land use (a) and correlation between SOM and total N stock (b).

The SOM stock at the three soil order was dominated (>52%) by particulate organic matter (POM). As TOM, POM content under forest was higher than that under corn cultivation type of land use. This was due to the effect of management given to the land. Particulate OM under forest land use was not disturbed by cultivation as it was done for corn cultivation. Under forest land use, POM content of Inceptisol < Oxisol < Ultisol. The same tendency was also found under corn cultivation. Inceptisol having coarse soil texture had higher macropores filled by air, which provided enough oxygen for microbe activity in decomposing OM. Therefore, it could be concluded that management is given, and soil texture affected POM content of the soils. As presented at Figure 2 that SOM stock increased by increasing clay content (2-a) with the $R^2 = 0.42$, and decreased, on the other hand, by increasing sand content (2-b) with
$R^2=0.63$. This agreed with what Yulnafatmawita and Yasin [8] found under selected land use in Padang city.

The percentage of POM inversely relates to the percentage of mineral associated OM (MOM) in the soil. The higher the amount of POM in a land, the lower the amount of MOM. The MOM, which is the type of SOM having been closely associated with mineral particles, especially clay, is hardly affected by microorganisms since it is physically protected against microorganism attack. However, lower MOM in general at corn cultivation type of land use was due to the effect of cultivation. Tillage can help MOM protected within micro aggregates to be exposed to decomposing microorganisms. Therefore, tillage must be reduced either the type or the intensity to save SOM as well as to avoid soil degradation.

As SOM tendency, soil N stock under forest was higher than that under corn cultivation. This was due to that the N element is part of OM; the higher the OM in the soil causes the higher of the N content. As provided in Figure 1-b, total N stock linearly positive correlated with the SOM stock ($R^2=0.98$). Under corn cultivation type of land use, N stock at Inceptisol < at Oxisol < at Ultisol. This indicated that, under coarse soil texture, N element or N-ion was easily diminished due to porous soil. Inceptisol with more percentage of sand particles contains more macropores providing more air or better aeration. Additionally, this is also caused by the fact that N is easily emitted to the atmosphere as it is decomposed from OM.

The C/N ratio of SOM under both land management, forest, and corn cultivation, as well as at all of those three soil orders on the top 0-20 cm soil, ranged between 14 and 19 (medium to high) as reported by Zinn et al [18] that land-use change in the humid tropics did not significantly affect the average C/N ratio of the SOM. The C/N ratio under corn cultivation tended to be higher than under forest type of land use. It means that the SOM was more susceptible to degradation, especially for the SOM under corn cultivation than under forest type of land use. In order to conserve the SOM, the type of soil tillage for corn cultivation must be wisely considered.

4. Conclusion
Based on the research conducted, it can be concluded that OM stock in the three suboptimal soil orders analyzed was much determined by the soil management and soil texture in each management. Generally, the stock of OM under forest was higher than that under the corn cultivation type of land use. Furthermore, in each land-use type, SOM stock at Oxisol > Ultisol > Inceptisol. Most (>50%) of the SOM was in the form of POM. However, among the three soil types, the SOM stock of Ultisols under forest and corn cultivation type of management was comparable.

Acknowledgments
The authors would like to thank GMIT friends for the sample collecting as well as to Desni Asrita for the laboratory analyses.

References
[1] Yulnafatmawita, Adrinal and Anggriani F 2013 J Tanah Tropika 18(1) 33-44
[2] Nursyamsi D and Suprihati 2005 Bul Agron 33 (3) 40 – 47
[3] Bortolanza DR and Klein VA 2016 Rev Bras Cienc Solo 40:e0150377
[4] Rezapour S and Samadi A 2012 Environ Monit Assess 184(3):1311-23
[5] Yulnafatmawita and Adrinal 2014 Agrivita J Agric Sci 36(1) 57–64
[6] Bayer LB Batjes NH and Bindraban PS 2010 Agric Ecosys & Environ 47-58
[7] Cambardella C A and Elliott E T 1992 *Soil Sci Soc Am J* 56(3) 777-783
[8] Yulnafatmawita and Yasin S 2018 IOP Conf Series: *Earth and Environ Sci* 129 (2018):1-9
[9] Yulnafatmawita 2005 *Dissertation Univ of Queensland* 219p
[10] Singh M, Sarkar B, Bolan N, Mandal S, Menon M, Purakayastha TJ and Beerling DJ 2018 *Adv in Agron* 148:33-38
[11] Bonfatti BR, Hartemink AE, Giasson E, Tornquist CG and Adhikari K 2016 *Geoderma*:204-221
[12] Zinn YL, Lal R and Resck DVS 2005 *Soil & Till Res* 84 (1) : 28-40
[13] Bonner MTL, Schmidt S and Shoo LP 2013 *Forest Ecol & Manag* 291 73-86
[14] Gonçalves DRP, Sá JCM, Mishra U, Furlan FJF, Ferreira LA, Inagaki TM, Romaniw J, Ferreira AO and Briedis C 2018 *Environ Pollution* 243 940-952
[15] Tornquist CG, Mielniczuk J and Cerri CEP 2009 *Soil & Till Res* 105(1) 33-43
[16] Maia SMF, Ogle SM, Cerri CEP and Cerri CC 2009 *Geoderma* 149 (1–2):84-91
[17] Martínez VA, Cruz L, Ramírez DS and Alegría LP 2007 *Applied Soil Ecol* 35(1):35-45
[18] Zinn YL, Marrenjo GJ and Silva CA 2018 *Agric Ecosys & Environ* 255:62-72