Distribution of carbon and soil quality in drylands of Aceh Besar, Indonesia

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Abstract. The organic matter is an important component of sustainable agricultural systems and as one of the indicators of soil quality. This research aims to estimate the content and distribution of soil organic carbon (SOC) and soil quality index in several soil orders of dryland areas in Aceh Besar Indonesia. SOC of soil was analyzed using the Walkley-Black method while the soil quality index (SQI) was evaluated by using the method of Mausbach and Seybold (1998). The results demonstrated that the contents of soil organic carbon in dryland areas of Aceh Besar District vary from low to very high (0.23-3.95%) depending on soil types. The organic C content on the soil surface, such as Entisols, Inceptisols, Mollisols, Oxisols, Ultisols were generally low (less than 2%), and only Andisols which have a high content of organic C (3.95%). The average organic C content of order of soil are: Oxisols (0.74 ± 0.12%), Ultisols (0.61 ± 0.14%), Mollisols (0.75 ± 0.23%), Inceptisols (0.78± 0.46%), Entisols (1.76 ± 1.33%), and Andisols (1.82 ± 0.71%) respectively. Soil quality index (SQI) of dryland in Aceh Besar District vary from a low to high with SQI range of 0.45-0.79. To increase the organic matter content and quality of the soils, adding organic amendments and biofertilizers is necessary.

1. Introduction

Aceh Province has extensive dryland to be developed as an agricultural area, especially for dryland farming. Some of the drylands has been used as mixed gardens, rainfed rice fields, pasture fields, and shrubland. The area of Aceh dryland is estimated at 278,581 hectares consisting of several types of soil such as Lithosol, Regosol, Alluvial, Renzina, Andosol, Cambisol, Podzoilic, and Latosol [1]. The results of the study by Sufardi et al. [2] discovered several soil orders developed in Aceh's dryland including Entisol, Inceptisol, Ultisol, Oxisol, Andisol, and Mollisol so that in terms of quality, this dryland varied greatly. Based on the results of research in various regions, most of the land found on dryland is a low level of soil fertility [3, 4, 2].

Some of the problems that are often found in dryland farming systems in humid tropical regions include low soil pH, low organic C content, low nutrient content, low cation exchange capacity and low base saturation, high phosphate fixation, erosion problems and water availability [5]. Soils in tropical climate region are classified as soil with a variable charge system which has low clay activity [6]. This little clay activity is due to the dominated compositions of Fe and Al oxides, and hydroxides contained in these soils [7]. The types of minerals that often dominate in tropical soils are kaolinite, halloysite and hydroxide oxides from Fe, Al, and Si fractions [8] and the composition of these minerals in soils is highly dependent on the level of soil development [5]. These soils are generally characterized by low
colloid negative charge and the high point of zero charges (PZC) that chemically adversely affects the quality of the soil [6]. Good soil quality is reflected in the composition of the soil constituent material, namely the balance between mineral components, air, water and organic matter [9]. Organic materials containing C around 56-58% [10-11] have a significant contribution to improving soil quality [12], because besides functioning as a source of C for microorganisms in the soil, they can also play a role in improving traits physics, chemistry, and soil biology [13]. The organic material is an essential component that is closely related to soil health [14]. Soil health is a concept that views the function of land on environmental health including the security of agricultural products [15].

On dryland farming systems, soil quality is a fundamental issue, especially if associated with soil C content. Among other soil quality indicators may be judged from several physicochemical parameters were expressed as an index of soil quality [16, 17]. Soil quality index (SQI) has been widely used as a benchmark to see sustainable soil quality [15, 18, 19]. In regions with a humid tropical climate, the content and the distribution of C in the soil become one of the major problems [5] for each year of 20-30% loss C [20]. Thus, to improve soil quality, an effort is needed to maintain the content of C and C distribution on each soil order by managing appropriate organic matter [13]. However, information about the content of C and its distribution is still minimal. This paper presents the results of the evaluation of the content and distribution of soil organic C and soil quality index on several orders of soil in dryland Aceh, Indonesia.

2. Methodology
This research uses descriptive survey method, namely through field observations and laboratory analysis for data collection. Field surveys were carried out for soil profile observations or identification of soil subgroup and sampling soils for review in the laboratory. This study was conducted on five soil orders from dryland of Aceh Besar district which includes Entisols from Jalin (05°36'58.41" N; 95°47'51.82" E), Andisols from Saree (05°27'15.6" N; 95°44'09,1" E), Oxisols from Lembah Seulawah (05°27'19.4" N; 95°46'19,2" E), Inceptisols from Blang Bintang (05°15'55" N; 95°39'02,6" E), Mollisols from Krueng Raya (05°36'36,6" N; 95°35'12,2" E), Ultisols from Jantho (05°16'58.41" N; 95°37'51.82" E). This research was conducted from May to July 2018.

2.1. Soil Profile Identification
The profile of the land is made by opening the hill cliff that has been exposed to the solum and then cleaning the cliff wall so that the pattern appears from the top layer to reach the parent material layer. The soil profile is then observed for the morphological properties which include the horizon boundary, symbol or name and thickness of each horizon layer, and soil physical properties such as soil color, texture, structure, consistency, and special characteristics such as coarse fractions, concretion, and others properties that might be found at the time of observation. Observation of soil morphological properties and determination of soil subgroups based on soil observation guidelines issued by Soil Survey Staff [21]. The taking of soil samples in each profile is done by taking the soil (1 kg) according to the predetermined horizon of each type (subgroup) of soil. Then, the samples are put into a plastic bag to be analyzed in the laboratory.

2.2. Soil Analysis
For laboratory analysis, soil samples are taken 1 kg at each horizon layer. Before being analyzed, soil samples were dried for a week, then crushed and sieved using a 2.0 mm sieve for analysis of soil texture, porosity, bulk density, and 0.5 mm sieve for analysis of soil chemical properties including: pH, total N (Kjeldahl), available P (Bray II), total of P₂O₅ and K₂O (25% HCl extract), cation exchange capacity (CEC) and exchangeable K (extracted with 1N CH₃COONH₄ pH7), and base saturation. Methods and procedures for soil analysis are guided by procedures issued by the Bogor Soil Research Center [22]. The properties of the soil above are used as supporting data for the assessment of soil fertility status and determination of soil subgroups and also used as parameters for analysis of soil quality index. Especially for soil organic carbon (SOC) content at each soil horizon layer analyzed using Walkley and Black
method that is by oxidizing the soil with concentrated sulfuric acid (H₂SO₄) and potassium bichromate (K₂Cr₂O₇), then titrated with FeSO₄ solution.

2.3. Soil Quality Index (SQI) Calculations
Soil quality index is calculated based on the criteria Mausbach and Seybold [16] as modified by Partoyo [17]. Modify some indicators can be seen in Table 1. Soil samples were used for analysis of soil quality index is taken from depths of 0-20 cm. Analysis of soil quality index was carried out based on data from field observations and laboratory analysis of selected soil quality indicators, are pH (H₂O), organic C, total N, available P, exchangeable K, soil depth, the texture of three fractions, bulk density and porosity.

| Soil function                     | Soil indicators          | Score | Score | Score | Lower limit | Upper limit |
|----------------------------------|--------------------------|-------|-------|-------|-------------|-------------|
| A. Rooting media                 | Soil depth (cm)          | 0.6   | 0.079 | 15    | 0           | 60          |
|                                  | Bulk density (Mg m⁻¹)    | 0.4   | 0.053 | 2.1   | 0           | 1.3         |
| B. Humidity                      | Porosity (%)             | 0.2   | 0.027 | 10    | 0           | 50          |
|                                  | Organic C (%)            | 0.4   | 0.053 | 0.2   | 0           | 3.5         |
|                                  | Silt+clay (%)            | 0.4   | 0.053 | 0     | 0           | 100         |
| C. Nutrition                     | pH                       | 0.1   | 0.013 | 6     | 0           | 8           |
|                                  | Available P (mg kg⁻¹)    | 0.2   | 0.027 | 2.5   | 0           | 150         |
|                                  | Exchangeable K (cmol kg⁻¹)| 0.2  | 0.027 | 2.22  | 0           | 35.5        |
|                                  | Organic C (%)            | 0.3   | 0.040 | 0.20  | 0           | 3.5         |
|                                  | Available N              | 0.2   | 0.027 | 0.02  | 0           | 0.1         |
| Regulation and distribution of water | Silt+clay (%)         | 0.6   | 0.180 | 0     | 0           | 100         |
|                                  | Porosity (%)             | 0.2   | 0.060 | 10    | 0           | 50          |
|                                  | Bulk density (Mg m⁻¹)    | 0.2   | 0.060 | 2.1   | 0           | 1.3         |
| Filtering and buffering          | Silt+clay (%)            | 0.6   | 0.180 | 0     | 0           | 10          |
|                                  | Porosity (%)             | 0.1   | 0.030 | 10    | 0           | 50          |
|                                  | Biological process       | 0.3   | 0.045 | 0.2   | 0           | 3.5         |
|                                  | Organic C (%)            | 0.5   | 0.045 | 0.04  | 0           | 0.07        |
|                                  | Total N (%)              | 0.5   | 0.045 | 0.04  | 0           | 0.07        |
| T o t a l                       |                          |      |       |       |             | 1.000       |

Source: Mausbach and Seybold [16].

The steps to calculate the soil quality index according to Partoyo [17] are as followed:
(a) The score index is calculated by multiplying the soil function score (score 1) with the subfunction score (score 2) and the land indicator score (weight 3). For example, the index score for porosity in Table 1 is obtained by multiplying 0.40 (score 1) with 0.33 (score 2) with 0.60 (score 3), and the result is 0.080.
(b) The score is calculated by comparing observational data from soil indicators and assessment functions. Scores range from 0 for bad conditions and 1 for good conditions. Score determination can be through interpolation or linear equations according to the range determined by price or based on the data obtained. The Linear Scoring Function (FSL) is:
\[ Y = \frac{(X - X_2)}{(X_1 - X_2)} \]  
\[ Y = 1 - \frac{(X - X_2)}{(X_1 - X_2)} \]  
where \( Y \) is a linear score, \( X \) is the value of soil properties, \( X_2 \) is the upper limit value and \( X_1 \) the lower limit value.

(c) The Soil Quality Index is calculated by multiplying the score index by the indicator score. Soil quality assessment using the equation of soil quality index [36], namely:

\[ SQI = \sum Wi \times Si \]  

Where \( SQI \) = soil quality index, \( Si \) = score on selected indicators, \( Wi \) = index score, \( n \) = number of soil quality indicators. Furthermore, the soil quality index value is categorized into five criteria classes as shown in Table 2.

| No | SQI value | Soil quality criteria |
|----|-----------|-----------------------|
| 1  | 0.80 - 1.00 | Very high (VH)        |
| 2  | 0.60 – 0.79 | High (H)              |
| 3  | 0.40 – 0.59 | Medium (M)            |
| 4  | 0.20 – 0.39 | Low (L)               |
| 5  | 0.00 – 0.19 | Very low (VL)         |

### 3. Results and Discussion

#### 3.1. Soil description

Based on observations of profiles, soil analysis, and mineral analysis, the classification of soil subgroups from six soil profiles from the dryland of the Aceh Besar District is presented in Table 3. There are six soil subgroups originating from dryland of Aceh Besar, namely: Typic Udorthents (Entisols), Eutric Hydrandeptss (Andisols), Plinthic Kandiudox (Oxisols), Oxic Haplustepts (Inceptisols), Typic Calcicaquolls (mollisols), and Typic Kandiaqults (Ultisols). These soils are mostly found in the humid climate (udic) zone, and some are in the rather dry climate zone (ustic) but all belong to the isohyperthermic temperature regime. The mineral composition contained in the soil is varied between soil orders and generally consists of mixed minerals which are a mixture of primary and secondary minerals [23].

From Table 3, it can be observed that the texture of topsoil of dryland of Aceh Besar varies from fine to medium, while the arrangement of the horizon also varies. Based on the composition of the horizon, then it can be said that the order of undeveloped soil is Entisol Interlace because it is composed of horizon A, AC, and C with the thickness of the solum <50 cm, while the order of the other relative has grown because it has occurred horizonization process that generates more horizons and complete land [10]. Based on the identification of the field, the allegedly developing soil groups are Blang Bintang Inceptisol, Andisol Saree, and Mollisol Krueng Raya, while the group that has developed further is Ultisol Jantho and Oxisol Lembah Seulawah.

#### 3.2. Soil organic carbon (SOC)

The results of the laboratory analysis of organic C content (Walkley and Black method) at each soil horizon of the six soil orders presented in Figure 1 below.

Fig. 1 shows that the soil organic carbon (SOC) content in Entisol Jalim ranges from 0.14-1.53% and is included in the criteria of very low to low. At the A horizon, SOC is classified as low with a content of 1.53% and decreases on the AC horizon to 0.21% to the C horizon to 0.14%. In Andisols Saree the organic C content of the soil ranges from 0.98-4.44% and varies from very low to high. High SOC
content was found at the Ap horizon followed by the AB horizon, while the Bw and BC horizons were low to very low. In the Oxisols of Lembah Seulawah and in the Inceptisols of Blang Bintang, the content of soil organic C are very low at both the upper horizon and the lower horizon and less than 1%, whereas in Mollisol Krueng Raya and Ultisols Jantho, the SOC content in the upper layer (Ap horizon) is low category, and the lower horizon is very low (0.13-0.49%). Based on these data, it can be said that of the six soil orders in the dryland of Aceh Besar districts only Andisols Saree have high SOC content (> 2%), while others are classified as very low to low. The results of this study similar than the results of previous studies which also found that most of the soils in dryland of Aceh have low SOC content [3, 4].

Table 3. Classification of soil subgroup according to Soil Survey Staff (2014) of six soil orders in dryland of Aceh Besar District.

| No | Soil Order / Site       | Subgroup          | Texture | Soil horizon     | Soil regime | Mineral composition |
|----|-------------------------|-------------------|---------|------------------|-------------|--------------------|
| 1. | Entisols/Jalin          | Typic Udorthents  | Fine    | A, AC, C        | Udic, IHP   | Mixed              |
| 2. | Andisols/Saree          | Eutric Hydrudands | Medium  | Ap, BA, Bw, BC  | Udic, IHP   | Allophanic         |
| 3. | Oxisols/                 | Plinthic          | Fine    | A, AB, BA, Bo1, | Udic, IHP   | Ferritic           |
|    | Lembah Seulawah         | Kandiudox         |         | Bw, Bo2         |             | Mixed              |
| 4. | Inceptisols/             | Oxic Haplustepts  | Medium  | AB, BA, Bw,     | Udic, IHP   | Mixed              |
|    | Blang Bintang           |                   |         | 2Bob1, 2Bob2    |             |                    |
| 5. | Mollisols/               | Typic Calcicaquolls | Medium | Ap, BA, Bk1, Bk2 | Udic, IHP   | Mixed              |
|    | Krueng Raya             |                   |         |                  |             |                    |
| 6. | Ultisols Jantho         | Typic Kandiaquils | Fine    | Ap, AB, BA, Bt1,| Udic, IHP   | Kaolinitic         |
|    |                         |                   |         | Bt2             |             |                    |

IHP = isohyperthermic

The results of this study indicated that one of the problems found in dryland of Aceh is low SOC and organic C content is usually <2% so that these soils require amelioration [2]. The SOC content of soil in tropical regions is generally low because soil organic matter will be mineralized quickly so that it is easy to lose [5]. High SOC content in Andisols Saree because this soil is formed from volcanic ash whose contains allophanic minerals and amorphous fractions [24] which can form complexes with humic substances [7]. The affinity of allophane minerals in binding topsoil compounds is very high and more resistant to microorganism attacks [25]. This condition causes the soils of Andisols to be dark colour because they contain humus compounds, especially in the upper layers [26].

3.3. Distribution of SOC

Distribution of soil organic C according to soil depth in each soil order in the dryland of Aceh Besar district shown in Fig. 2.

From Fig. 2, it can be seen that the distribution or changes in the SOC content according to soil depth in all soil orders turns out to be the same which is decreasing with increasing depth. The difference only SOC content which shows Andisols Saree has a higher SOC than other orders. Soil organic C content which decreases with increasing soil depth is a common phenomenon in most soils which tend to concentrate the soil organic matter in the upper layer. Although the SOC distribution pattern, in general, is almost the same in most soils from the six land orders studied there are slightly different patterns of distribution. In Figure 2 it can be observed that there is a slight difference between the soil order and the distribution of soil organic C. In Entisols Jalin, initially the SOC content tends not to change to a depth of 20 cm, but after that, the content drops dramatically to a depth of 60 cm. In Andisols Saree, a high decrease in C content in the new top layer occurs at a depth of 40 cm to 80 cm. The C content dropped dramatically from very high criteria to very low, whereas in Oxisols Lembah Seulawah, Inceptisols Blang Bintang, and Ultisols Jantho the pattern of change was relatively small because the SOC content in the three soil orders was low to very low. Furthermore, the organic C distribution pattern in Mollisols Krueng Raya is similar to the Andisols Saree, but the SOC content in Mollisol is lower than SOC content.
in Andisols Saree. The order of SOC content from high to very low is as follows: Andisols > Mollisols > Entisols > Inceptisols = Ultisols = Oxisols.

![Figure 1: Content of soil organic carbon at horizon layers of several soil orders in dryland of Aceh Besar.](image)

Based on these data it can be said that the accumulation of soil organic C in the dryland of Aceh Besar is generally found in the upper layer with a depth of 0-40 cm, while in the deeper layers, the organic C content is very low. Researchers have proved the tendency of decreasing SOC in deeper depths. The results of the study on Entisol also found that the organic C content decreased with increasing depth. Similar results were also reported by Helmi et al. [27] who also found that the soil organic C content in suboptimal dryland decreased at deeper depths. The source of C in the soil came from plant biomass, animals, and organic waste and microorganisms [10]. These living materials contain C in varying amounts, and all of these materials will accumulate on the soil surface which then decomposes into humus compounds lost due to erosion, washing, or mineralization [28]. High SOC content does not guarantee the humification process that produces complex humus compounds, so that the return of organic mass into the soil needs to be carried out continuously to conserve soil organic matter [29]. Based on this, the amount of organic matter and its distribution in the soil is very important to maintain soil quality [30, 29]. The quality and nature of fertility is closely related to the organic C content of the soil, especially soils that develop in humid tropical climates [5], because the loss of soil organic matter in this region is relatively high [31, 32].
Figure 2. Distribusi of soil organic carbon in the soil profile of several soil orders in dryland of Aceh Besar.

3.4. Soil quality index (SQI)

The results of observations and analyzes of the physical, chemical and biological characteristics of the soil as a parameter of soil quality index (SQI) are presented in Table 4.

| Table 4. The parameter of soil quality index on soil order of dryland in Aceh Besar District |
|-----------------------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Parameter of Soil Quality Index               | Entisols Jalin                  | Andisols Saree                  | Oxisols Lembah Seulawah         | Inceptisols Blang Bintang       | Mollisols Krueng Raya           | Ultisols Jantho                  |
| Soil depth (cm)                               | 44                              | 90                              | 104                             | 80                              | 75                              | 125                             |
| Sand (%)                                      | 34                              | 14                              | 10                              | 20                              | 17                              | 29                              |
| Silt (%)                                      | 61                              | 66                              | 49                              | 46                              | 23                              | 30                              |
| Clay (%)                                      | 05                              | 20                              | 41                              | 34                              | 50                              | 41                              |
| Bulk density (Mg m⁻¹)                         | 1.28                            | 0.94                            | 1.28                            | 1.26                            | 1.15                            | 1.29                            |
| Porosity (%)                                  | 31.9                            | 41.2                            | 45.4                            | 46.1                            | 42.1                            | 42.3                            |
| pH (H₂O)                                      | 6.41                            | 5.56                            | 5.43                            | 5.36                            | 8.36                            | 5.97                            |
| Total N (%)                                   | 0.04                            | 0.25                            | 0.06                            | 0.06                            | 0.14                            | 0.04                            |
| Available P (mg kg⁻¹)                         | 1.20                            | 2.30                            | 1.35                            | 1.55                            | 16.9                            | 2.85                            |
| Exchangeable K (cmol kg⁻¹)                    | 0.03                            | 0.56                            | 0.18                            | 0.10                            | 0.65                            | 0.19                            |
| Organic C (%)                                 | 0.53                            | 3.95                            | 0.48                            | 0.71                            | 1.82                            | 0.53                            |
From Table 4, it can be seen that the soil depth in several soil orders in dryland of Aceh Besar varies from 44-125 cm (shallow to very deep). Shallow soil depth (<50 cm) is only found in Entisols Jalin (<50 cm), while other soil orders are relatively deep (>70 cm). Similarly, the texture of the soil is also quite varied and is generally classified as medium to fine. The bulk density of soils also varies from 0.94-1.29 Mg m\(^{-3}\) while soil porosity is typically good (31.9-46.1%). Based on soil physical properties, it can be said that soil quality is good because there are not many significant obstacles found. However, from the chemical aspects of the soil, it can be seen that there are several problematic parameters on dryland of Aceh Besar, namely soil pH, total N, available P, exchangeable K, and SOC content. The soil pH value is generally acidic to slightly acidic (5.36-6.41) and only in Mollisols Krueng Raya has pH value somewhat alkaline (8.36). The total N content is generally very low to low (0.04-0.14%) and only in Andisols Saree has a moderate total N (0.25%), while the SOC content is also low to moderate. The exchangeable K content also varies from very low to high (0.03-0.65 cmol kg\(^{-1}\)).

Soil quality index according to its function on every order of soil in dryland of Aceh Besar shown in Table 5, while proportional soil function that most contribute to soil quality index value of each soil order is shown in Table 6. The table shows that the value of SQI on dryland in Aceh Besar varies quite varied and is generally classified as medium to high. The highest SQI was found in Andisols Saree, the lowest was found in Entisols Jalin. The sequence order of the soil that has the highest SQI to lowest are Andisols > Mollisols > Inceptisols > Oxisols > Ultisols > Entisols. Soil quality refers to the capacity of the soil to perform its functions. Soil plays a vital role in regulating runoff of stormwater and in supporting trees, shrubs, lawns, and gardens. Management practices are often needed to restore soil quality after development [33]. The higher the SQI, the better the soil quality or better in carrying out its functions [16, 15].

**Table 5.** The calculation of soil quality index based on soil function and assessment indicators on each soil order in dryland of Aceh Besar

| Soil function | Soil Quality Index (SQI) | Entisols Jalin | Andisols Saree | Oxisols Lembah Seulawah | Inceptisols Blang Bintang | Mollisols Krueng Raya | Ultisols Jantho |
|---------------|-------------------------|----------------|----------------|-------------------------|--------------------------|----------------------|----------------|
| A | Soil depth | 0.0022 | 0.0578 | 0.0480 | 0.0404 | 0.0567 | 0.0467 |
| | Bulk density | 0.0451 | 0.0426 | 0.0458 | 0.0435 | 0.0431 | 0.0457 |
| | Porosity | 0.0131 | 0.0187 | 0.0276 | 0.0216 | 0.0197 | 0.0098 |
| | Organic C | 0.0186 | 0.0694 | 0.0112 | 0.0232 | 0.0190 | 0.0216 |
| | Silt + clay | 0.0352 | 0.0451 | 0.0273 | 0.0280 | 0.0134 | 0.0284 |
| | pH (H\(_2\)O) | 0.0666 | 0.0556 | 0.0067 | 0.0080 | 0.0120 | 0.0054 |
| | Available P | 0.0626 | 0.0025 | 0.0166 | 0.0267 | 0.2606 | 0.0003 |
| | Exchangeable K | 0.0018 | 0.0129 | 0.0037 | 0.0135 | 0.0060 | 0.0002 |
| | Organic C | 0.0141 | 0.0524 | 0.0085 | 0.0175 | 0.0143 | 0.0163 |
| | Total N | 0.0006 | 0.0029 | 0.0006 | 0.0003 | 0.0008 | 0.0007 |
| | Total (A) | 0.1998 | 0.3926 | 0.1960 | 0.2226 | 0.4439 | 0.1749 |
| B | Silt + clay | 0.1196 | 0.1530 | 0.0929 | 0.0950 | 0.0454 | 0.0963 |
| | Porosity | 0.0292 | 0.0416 | 0.0613 | 0.0481 | 0.0437 | 0.0218 |
| | Bulk density | 0.0510 | 0.0483 | 0.0519 | 0.0493 | 0.0488 | 0.0518 |
| | Total (B) | 0.2082 | 0.2502 | 0.1026 | 0.1924 | 0.0933 | 0.2145 |
| C | Silt + clay | 0.0160 | 0.1530 | 0.0929 | 0.0950 | 0.0454 | 0.0963 |
| | Porosity | 0.0146 | 0.0208 | 0.0307 | 0.0240 | 0.0219 | 0.0109 |
| | Organic C | 0.0159 | 0.0589 | 0.0095 | 0.0197 | 0.0183 | 0.0161 |
| | Total N | 0.0010 | 0.0048 | 0.0009 | 0.0004 | 0.0011 | 0.0014 |
| | Total (C) | 0.0391 | 0.1475 | 0.2375 | 0.1340 | 0.1266 | 0.0820 |

SQI = A + B + C

A = Preserve biological activity, B = Regulation and distribution of water, C = Filtering and buffering


Table 6. The results of scoring assessment indicators and soil quality index based on soil functions

| Soil function                          | Entisols Jalin | Andisols Saree | Oxisols Lembah Seulawah | Inceptisols Blang Bintang | Mollisols Krueng Raya | Ultisols Jantho |
|---------------------------------------|----------------|----------------|-------------------------|--------------------------|-----------------------|-----------------|
| Preserve biological activity          | 0.1998         | 0.3926         | 0.1960                  | 0.2226                   | 0.4439                | 0.1747          |
| Regulation and distribution of water  | 0.2082         | 0.2502         | 0.1026                  | 0.1924                   | 0.0933                | 0.2145          |
| Filtering and buffering               | 0.0391         | 0.1475         | 0.2375                  | 0.1340                   | 0.1266                | 0.0820          |
| Total                                 | 0.4471         | 0.7903         | 0.5361                  | 0.5490                   | 0.6638                | 0.4712          |
| Criteria                              | Medium         | High           | Medium                  | Medium                   | High                  | Medium          |

Source: Analysis of parameters score (2018)

3.5. Soil fertility status (SFS)

The results of the analysis of soil fertility criteria (Table 7) indicate that soil fertility status in some land orders in the dry land of Aceh Besar varies from low to high. Low fertility status land orders were found in the Oxisols Seulawah Valley and Blang Bintang Inceptisols while the medium was found in Interlace Entisols, Andisols Saree, and Ultisols Jantho. The only order of land with high fertility status is Krueng Raya Mollisol. Sequentially soil orders based on soil fertility status from high to low are: Mollisols > Andisols = Ultisols = Entisols > Inceptisol = Oxisols. There are three obstacles that affect soil fertility in Aceh Besar dryland, namely SOC content, CEC and low base saturation. Furthermore, if examined further, it can be seen that the SQI value is not always the same as the soil fertility status.

Table 7. Soil fertility status of several soil orders in dryland of Aceh Besar District

| Soil fertility indicators | Entisols Jalin | Andisols Saree | Oxisols Lembah Seulawah | Inceptisols Blang Bintang | Mollisols Krueng Raya | Ultisols Jantho |
|--------------------------|----------------|----------------|-------------------------|--------------------------|-----------------------|-----------------|
| Cation exchange cations/CEC (cmol kg⁻¹) | 32.9 (H)       | 20.0 (M)       | 14.6 (L)                | 10.5 (L)                 | 49.4 (H)              | 34.1 (H)        |
| Base saturation/BS (%)   | 16.9 (L)       | 19.9 (L)       | 18.4 (L)                | 28.7 (L)                 | 60.8 (H)              | 34.5 (L)        |
| Organic matter (%)       | 1.76 (L)       | 1.82 (L)       | 0.74 (L)                | 0.78 (L)                 | 0.75 (L)              | 0.61 (L)        |
| P₂O₅ content (mg/100 g)  | 181 (H)        | 281 (H)        | 112 (H)                 | 76 (H)                   | 55 (H)                | 146 (H)         |
| K₂O content (mg/100 g)   | 81 (H)         | 41 (H)         | 25 (M)                  | 31 (M)                   | 105 (H)               | 48 (H)          |
| Soil fertility status     | Medium         | Medium         | Low                     | Low                      | High                  | Medium          |

Source: Analysis of the soil fertility criteria (2018); L/M/H = low/medium/high

Table 7 can be seen that SQI on Aceh Besar dryland has two criteria, namely medium and high, while the criteria for soil fertility status are three, namely low, medium and high. This difference occurs because the SQI analysis uses more parameters which include the physical, chemical, and biological properties of the soil, while the study of soil fertility status (SFS) uses only five criteria from soil chemistry indicator, namely CEC, saturation of bases, organic matter, and total of P₂O₅ and K₂O [22].

The classification of soil properties that contribute to soil quality is based on its permanent and sensitivity to management [34]. Soil properties such as water content, soil respiration, pH, N total, minerals, available P and bulk density, can change as a result of routine management practices or the influence of weather. While the permanent properties which are inherent in the soil or location (site) such as, slope, soil depth, texture, mineralogy, the boundary layer are slightly affected by management. Based on this, the soil management needs to be selected for materials that can improve soil quality so that it can improve soil fertility status. If we look at the constraints and functions of the soil, the addition of organic matter to the soil is one of the good practices actions because in addition to increasing carbon (C) into the soil, organic matter is also able to improve the physical, chemical and biological properties of the soil [13, 7, 29, 5, 30]. The return of organic matter to the soil has now
become an environmentally friendly sustainable agricultural solution [35] and with organic matter can improve soil health [19].

4. Conclusions

The results showed that the contents of soil organic carbon in dryland areas of Aceh Besar District vary from low to very high (0.23-3.95%) depending on soil types (or soil order). The organic C content on the soil surface of Entisols, Inceptisols, Mollisols, Oxisols, Ultisols was generally low (less than 2%), and only Andisols which have a high content of organic C (3.95%). The average organic C content of order of soil are: Oxisols (0.74 ± 0.12%), Ultisols (0.61 ± 0.14%), Mollisols (0.75 ± 0.23%), Inceptisols (0.78± 0.46 %), Entisols (1.76 ± 1.33%), and Andisols (1.82 ± 0.71%) respectively.

Soil quality index (SQI) of dryland in Aceh Besar District vary from a low to high with SQI range of 0.37-0.86. The soil order with a medium SQI include of Entisols Jalin, Oxisols Lembah Seulawah, Inceptisols Blang Bintang, and Ultisols Jantho, whereas a high SQI include of Andisols Saree and Mollisols Krueng Raya. Soil carbon management is an important strategy for improving soil quality, increasing crop yields, and reducing soil loss. To increase the organic matter content and quality of the soils, adding organic amendments and biofertilizers is necessary.

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