Distribution of organic carbon in Ultisol soils with citronella and pine vegetation, at Gayo Highlands, Aceh

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Abstract. Soil organic matter is an indicator of soil fertility. The purpose of this study was to analyse various forms of soil organic carbon in citronella plantation, citronella plantation under pine tree, and soil under pine tree. Soil organic carbon in various forms was analysed from soil samples taken from each horizon and soil profile. The soil profiles observed were ultisol profiles planted with citronella, citronella under pine tree, and under pine tree, and slopes; 0-8%, 8-15%, 15-25%, and 25-40%, in order to obtain 12 soil profiles with a total of 39 soil samples. Ultisols planted with citronella had higher soil organic carbon than ultisols planted with citronella under pine tree and ultisols under pine trees. Based on the slope, the highest soil organic carbon was obtained in the soil with a slope of 0-8%, and decreased with increasing slope. Based on soil depth, the highest soil organic carbon was obtained in the upper horizon, compared to the horizon below. The highest total soil organic carbon was obtained at the soil surface horizon with a slope of 0-8% and citronella was planted. This pattern of total soil organic carbon is similar to that of sesquioxide bound organic carbon, but is not consistent with that of free clay bound organic carbon.

1. Introduction
The Gayo Highlands, besides being known as a centre for Arabica coffee cultivation, is also known as a centre for producing citronella oil. In addition to these two commodities, the area is also known for having pine forests. Generally, less fertile dry land in the Gayo Highlands is overgrown with *P. merkusii* and planted with citronella. This soil is not fertile, but the citronella grows well regardless. The citronella cultivation technique implemented by farmers does not return the litter after distillation. Consequently, the land is bound to become less fertile. Apart from having high nutrient content, fertile land is also characterized by relatively high soil organic matter.

Soil organic matter is the remains of plant, animal and microorganism after undergoing decay and weathering, due to the activities of soil fauna and microorganisms [1]. According to [2], soil organic matter is determined by several factors, and these are climate, soil parent material, clay content, cation exchange capacity as well as vegetation. Furthermore, soil organic matter is an important material for soil, physically, chemically and biologically [3]. Soil physical properties, particularly soil organic matter, play an important role in the process of forming and maintaining soil structure stability, as well
as increasing soil water-holding capacity. Chemically, organic matter has a very important role in increasing the Cation Exchange Capacity (CEC) of soil, because decomposed, stable and active organic matter has a high CEC [4]. Organic matter also plays a very important role in storing and recycling nutrients, both macro and micro nutrients [3]. Biologically, organic matter is a provider of energy sources to increase the activities of micro- and macro-organisms in the soil, consequently, increasing soil fertility [3].

Carbon is the main component of organic matter. Therefore, measurement of soil organic C is a suitable approach to determine the soil organic matter content [5]. Carbon uptake into the soil depends on the type of surface vegetation. On agricultural soils, reduction of carbon gain into the soil is also caused by the removal of biomass during harvesting, and tends to worsen in cases where crop residues are removed [6–9].

A study by [2] showed soil organic C content in different vegetation is bound to cause different content in the soil. According to [9], forest vegetation has high soil organic C content, influenced by plant litter originating from vegetation cover and all of these return to the soil. Meanwhile, vegetation in vegetable fields with high organic C content on the soil surface are possibly due to the addition of manure in every planting preparation. However, the organic C value in soil with vegetable vegetation bound to clay, is the main factor responsible for high organic C value in the land [6–8] [10].

Merkusii is the only type of pine capable of growing in Indonesia. This pine belongs to a multi-purpose tree species, and these species are bound to be continually developed as well as expanded in the future, for timber production, sap production, and land conservation. In Java Island, pine or tusam is known as a source of wood, resin, as well as gondorukem or rosin, and these are further processed to obtain therefore higher economic value [7,11,12]. Citronella (Cymbopogon nardus L.) plants have several uses, including serving as ground cover plant with the ability to prevent soil erosion and rehabilitate critical lands [13,14]. This plant, particularly the stems and leaves, contain 32–45% citronellol compounds, 10–12% geraniol, 11-15% citronellol, 3-8% geranyl acetate, 2-4% citronellal acetate, and little sesquiterpenes as well as other compounds, and are therefore suitable mosquito repellents [15,16].

The Gayo Highlands (including Gayo Lues District) is a known producer of wood, resin and rosin from merkusii pine, as well as geraniol, methyl heptnon, terpenes, terpenes-alcohol, organic acids and citronellal from citronella (Cymbopogon nardus L.). Furthermore, the citronella plant thrives in the pine forest area and is the only plant able to grow and produce well under pine tree stands. This study therefore aims to analyse the horizontal and vertical distribution of soil organic carbon in the land cover of citronella and merkusii pine forest stands.

2. Materials and methods
This study was conducted from March 2018 to December 2019 in the Gayo Highlands, precisely in Gayo Lues District, as the main centre for citronella oil production. The citronella land area in the Gayo Highlands amounts to 17,565 ha, with 15,116 ha (about 86%) in Gayo Lues District [17,18]. According to [18], the potential for citronella development in Gayo Lues District is about 44,510 ha. This study was conducted on ultisol soil planted with citronella under pine tree stands and without pine stands. Figure 1a shows the distribution of citronella plantations in Gayo Lues District.
Soil organic carbon content analysis was performed on soil samples collected from each horizon in each defined soil profile. The soil profiles were defined on ultisol based soils in terms of land cover planted with (a) citronella, (b) citronella planted under merkusii pine stands, and (c) merkusii pine (Figure 1b), as well as slopes, comprising grades 0-8%, 8-15%, 15-25%, and 25-40%. Thus, 12 soil profiles were obtained and about 1 kg of soil sample was obtained from each horizon in each profile.

The samples collected were prepared according to soil analysis standards, then analysed to determine the organic carbon content in the form of total-C, C-free, C-bound clay, and C-bound sesquioxide. This analysis was conducted at the Laboratory of Soil and Plant Analysis, Faculty of Agriculture, Syiah Kuala University. Subsequently, the data obtained were analysed descriptively by comparing the content of soil organic carbon forms obtained from each horizon on each soil profile.

3. Results and discussion
Soil organic carbon content analysis was performed on soil samples collected from each horizon in each defined soil profile. Table 1 shows the results of soil analysis on soil organic C-forms from each horizon in 12 soil profiles.

3.1. Relationship between land cover, slope, and soil depth to soil organic carbon
This section describes the presence of soil organic C forms planted with citronella, citronella under pine, and pine on slopes and soil effective depths various. Figure 2 shows the relationship between soil organic carbon in various forms and land cover, soil depths, as well as slopes.
Therefore, merkusii pines have the capacity to prevent or inhibit other plants from growing in the secondary metabolites with allelopathic properties, and compounds with toxicity to plants and insects.

According to the results (Table 1, Figure 2a), land cover affected the distribution of soil organic C-forms. The soil planted with Citronella had a higher organic C content, compared to the soils planted with citronella under pine tree stands and with only pine tree stands. In addition, the high levels of organic C in the soil planted with Citronella are related to the production of un-harvested Citronella litter. Meanwhile, in the soil planted with citronella under pine tree stands and with only pine tree stands, high organic C levels is related to the production of resin from pine trees, with the capacity to produce secondary metabolites with allelopathic properties, and compounds with toxicity to plants and insects. Therefore, merkusii pines have the capacity to prevent or inhibit other plants from growing in the

| Soil Profile | Soil Depth (cm) | total-C (%) | free-C (%) | clay-C (%) | sesquioxide-C (%) |
|--------------|----------------|-------------|------------|------------|------------------|
| C1 (0-8%)    | 0-22           | 5.23        | 0.05       | 0.48       | 4.70             |
|              | 22-68          | 2.56        | 0.03       | 0.40       | 2.13             |
|              | + 68           | 1.57        | 0.01       | 0.32       | 1.24             |
| C2 (8-15%)   | 0-21           | 4.03        | 0.02       | 0.33       | 3.69             |
|              | 21-75          | 2.00        | 0.02       | 0.25       | 1.73             |
|              | + 75           | 1.20        | 0.01       | 0.42       | 0.77             |
| C3 (15-25%)  | 0-19           | 1.45        | 0.08       | 1.05       | 0.32             |
|              | 19-68          | 0.96        | 0.02       | 0.73       | 0.21             |
|              | 68-89          | 0.91        | 0.01       | 0.69       | 0.21             |
|              | 89-127         | 0.56        | 0.01       | 0.42       | 0.13             |
| C4 (25-40%)  | 0-18           | 1.40        | 0.01       | 0.65       | 0.74             |
|              | 18-61          | 1.63        | 0.03       | 0.16       | 1.44             |
|              | + 61           | 1.20        | 0.01       | 0.50       | 0.69             |
| CP1 (0-8%)   | 0-27           | 4.47        | 0.02       | 0.75       | 3.70             |
|              | 27-115         | 1.56        | 0.03       | 0.57       | 0.96             |
| CP2 (8-15%)  | 0-23           | 2.86        | 0.03       | 0.67       | 2.16             |
|              | 23-115         | 0.74        | 0.02       | 0.68       | 0.04             |
| CP3 (15-25%) | 0-21           | 1.55        | 0.03       | 0.41       | 1.11             |
|              | 21-115         | 0.73        | 0.02       | 0.68       | 0.04             |
|              | 115-218        | 0.40        | 0.01       | 0.33       | 0.06             |
|              | +218           | 0.24        | na         | 0.17       | 0.07             |
| CP4 (25-40%) | 0-20           | 0.95        | 0.04       | 0.73       | 0.26             |
|              | 20-115         | 0.80        | 0.01       | 0.40       | 0.38             |
| P1 (0-8%)    | 0-23           | 2.45        | 0.05       | 0.68       | 1.73             |
|              | 23-42          | 1.16        | 0.03       | 1.11       | 0.02             |
|              | 42-76          | 0.48        | 0.01       | 0.33       | 0.14             |
|              | +76            | 0.40        | na         | 0.17       | 0.23             |
| P2 (8-15%)   | 0-18           | 2.46        | 0.02       | 1.06       | 1.37             |
|              | 18-35          | 0.89        | 0.01       | 0.34       | 0.54             |
|              | 35-65          | 0.24        | 0.01       | 0.17       | 0.06             |
|              | +65            | 0.16        | 0.01       | 0.08       | 0.07             |
| P3 (15-25%)  | 0-18           | 1.02        | 0.02       | 0.97       | 0.04             |
|              | 18-32          | 0.93        | 0.01       | 0.81       | 0.10             |
|              | 32-65          | 0.72        | na         | 0.68       | 0.04             |
|              | +65            | 0.48        | na         | 0.16       | 0.32             |
| P4 (25-40%)  | 0-15           | 0.63        | 0.04       | 0.57       | 0.03             |
|              | 15-41          | 0.56        | 0.01       | 0.41       | 0.13             |
|              | 41-65          | 0.32        | 0.01       | 0.25       | 0.06             |
|              | 65-109         | 0.16        | na         | 0.08       | 0.08             |

Description: C1 … C4 = Citronella; CP1 … CP4 = Citronella planted under pine forest stands, and P1 … P4 = Merkusii pines; (0-8%) = slope class. total-C = total soil organic carbon, free-C = free soil organic carbon, clay-C = clay-bound soil organic carbon, sesquioxide-C = sesquioxide bound soil organic carbon.
vicinity [19]. Consequently, the pines do not produce a lot of litter on soil planted with citronella plants under pine tree stands, or on soil planted with only pine tree stands.

The land use of merkusii forest pine has lower organic C distribution because carbon distribution in land is determined by biomass production. This means the biomass present in a stand or forest indicates how much carbon has been sequestered during the stand or forest’s lifetime [20,21]. The ability of a land to store carbon also depends on the forest type and age, as well as the size of the trees. Merkusii pines have needle-shaped leaves, upright stems and relatively limited lateral branching, therefore biomass is only stored on the main stem. Soil organic carbon content is determined by how change in vegetation affects the distribution of organic carbon based on soil depth [22].

The reduction in soil organic C content according to the soil depth (Table 1, Figure 2b), is believed to be influenced by the soil organic matter content, where increased soil depth implies is accompanied by reduced organic matter content, and consequently, reduced microorganism activity in the soil. This organic matter tends to be concentrated in the topsoil. The high soil organic carbon content comes from the litter on the soil surface, while at a depth of 30-100 cm further, the availability of litter decreases with increasing soil depth, causing low soil organic carbon content [23,24].

Furthermore, the soil free organic C content decreased from the top to bottom layers in each slope class. However, this condition was different on the slope of 26-40%, where the free organic C content is relatively high in the second soil layer. This happens because erosion often occurs in the first layer, and in dry season the fallen plant litter piles up and decomposes. The high organic C soil is bound to improve soil properties, physically, chemically and biologically. Soil organic C content is an energy source for soil microorganisms activities, and therefore has the capacity to increase the decomposition of soil organic matter [3,24].

The clay-bound organic C content decreased from the top to the bottom layer. This is because organic C content decrease with increasing soil depth. The horizon above the soil is provided with a lot of organic material from plant residues, including citronella roots, and therefore has high clay-bound soil organic C content. This high content causes a small amount of free organic matter to be available in the soil, and consequently, a shortage of free organic matter decomposed by microorganisms as a food source. However, the return of crop residues from previous cultivation helps to increase the clay-bound soil organic C content, where the increase is greater with increase in the quantity of plant residues returned [25,26]. Other soil chemical properties, including pH, also affect the soil organic C content, such as soil pH. In the land-use of citronella with the red yellow podsolic soil type in this study, the soil pH value is categorised as acidic.

Table 1 and Figure 2c show the relationship between soil organic C content and slope. Furthermore, Table 1 shows the distribution of total soil organic C with varying slopes. The steeper the slope of the soil, the lower the organic C content in ultisol soil at pine forest and citronella plantations, a steeper slope implies lower organic C content.

According to [24,27], there is a negative relationship between the slope and soil organic C content. Thus, slope also affects the soil organic C content, as a steeper slope means greater erosion, and consequently, greater loss of organic C.

3.2. *The relationship between land cover and soil depth, towards soil organic carbon in various forms*

Figure 3 shows the relationship between land cover and soil depth towards the forms of soil organic carbon. Table 1 shows the measurements results of total, free-C, C-clay, and C-sesquioxide soil organic C content on land cover planted with citronella on ultisols in various slope classes and each horizon. Generally, the organic C content of land cover planted with citronella decreased from the top to the bottom layer (Figure 3a). The reduction in organic C content increased with reduction in soil depth, but at a slope of 26-40%, the second layer had higher organic content, compared to the layer above. This is due to the steeper slopes resulting in more erosion. Polosakan and Alhamd [28] showed this decrease in organic C corresponds to the organic matter source from top to bottom and is influenced by litter from land cover crops returning completely to the soil and decomposed by microorganisms into soil organic matter.
Furthermore, the total organic C content in citronella and pine land cover decreased in each soil layer, because the organic matter content is concentrated in the top layer. The highest levels of organic C were found in the upper layer. In this study, the distribution pattern of soil organic carbon forms was in line with previous studies \([4,22,25]\).

![Figure 3.](image)

**Figure 3.** (a) The relationship between soil organic carbon and soil depth on land cover planted with citronella; (b) citronella under pine trees; (c) only pine trees.

The free organic C content in the land cover of citronella and pine decreased in each soil layer but differed in the topsoil at a slope < 8%, and was slightly lower, compared to the second layer. This condition possibly occurs in the second layer of clay deposit, therefore, the organic C content is higher, compared to the top layer. Furthermore, this is also caused by tillage, leading to accelerated decomposition of soil organic carbon. \([2]\) disclosed the low soil organic carbon content in the top layer is caused by land preparation using a cutting system, causing major disturbances to the top layer. In addition, soil physical properties, for instance, texture also affect the availability of soil organic C. Soils with high clay content tend to have higher organic carbon due to low leaching rates. In contrast, sandy textured soils lose more soil organic carbon through decomposition by microorganisms. Texture has the capacity to affect soil organic carbon content, as soil with fine texture tends to have higher organic C content, compared to coarse-textured soil \([29]\).

### 3.3. The relationship between land cover and slope, towards soil organic carbon in various forms

This section describes the content of soil organic-C forms various planted with citronella, citronella planted under pine, and under pine on various slopes of the soil. Figure 4 shows the relationship between land cover and slope, towards forms of soil organic carbon.

Table 1 and Figure 4 show the total, free, clay-bound, and sesquioxide-bound soil organic carbon contents in the slope class < 8% to 26-40% on the citronella and pine land cover. Generally, a steeper the ultisol slope implies lower distribution of soil organic carbon content on the land cover, by citronella. Each slope and soil depth has different soil organic carbon values, as influenced by land cover, especially the soil surface horizon. Furthermore, microorganism activity in the soil affects the availability of total, free, clay-bound, and sesquioxide-bound soil organic carbon.

According to \([12,21]\), as well as \([29]\), the low soil organic C content at different slopes and soil depths also differs, because these soils generally contain low organic carbon. Ultisols are soils with low nutrient content, especially organic matter. Generally, the organic matter content in these soils is very low within the upper soil layer \([21,25,30,31]\).

The distribution of soil organic carbon content in pine forest land cover with slopes varies widely more at 8-15%, compared to other slope classes. This is possibly due to the occurrence of erosion on the
slope class. Also, a build-up of litter occurs in the dry season. Therefore, a higher slope class is bound to have lower soil organic carbon content (Table 1).

Generally, the organic C content in ultisol soil at pine forest land cover is low, due to the slightly acidic pH. Consequently, the microorganism activity in these soils also does not decompose soil organic matter, leading to high C/N content in this soil type and land use. Also, soil texture affects the availability of organic C in the soil.

4. Conclusions
In terms of land cover, the soil planted with citronella has higher soil organic content, compared to soil planted with citronella under pine tree stands and only pine tree stands. Meanwhile, in terms of slope, the highest content of all forms of soil organic carbon was obtained on slopes of 0-8%, and was found to decrease with increasing steepness. With regard to soil depth, the highest content of all forms of soil organic carbon in all profiles was obtained in the upper horizon, compared to the horizons below. The highest total soil organic carbon was obtained on land cover planted with citronella on a slope class of 0-8%, especially within the surface horizon. This was the same with sesquioxide bound soil organic carbon, but was not consistent with clay-bound and soil free organic carbon.

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