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Assessing the Level of Soil Development as a Strategy for Land Management a Case Study in West Halmahera Regency of Indonesia

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ABSTRACT

Signs of soil that has undergone advanced development include clearer horizons, higher fine fraction and lower coarse fraction, brighter soil color, higher levels of free Al and Fe. Soil aggregation is increasing, to a certain extent organic matter and nutrient levels are increasing as well as CaCO levels, and soluble salts. Soil development is characterized by the occurrence of horizon differentiation as a representative of the process of change in the earth's skin both physically, chemically and biologically by reactions in the soil profile there is an addition of organic and mineral materials in the form of solid, liquid or gaseous materials, the disappearance of materials above the soil, the transfer of materials from one part to another in the soil body, the transfer of the form of mineral compounds and organic matter in the soil body This research was carried out in the village of Bobaneigo Madihutu, South Jailolo District, West Halmahera Regency from June to July 2023. The method used in data collection is a free survey method, which is an observation made directly in the field by determining the research location based on land use maps, and administrative maps. The variables observed were C-Organic, N-Total, C/N Ratio, CEC, KB which are soil chemical properties. The results showed that the study of the level of soil development in several types of land use has not experienced weathering or advanced development due to the low content of nutrients.

Keywords: Level of soil development, Land management, West Halmahera Regency

ABSTRAK

Tanda-tanda tanah yang telah mengalami perkembangan lanjut antara lain horizontal lebih jelas, fraksi halus makin tinggi dan fraksi kasar makin rendah, warna tanah makin cerah, kadar Al dan Fe bebas makin tinggi. Agregasi tanah makin meningkat, pada batas tertentu bahan organik dan kadar hara makin meningkat serta kadar CaCO, dan garam-garam mudah larut. Perkembangan tanah dicirikan oleh terjadinya diferensiasi horizon sebagai wakil proses perubahan dalam kulit bumi baik fisik, kimia dan biologi yang oleh reaksi dalam profil tanah terjadi penambahan bahan organik dan mineral berupa bahan padatan, cair atau gas, menghilangnya bahan diatas tanah, alih tempat bahan dari satu bagian ke bagian lain dalam tubuh tanah, alih rupa senyawa mineral dan bahan organik di dalam tubuh tanah Penelitian ini di laksanakan di desa Bobaneigo Madihutu Kecamatan Jailolo Selatan, Kabupaen halmahera Barat pelaksanaan mulai bulan Juni hingga Juli 2023. Metode yang digunakan dalam pengumpulan data merupakan metode survei bebas yaitu suatu pengamatan yang dilakukan secara langsung di lapangan dengan menentukan lokasi penelitian berdasarkan peta penggunaan lahan, dan peta administrasi.Variabel yang diamati C-

Organik, N-Total, Nisbah C/N, KTK, KB yang merupakan sifat kimia tanah. Hasil penelitian menunjukan bahwa kajian tingkat perkembangan tanah pada beberapa tipe penggunaan lahan tersebut belum mengalami pelapukan atau perkembangan lanjut akibat dari rendahnya kandungan unsur haranya.

Kata kunci: Tingkat perkembangan tanah, Pengelolaan lahan, Kabupaten Halmahera Barat

INTRODUCTION

The rate of population growth and development is accelerating over time. This issue impacts the agricultural sector, which is gradually decreasing in area, so that in some regions only a small part of the available land is utilized. Additionally, the level of soil development in each area varies depending on local environmental conditions. Soil development is fundamentally characterized by both vertical and horizontal characteristics. Soil development is influenced by both internal and external factors of the soil body, such as parent material, climate conditions, organisms, topography, and relief (Widiatmaka, 2015; Ladjinga et al., 2020; Hartono & Hadun, 2021). Currently, soil management is still dependent on horizontal approaches, which gradually leads to a decline in soil management and impacts the ecosystem's condition within it, resulting in land degradation (Aji et al., 2020; Zhang & Zhang, 2020). Proper soil management needs to be conducted vertically and horizontally as an effort to support Sustainable Development Goals (SDGs) 15, which aims for a sustainable terrestrial ecosystem (Lal et al., 2021).

Sustainable land management is one of the main challenges in regional development, especially in tropical areas that are vulnerable to land degradation (Malihah, 2022). In Indonesia, with its diverse geological and climatic characteristics, an approach based on understanding soil conditions is very important in land planning and use. One approach that is increasingly receiving attention is the assessment of the level of soil development as an indicator to determine the potential and limitations of an area in supporting various forms of land use (Rachman et al., 2017; Fauzia, 2024). The level of soil development reflects the pedogenic processes that have taken place over a certain period of time and is greatly influenced by factors such as parent rock, climate, topography, organisms, and time (Joyontono & Sartohadi, 2016; Adhikari et al., 2024; Doetterl et al., 2025). The understanding the extent to which the soil has developed, land managers can identify the physical and chemical characteristics of the soil that directly affect agricultural productivity, soil conservation, and ecosystem stability (Sharma, 2024). Therefore, this assessment not only provides scientific information on soil status, but also becomes a strong basis for making land management decisions (Wu et al., 2024; Hernández & Camerin, 2024).

The process of pedogenesis significantly affects the formation of a soil type's characteristics, which in turn broadly determines the condition of the land in an area (Luo et al., 2024). This can be linked to the level of land management based on the soil's characteristics, with the goal of maintaining the soil's capability and productivity. Pedogenesis processes indicate the level of development of a type of soil which will be indicated by various soil properties, both physical, chemical, biological and mineral content in the soil, which will become a parameter in assessing the condition of the characteristics of a type of soil (Wang et al., 2022; Adyanova et al., 2023). The characteristics shown both morphologically and in the results of laboratory analysis will show how we treat the land for both agricultural and non-agricultural purposes (Mc.Garry, 2003).

This study is conducted in Bobaneigo Madihutu Village, South Jailolo District, West Halmahera Regency, North Maluku Province. Soil resource inventory research involves soil characteristics activities through soil profiles and laboratory analysis to produce outputs in the form of soil management procedures. Therefore, managing soil based on the level of soil development is crucial to be implemented in the research area. This study aims to address the issue of soil management based on the level of soil development in the area of Bobaneigo Madihutu Village, South Jailolo, West Halmahera Regency, North Maluku.

The novelty of this research can be described in: a) spatial approach and tropical soil taxonomy, namely by utilizing the analysis of soil development levels based on morphological, physical, and chemical parameters of the soil studied spatially in various land units in West Halmahera, b) the use of soil development as a strategic land management tool that adds a new dimension by making the soil development index an evaluative instrument to determine the level of land sensitivity to certain uses, as well as the potential risk of degradation in the long term, c) contribution to regional planning based on soil science that can strengthen the argument that understanding the natural processes of the soil must be the basis for formulating sustainable spatial use policies.

METHODOLOGY

Time and Place

The research was conducted from April to November 2023. It was divided into two parts: field research and laboratory analysis. The field research took place in Bobaneigo Madihutu Village, South Jailolo District, West Halmahera Regency, North Maluku Province, and the laboratory analysis was conducted at Hasanuddin University in Makassar.

Equipment and Materials

The equipment used included a soil auger, dodos (a traditional digging tool), geological and pedological hammers, a machete, a clinometer compass, a tape measure, a soil scoop, a GPS (Global Positioning System), writing materials, the Munsell Soil Color Chart, forms for soil boring and soil profile observation, a camera for documentation, pH meter, EC (Electrical Conductivity) meter. The software used was ArcGIS 10.5. The materials used were an Administrative Map at a scale of 1:50,000, and a Land Use Map from the Indonesian Geospatial Information Map at a scale of 1:50,000.

Research Method

The method for determining sample points used the purposive random sampling survey method, and soil samples were taken from three types of land use: residential areas, mixed gardens, and open land. Soil sampling was conducted by creating a soil profile.

Research Procedure

Figure 1 illustrates the research procedure which includes three stages, namely preparation, field observation, and data analysis. In the preparation stage, base maps were created, including an administrative map and a land use map, both at a 1:50,000 scale, obtained from the Indonesian Geospatial Information Map. Additionally, equipment for soil sampling was prepared. The field observation stage encompassed two activities: examining physiographic conditions and soil profiles with the aid of a soil auger, adhering to USDA standards (Schoeneberger et al., 2012), and conducting laboratory analyses based on the protocols established by the Central Research Institute for Agriculture Resources (2006). Finally, the data tabulation stage involved organizing the collected data using Microsoft Office 2019 software.

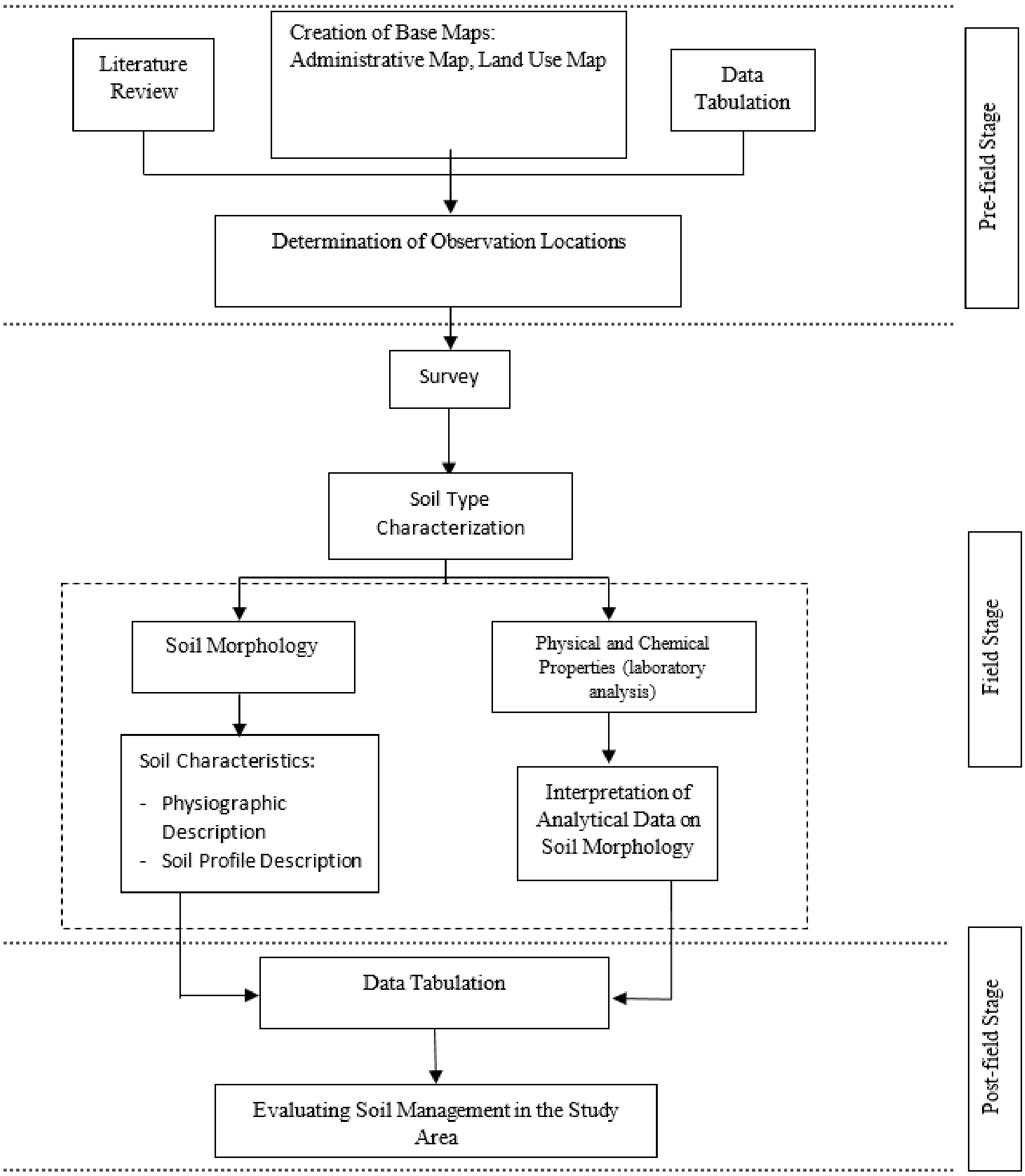

Figure 1. Research Flowchart

RESULTS AND DISCUSSION

In this study, observations were made on various types of land use to assess their soil development levels. This was done to facilitate the designation of representative soil sample locations with limiting factors for land use levels and to ease the comparison of soil development levels for each different land use.

Soil Development Level in Residential Land Use Types

The soil profile is located at an elevation of 522 meters above sea level at the coordinate point N 00° 50'10.5" E 127° 40'40.6" in Bobaneigo Madihutu Village, South Jailolo District, West Halmahera Regency, with a slope of 0-8% and flat topography. Based on the morphological observation of the soil profile in the residential land use type, the characteristics of the soil indicate that the soil in this land use type has a relatively high oxidation level, as seen from the dominant soil color in this profile as shown in table 1 and figures 2 to 5. It has a hue range around 10 YR in its topsoil layer, which is known to characterize the oxidation-reduction processes occurring in a type of soil.

Table 1. Morphological characteristics of the soil profile I

Layer	Soil Depth	Soil Color	Soil Structure	Consistency	Root Presence
I	0 – 15/18 cm	10 YR. 3/3 (Dark Brown)	Rounded clumps	Somewhat firm	Many
II	15/18 – 34/40 cm	10 YR 4/4 (Dark Yellowish Brown)	Rounded clumps	Somewhat firm	Few
III	34/40– 46/50 cm	7.5 YR 4/6 (Strong Brown)	Rounded clumps	Somewhat firm	Few
IV	46/50-110 cm	5 YR 5/8 (Yellowish red)	Rounded clumps	Somewhat firm	None

Source: Field Observation Results, 2023

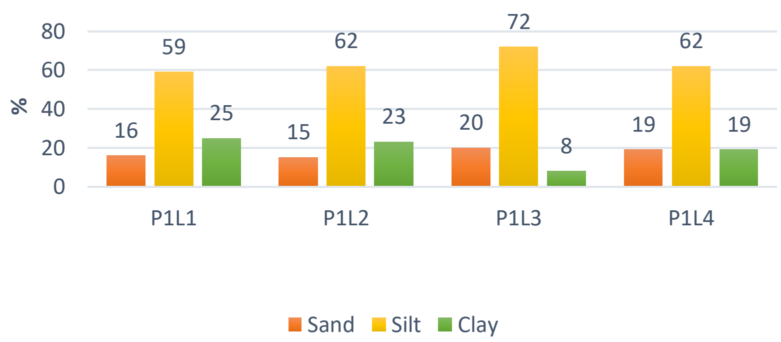

Figure 2. Soil texture content of the soil profile I

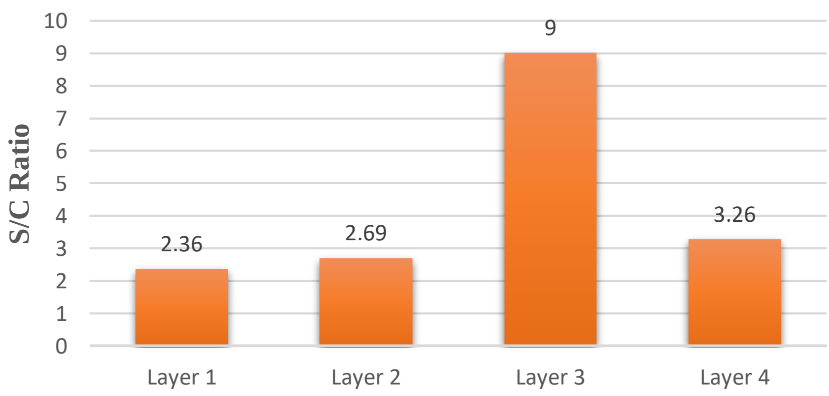

Figure 3. Silt/clay ratio of the soil profile I

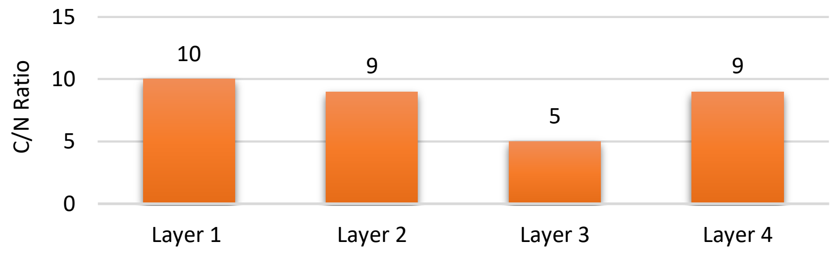

Figure 4. C/N Ratio of the soil profile I

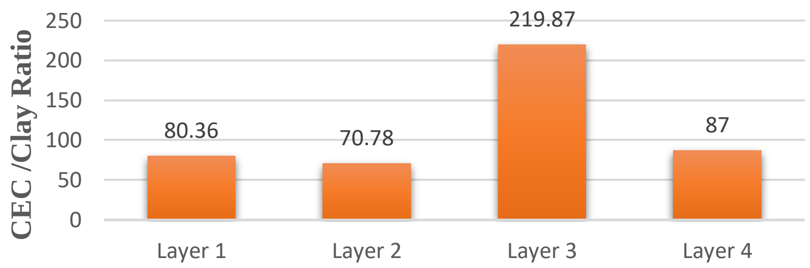

Figure 5. CEC/clay ratio (cec clay) of the soil profile I

From the data description above, it is evident that the soil in the residential land use type is still not highly developed, as indicated by the dominance of the silt fraction compared to the clay fraction, which is an indicator that shows a higher level of weathering. The mineralization parameters occurring in this soil profile are very small, indicating that the soil development has not reached an advanced level. This is evident from the low Organic C content in the soil profile in the residential land use type.

The CEC Clay value indicates that in the third layer of this soil profile, the CEC clay content is quite high, suggesting that this soil layer can be categorized as a B horizon that has undergone illuviation. In terms of soil development processes, this indicates that the soil in this land use type is already showing weathering activity with the presence of translocation processes occurring within this soil.

Soil Development Level in Mixed Garden Land Use Type

The soil profile is located at an elevation of 100 meters above sea level with coordinates 0° 50'12.8" N 127° 40'45.95" E in Bobaneigo Madihutu, featuring a slope of 0-8% and flat topography. Based on the morphological observation of the soil profile in the mixed garden land use type, the soil characteristics indicate that the soil in this land use type has a good level of oxidation-reduction, as seen from the dominant soil color in this profile as shown in table 2 and figures 6 to 9. It has a hue range around 7.5 YR in its topsoil layer, which is known to characterize the oxidation-reduction processes occurring in a type of soil.

Table 2. Morphological characteristics of the soil profile II

Layer	Soil Depth	Soil Color	Soil Structure	Consistency	Root Presence
I	0 – 13/16 cm	7.5 YR. 3/4 (*Dark Brown*)	Rounded clumps	Somewhat firm	Many
II	13/16 – 29/35 cm	7.5 YR 4/4 (*Brown*)	Rounded clumps	Somewhat firm	Many
III	29/35– 61/63 cm	7.5 YR 4/6 (*Strong Brown*)	Rounded clumps	Somewhat firm	Few
IV	61/63-130 cm	5 YR 5/6 (*Strong brown*)	Rounded clumps	Somewhat firm	None

Source: Field Observation Results, 2023

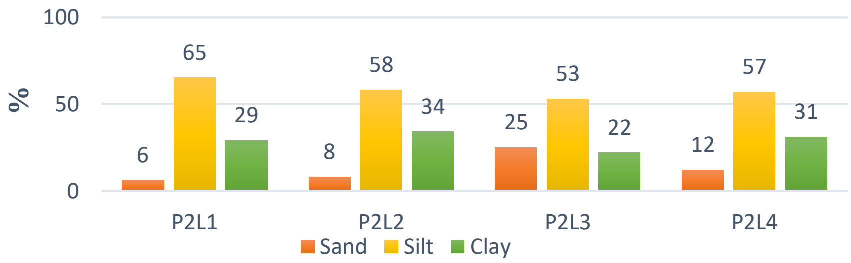

Figure 6. Soil texture content of the soil profile II

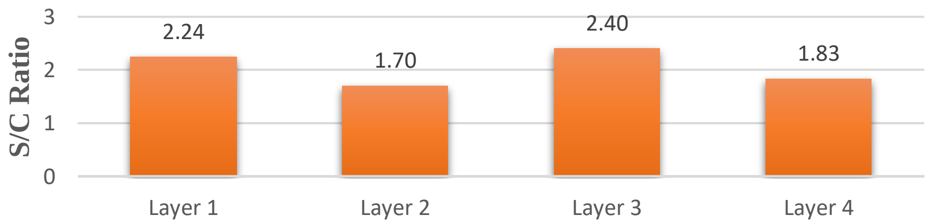

Figure 7. S/C ratio of the soil profile II

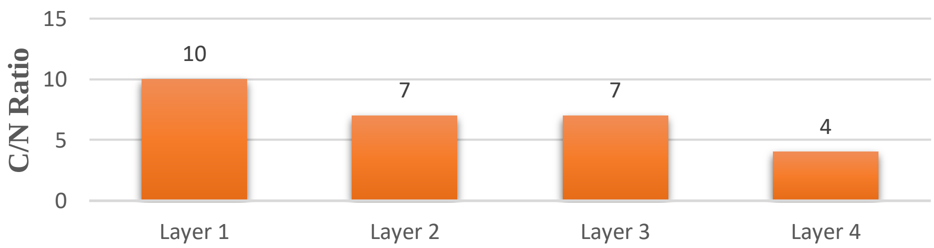

Figure 8. C/N ratio of the soil profile II

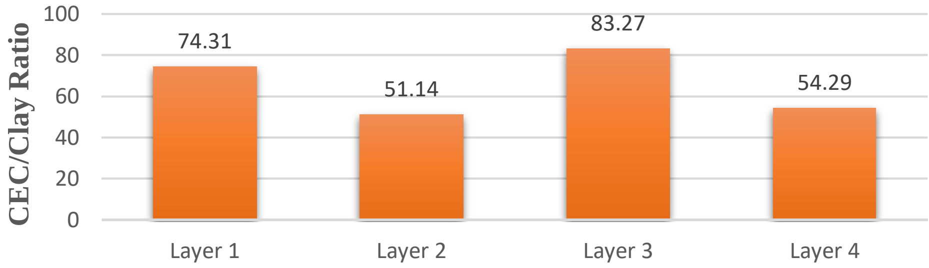

Figure 9. CEC/clay ratio of the soil profile II

From the data description above, it can be understood that the soil in the mixed garden land use type shows clear signs of more intensive soil development from the aspect of disintegration. This is indicated by the significant development of the clay fraction and the decreasing sand fraction, suggesting more active weathering activity. The mineralization indicators in this soil show that the soil development process in terms of decomposition has not yet reached an advanced level, as seen from the low Organic C content in this soil profile. However, the Organic C content is higher compared to the soil profile in the previous land use type. The CEC Clay value indicates a high CEC clay content, showing that the soil in this profile has developed further with the influence of vegetation contributing organic material, thus intensifying the weathering process.

Soil Development Level in Land Use Type of Open Land

The third soil profile observed in Bobaneigo Village is located at an elevation of 216 meters above sea level with a slope of 0-8% and coordinates at 0° 50'02.0" N 127° 40'41.4" E, and flat topography. Based on the morphological observation of the soil profile in the open land land use type, the soil characteristics indicate that the soil in this land use type has a relatively high oxidation level, as seen from the dominant soil color in this profile as shown in table 3 and figures 10 to 13. It has a hue range around 10 YR in its topsoil layer, which is known to characterize the oxidation-reduction processes occurring in a type of soil.

Table 3. Morphological characteristics of the soil profile III

Layer	Soil Depth	Soil Color	Soil Structure	Consistency	Root Presence
I	0 – 13/16 cm	10 YR. 3/2 (Very *Dark Grayish Brown*)	Granular	Loose	Moderate
II	13/16 – 29/35 cm	10 YR 5/2 (Grayish *Brown*)	Rounded clumps	Firm	Moderate
III	29/35– 61/63 cm	10 YR 5/4 (*Yellowish Brown*)	Rounded clumps	Firm	Moderate
IV	61/63-130 cm	7.5 YR 6/6 (*Reddish Yellow*)	Rounded clumps	Firm	Moderate

Source: Soil Observation Results, 2023

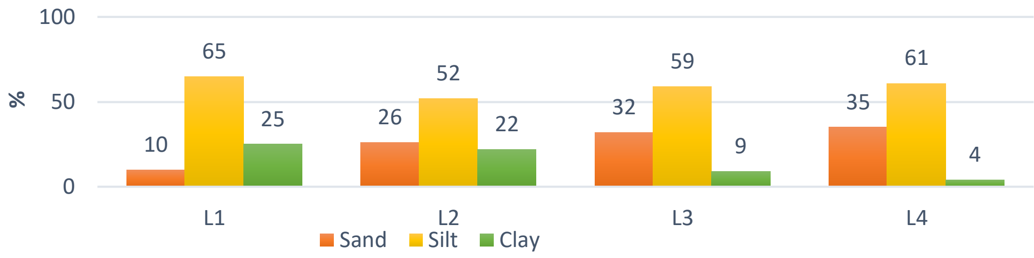

Figure 10. Soil texture content of the soil profile III

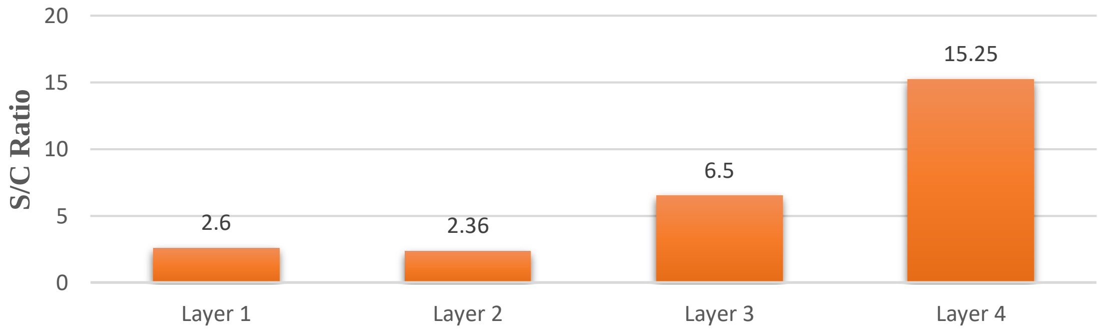

Figure 11. Silt/Clay ratio of the soil profile III

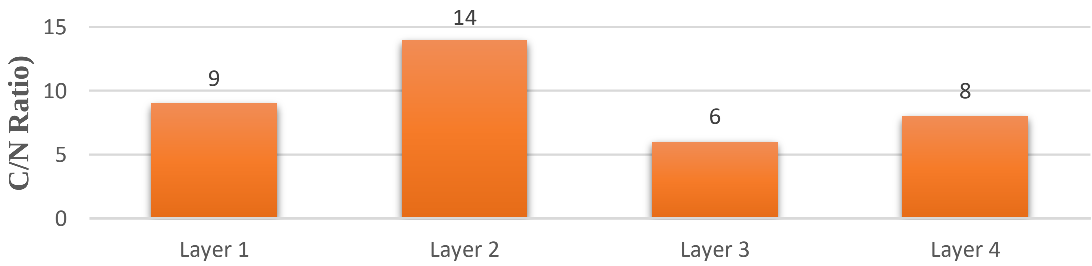

Figure 12. Silt/Clay ratio of the soil profile III

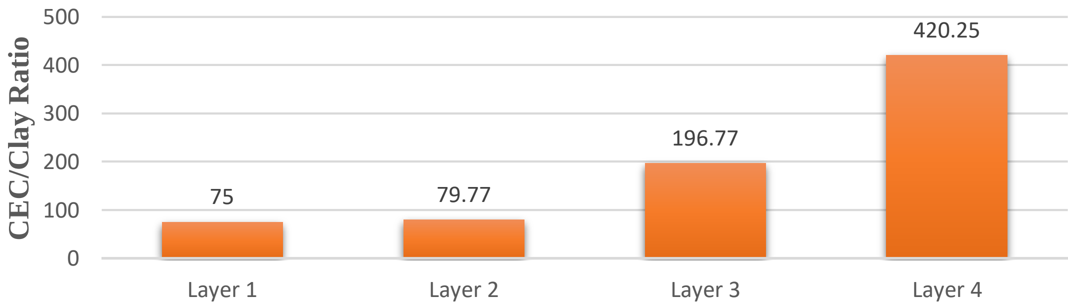

Figure 13. CEC/Clay ratio of the soil profile III

From the data description above, it is evident that the soil in the open land use type has a very low level of development, as seen from the texture analysis data showing a low Silt/Clay Ratio. This indicates that the soil has been cleared of its topsoil for land clearing purposes and has not undergone any rehabilitation process. The mineralization parameters occurring in this soil profile are very small, indicating that the soil development process has not yet reached an advanced level. This is evident from the low Organic C content in the soil profile in the open land use type, which could be due to a lack of organic material supply caused by scarce vegetation growing on this land use type or the lack of intensive decomposition processes occurring (Alam et al., 2012). The CEC Clay value shows that the deeper the soil layer, the higher the CEC clay content. This indicates that the soil in this profile is in an open condition and there is not much influence of vegetation on this soil in terms of supplying organic materials.

Soil Management

The results obtained from the analysis of field and laboratory data show that the soil at the study site is an aged soil with a high degree of weathering. This is evidenced by the morphological characteristics of the soil that point to a podzolic yellow red color, as well as a base saturation level below 35%. The soil texture is dominated by dust and clay fractions, indicating that the weathering process has occurred, although not intensively. It can be assumed that the ultisol soil in the study area is a young ultisol soil that developed from volcanic tuff parent rock. This condition causes the dominance of fine textures (dust and clay) over coarse fractions (sand), consistent with the researcher findings state that the differences in fractions in old soils based on the origin of the parent rock (Acosta et al., 2021).

The climate in the region, which is dominated by Udik conditions, makes Ultisol soils have plenty of water but are limited in nutrients. The source of nutrients can be obtained from volcanic activity (Uehara, 2005; Arifin et al., 2022). This is in line with the research location which is an area of exitu soil development from volcanic rocks. These volcanic soils have an important role for communities in humid areas, where ultisols soils are maintained similar to alfisols conditions by periodic addition of nutrient-rich volcanic ash (Ugolini & Dahlgren, 2002).

This study suggests that a suitable soil management model for the soil characteristics in the study area is through significant addition of organic matter to increase nutrient availability, aggregate stability and improve soil structure. This is particularly important given the high content of dust and clay fractions, especially on residential land that has the potential for agricultural development on narrow land or yards, as well as open land for the development of crop cultivation. The provision of organic materials can be in the form of organic fertilizers, bokashi, and the like, which are adapted to the process of sustainable crop cultivation.

CONCLUSION

The soil in mixed garden lands shows more advanced developmental activity, both in terms of disintegration and decomposition, compared to the soil in residential and open lands. Studies on the level of soil development suggest a soil management model tailored to the specific soil characteristics in the research area. This involves adding a significant amount of organic matter to support the weathering process and soil development, especially in improving soil aggregate stability. This is crucial considering the high content of sand fractions in the soil, particularly in residential and open lands.

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