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Soil Chemical Properties and Nutrient Status on Various Land Slopes of Gayo Arabica Coffee Plantation, Aceh, Indonesia

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Abstract – The chemical and soil nutrients on different land slopes are intriguing and crucial to investigate since they constitute the most significant impediment in sustaining soil fertility in coffee plantations. The issue is whether the slope of the soil can impact the soil's nutrient and chemical characteristics. This study aimed to identify soil chemical characteristics and available nutrients on different slopes of Gayo Arabica coffee plantations. The study used a survey method on smallholder coffee plantations in 6 villages in Bandar District, Bener Meriah Regency, and 12 composite soil samples were taken for laboratory analysis. The determination of the research location and sample points was selected by purposive sampling, with the slope of the land serving as the independent variable and the chemical composition of the soil serving as the dependent variable. The results showed that C-organic, C/N ratio, and base saturation differed significantly at various land slopes, while pH, CEC, N, P, and K were not significantly different. The soil C/N ratio in Gayo coffee plantations is modest, and the amount of C-organic material decreases with increasing land slope. Soil base saturation in Gayo Coffee plantations is very low, where the highest values are found on land slopes of 8-15%. Nitrogen and potassium content are moderate, while Phosphate is very low. The amount of these three nutrients is not affected by the land slope.
Keywords: slope, Gayo Arabica coffee, soil chemical properties

Introduction

Gayo Arabica coffee is one of the best national specialty coffee spreads throughout all sub-districts within Bener Meriah Regency (Suhandy, Yulia, 2021; Martauli, 2018; Nasution, 2018). In 2021, the area of coffee plantations (PR) was recorded at 4,702 ha and was the primary source of income for 23,387 residents (BPS, 2020). This commodity has a relatively high selling price depending on the type of coffee. Gayo coffee costs between Rp. 140.00 and Rp. 300,000 per kg on the national market in 2021 (Purba, Sukartiko, and Ainuri, 2020; Quirinno, 2021).

The main barrier to Arabica coffee farming in the Gayo Highlands is production, which is classified as very low, with an average production of 0.79 tons/ha (Director General of Plantations, 2017). Furthermore, Gayo Arabica coffee production faced several problems, such as conventional cultivation systems (Asis, Ardiansyah, and Jaya, 2020), pest and plant disease attacks, poor cultivation systems, and global warming (Dishutbun Bener Meriah, 2015). Other issues include topography (hilly to steep), land slopes that limit land suitability, and high erosion potential. Soil chemical properties and nutrients vary at the slopes' top, middle, and foot.

Several related findings indicate that slope significantly affects total (Jaya *et al.*, 2014). Altitude correlates positively and significantly with pH, C-organic, N-total, Na, and CEC)(Supriadi, Randriani, and Towaha, 2016). The chemical and nutrient properties of the soil can limit the growth and yield of coffee plants. A nutrient deficiency can result from a lack of one or more essential nutrients, causing a decrease in growth and productivity (Wilson, Supriadi, and Guchi, 2015).

Information on soil's chemical properties and nutrient content on various land slopes is critical for preparing recommendations for adequate and balanced fertilization in Gayo Arabica coffee plantations. Furthermore, this paper can be used as a guide in developing integrated soil management to sustainably increase the production and quality of Gayo Arabica coffee.

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Materials and Methods

This research was conducted in community coffee plantations in Bandar District, Bener Meriah Regency. Soil analysis was conducted at the Laboratory of Soil Chemistry, Faculty of Agriculture, University of Syiah Kuala, and Laboratory of Service and Assessment, Aceh Agricultural Technology Study Center (BPTP). Field research and sample analysis took place from August 2020 to January 2021. Sampling locations and coordinates can be found in Figure 1 and Table 1.

Figure 1. Sample location

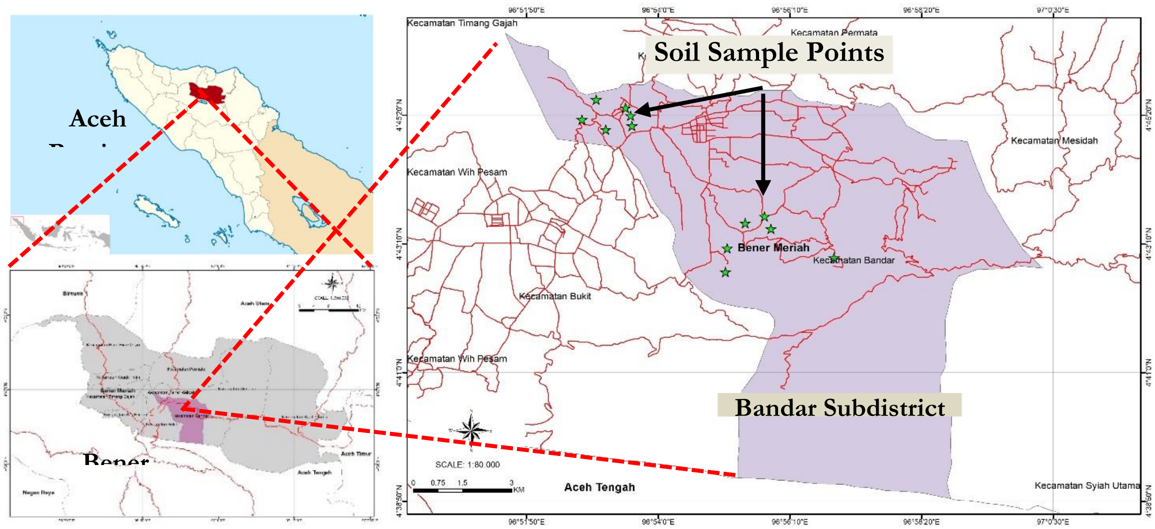

Table 1. Coordinates of sampling sites in Bandar District, Bener Meriah Regency

Repetition	Slope (%)		
	0-8	8-15	15-30
1	04°43'37,69"N	04°43'25,355"N	04°42'55,961"N
	96°55'44,919"E	96°55'51,497"E	96°56'53,768"E
2	04°43'05,619"N	04°43'30,989"N	04°42'41,566"N
	96°55'08,119"E	96°55'25,961"E	96°55'06,474"E
3	04°45'9,176"N	04°45'05,475"N	04°45'15,549"N
	96°53'34,166"E	96°53'08,263"E	96°52'44,62"E
4	04°45'19,661"N	04°45'27,473"N	04°45'35,902"N
	96°53'32,727"E	96°53'27,793"E	96°52'58,806"E

Soil samples were collected from Gayo Arabica coffee plantations belonging to the community with different slope conditions: flat (0-8%), slightly slanted (8-15%), and slanted (15-30%). Four (4) samples were taken randomly on three slope classes by drilling at a depth of 0-40 cm (Figure 2). A total of 12 (twelve) soil samples were then taken to laboratory for chemical property analysis.

Soil samples were taken from ±15 years old Gayo arabica coffee plantations owned by the community (Figure 2), grow on different land slope namely; flat (0-8%), slightly slanted (8-15%), and slanted (15-30%). A total of 4 soil samples were randomly collected at a depth of 0-40 cm using a sample drill for each slope class (Figure 3), yielding 12 (twelve) soil sample which were used for soil chemical analysis in the laboratory.

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Figure 2. Gayo Arabica coffee plantations

Figure 3. Soil sampling

Soil reaction (pH) (H_2O) was measured potentiometrically with the ratio of soil and water was 1:2.5 supernatant was determined with a digital pH meter following the procedure (Soil Research Center, 2005). Soil organic carbon was determined by the wet oxidation method (Walkley and Black, 1934), in which soil samples were oxidized with potassium dichromate in sulfuric acid solution and titrated with 0.5 N ferrous sulfate solution. The percent organic matter was calculated by multiplying soil organic carbon by a conversion factor 1.724. The total N content of the soil was determined by wet oxidation, distillation, and titration procedures according to the Kjeldahl method described by Black (1965). Soil Phosphate content was measured using the Olsen extraction method (Olsen *et al*., 1954). The bases can be determined by the 1M Ammonium Acetate extraction method at pH 7.0. The Ca and Mg ions in the soil solution were analyzed by Atomic Absorption Spectrophotometer (AAS), while Flame Spectrophotometer analyzed K and Na ions. The cation exchange capacity was determined by washing the soil sample with 1N Ammonium Acetate solution, followed by washing the adsorbed Ammonium with a neutral salt and determined by titrimetric. The percent base saturation of the soil is calculated by dividing the percentage of exchangeable cations (Ca, Mg, K, and Na) by the CEC of the soil (Bohn *et al*., 2001). Data were analyzed using an analysis of variance alpha level of 0.05. If the slope affects the response variable, the 0.05 level of the LSD test will be performed.

Results

Soil Chemical Properties

The results showed that the degree of the slope had no significant effect on soil pH and Cation Exchange Capacity (CEC). However it significantly affects C-organic, C/N ratio, and Base Saturation of Gayo arabica soil plantation (Table 2).

Table 2. Results of land slope analysis on chemical properties and soil nutrients

No	Variables	F	P-Value	Coefficient of Variation (%)	Standard Error (±)
1	pH	3.035	0.086	3.79	0.069
2	C-Organic (%)	4.284	**0.039***	15.37	0.202
3	C/N Ratio	4.142	**0.043***	19.39	1.387
4	CEC (Cmol kg^{-1})	2.369	0.136	19.34	0.892
5	Base saturation (%)	5.260	**0.023***	17.54	1.630
6	N-total (%)	0.422	0.665	15.42	0.022
7	P-available (ppm)	0.442	0.653	22.13	0.041
8	K-exchangeable (Cmol kg^{-1})	1.511	0.260	19.99	0.027

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Soil pH on the slopes of Gayo Arabica coffee plantations ranges from 5.90 to 6.30 (slightly acidic) and rises with increasing land slope as shown in Figure 4. These results are in line with the findings of(Hifnalisa at al., 2020) on Andisols in Bukit and Timang Gajah, Bener Meriah Districts (5.7 to 6.6), and 5.16 to 6.89 around the southern slopes of Mount Burni Telong, Bukit Bener Meriah (Thasniema Putri, Purba Marpaung, 2015). According to the requirements for growing coffee plants in general, the soil pH value suitable for growth and production and quality of Arabica coffee is 5.8 - 6.2 (Maro, 2014).

Arabica coffee crops typically have high C-organic content, which decreases with rising land slopes of 15–30%. The decrease in organic C on each land slope is estimated at 0.58% and is only significantly different between the 8-15% and 15-30% slopes, as shown in Figure 5. The land's slope significantly affects the distribution of organic matter (Soil Organic Carbon) in forest soil and vineyards. The organic carbon content of the topsoil is higher than that of the subsoil. and will decrease with increasing land slope (Jakšić *et al.*, 2021).

The soil analysis result revealed that soil carbon and nitrogen continuously dropped as the slope of Arabica coffee crops increased. The carbon and nitrogen ratio on the slopes of 0-8% is high and significantly different from the C/N on other slopes, categorized as moderate (Figure 6).

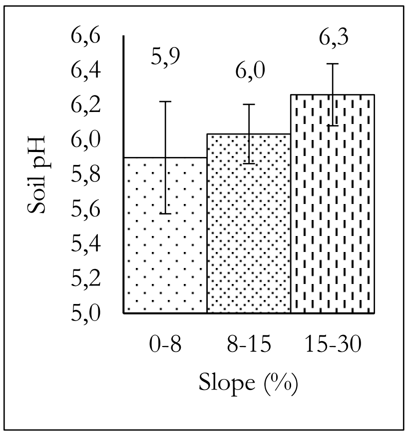

Figure 4. Average soil pH on different slopes of Gayo Arabica coffee plantation

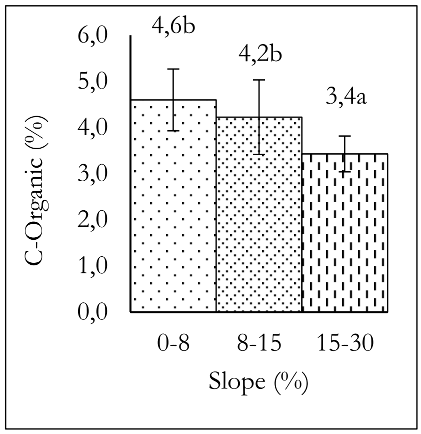

Figure 5. Average of C-organic soil on different slopes of Gayo arabica coffee plantation

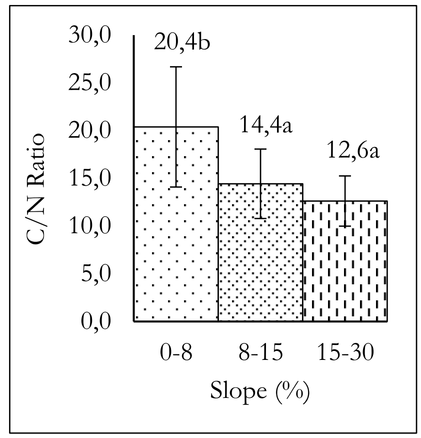

Figure 6. Average of C/N ratio soil on different slopes of Gayo Arabica coffee plantation

The process of composting biomass is affected by various factors, including the C/N ratio and the level of soil aeration. A C/N ratio above 25 indicates that organic matter is difficult to decompose completely. In reverse, decomposition becomes easier when soil C/N ratio is lower than 25. Water content decreases by 0.38% for every 1% increase in slope land. This condition aligns with Banjarnahor, Hindarto, and Fahrurrozi (2018), that the sleeper the slope, the lower the water content. The availability of energy for microorganisms is estimated to be more sufficient at higher land slopes, resulting in an intensive biomass decomposition. This process caused a lower C/N ratio compared to a lower slope.

The Cation Exchange Capacity (CEC) value shows a slight increase as the slope rises and is categorized as Medium (Figure 7). Among the factors affecting soil CEC are organic matter content and soil pH. Soils with a high organic matter typically have a higher CEC. The CEC values of organic matter ranged from 200 to 400 cmol kg^{-1}, while the CEC values of clay minerals (inorganic) ranged from 10 to 150 cmol kg^{-1}. This number may fluctuate due to the dynamics of soil pH. Organic colloids and silicate clays (Kaolinite), which hold hydrogen, become ionized and replaceable as soil pH rises. Overall, this generates a rise in CEC and the negative charge on the colloid.

Base saturation in Gayo Arabica coffee plantations ranges from 19% to 29%. The highest percentage is found at an 8-15% slope, which is 10.20%, and is significantly different on the lower as well as higher slopes of the land (Figure 8). The difference in the percentage of Base Saturations is considered to be affected by soil pH and alkaline cations contained in the soil. The percentage of soil base saturation is greatly impacted by land slope and tends to decline with the increasing land slope gradient (Aytenew, 2015).

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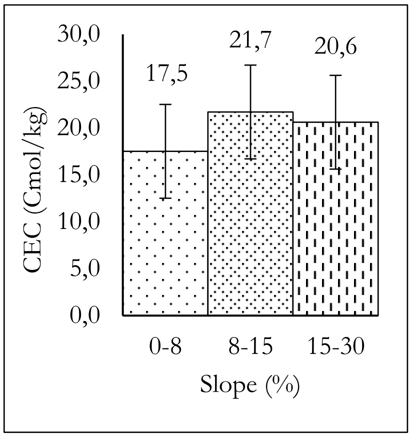

Figure 7. The average soil CEC on different slopes of the Gayo arabica coffee plantation

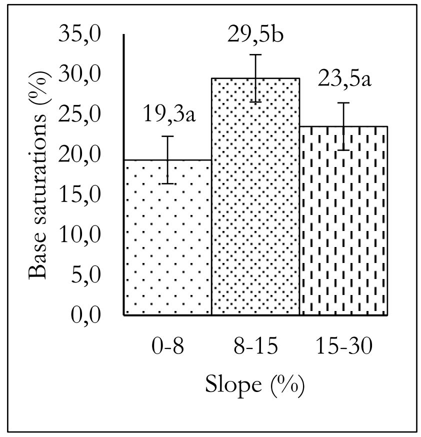

Figure 8. Average of soil Base Saturation on differ-rent slopes in Gayo Arabica coffee

Nutrient Availability

Soil total nitrogen on different slopes of the Gayo coffee plantation ranged from 0.25% to 0.3% and was not statistically different from other land slopes, as illustrated in Figure 9. According to soil analysis results, the Total nitrogen of the Gayo Arabica coffee plantation is classified as Medium, which was higher than the nitrogen critical level in the soil. This amount is recommended for coffee growth and production (Iloyanomon, Taiwo, and Ogbeide, 2020).

Soil available phosphorus of the Gayo coffee plantation was classified as low (0.86 mg kg^{-1} to 0.95 mg kg^{-1}) and did not differ significantly by land slope class (Figure 10). Although slope land has no significant effect on available P, Mulugeta Aytenew, (2015) reported a similar result thasoil phosphorus availability decreases with the increasing land slope. This condition may be closely related to the C-organic content of the soil on different slope land.

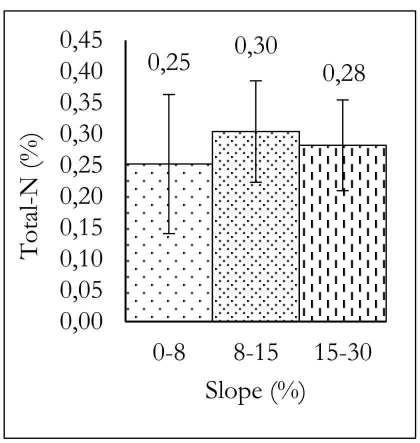

Figure 9. Soil total nitrogen on different slopes of Gayo Arabica coffee plantation

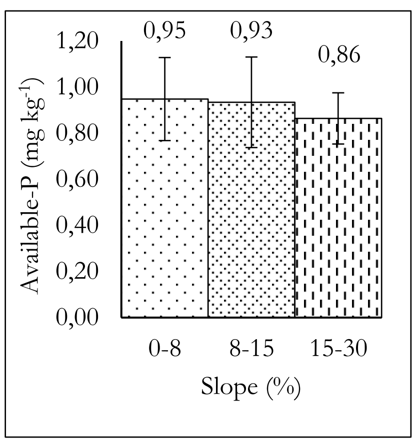

Figure 10. Available-P on dif-ferrent slopes of Gayo Arabica coffee plantation coffee

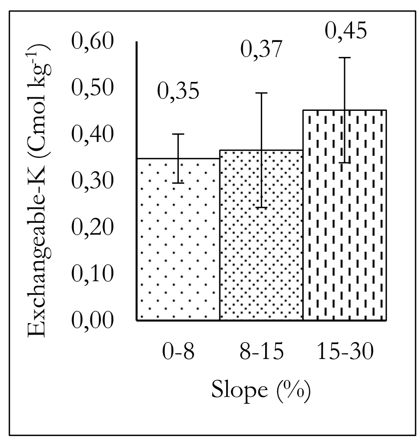

Figure 11. Exchangeable K on different slopes of Gayo Arabica coffee plantation

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The slope gradient of the land has no statistically significant effect on the exchangeable K content of the topsoil of Arabica coffee plantations. The K-exchangeable distribution was in the medium category (ranging from 0.35 cmol kg^{-1} to 0.55 cmol kg^{-1}) (Figure 11). The results of other studies found a negative correlation between the slope gradient and potassium exchangeability (Wubie and Assen, 2020), and the distribution of exchangeable K on the horizon surface is not statistically significant (Samndi and Tijjani, 2014)

Discussion

The reaction (pH) of slightly acidic soil in Gayo Arabica coffee plantations is thought to be the result of soil parent material and similar land management on each slope. The main material of the soil around Mount Burni Telong Bener Meriah is volcanic ash, which develops into Andisols, with a pH between 3.8 6.4 (Putri, Marpaung, and Razali, 2015). In the process of Andisol formation, primary mineral weathering releases basic cations and Si. Rainwater washes off Si more easily and accumulates it on slopes >15%, whereas on slopes <15%, there are deposits of Al and Fe acid cations. Rainfall and soil texture naturally affect soil pH, its value is directly proportional to soil base saturation (Ahmad, 2014).

C-organic content in Gayo coffee plantations is categorized as high and is not significantly different at a slope of 0-15% but is significantly different at a slope of >15%. At slope 0-15%, it is estimated to have an addition of C-organic biomass from coffee husk compost and manure given by farmers. However, on slopes greater than 15%, there is a greater transfer of biomass by gravity or water, which lowers the amount of breakdown products (C-organic) produced. Temperature affects the decomposition of organic matter, with low temperatures slowing the process (Salima, Karim, and Sugianto, 2012). High humidity and low temperatures will increase the amount of litter as the primary source of soil organic matter (Ping *et al.*, 2013). On lower slopes, the C-organic mass is higher due to compost deposits, manure, and coffee litter. On higher slopes, C-organic is lower due to runoff carrying it to the bottom of the slope and the extensive breakdown process.

Colloids that are either organic (humus) or inorganic (clay) regulate the soil's capacity for cation exchange. The soil's capacity to absorb and exchange cations is determined by the negative charges of both of these constituents. The land cover system, soil texture, and clay minerals in Andisols on each slope of the coffee plantation land are similar. The amount of CEC soil is determined by soil texture, organic matter, and the type of clay minerals in the soil (Suryani, 2014).

The total N-content on each slope is moderate and not significantly different due to the very mobile behavior of N in the soil. It is suspected that N, which originates from the decomposition of organic matter, fertilizers, fixation of microorganisms, and rainwater on each slope of the land, is absorbed by plants, evaporated into the air, washed into the deeper layers of the soil, and evaporated into the air.

Andisols are soils characterized by the presence of the mineral allophane, which is thought to have fixed available Phosphate so that the amount is meager on each slope of the land. The amount of allophane in Andisols is inversely proportional to the availability of N, P, S, and Cl nutrients due to strong fixation by these amorphous minerals (Ajidirman, 2010) ; (Gebhardt, and Coleman, 1984). The K-exchangeable content at the study site was classified as moderate and not significantly different for each land area. This is thought to be due to the application of inorganic and organic fertilizers and the results of the decomposition of coffee leaves, branches, and exocarp.

Conclusion

Soil chemical properties and nutrient status on various land slopes of Gayo Arabica coffee plantation show various categories in term of cemical pripertis and nutrient content. The C-organic, C/N ratio, and base saturation differed significantly at various land slopes, while pH, CEC, N, P, and K were not significantly different. The soil C/N ratio in Gayo coffee plantations is modest, and the amount of C-organic material decreases with increasing land slope. Soil base saturation in Gayo Coffee plantations is very low, where the highest values are found on land slopes of 8-15%. Nitrogen and potassium content are moderate, while Phosphate is very low. The amount of these three nutrients is not affected by the land slope.

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