eISSN: 1984-3909
Coffee Science, e182123, 2023

Doi: https://doi.org/10.25186/.v18i.2123

Identification of soil physicochemical, land suitability, and its relationship to *Coffee arabica* yielding based on plant age groups

Posma Marbun[1], Bintang[1], Koko Tampubolon[1], Fransisca Natalia Sihombing[2], Desi Ratnasari Simanjuntak[3], Irene Irly[3], Mariati Sinuraya[1]

[1]Universitas Sumatera Utara, Faculty of Agriculture, Program Study of Agrotechnology, Medan, North Sumatra, Indonesia
[2]Universitas Sumatera Utara, Faculty of Agriculture, Graduate in Program Magister of Agribusiness, Medan, North Sumatra, Indonesia
[3]Universitas Sumatera Utara, Faculty of Agriculture, Graduate in Program Study of Agrotechnology, Medan, North Sumatra, Indonesia
Contact authors: posmamarbun12@gmail.com; bintangsitorus@ymail.com; koko.tampubolon@gmail.com; sihombingfransisca93@gmail.com; desisimanjuntak2112@gmail.com; ireneirly@gmail.com; mariati@usu.ac.id
Received in April 18, 2023 and approved July 12, 2023

ABSTRACT

The low yield of *Coffee arabica* could be caused by several factors such as low soil characteristics and depending on the plant age. This study aimed: (1) to obtain information on soil physicochemical characteristics and productivity of *Coffee arabica* in different age groups, (2) to evaluate the land suitability for *C. arabica* plants and obtain the relationship between land characteristics and *C. arabica* yielding. This study was conducted on *C. arabica* smallholders in Tarutung Subdistrict, North Tapanuli District, North Sumatra, Indonesia from October 2021 to February 2022 and used a descriptive-analytic method. Overlay maps of soil type, altitude, and slope to obtain a Soil Map Unit (SMU) then surveyed for the plant age distribution of 6-10 and 11-15 years. Land characteristics were analyzed by matching method and multiple linear regression of yielding using IBM SPSS software. The results showed that the soil physicochemical characteristics were classified as low and higher productivity was found at 11-15 years old. It was found that the potential and actual land suitability classes were not suitable (N) in SMU-1 at 11-15 years, and other SMUs were classified as marginally suitable (S3). Altitude, silt, and clay fractions significantly affected the productivity of *C. arabica* plants at 6-10 years. However, an increase in altitude, cation exchange capacity, base saturation, and organic-C could be increased the productivity of *C. arabica* at 6-10 years.

Key words: Land suitability; overlay; physicochemical; productivity; soil map unit.

1 INTRODUCTION

Coffee plants are a strategic agricultural commodity that generates foreign exchange in Indonesia, it could be seen that coffee exports had increased by 3.41% annually from 2000-2021 and coffee export demand reached 384,510.60 tons in 2021 (Statistics Indonesia, 2021). International Coffee Organization (2018) reported that Indonesia is the fourth largest coffee exporter in the world after Brazil, Vietnam, and Colombia. This demand for coffee exports must be balanced with an increase in coffee yields. It was been reported by Sihombing, Supriana and Ayu (2021) that coffee yield significantly increased the export volume to the United States, Japan, and Malaysia. In addition, the specific flavor and aroma are also benchmarks for determining coffee exports (Ministry of Trade, 2018). Farah (2012) added that *Coffee arabica* had a greater aroma compared to *Coffee robusta*.

In Indonesia, the third highest *C. arabica* yield was found in North Sumatra Province by 10.05% (Statistics Indonesia 2020) with the highest yield distribution by 15,220 tons was found in North Tapanuli District in 2020 (Statistics of Sumatera Utara, 2022). Based on the geography, North Tapanuli District was classified as a highland area that supports the growth and yield of *C. arabica*. Situmeang and Mutaali (2017) reported that *C. arabica* from North Tapanuli had superior quality such as flavor, aroma, taste, and a long productive age compared to *C. arabica* from other districts. Several sub-districts in North Tapanuli reported a coffee yield is less than one ton or classified as low in 2021, such as the Tarutung Subdistrict had a productivity of 612.50 kg year^{-1} (Statistics of Tapanuli Utara, 2022). The low yield is feared to be less supportive of *C. arabica* exports.

The low yield of *C. arabica* could be caused by several factors such as low soil physicochemical characteristics (Chaudhari et al., 2013; Cyamweshi et al., 2014; De Bauw et al., 2016; Siahaan et al., 2022), depending on the plant age (Rubiyo; Martono; Dani, 2013; Anggraeni; Setiawan; Isyanto, 2020), and other factors. Cyamweshi et al. (2014) reported that soil pH, Ca, available-P, total-N, and organic-C levels were positively correlated with *C. arabica* yield with coefficient values of 71%; 56%; 62%; 30%; and 53%, respectively. Rubiyo, Martono and Dani (2013) noted that *C. arabica* plants have produced at the age of 4-5 years with a productive period of 20 years and productivity reaches 1.5 to 2 tons ha^{-1} year^{-1}. Anggraeni, Setiawan and Isyanto (2020) said that the volume of coffee yield will increase annually in the range of 6-15 years and the highest coffee yield at the age of 9 years. Therefore, several alternatives to support *C. arabica* productivity are identifying soil physicochemical characteristics, evaluating land suitability, and their effect on *C. arabica* yield by plant age cluster. The objective of this work: (1) to obtain information on soil physicochemical characteristics and *C. arabica* productivity in different age groups, (2) to evaluate land suitability for *C. arabica* and obtain the relationship between land characteristics on *C. arabica* yield in Tarutung Subdistrict, North Tapanuli District, Indonesia.

2 MATERIAL AND METHODS

2.1 Study area and map overlay techniques

The smallholders of *C. arabica* were selected in this study from Tarutung Subdistrict, North Tapanuli District, North Sumatra, Indonesia from October 2021 to February 2022. Overlay maps (soil type, altitude, slope) was conducted to produce 19 SMUs (Figure 1) and this study used a descriptive-analytic method. An initial survey was conducted on 19 SMUs by collecting data on the distribution of *C. arabica* plants aged 6-10 and 11-15 years. Based on the survey, there were four SMUs at 6-10 years and five SMUs at 11-15 years (Figure 2). Soil samples were collected as deep as 0-30 cm using a soil auger from each SMU with a distance of 75 cm from the plant in four cardinal directions and then composited. For each SMU from the plant age cluster were collected five soil samples and *C. arabica* seeds were taken from the soil sample area.

2.2 Data collection and analysis of soil characteristics

Climatic data (temperature and rainfall) were collected from the Medan Sampali Climatology Station for the last 10 years (2010-2020). Soil samples were analyzed at the Research Laboratory, Faculty of Agriculture, Universitas Sumatera Utara, and the laboratory in Socfin Indonesia, Inc., Medan. The soil physical characteristics were measured, such as soil texture using the hydrometer method and bulk density using the ring sample method, meanwhile, the coarse, drainage, soil depth, flooding, surface rock, rock outcrop, and erosion were observed directly in the field. Measurement of coarse material was carried out by separating gravel with a size of 0.2-2 cm in the soil sample. Drainage measurements were conducted on soil drilling to a certain soil depth until the iron spots were found. Soil depth was carried out by drilling profusely. Flooding was observed through interviews with farmers about the duration and depth of the flood. Surface rocks and rock outcrops were measured by making a square plot. Measured the area and the number of rocks on the ground surface. Erosion was calculated using the Universal Soil Loss Equation method. The soil chemical characteristics were also analyzed including pH-H_2O using an electrometric method, organic-C using the Walkley-Black method, base saturation (BS), cation exchange capacity (CEC), and exchangeable cations using ammonium acetate pH 7.

2.3 Yielding characteristics

The yielding characteristics of *C. arabica* were measured by collecting coffee cherries from all branches that had harvest criteria, such as reddish-purple, pulpy mesocarp, etc. The coffee cherries were peeled and the seeds were washed and then dried for a day until the moisture content of 14% and weighed. Measurement of water content using the Grain Moisture Meter GM640, then the seeds were counted and weighed to obtain the seed dry weight per plant and the 100-seed dry weight. Based on the farmer's information, harvesting *C. arabica* in the field was conducted with small harvests for eight months and large harvests in four months in annually. The productivity was calculated using the equation 1, 2 and 3 based on the author's formulation from a series of farmer information and field findings.

Small harvest (g)= populations ha^{-1} × seed dry weight per plant × number of small harvests (1)

Large harvest (g)= populations ha^{-1} × seed dry weight per plant × number of large harvests (2)

$$\text{Productivity (kg ha}^{-1}) = \frac{\text{Small+large harvest}}{1000\text{g}} \qquad (3)$$

2.4 Data interpretation

Climatic and soil physicochemical data from each SMU were matched with the land suitability table for *C. arabica* based on Sys et al. (1993) using the matching method. Land characteristics data were analyzed by multiple linear regression and t-test to the 100-seed dry weight and productivity using IBM SPSS software.

3 RESULTS

3.1 Land characteristics and yielding of *Coffee arabica*

Data on soil physicochemical characteristics and *C. arabica* productivity from each SMU at the age of 6-10 and 11-15 years in Tarutung Subdistrict, North Tapanuli District could be seen in Tables 1-3. The dominant soil texture was sandy loam except for SMU-1 at the age of 11-15 years. Bulk density (BD) in each cluster of plant age ranged from 1.24-1.76 and 0.88-1.20 g cm^{-3}. Bulk density is closely related to root penetration in the soil, drainage, and aeration. Coarse materials were also obtained in the ranged of 8.22 to 14.26 and 5.49 to 11.62% (classified as slight). The soil chemical showed that the *C. arabica* plants aged 6-10 and 11-15 years in Tarutung Subdistrict were classified as low. It was seen from the soil pH classified as very acidic to acid, BS and exch-Mg were classified as very low to low, CEC and exch-K were classified as low to moderate, exch-Ca was classified as very low, and exch-Na classified as low. However, several SMUs had higher organic-C, namely SMU-1 and SMU-5 for 6-10 years as well as SMU-5 at 11-15 years. Other results

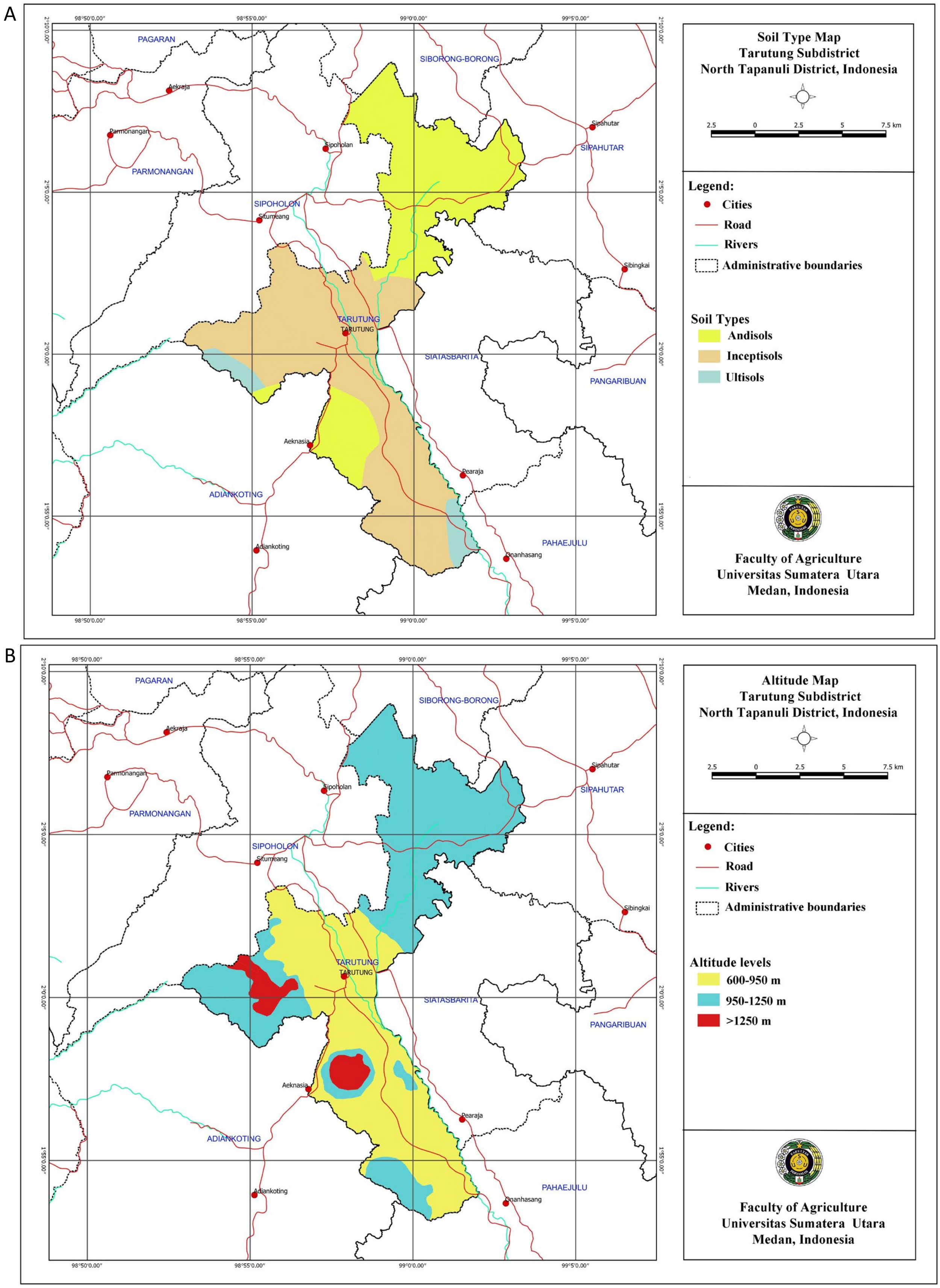
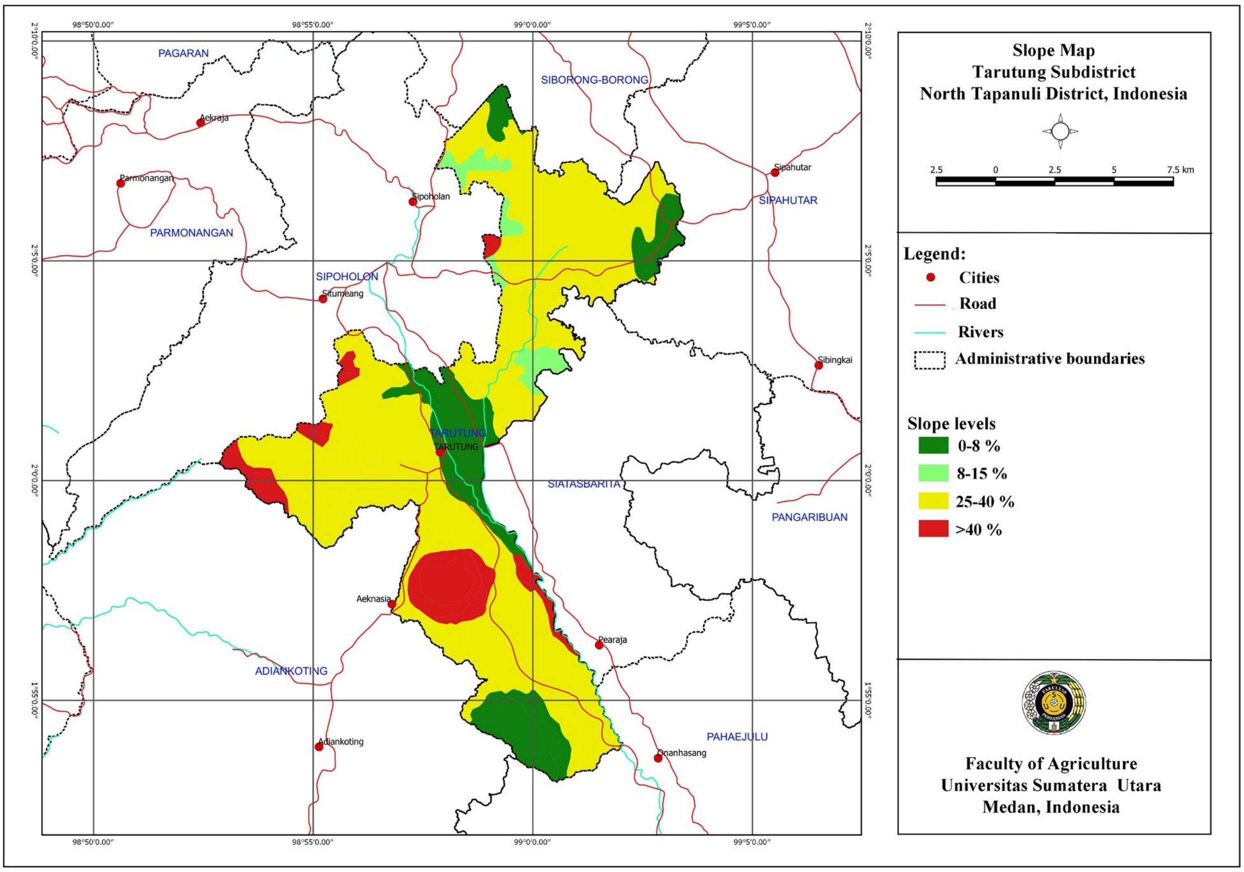


Figure 1: Maps of soil type (A), altitude (B), slope (C), and soil map unit (D) for *Coffee arabica* in Tarutung Subdistrict, North Tapanuli District, Indonesia.

Continua.

C



D

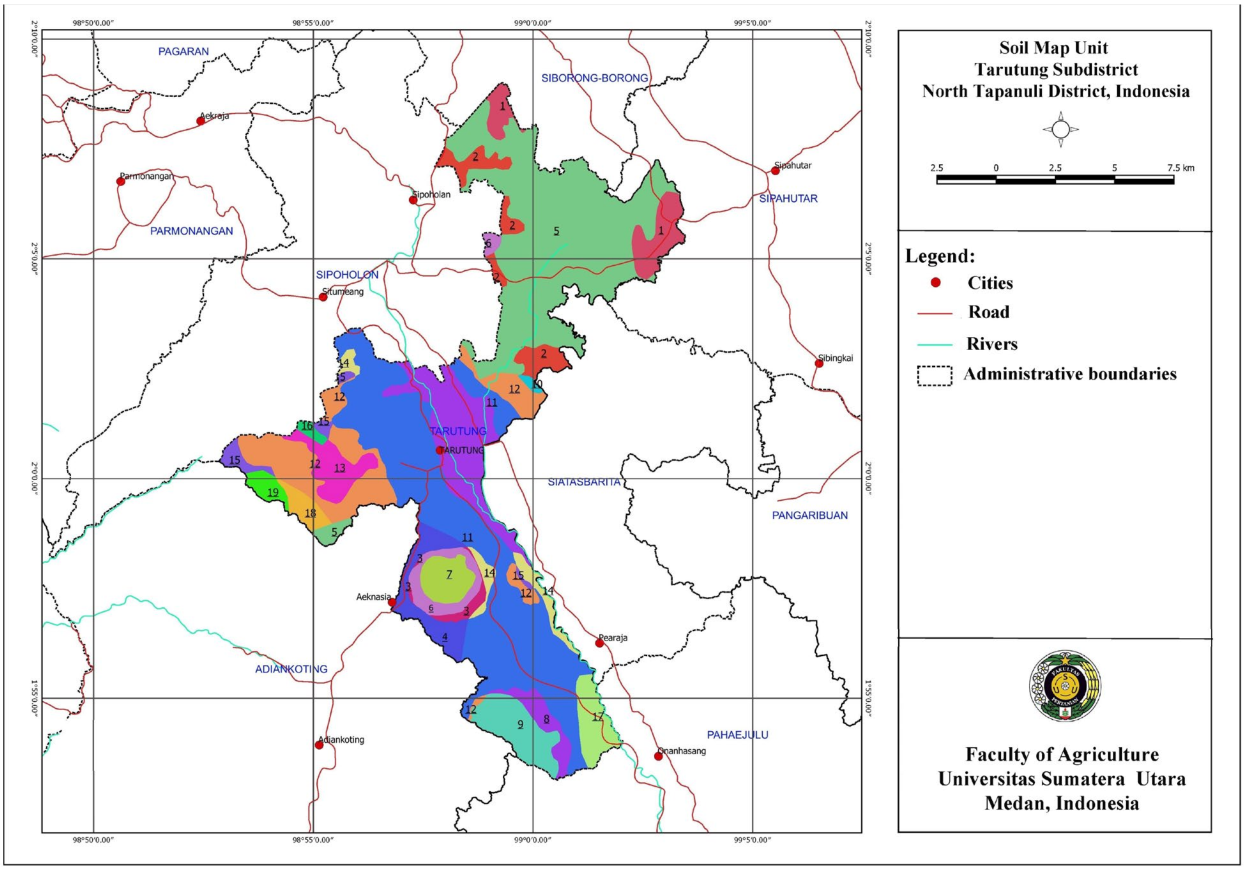


Figure 1: Continuation.

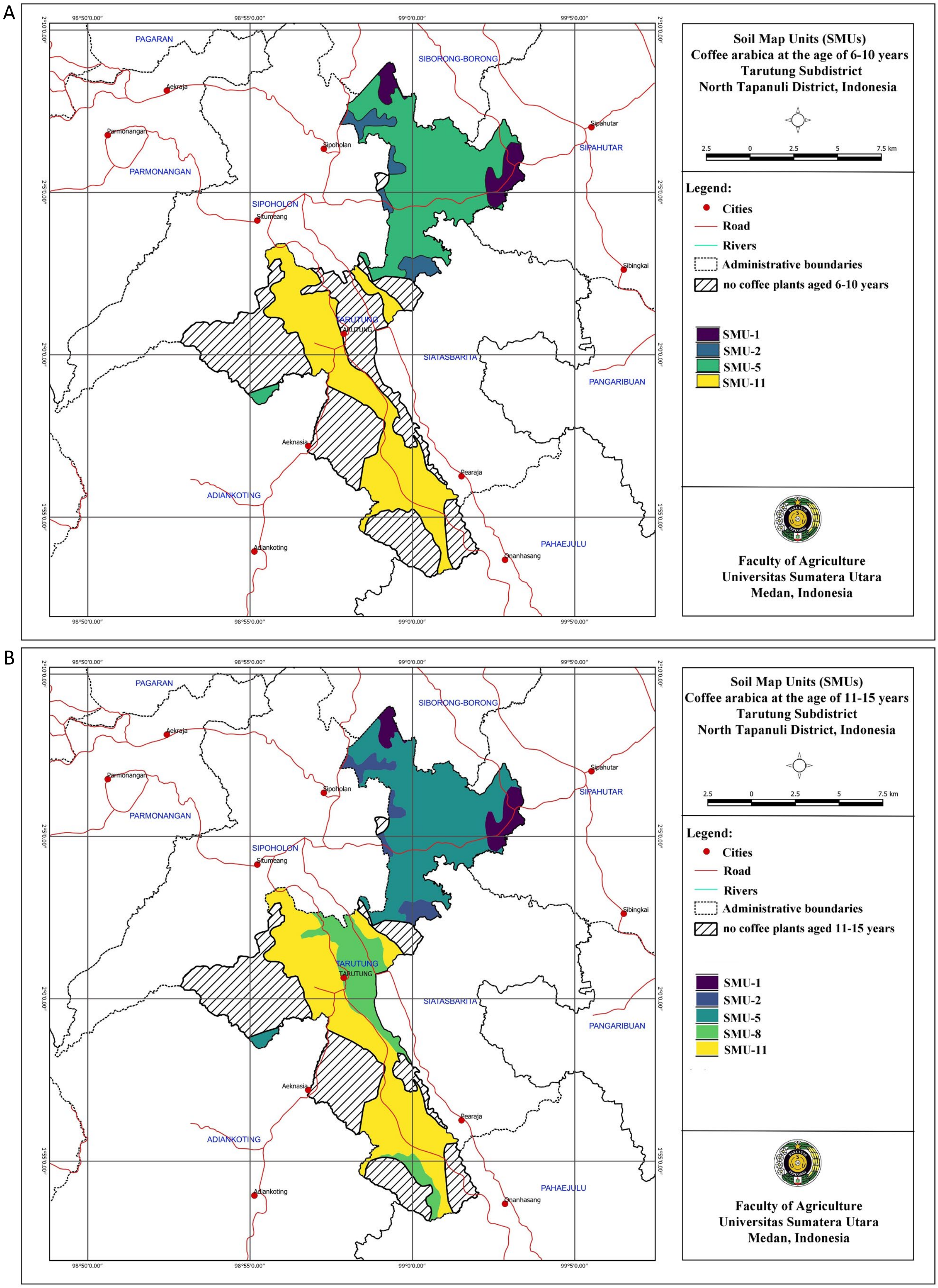


Figure 2: Distribution of SMUs with *Coffee arabica* plants at the age of 6-10 (A) and 11-15 years (B) in Tarutung Subdistrict, North Tapanuli District, Indonesia.

also showed that the productivity of *C. arabica* at the age of 6-10 and 11-15 years ranged from 106.51-495.42 and 222.45-822.34 kg ha^{-1} year^{-1}, respectively (Table 3). It was indicated that the productivity of *C. arabica* at the age of 11-15 years was higher than the age of 6-10 years and both productivities were classified as low.

3.2 The potential and actual land suitability

The results showed that *C. arabica* plants at the age of 6-10 years for all SMUs had actual land suitability were classified as marginally suitable/S3 (Table 4). In general, the limiting factors found in the actual land suitability of *C. arabica* plants at the age of 6-10 years include water availability (wa), rooting conditions (rc), nutrient retention (nr), and erosion hazard (eh). The potential land suitability of all SMUs at the age of 6-10 years was classified as marginally suitable (S3) with the limiting factors of water availability (wa) and rooting conditions (rc). In *C. arabica* plants aged 11-15 years showed different assessment results. Actual and potential land suitability in SMU-1 was classified as not suitable (N rc). Actual land suitability in SMU-2 and SMU-8 were classified as marginally suitable (S3 wa, rc, nr), SMU-5 (S3 wa, rc, nr, eh), SMU-11 (S3 wa, oa, rc, nr, eh). In general, the limiting factors found in the actual land suitability of *C. arabica* plants at the age of 11-15 years include water availability, oxygen availability, rooting conditions, nutrient retention, and erosion hazard. The potential land suitability at SMU-2; 5; 8; and 11 were classified as marginally suitable (S3) with limiting factors for water availability (wa) and rooting conditions (rc). Among all the limiting factors, the water availability and rooting conditions be unable to improve, meanwhile, other limitations can be improved by adding organic matter, liming (dolomite, calcite), planting a cover crop, setting planting distances, and setting terraces.

Table 1: Soil physical characteristics of *C. arabica* plants based on the age of 6-10 and 11-15 years in Tarutung Subdistrict, Indonesia.

Plant age	SMUs	Soil texture fraction (%)			Soil texture	Coarse material (%)	BD (g cm^{-3})
		Sand	Silt	Clay			
6-10	1	72.40	16.28	11.32	SL	8.25 (S)	1.24
	2	63.82	18.47	17.70	SL	8.51 (S)	1.61
	5	68.25	18.75	13.30	SL	8.22 (S)	1.71
	11	58.90	25.44	15.66	SL	14.26 (S)	1.76
11-15	1	79.00	13.00	8.00	LS	11.62 (S)	0.99
	2	74.00	15.67	10.33	SL	11.27 (S)	0.88
	5	71.90	17.70	10.40	SL	11.24 (S)	0.93
	8	61.00	25.00	14.00	SL	9.37 (S)	1.20
	11	65.00	18.00	17.00	SL	5.49 (S)	0.96

Note: The classification of soil texture and coarse materials refers to Djaenudin et al. (2011). (SL= sandy loam; LS= loamy sand; S/slight <15%).

Table 2: Soil chemical characteristics of *C. arabica* plants based on the age of 6-10 and 11-15 years in Tarutung Subdistrict, Indonesia.

Plant age	SMUs	pH-H_2O	Organic-C (%)	CEC (me/100 g)	BS (%)	Exchangeable cations (me/100 g)			
						K^+	Ca^{2+}	Mg^{2+}	Na^+
6-10	1	3.88 (VA)	4.35 (H)	21.40 (M)	4.21 (VL)	0.26 (L)	0.34 (VL)	0.14 (VL)	0.16 (L)
	2	4.16 (VA)	2.97 (M)	13.93 (L)	14.68 (VL)	0.39 (M)	0.64 (VL)	0.31 (VL)	0.21 (L)
	5	4.21 (VA)	3.35 (H)	20.17 (M)	8.45 (VL)	0.33 (M)	0.61 (VL)	0.23 (VL)	0.20 (R)
	11	3.97 (VA)	2.29 (M)	14.25 (L)	7.18 (VL)	0.20 (L)	0.39 (VL)	0.18 (VL)	0.21 (L)
11-15	1	4.10 (VA)	2.38 (M)	9.68 (L)	9.92 (VL)	0.22 (L)	0.36 (VL)	0.17 (VL)	0.21 (L)
	2	4.31 (VA)	2.68 (M)	11.31 (L)	25.69 (L)	0.50 (M)	0.94 (VL)	0.39 (VL)	0.23 (L)
	5	4.35 (VA)	3.92 (H)	16.36 (L)	16.88 (VL)	0.41 (M)	0.84 (VL)	0.43 (L)	0.26 (L)
	8	4.99 (A)	0.72 (VL)	8.08 (L)	32.92 (L)	0.44 (M)	1.43 (VL)	0.54 (L)	0.25 (L)
	11	4.18 (VA)	2.31 (M)	16.36 (L)	6.42 (VL)	0.16 (L)	0.44 (VL)	0.21 (VL)	0.20 (L)

Note: criteria for pH H_2O (very acidic/VA< 4.5; acid/A= 4.5-5.5); organic-C (very low/VL<1%; moderate/M= 2.01-3%; high/H= 3.01-5%); CEC (low/L= 5-16 me/100 g; moderate/M= 17-24 me/100 g); base saturation (very low/VL<20%; low/L= 20-40%); exch-K (low/L= 0.1-0.3 me/100 g; moderate/M= 0.3-0.5 me/100 g); exch-Ca (very low/VL< 2 me/100 g); exch-Mg (very low/VL< 0.4 me/100 g; low/L= 0.4-1 me/100 g); exch-Na (low/L= 0.1-0.3 me/100 g) (Indonesia Soil Research Institute 2009).

Table 3: Yielding characteristics of *C. arabica* based on the age of 6-10 and 11-15 years in Tarutung Subdistrict, Indonesia.

Plant age	SMUs	Land area (ha)	Total populations	Seed fresh weight per plant (g)	Seed dry weight per plant (g)	100-seed dry weight (g)	Productivity (kg ha^{-1} $year^{-1}$)
6-10	1	0.20	200	290.00	44.38	18.50	106.51
	2	0.58	1145	187.29	22.65	19.66	273.41
	5	0.45	950	250.60	32.80	20.44	357.22
	11	0.54	880	190.00	37.08	20.80	495.42
Average				229.47	34.23	19.85	308.14
11-15	1	0.50	1250	190.00	34.12	22.80	511.80
	2	0.31	794	131.33	23.77	18.20	237.60
	5	0.50	924	170.66	33.47	18.89	414.10
	8	0.25	625	102.00	29.66	15.70	222.45
	11	0.75	1200	177.50	56.22	21.75	822.34
Average				154.30	35.45	19.47	441.66

3.3 The regression and partial test

The results of the regression, partial, and regression equations of land characteristics on the *C. arabica* productivity at the age of 6-10 and 11-15 years in Tarutung Subdistrict, North Tapanuli District could be presented in Tables 5-7. The land characteristics significantly increased the productivity of *C. arabica* plants at the age of 6-10 years, but it had an insignificant effect on the 100-seed dry weight (Table 5). The land characteristics also had an insignificant effect on the yielding character of *C. arabica* at the age of 11-15 years.

Based on the t-test, it was found that land characteristics such as altitude, silt, and clay fractions significantly increased the productivity of *C. arabic*a plants at the age of 6-10 years, but other land characteristics had an insignificant effect (Table 6). All land characteristics had an insignificant effect on the productivity of *C. arabic*a plants at the age of 11-15 years. The regression equation of land characteristics on the yielding character of *C. arabica* at the age of 6-10 and 11-15 years could be presented in Table 7. At the age of 6-10 years, an increase in altitude, slope, and soil pH to a certain extent can be increased 100-seed dry weight, as well as an increase in altitude, CEC, BS, and organic-C can increase *C. arabica* productivity. At the age of 11-15 years, an increase in altitude, slope, pH, and organic-C could increase 100-seed dry weight, as well as an increase in altitude and CEC could improve *C. arabica* productivity. The increase in silt and clay fractions leads to a soil texture that is suitable to support the yield of *C. arabica* plants.

4 DISCUSSION

The results showed that the soil physicochemical characteristics of each SMU at the age of 6-10 and 11-15 years in Tarutung Subdistrict, North Tapanuli District were classified as less fertile (Tables 1-2). It was seen from the soil pH, CEC, BS, organic-C, and exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) were classified as very acidic to acid, and very low to moderate, except for organic-C at SMU-1 and SMU-5 in 6-10 years and SMU-5 for 11-15 years were classified as high. In addition, the soil texture and coarse material are also dominantly sandy loam and relatively slight, and it had bulk density ranging from 0.88-1.76 g cm^{-3}. Soil chemical characteristics are closely related to plant growth and yield, meanwhile, soil physical are closely related to porosity, infiltration rate, water availability, root penetration in the soil, drainage, and aeration. This finding was supported by Estrada-Herrera et al. (2017) that soil chemical indicators are categorized as fertile from agricultural areas if the pH-H_2O, organic-C, CEC, exch-Ca, exch-Mg, and exch-K were 5.0-7.5; 2-6%; 15-40; 8-35; 2-5; and 0.2-1 cmol/kg. Doran and Parkin (1994) added physical indicators for soil quality, namely soil texture, soil depth, infiltration, bulk density, and water capacity. Marbun et al. (2020a) reported that CEC, BS, total-P, total-K, and organic-C significantly increased the productivity of *Coffee robusta* by 89.30%.

The productivity of *C. arabica* at the age of 11-15 years was higher at 441.66 kg ha^{-1} $year^{-1}$ than at the age of 6-10 years (308.14 kg ha^{-1} $year^{-1}$) in Tarutung Subdistrict, North Tapanuli District (Table 3). It was indicated that the productivity of both plant age groups is still relatively low compared to data from Statistics of Tapanuli Utara (2022) that the productivity of *C. arabica* from Tarutung Subdistrict was 1.16 tons ha^{-1}. The low productivity of *C. arabica* could be caused by low soil fertility such as pH, organic-C, CEC, BS, and exchangeable cations in all SMUs in both plant age groups (Tables 1-2). This finding was supported by McCauley et al. (2017) that soil organic matter had the function of nutrient retention, soil aggregation, and the main indicator of soil quality. Higher soil organic matter had a greater cation exchange capacity (CEC) and can bind more cations such as calcium or potassium and it also had a greater buffering capacity. Sousa et al. (2018) reported that soil organic matter significantly increased the total-N and

Table 4: Land suitability for *C. arabica* plants based on the age of 6-10 and 11-15 years in Tarutung Subdistrict, Indonesia.

Land characteristics	6-10 years							
	SMU-1		SMU-2		SMU-5		SMU-11	
	Data	ALS/PLS	Data	ALS/PLS	Data	ALS/PLS	Data	ALS/PLS
Temperature (tc)								
Average temperature (°C)	19.40	S1 / S1	19.40	S1 / S1	19.40	S1 / S1	19.40	S1 / S1
Altitude (m asl)	950-1250	S1 / S1	950-1250	S1 / S1	950-1250	S1 / S1	600-950	S1 / S1
Water availability (wa)								
Rainfall (mm/year)	2536.30	S3 / S3	2536.30	S3 / S3	2536.30	S3 / S3	2536.30	S3 / S3
Oxygen availability (oa)								
Drainage	Well-drained	S1 / S1	Well-drained	S1 / S1	Well-drained	S1 / S1	Imperfectly drained	S3 / S1
Rooting conditions (rc)								
Texture	Sandy loam	S3 / S3	Sandy loam	S3 / S3	Sandy loam	S3 / S3	Sandy loam	S3 / S3
Coarse material (%)	<15	S1 / S1	<15	S1 / S1	<15	S1 / S1	<15	S1 / S1
Soil depth (cm)	162	S1 / S1	165	S1 / S1	192	S1 / S1	169	S1 / S1
Nutrient retention (nr)								
Clay CEC (cmol)	2.14	S2 / S1	13.93	S2 / S1	20.17	S1 / S1	14.25	S2 / S1
Base saturation (%)	4.21	S3 / S1	14.68	S3 / S1	8.45	S3 / S1	7.18	S3 / S1
pH-H_2O	3.88	S3 / S1	4.16	S3 / S1	4.21	S3 / S1	3.97	S3 / S1
Organic-C (%)	4.35	S1 / S1	2.97	S1 / S1	3.35	S1 / S1	2.29	S1 / S1
Erosion hazard (eh)								
Slope (%)	0-8	S1 / S1	8-15	S2 / S1	25-40	S3 / S1	25-40	S3 / S1
Erosion (ton ha^{-1} $year^{-1}$)	27.01	S2 / S1	77.64	S2 / S1	109.75	S2 / S1	108.40	S2 / S1
Flooding hazard (fh)								
Inundation flood	F0	S1 / S1	F0	S1 / S1	F0	S1 / S1	F0	S1 / S1
Land preparation (lp)								
Surface rock (%)	<5	S1 / S1	<5	S1 / S1	<5	S1 / S1	<5	S1 / S1
Rock outcrops (%)	<5	S1 / S1	<5	S1 / S1	<5	S1 / S1	<5	S1 / S1
ALS/PLS	S3 wa,rc,nr / S3 wa,rc		S3 wa,rc,nr / S3 wa,rc		S3 wa,rc,nr,eh / S3 wa,rc		S3 wa,rc,nr,eh / S3 wa,rc	

Land characteristics	6-10 years									
	SMU-1		SMU-2		SMU-5		SMU-08		SMU-11	
	Data	ALS/PLS	Data	ALS/PLS	Data	ALS/PLS	Data	ALS/PLS	Data	ALS/PLS
Temperature (tc)										
Average temperature (°C)	19.36	S1 / S1	19.36	S1 / S1	19.36	S1 / S1	19.36	S1 / S1	19.36	S1 / S1
Altitude (m asl)	950-1250	S1 / S1	950-1250	S1 / S1	950-1250	S1 / S1	600-950	S1 / S1	600-950	S1 / S1
Water availability (wa)										
Rainfall (mm/year)	2536.30	S3 / S3	2536.30	S3 / S3	2536.30	S3 / S3	2536.30	S3 / S3	2536.30	S3 / S3
Oxygen availability (oa)										
Drainage	Well-drained	S1 / S1	Well-drained	S1 / S1	Well-drained	S1 / S1	Well-drained	S1 / S1	Imperfectly drained	S3 / S1
Rooting conditions (rc)										
Texture	Loamy sand	N / N	Sandy loam	S3 / S3	Sandy loam	S3 / S3	Sandy loam	S3 / S3	Sandy loam	S3 / S3
Coarse material (%)	< 15	S1 / S1	< 15	S1 / S1	< 15	S1 / S1	< 15	S1 / S1	< 15	S1 / S1
Soil depth (cm)	162	S1 / S1	162	S1 / S1	192	S1 / S1	142	S1 / S1	169	S1 / S1

Continue.

Table 4: Continuation.

Land characteristics	6-10 years									
	SMU-1		SMU-2		SMU-5		SMU-08		SMU-11	
	Data	ALS/PLS	Data	ALS/PLS	Data	ALS/PLS	Data	ALS/PLS	Data	ALS/PLS
Nutrient retention (nr)										
Clay CEC (cmol)	9.86	S2 / S1	11.31	S2 / S1	16.36	S1 / S1	8.08	S2 / S1	16.36	S2 / S1
Base saturation (%)	9.92	S3 / S1	25.69	S3 / S1	16.88	S3 / S1	32.92	S3 / S1	6.42	S3 / S1
$pH-H_2O$	4.10	S3 / S1	4.31	S3 / S1	4.35	S3 / S1	4.99	S3 / S1	4.18	S3 / S1
Organic-C (%)	2.38	S1 / S1	2.68	S1 / S1	3.92	S1 / S1	0.72	S3 / S1	2.31	S1 / S1
Erosion hazard (eh)										
Slope (%)	0-8	S1 / S1	8-15	S1 / S1	25-40	S3 / S1	0-8	S1 / S1	25-40	S3 / S1
Erosion (ton ha^{-1} $year^{-1}$)	18.66	S2 / S1	89.78	S2 / S1	124.42	S2 / S1	243.20	S2 / S1	381.66	S3 / S2
Flooding hazard (fh)										
Inundation flood	F0	S1 / S1	F0	S1 / S1	F0	S1 / S1	F0	S1 / S1	F0	S1 / S1
Land preparation (lp)										
Surface rock (%)	< 5	S1 / S1	< 5	S1 / S1	< 5	S1 / S1	< 5	S1 / S1	< 5	S1 / S1
Rock outcrops (%)	< 5	S1 / S1	< 5	S1 / S1	< 5	S1 / S1	< 5	S1 / S1	< 5	S1 / S1
ALS/PLS	N rc / N rc		S3 wa,rc,nr / S3 wa,rc		S3 wa,rc,nr,eh / S3 wa,rc		S3 wa,rc,nr / S3 wa,rc		S3 wa,oa,rc,nr,eh / S3 wa,rc	

Table 5: Regression test of land characteristics on the 100-seed dry weight and yielding of *C. arabica* plants at the age of 6-10 and 11-15 years.

Plant age	Yielding characters	Number of squares	df	Mean of squares	F	Sig
6-10	100-seed dry weight	16.272	9	1.808	0.574	0.792^{ns}
		31.518	10	3.152		
		47.790	19			
	Productivity	6533.441	9	725.938	26.318	0.000^{**}
		275.833	10	27.583		
		6809.274	19			
11-15	100-seed dry weight	62.747	9	6.972	2.060	0.138^{ns}
		33.843	10	3.384		
		96.590	19			
	Productivity	7066.673	9	785.186	0.198	0.989^{ns}
		39671.860	10	3967.186		
		46738.533	19			

Note: **Correlation is significant at the 0.01 levels (2-tailed). ns= not significant.

S content in coffee plant leaves. Marbun et al. (2020b) also added that soil fertility based on CEC, organic-C, total-P, and total-K showed that entisols were higher than other soil types (inceptisols and ultisols) and it had a linear relationship with *C. arabica* productivity in Humbang Hasundutan District, Indonesia.

The actual land suitability of *C. arabica* plants at the age of 6-10 and 11-15 years were classified as marginally suitable (S3), except for SMU-1 at the age of 11-15 years (not suitable/N) in Tarutung Subdistrict, North Tapanuli District (Table 4). The limiting factors found in both age groups of *C. arabica* plants include water availability (rainfall), rooting conditions (soil texture), nutrient retention (CEC, BS, organic-C, pH), and erosion hazard (slope). Among the limiting factors, rainfall and soil texture be unable to improve resulting in the potential land suitability was also similar to the actual, but the limiting factor is the water availability and rooting conditions. The limiting factor of water availability (rainfall) is one of the factors that affect the growth process and yield of *C. arabica* plants and their needs to a certain extent. According to the Ministry of Agriculture (2014) that *C. arabica* requires rainfall in the range of 1500-2000 mm year^{-1} and is classified as highly suitable. Other results showed the limiting factor of the rooting conditions, especially soil texture in both plant age groups dominant was sandy loam. It was caused by the sand fraction in all SMUs being higher compared to the clay and silt fraction (Table 1), resulting in inhibited root development and the uptake of nutrients and water by plants. This finding was supported by Gil et al. (2012) that soil texture can affect the movement and availability of nutrients and water. Chaudhari et al. (2013) reported that soil texture affects bulk density and supports plant yield. Other limiting factors such as nutrient retention (CEC, BS, organic-C, pH), and erosion hazard (slope) could be improved by adding organic matter, liming (dolomite, calcite), planting a cover crop, setting terraces, planting along contour lines. Cyamweshi et al. (2014) added that there was an increase in the exchangeable cations (Ca^{2+}, Mg^{2+}, and K^{+}) by 5.45; 1.86; and 3.69 cmol/kg, respectively, and significantly neutralized soil acidity in coffee plants due to liming. Lanamana and Fatima (2018) also found that contour planting and terracing were greater for reducing soil erosion than other soil conservation technologies.

In overall, productivity of *C. arabica* plants at the age of 6-10 years was significantly affected by land characteristics and based on the t-test showed that altitude, silt, and clay fractions significantly increased productivity (Tables 5-6). In contrast for 11-15 years. Regression equations at the age of 6-10 years showed that an increase in altitude, CEC, BS, and organic-C could increase the productivity of *C. arabica* plants (Table 7). It could be due to the average organic-C and CEC levels of soil at the age of 6-10 years being higher than at the age of 11-15 years (Table 2). This finding was supported by Rubiyo, Martono and Dani (2013) that coffee yield was influenced by the plant age and it had produced at

Table 6: The partial test of land characteristics on the 100-seed dry weight and productivity of *C. arabica* plants at the age of 6-10 and 11-15 years.

Yielding characters	Land characteristics	6-10 years		11-15 years	
		t-test	Sig	t-test	Sig
100-seed dry weight	(Constant)	-0.379	0.712	0.790	0.448
	Altitude	0.175	0.491^{ns}	0.294	0.775^{ns}
	Slope	0.576	0.577^{ns}	0.445	0.666^{ns}
	Silt	1.007	0.338^{ns}	-0.930	0.082^{ns}
	Clay	0.308	0.765^{ns}	1.790	0.104^{ns}
	CEC	-0.710	0.494^{ns}	-0.640	0.536^{ns}
	BS	-1.050	0.318^{ns}	-1.185	0.263^{ns}
	pH	1.076	0.307^{ns}	0.384	0.709^{ns}
	Organic-C	-0.087	0.933^{ns}	1.091	0.301^{ns}
Productivity	(Constant)	-6.597	0.000	0.352	0.732
	Altitude	2.573	0.028*	-0.166	0.872^{ns}
	Slope	-0.135	0.895^{ns}	-0.247	0.810^{ns}
	Silt	7.919	0.000**	-0.503	0.626^{ns}
	Clay	6.954	0.000**	0.670	0.518^{ns}
	CEC	0.218	0.832^{ns}	0.091	0.929^{ns}
	BS	0.019	0.986^{ns}	-0.168	0.870^{ns}
	pH	-0.318	0.757^{ns}	-0.440	0.669^{ns}
	Organic-C	1.534	0.156^{ns}	-0.437	0.672^{ns}

Note: * and **Correlation is significant at the 0.05 and 0.01 levels (2-tailed). ns= not significant.

Table 7: Regression equation of land characteristics on the yielding character of C. arabica at the age of 6-10 and 11-15 years.

Plant age	Yielding characters	Regression equation
6-10	100-seed dry weight	Y=-13.481+0.013AL+0.013SL+0.165SI+0.089CL-0.114CEC–0.135BS+2.364PH–0.065OC
	Productivity	Y=-693.577+0.136AL-0.025SL+3.837SI+5.952CL+ 0.103CEC+0.007BS-2.068PH+3.414OC
11-15	100-seed dry weight	Y=14.896+0.003AL+0.048SL-0.263SI+0.226CL-0.100CEC-0.059BS+0.850PH+0.604OC
	Productivity	Y=227.083+0.066AL-0.921SL-2.342SI+2.889CL+ 0.487CEC-0.286BS-33.356PH-8.272OC

Note: AL= altitude; SL= slope; SI= silt; CL= clay; CEC= cation exchange capacity; BS= base saturation; PH= soil pH; OC= organic-C.

the age of 4-5 years with a productive age of 20 years and its productivity was 0.45-0.50 tons ha^{-1} $year^{-1}$, but if managed intensively the productivity reaches 1.5-2.0 tons ha^{-1} $year^{-1}$. Anggraeni, Setiawan and Isyanto (2020) added that the plant age significantly affected coffee yield and it will an increasing annually from 6 to 15 years, and the maximum yield was found at 9 years old. Defrenet et al. (2016) reported that the ring width at the stem base of coffee plants significantly increased ($P< 0.001$) from 1-12 years old. De Bauw et al. (2016) found that a higher altitude can increase soil pH to be more acidic and significantly decrease the available-P, exch-K, exch-Ca, and exch-Mg. Siahaan et al. (2022) also reported that altitude was negatively correlated with N, K, C, and soil pH, but positively correlated with CEC, available-P, and *C. arabica* yield.

These findings prove that there are differences in the productivity of *C. arabica* plants at different age ranges. Even though the land suitability in the study were classified as marginal, it is necessary to increase the CEC, BS, and organic-C to support *C. arabica* yields. These findings provide information for *C. arabica* farmers to manage the exact nutrients in increasing production through soil ameliorants, balanced fertilization, liming, and other efforts.

5 CONCLUSION

The soil physicochemical characteristics in *C. arabica* at the age of 6-10 and 11-15 years in Tarutung Subdistrict, North Tapanuli District were classified as less fertile, dominantly sandy loam texture, and productivity at the age of 11-15 years was higher than 6-10 years. All SMUs at the ages of 6-10 and 11-15 years were classified as marginally suitable (S3), except SMU-1 at 11-15 years was not suitable (N). The productivity of *C. arabica* at the age of 6-10 years was significantly influenced by land characteristics such as altitude, silt, and clay fractions. The regression equation showed that an increase in altitude, CEC, BS, and organic-C can be increased the productivity of *C. arabica* plants at the age of 6-10 years. Efforts are needed to increase CEC, BS, and organic-C through the application of liming, biochar, manure, crop residue compost, and others to improve soil fertility in *C. arabica* growing areas.

6 AUTHORS CONTRIBUTION

PM and KT wrote the manuscript and performed the experiment; B and FNS supervised the experiment and co-work the manuscript, and; PM, KT, DRS, II review and approved the final version of the work; FNS, DRS, II, MS interviewed coffee farmers; PM, B, KT, FNS, DRS, II, MS conducted all statistical analyses.

7 REFERENCES

ANGGRAENI, Y.; SETIAWAN, I.; ISYANTO, A. Y. Factors affecting coffee production in Kertamandala Village, Panjalu District, Ciamis Regency. **Jurnal Ilmiah Mahasiswa Agroinfo Galuh**, 7(3):625-633, 2020.

CHAUDHARI, P. R. et al. Soil bulk density as related to soil texture, organic matter content and available total nutrients of coimbatore soil. **International Journal of Scientific and Research Publications**, 3(2):1-8, 2013.

CYAMWESHI, R. A. et al. Enhancing nutrient availability and coffee yield on acid soils of the Central Plateau of Southern Rwanda. **Global Journal of Agricultural Research**, 2(2):44-55, 2014.

DE BAUW, P. et al. Soil fertility gradients and production constraints for coffee and banana on volcanic mountain slopes in the East African Rift: A case study of Mt. Elgon. **Agriculture, Ecosystems & Environment**, 231:166-175, 2016.

DEFRENET, E. et al. Root biomass, turnover and net primary productivity of a coffee agroforestry system in Costa Rica: Effects of soil depth, shade trees, distance to row and coffee age. **Annals of Botany**, 118(4):833-851, 2016.

DJAENUDIN, D. et al. **Technical guidelines for land evaluation for agricultural commodities**. Indonesian Center for Agricultural Land Resources Research and Development. Bogor, Indonesia, 2011. 36p.

DORAN, J. W.; PARKIN, T. B. Defining and assessing soil quality. *In*: DORAN, J. W. et al. **Stewart Defining soil quality for a sustainable environment**. United States: Soil Science Society of America, v.35, p.1-21, 1994.

ESTRADA-HERRERA, I. R. et al. Soil quality indicators to evaluate soil fertility. **Agrociencia**, 51(8):813-831, 2017.

FARAH A. Coffee constituents. *In*: CHU, Y-F. **Coffee**: Emerging health benefits and disease prevention. United States: John Wiley & Sons, p. 21-58, 2012.

GIL, P. M. et al. Effect of soil water-to-air ratio on biomass and mineral nutrition of avocado trees. **Journal of Soil Science and Plant Nutrition**, 12(3):609-630, 2012.

INDONESIA SOIL RESEARCH INSTITUTE. **Chemical analysis of soil, plants, water and fertilizer**. Indonesia: Ministry of Agriculture, 2009. 246p.

INTERNATIONAL COFFEE ORGANIZATION. **Coffee consumption in East and Southeast Asia:** 2000-2018. 2018. Available in: <http://www.ico.org/prices/m1-exports.pdf>. Access in: July 31, 2023.

LANAMANA, W.; FATIMA, I. Effects of different land status on conservation land and income of upland rice farming in Mausambi Village, Maurole Subdistrict, Ende Regency. **Caraka Tani: Journal of Sustainable Agriculture**, 33(2):126-135, 2018.

MARBUN, P. et al. Classification, physicochemical, soil fertility, and relationship to *Coffee robusta* yield in soil map unit selected. **Coffee Science**, 15:e151818, 2020a.

MARBUN, P. et al. The classification, characteristics, and assessment of soil profile fertility on *Coffea arabica* productivity in North Sumatra. **Bulgarian Journal of Agricultural Science**, 26(3):622-632, 2020b.

MCCAULEY, A.; JONES, C.; OLSON-RUTS, K. Soil pH and organic matter. **Nutrient Management Module**, 8:1-12, 2017.

MINISTRY OF AGRICULTURE. **Good agriculture practices on coffee**. Indonesia: Directorate General of Estate Crops, Ministry of Agriculture, 2014. 72p.

MINISTRY OF TRADE. **Indonesia coffee speciality**. Warta Ekspor, 2018. p.1-20. Available in: <https://djpen.kemendag.go.id/app_frontend/admin/docs/publication/9321548126511.pdf>. Access in: July 31, 2023.

RUBIYO.; MARTONO, B.; DANI. **Assembling technology to increase production and quality of smallholder coffee plantations. Indonesia:** Indonesian Center for Estate Crops Research and Development, p.30-43, 2013.

SIAHAAN, A. S. et al. The correlation of elevation, soil chemical properties and yield of *Coffea arabica* L. in shaded conditions. **Pakistan Journal of Scientific and Industrial Research Series B: Biological Sciences**, 65(3):282-291, 2022.

SIHOMBING, F. N.; SUPRIANA, T.; AYU, S. F. Identifying the factors contributing to the volume of coffee export from North Sumatra to The United States, Malaysia, and Japan. **Caraka Tani: Journal of Sustainable Agriculture**, 36(1):83-96, 2021.

SITUMEANG, D. I. H.; MUTAALI, L. Identification of the influence of coffee commodities on the economic development of the community in Siborongborong District, North Tapanuli Regency. **Jurnal Bumi Indonesia**, 6(1):1-10, 2017.

SOUSA, J. S. et al. Relationship between coffee leaf analysis and soil chemical analysis. **Revista Brasileira de Ciência do Solo**, 42:e0170109, 2018.

STATISTICS INDONESIA. **Indonesian coffee statistics 2020.** Indonesia: Statistics Indonesia, 2020. 100p.

STATISTICS INDONESIA. **Exports of coffee by major countries of destination, 2000-2021**. Indonesia, 2021. Available in: <https://www.bps.go.id/statictable/2014/09/08/1014/ekspor-kopi-menurut-negara-tujuan-utama-2000-2021.html>. Access in: July 31, 2023.

STATISTICS OF SUMATERA UTARA. **Sumatera Utara Province in figures 2022.** Indonesia: Statistics of Sumatera Utara, 2022. 1072p.

STATISTICS OF TAPANULI UTARA. **Tapanuli Utara Regency in figures 2022.** Indonesia: Statistics of Tapanuli Utara, 2022. 433p.

SYS, C. et al. **Land evaluation. part III: crop requirements**. Belgium: Agricultural Publications, GADC, 1993. 191p.