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The classification, characteristics, and assessment of soil profile fertility on *Coffea arabica* productivity in North Sumatra

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Abstract

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There is a problem with low yield of *Coffea Arabica* in North Sumatra that is supposed to be caused by the low of soil fertility. The research was aimed to classification, characteristic, and assessment fertility of soil profile from the epipedon subgroup on *Coffea arabica* in North Sumatra Province. The investigation was conducted in Lintong Nihuta Subdistrict, Humbang Hasundutan District from July 2014 until June 2017 using the descriptive analytic method. The experiment began with collecting climate data, than making an overlay map, soil classification, soil characteristic and assessment fertility of the soil profile. The results were demonstrated in thirteen soil map units (SMU) in Lintong Nihuta Subdistrict, Humbang Hasundutan District – the widest result was found in SMU 6 of 37.55%. Soil classification showed that the first profile consisted of SMU 1, 2, 3, 4, 13 with the horizon Ap-A-B-C, the second profile-SMU 5, 9 with the horizon Ap-A-B-C, the third profile-SMU 6, 10, 11, 12 with the horizon Ap-Ah_1-Ah_2-C, the fourth profile-SMU 7 with the horizon Ap-Bt-C, and the fifth profile-SMU 8 with the horizon A-B-C. Soil classification resulted in three soil orders, including inceptisol found in the first, second, and fifth profile with 37.55%, entisol in the third profile with 54.08%, and ultisol in the fourth profile with 8.37%. The soil chemical characteristics of entisol and inceptisol were higher compared to ultisol. The soil physical characteristics showed granular and angular blocky structure that was very soft till hard consistency – from 1.04 to 1.42 $g.cm^{-3}$ bulk density and four types of texture including sandy loam, loamy sand, sandy clay loam, and sandy. Soil fertility based on cation exchange capacity, C-organic, P-total, and K-total showed entisol was higher compared to inceptisol and ultisol. A linear relationship with the highest productivity of *Coffea Arabica* found in entisol of 865.28 $kg.ha^{-1}.year^{-1}$, followed by inceptisol and ultisol of 834.56 and 747.52 $kg.ha^{-1}.year^{-1}$, respectively.

Keywords: Coffea arabica; overlay; soil classification; soil fertility; soil map unit; soil profile

Introduction

Coffea plant (*Coffee* sp.) is one of the genera in the Rubiaceae family with approximately 100 species, however only two, arabica and robusta, have an economic value. Coffea arabica has the ability to grow and produce at an altitude ranged from 1000 until 1500 m above sea level (MASL) and temperature between 18 until 21°C (DaMatta, 2004). International Coffee Organization (2016) reported the preferable zone to grow coffea is a location between 20° North *Latitude* (NL) and 20° South *Latitude (SL)*. Meanwhile, Indonesia is located on 5° NL and 10° SL and this means it has the potential for coffee plantation with most of the plants, especially arabica and robusta, found in provinces located between 0° and 10° SL such as South Sumatra, Lampung, Bali, and South Sulawesi as well as those located between the small area 0° to 5° NL including Aceh and North Sumatra. The country is the fourth major coffee-producing country in the world after Brazil, Vietnam, and Colombia. These four countries have been reported to be producing 63.48% of the world's coffee yield.

Directorate General of Estate Crops (2019) reported that Indonesia had 346 765 ha of *Coffea arabica* with 194 717 t yield in 2019. North Sumatra was found to be the second province with the widest area recorded as 70 546 ha after Aceh as well as the highest productivity at 0.828 tons.ha^{-1}. Plantation Agency of North Sumatra Province (2016) report showed the *Coffea arabica* has high economic value based on the 2.8 US$.kg^{-1} world market price recorded in March 2015 and approximately 40% increment to 4.02 US$.kg^{-1} in September of the same year. The type *Coffea arabica* specialty had selling value of 5.3 US$.kg^{-1} and it was higher of 30% compared to *Coffea arabica* commercial of 4.02 US$.kg^{-1}.

Statistics of Sumatera Utara (2018) reported that North Sumatra Province has 12 of 33 districts producing yields. Therefore, sequentially arranged based on the quantity they produced in 2018 from the highest to the lowest: North Tapanuli, Karo, Dairi, Humbang Hasundutan, Samosir, Toba Samosir, Simalungun, Mandailing Natal, South Tapanuli, Pakpak Bharat, Deli Serdang, and Langkat. Humbang Hasundutan District had the fourth highest with approximately 7067.36 t. Statistics of Humbang Hasundutan Regency (2018) found that Lintong Nihuta to be the second subdistrict to produce the highest yield with 1679.09 t or 23.76% and the productivity of 0.56 t.ha^{-1} in the district. This value was classified to be low compared to the 0.82 ton.ha^{-1} recorded for the province (Statistics of Sumatera Utara, 2018) and this was associated with low soil fertility in the area. According to Salima et al. (2012) planting *Coffea arabica* on a soil slope > 15% causes low conservation of soil and water, soil fertility, and shade management, and these further lead to low productivity. Marbun et al. (2019) classified the land in Lintong Nihuta Subdistrict of Humbang Hasundutan to be marginally suitable with limiting factor of soil fertility for the plant.

However, the soil classification based on epipedon until subgroup and the assessment fertility of soil profile has never been reported on *Coffea arabica* in Lintong Nihuta Subdistrict, Humbang Hasundutan District is based on the criteria of acidic upland soils in ASEAN region. Therefore, detailed assessment fertility of soil profile is needed because the low productivity of *Coffea arabica*. This research was aimed to soil classify from the epipedon until subgroup, soil characteristics, and assessment fertility of soil profile on *Coffea arabica* in North Sumatra Province.

Material and Methods

Yield Location of *Coffea arabica*

This research was conducted in the location producing *Coffea arabica* yield in Lintong Nihuta Subdistrict, Humbang Hasundutan District, North Sumatra Province, Indonesia which was situated in 2°13′-2°20′ N and 98°47′-98°57′ E with an altitude between 1200 until 1500 m above sea level (MASL). Data were collected on climate, overlay maps on soil types, altitude, and slope as well as soil classification, characteristics both physical and chemical, and soil fertility in July 2014 until June 2017.

Climate Data Collection

The climatic data include rainfall, temperature, and humidity for the last 18 years ranged from 1996 until 2013 that wer obtained from Badan Meteorologi, Klimatologi, dan Geofisika (BMKG) Sampali, Medan, Indonesia to represent the condition of the Soil Map Units (SMU) in Lintong Nihuta Subdistrict as shown in Table 1.

Table 1. Rainfall, temperature, and humidity data for the last 18 years in Lintong Nihuta Subdistrict, Humbang Hasundutan District, North Sumatra Province, Indonesia

Years	Climate Data		
	Rainfall, mm	Temperature,°C	Humidity, %
1996	166.75	19.78	84.33
1997	128.67	20.01	84.67
1998	150.75	20.46	82.67
1999	203.58	19.73	83.42
2000	126.67	19.85	82.92
2001	140.83	19.99	83.83
2002	173.58	20.17	83.25
2003	238.67	20.04	84.25
2004	244.42	20.01	83.08
2005	141.33	20.01	82.92
2006	170.50	20.11	83.58
2007	240.42	20.07	84.17
2008	239.33	19.86	85.67
2009	189.67	19.91	85.00
2010	157.08	20.16	84.83
2011	125.83	20.02	83.92
2012	145.92	19.78	85.58
2013	160.67	19.82	84.33
χ	174.70	19.99	84.02

Source: BMKG Sampali, Medan

Soil Profile Classification

The preliminary stage of the research involvedsurveying the establishment of the soil profile in the SMU based on the mapping overlay technique for the soil type, altitude, and slope using a 1: 25 000 scale, respectively. Furthermore, the morphology and characteristics of the soil profile were observed using reference books such as "Pedoman Pengamatan Tanah di Lapangan" by the Ministry of Agriculture (2017) and "Key to Soil Taxonomy" by Soil Survey Staff USDA (2014). The observation data such as landscape, macro, and microtopography as well as those related to the environment including the vegetation, land use, drainage, altitude, and geographical location were described in the profile form. The soil was also classified to determine its epipedon and subsuface horizons as well as other identifier properties such as the order, suborder, great, and subgroup.

Soil Characteristic (Physical and Chemical)

The soil characteristics were determined using samples from each horizon in the thirteen SMUs. Moreover, chemical data such as Cation Exchange Capacity (CEC) and Base Saturation (BS) were evaluated using NH_4OAc (pH 7) extraction method, C-organic used Walkley & Black method, soil pH involved H_2O, KCl, and NaF method, P-available by HCl extraction method, and salinity by platinum electrode method. The physical aspect involved the determination of the soil color using the Munsell Soil Color Chart, soil structure, soil consistency by the Atterberg method, soil texture by Hydrometer method, and bulk density used the sample ring. All the soil samples were analyzed at the Research and Technology Laboratory, Faculty of Agriculture, Universitas Sumatera Utara, Medan, Indonesia.

Soil Fertility

The soil profile fertility was assessed using main chemical characteristics such as CEC and base saturation while others include P-total, K-total, and C-organic. In overall, the chemical characteristics were evaluated using a parametric method while the soil profile fertility was based on the acidic upland soils in the ASEAN region by Dierolf et al. (2001).

Results and Discussion

Soil Map Unit (SMU)

The mapping overlay technique was conducted on the thirteen SMU with *Coffea arabica* in Lintong Nihuta Subdistrict of Humbang Hasundutan. The widest result was found to be SMU 6 with 37.55% and characterized by humitropepts soil type, 0 to 4% slope, and 1400 to 1500 m above sea level (MASL) altitude as shown in Figure 1. The second widest result was found in SMU 3 at 15.34% with similar soil type and slope to SMU 6 however the altitude ranged from 1300 to 1400 MASL. The dominant altitude required for *Coffea arabica* in the Lintong Nihuta Subdistrict, Humbang Hasundutan District ranged from 1300 and 1500 MASL. The productivity of *Coffea arabica* could be influenced by the altitude and slope of the soil. The altitude was from 1300 to 1400 MASL and the slope - from 0 to 4% having the highest productivity of *Coffea arabica* was found in the SMU 11 – 983.04 $kg.ha^{-1}.year^{-1}$, followed by SMU 3 of 972.80 $kg.ha^{-1}.year^{-1}$ (Table 6). Indonesian Center for Estates Crops Research and Development (2010) stated that the *Coffea arabica* grow with quality flavors at the altitude > 1000 MASL. Sihite et al. (2015) also found a positive linear correlation between altitude and 32.60% beans weight of *Coffea arabica* in Lintong Nihuta Subdistrict. Ping et al. (2013); Saeed et al. (2014) stated that the altitude can affect temperature and rainfall. Sari et al. (2013); Van Beusekom et al. (2015) stated that the greater altitude could cause lower temperature, higher rainfall, and increase the soil fertility. Somporn et al. (2012) stated that the changes in the temperature and rainfall could affect the process of decomposition the organic matter and the composition of the anions and cations in the soil as well as the process of fruit ripening. Supriadi et al. (2016) stated that the altitude positively affected several properties of the soil chemical and the beans quality of *Coffea arabica* in the upland Garut. Higher altitude increased the soil pH, C-organic, N-total, sodium, CEC, the percentage of natural beans and the 100-beans weight of *Coffea arabica*.

Land Classification of *Coffea arabica* Plants

The epipedon and subsurface horizons as well as other identifier properties such as order, suborder, great, and subgroup in thirteen SMU of *Coffea arabica* in Lintong Nihuta Subdistrict, Humbang Hasundutan District were also determined and the results showed in Tables 2 and 3. Five representative soil profiles were obtained in study location and the first profile was found in SMUs 1, 2, 3, 4, and 13 with Ap-A-B-C horizon at 3652.34 ha, the second profile in SMUs 5 and 9 with the Ap-A-B-C horizon at 1659.56 ha, the third profile in SMUs 6, 10, 11, and 12 with Ap-Ah_1-Ah_2-C horizon at 8700.33 ha, the fourth profile in SMU 7 with Ap-Bt-C horizon at 1347.11 ha, and the fifth profile in SMU 8 with the A-B-C horizon at 730.67 ha. In addition, it was found in three soils with *Coffea arabica* in Lintong Nihuta Subdistrict, Humbang Hasundutan District, including inceptisol of 37.55%, entisol of 54.08%, and ultisol of 8.37%.

The thirteen SMUs found in the first, second, and fifth profiles had identical soil order, suborder, and great group (inceptisol, udept, and humudept) however different sub-

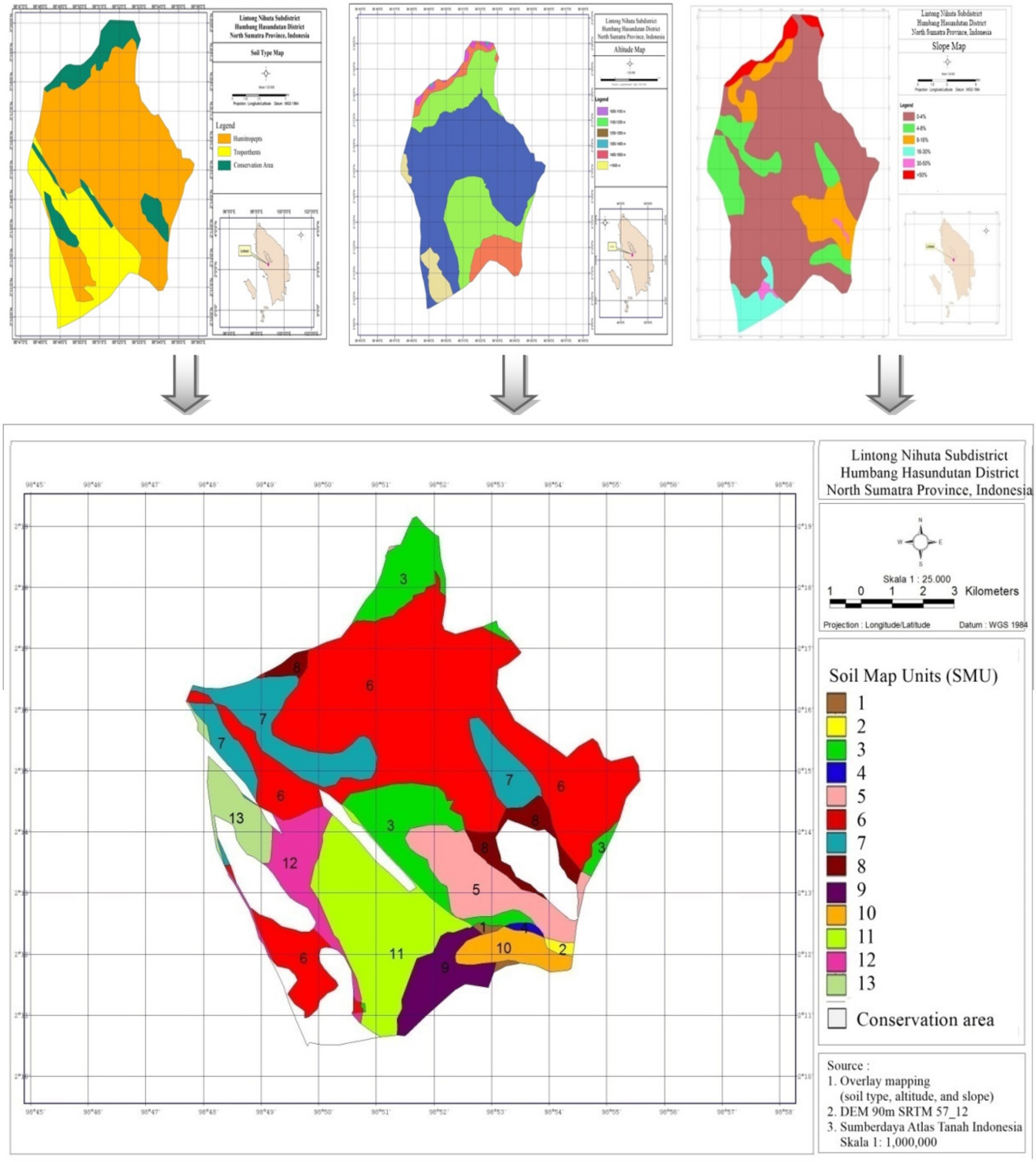

Fig. 1. The SMU of *Coffea arabica* using the mapping overlay technique between soil type, altitude, and slope in Lintong Nihuta Subdistrict, Humbang Hasundutan District, North Sumatra.

Table 2. Determination of the epipedon horizons, the subsurface horizons, the other identifier properties in the thirteen SMU of *Coffea arabica* in Lintong Nihuta Subdistrict, Humbang Hasundutan District

SMUs	Soil Profiles	Epipedon Horizons	Subsurface Horizons	Other Identifier Properties
1, 2, 3, 4, 13	1	Including umbric epipedon, because of the surface position, the structure is un-massive (granular), the humid state value of 3, C-organic > 0.6%, (2.33%); base saturation < 50% (6.42%) and soil moist > 3 months.	Including the cambic horizon, because it has a sandy texture, the horizon thickness >15 cm, the horizon did not have aquicconditions at the depth of 50 cm from the soil surface, does not occur clay illuviation, and it is not part of the Ap horizon.	In all SMU had the udic soil humidityregime because the soil never dries within 90 days (cumulative) is more 90 days, or rainfall data, the average wet months of 7 to 10 in the year or 210 days up to 300 days (cumulative).
5, 9	2	Including umbric epipedon, because of the surface position, the structure is un-massive (granular), the humid state value of 3, C-organic >0.6% (2.33%), base saturation <50% (6.42%) and the soil moist >3 months.	Including the cambic horizon, because it had the sandy texture, the horizon thickness >15 cm, the horizon did not have aquicconditions at the depth of 50 cm from the soil surface, does not occur clay illuviation, and not part of the Ap horizon.	
6, 10, 11, 12	3	Including ochric epipedon, because the soil color with the value and chromaare ≥ 3 of 4 and 3, narrow to be included as umbric epipedon.	It does not have the subsurface horizon because the horizon had undeveloped.	
7	4	Including umbric epipedon, because of the surface position, the structure is un-massive (granular), C-organic > 0.6%, (1.95%), base saturation < 50%, (24.46%), the soil color with valueand chroma (moist condition) ≤ 3, namely: 3 and 2, the soil moist > 3 months.	Including argillic horizon, because had clay illuviationin B horizon by 1.2-fold or more, the Ap horizon of 14.88% and the B horizon of 32.88%.	
8	5	Including umbric epipedon, because of the surface position, the structure is un-massive (granular), C-organic > 0.6%, (1.95%), base saturation < 50% (24.46%), the soil color with value and chroma (moist condition) ≤ 3, namely: 3 and 2, the soil moist > 3 months.	Including the cambic horizon, because it had the sandy texture, the horizon thickness > 15 cm, the horizon did not have aquicconditions at the depth of 50 cm from the soil surface, does not occur clay illuviation, and not part of the Ap horizon.	

groups including typic, fluventic, and cumulic humudepts, respectively. Moreover, the third profile had entisol order, orthent suborder, udorthent great group, and udorthent typic subgroup while the fourth profile had ultisol, humult, haplohumult, and haplohumult typic, respectively. It was found that the *Coffea arabica* in Lintong Nihuta Subdistrict, Humbang Hasundutan District are dominant in inceptisol and entisol compared to the ultisol. The inceptisol and entisol orders were found to be more dominant with 865.28 and 834.56 kg.ha^{-1}.year^{-1} productivity compared to the ultisol with 747.52 kg.ha^{-1}.year^{-1} as shown in Table 6. In addition, the C-organic values of the inceptisol and entisol were higher ranging from 0.38 to 3.30% and from 0.68 to 3.56%, respectively compared to the ultisol ranged from 0.45 to 2.11% as shown in Table 5. According to Núñez et al. (2011) reported that 98.6% of the soil cultivated with *Coffea arabica* is with soil types of the inceptisol and entisol in Barahona Province, Dominican Republic. Sousa et al. (2018) stated that an increase in soil organic matter hasapositive influence on coffee yield. Silva & Mendonça (2007); Schmidt et al. (2011) also stated that the soil organic matter could improve the physical, chemical, biological value of soil and the biogeochemical cycle processes of N, P, S, as well as the other nutrients.

Soil Characteristics of *Coffea arabica* Plants

The physical and chemical characteristics results of the soil profile in thirteen SMU of *Coffea arabica* in Lintong Nihuta Subdistrict, Humbang Hasundutan District can be presented in Tables 4 and 5. In overall, soil physics characteristics of the soil profile in thirteen SMU of *Coffea arabica* in Lintong Nihuta Subdistrict, Humbang Hasundutan District had the soil structures of granular until angular blocky, soil consistency of very soft until hard, bulk density ranged from 1.04 to 1.42 g.cm^{-3}, and four type's texture including san-

Table 3. Determination of the order, suborder, great group, subgroup in the thirteen SMU of *Coffea arabica* in Lintong Nihuta Subdistrict, Humbang Hasundutan District

SMUs	Soil Profiles	Order	Suborder	Great group	Subgroup
1, 2, 3, 4, 13	1	Including Inceptisol, because it had an umbric epipedon and had the sub-surface horizon of cambic.	Including udepts, because it had other characteristics of Inceptisol with the udic soil moisture regime; the soil has never been dry for 90 days.year^{-1} (cumulative).	Including humudepts because it had the umbric epipedon.	Including typichumudeptsis other humudepts
5, 9	2	Including Inceptisol, because it had the umbric epipedon and had the sub-surface horizon of cambic.	Including udepts, because it had other characteristics of Inceptisol with the udic soil moisture regime, the soil has never been dry for 90 days.year^{-1} (cumulative).	Including humudepts because it had the umbric epipedon.	Including fluventichumud-ept, because it had a slope <25%, had the C-organic >0.2% and has decreased C-organic systematically at the depth of 25 to 125 cm.
6, 10, 11, 12	3	Including Entisol,because it does not had the subsurface horizon and had the unde-veloped horizon.	Including orthents, because it had other characteristicsof Entisol.	Including udorthent, because it had the other characteristics of orthents.	Including typicudorthent, because it had the others characteristic of udorthents.
7	4	Including Ultisol, because it had an argillic horizon.	Including humults, because it had the organic matter of 0.9 above 15 cm of the argillic horizon.	Including haplohumults, because it had other charac-teristics of humult.	Including typic haplohu-mult, because it had other characteristics of haplohu-mult.
8	5	Including Inceptisol, because it had the umbric epipedon and had the sub-surface horizon of cambic.	Including udept, because it had other characteristics of Inceptisol with the udicsoil moisture regime, the soil has never been dry for 90 days.year^{-1} (cumulative).	Including humudepts because it had the umbric epipedon.	Including cumulichumudept because it was located on the slope < 25%, had the umbric epipedon thick > 50 cm of 77 cm, it had the C-organic of 0.2% or more at the depth of 125 cm from the surface of mineral soil, and it had the contact of densic, illitic, or paralithic, has decrease un-systemati-cally in C-organic between depth of 25 to 125 cm in below the surface

dy loam, loamy sand, sandy clay loamy, and sandy. The soil physics characteristics in thirteen SMU of *Coffea arabica* had the soil structures; consistency, bulk density, and texture are different for each soil profile. It was showed that the soil physics characteristics in Lintong Nihuta Subdistrict, Humbang Hasundutan District can indirectly affect on the yield of *Coffea arabica*. According to Avelino et al. (2002) reported that the texture and acidity of the soil could be affected the quality of coffee beans.

The results on the soil chemical characteristics found inceptisol in the first, second and fifth profiles with soil pH recorded of 3.84 to 5.72 and classified as very acidic to slightly acidic, the CEC of 10.77 to 28.75 me/100 g and classified as moderate to high, C-organic of 0.38 to 3.30% and classified as very low to high, base saturation of 4.31 to 40.23% and classified as very low to low, and the P-available of 3.13 to 20.60 ppm and classified as very low to low. The third profile contained entisol with soil pH of 5.06 to 5.98 and classified as acidic to slightly acidic, CEC of 11.43 to 21.42 me/100 g and classified as low to moderate, C-organic of 0.68 to 3.56% and classified as very low to high, base saturation of 6.82 to 21.99% and classified as very low to low, and P-available of 4.33 to 7.01 ppm and classified as very low. The fourth profile had ultisol with soil pH ranged from 4.65 to 5.52 and classified as acidic to slightly acidic, CEC of 11.43 to 12.88 me/100 g and classified as low, C-organic of 0.45 to 2.11% and classified as very low to moderate, base saturation of 16.07 to 36.68% and classified as very low to low, and P-available of 3.28 to 7.01 ppm and classified as very low.

Table 4. Soil physics characteristics of the soil profile in the thirteen SMU of *Coffea arabica* in Lintong Nihuta Subdistrict, Humbang Hasundutan District

Soil Profile	Horizons	Depth, cm	Soil Color	Soil Structures	Soil Consistency	Texture Fraction, %			Soil Texture	BD, g.cm^{-3}
						Sand	Silt	Clay		
Profile 1 (SMU 1, 2, 3, 4, 13)	Ap	0-30	10YR 3/2	G	S	80.56	11.28	8.16	LS	1.09
	A	30-65	10YR 2/1	G	VS	74.56	17.28	8.16	SL	1.12
	B	65-113	10YR 7/6	G	VS	92.56	2.00	5.44	Sa	1.04
	C	113-150	10YR 7/1	G	VS	86.20	6.00	7.80	LS	1.10
Profile 2 (SMU 5, 9)	Ap	0-21	10YR 3/2	G	S	68.56	21.28	10.16	SL	1.15
	A	21-43	10YR 3/6	G	S	80.56	11.28	8.16	LS	1.04
	B	43-88	10YR 4/6	G	S	83.84	8.36	7.80	LS	1.16
	C	88-150	10YR 6/6	G	S	66.20	16.00	17.80	SL	1.18
Profile 3 (SMU 6, 10, 11, 12)	Ap	0-29	10YR 4/2	G	VS	74.20	18.00	7.80	SL	1.19
	Ah_1	29-75	10YR 4/3	G	S	65.84	22.58	8.88	SL	1.22
	Ah_2	75-100	10YR 3/3	B	SH	77.84	16.00	6.16	SL	1.24
	C	100-150	10YR 7/6	B	S	87.84	6.00	6.16	LS	1.22
Profile 4 (SMU 7)	Ap	0-60	10YR 3/2	G	S	70.20	14.92	14.88	SL	1.20
	Bt	60-80	10YR 3/4	G	S	47.84	19.28	32.88	SCL	1.30
	C	80-150	2.5YR 7/3	SB	H	47.84	20.00	32.16	SCL	1.42
Profile 5 (SMU 8)	A	0-77	10YR 3/4	G	S	67.84	23.28	8.88	SL	1.18
	B	77-132	10YR 3/6	G	SH	65.84	26.00	8.16	SL	1.21
	C	132-150	2.5Y 4/3	G	SH	57.84	14.00	28.16	SL	1.26

Note: Soil Structures (G = granular; B = blocky; SB = subangular blocky), Soil Consistency (VS = very soft; S = soft; SH = slightly hard; H = hard), Soil Texture (SL = sandy loam; LS = loamy sand; SCL = sandy clay loam; Sa = sandy)

The chemical characteristics of entisol in profile 3 and inceptisol in profiles 1, 2, and 5 were higher compared to ultisol in profile 4. It was evidenced by the highest C-organic and CEC values obtained for entisol of 3.56% and 21.42 me/100 g and inceptisol of 3.30% and 28.75 me/100 g compared to ultisol 2.11% and 12.88 me/100 g. The higher C-organic and CEC content indicates better soil fertility due to their ability to exchange anions and cations absorbed by *Coffea arabica* to increase yield. It was proved the C-organic and CEC content in entisol had average productivity of *Coffea arabica* in Lintong Nihuta Subdistrict, Humbang Hasundutan District of 865.28 kg.ha^{-1}.year^{-1} and followed by inceptisol of 834.56 kg.ha^{-1}.year^{-1} and the lowest productivity was found in ultisol of 747.52 kg.ha^{-1}.year^{-1} as shown in Table 6. According to McCauley et al. (2017) stated that the soil organic matter had more functions including nutrient retention, aggregation, and also serve as the main indicators of the soil quality. Moreover, the cation and anion exchange capacity were determined by the particle charge and soil organic matter,because a higher soil organic matter increases the cation exchange capacity (CEC) capable of bind more cations such as calcium or potassium and also produce greater buffering capacity. Sousa et al. (2018) stated that the soil organic matter significantly increased the content of N-total and sulfur in the leaves of coffee plants from Minas Gerais. Kufa (2011) and Kilambo et al. (2015) stated that the organic colloids had higher cation absorption compared to clay colloids with the result that the higher organic matter can increase the soil CEC value.

Soil Fertility and Productivity of *Coffea arabica*

The assessment of soil fertility and productivity of *Coffea arabica* in Lintong Nihuta Subdistrict, Humbang Hasundutan District are presented in Table 6. The results showed that the soil fertility of inceptisol was classified as very low until low, whereas the order of entisol and ultisol were classified as low.

Based on the main soil chemical characteristics, the highest CEC was found in SMU 12 of entisol and the highest base saturation was found in SMU 3 of inceptisol amounted to 38.96 me/100 g and 15.71%, respectively. Based on the other soil chemical characteristics showed that the highest C-organic, P-total, and K-total was found in entisol of 5.31%, 0.16%, and 0.40%, respectively and followed by inceptisol and ultisol. It was linear with the highest productivity of *Coffea arabica* was found in entisol of 865.28 kg.ha^{-1}.

Table 5. Soil chemical characteristics of the soil profile in the thirteen SMU of *Coffea arabica* in Lintong Nihuta Subdistrict, Humbang Hasundutan District

Soil Profile	Horizons	Depth, cm	Soil pH			CEC, me/100g	C-organic, %	EC, dS/m
			H_2O	KCl	NaF			
Profile 1 (SMU 1, 2, 3, 4, 13)	Ap	0-30	5.72 (SlA)	4.66	11.21	27.31 (H)	2.33 (M)	0.45 (VL)
	A	30-65	5.60 (SlA)	4.56	11.22	18.54 (M)	3.30 (H)	1.70 (L)
	B	65-113	5.54 (SlA)	4.72	11.23	28.75 (H)	1.80 (L)	0.45 (VL)
	C	113-150	5.50 (SlA)	5.11	11.38	18.20 (M)	1.71 (L)	0.30 (VL)
Profile 2 (SMU 5, 9)	Ap	0-21	5.46 (A)	4.73	10.97	28.19 (H)	2.75 (M)	1.45 (L)
	A	21-43	5.48 (A)	4.78	11.33	22.09 (M)	1.78 (L)	0.35 (VL)
	B	43-88	5.38 (A)	5.02	11.34	11.66 (L)	1.53 (L)	1.30 (L)
	C	88-150	5.72 (SlA)	4.62	11.27	10.77 (L)	1.11 (L)	0.30 (VL)
Profile 3 (SMU 6, 10, 11, 12)	Ap	0-29	5.98 (SlA)	4.42	10.96	18.87 (M)	3.56 (H)	1.30 (L)
	Ah_1	29-75	5.06 (A)	4.60	11.08	21.42 (M)	2.78 (M)	0.40 (VL)
	Ah_2	75-100	5.72 (SlA)	4.43	11.03	20.98 (M)	2.85 (M)	0.35 (VL)
	C	100-150	5.67 (SlA)	4.84	11.39	11.43 (L)	0.68 (VL)	0.25 (VL)
Profile 4 (SMU 7)	Ap	0-60	5.17 (A)	3.63	11.20	12.88 (L)	1.95 (L)	0.25 (VL)
	Bt	60-80	4.65 (A)	3.61	11.10	11.43 (L)	0.45 (VL)	0.60 (VL)
	C	80-150	5.52 (SlA)	3.62	11.31	12.21 (L)	2.11 (M)	0.85 (VL)
Profile 5 (SMU 8)	A	0-77	3.84 (SoA)	3.93	11.40	16.21 (L)	1.65 (L)	0.30 (VL)
	B	77-132	5.41 (A)	4.13	11.34	17.09 (M)	1.99 (L)	0.30 (VL)
	C	132-150	5.27 (A)	3.58	11.51	14.43 (L)	0.38 (VL)	0.35 (VL)

Note: Soil pH H_2O (strongly acid/SoA < 4.5; acid/A= 4.5-5.5; slightly acid/SlA= 5.5-6.5; neutral/N= 6.6-7.5; slightly alkaline/SAl= 7.6-8.5; alkaline/Al >8.5); CEC (very low/VL < 5 me/100 g; low/L= 5-16 me/100 g; moderate/M= 17-24 me/100 g; high/H= 25-40 me/100 me/100 g; very high/VH > 40 me/100 g); C-organic (very low/VL < 1%; low/L= 1-2%; moderate/M= 2.01-3%; high/H= 3.01-5%; very high/VH > 5%); salinity (very low/VL < 1 dS/m; low/L= 1-2 dS/m; moderate/M= 2-3 dS/m; high/H= 3-4 dS/m; very high/VH > 4 dS/m) (Soil Research Institute, 2009)

Soil Profile	Horizons	Depth (cm)	Exchangeable Cations, me/100g				Base Saturation, %	P-available, ppm
			Ca	Mg	K	Na		
Profile 1 (SMU 1, 2, 3, 4, 13)	Ap	0-30	0.97 (VL)	0.29 (VL)	0.31 (L)	0.40 (M)	6.42 (VL)	5.91 (VL)
	A	30-65	0.29 (VL)	0.29 (VL)	0.01 (VL)	0.51 (M)	5.94 (VL)	4.78 (VL)
	B	65-113	1.92 (VL)	0.16 (VL)	0.33 (L)	0.31 (L)	9.45 (VL)	6.27 (VL)
	C	113-150	0.41 (VL)	0.10 (VL)	0.02 (VL)	0.37 (L)	4.91 (VL)	15.07 (L)
Profile 2 (SMU 5, 9)	Ap	0-21	0.20 (VL)	1.42 (M)	0.27 (L)	0.28 (L)	7.68 (VL)	5.82 (VL)
	A	21-43	0.11 (VL)	0.44 (L)	0.03 (VL)	0.36 (L)	4.31 (VL)	7.76 (VL)
	B	43-88	0.22 (VL)	1.13 (M)	0.17 (L)	0.25 (L)	15.24 (VL)	16.87 (L)
	C	88-150	1.67 (VL)	2.12 (H)	0.21 (L)	0.33 (L)	40.23 (L)	20.60 (L)
Profile 3 (SMU 6, 10, 11, 12)	Ap	0-29	2.66 (L)	0.90 (L)	0.12 (L)	0.46 (M)	21.99 (L)	5.67 (VL)
	Ah_1	29-75	0.92 (VL)	0.08 (VL)	0.03 (VL)	0.43 (M)	6.82 (VL)	4.33 (VL)
	Ah_2	75-100	0.86 (VL)	0.81 (L)	0.03 (VL)	0.53 (M)	10.62 (VL)	6.27 (VL)
	C	100-150	0.44 (VL)	0.18 (VL)	0.24 (L)	0.36 (L)	10.70 (VL)	7.01 (VL)
Profile 4 (SMU 7)	Ap	0-60	1.74 (VL)	0.97 (L)	0.15 (L)	0.29 (L)	24.46 (L)	7.01 (VL)
	Bt	60-80	2.66 (L)	0.66 (L)	0.41 (M)	0.46 (M)	36.68 (L)	3.73 (VL)
	C	80-150	0.60 (VL)	0.71 (L)	0.22 (L)	0.44 (M)	16.07 (VL)	3.28 (VL)
Profile 5 (SMU 8)	A	0-77	0.52 (VL)	0.16 (VL)	0.02 (VL)	0.32 (L)	6.32 (VL)	4.75 (VL)
	B	77-132	1.74 (VL)	0.15 (VL)	0.05 (VL)	0.29 (L)	13.08 (VL)	4.48 (VL)
	C	132-150	1.11 (VL)	0.66 (L)	0.08 (VL)	0.46 (M)	16.05 (VL)	3.13 (VL)

Note: base saturation (very low/VL < 20%; low/L = 20–40%; moderate/M = 41–60%; high/H = 61–80%; very high/VH > 80%); P–available (very low/VL < 15 ppm; low/L= 15–20 ppm; moderate/M= 21–40 ppm; high/H = 41–60 ppm; very high/VH > 60 ppm); Ca–dd (very low/VL < 2 me/100 g; low/L = 2–5 me/100 g; moderate/M = 6–10 me/100 g; high/H = 11–20 me/100 g; very high/VH > 20 me/100 g); Mg–dd (very low/VL < 0.3 me/100 g; low/L = 0.4–1 me/100 g; moderate/M = 1.1–2 me/100 g; high/H = 2.1–8 me/100 g; very high/VH > 8 me/100 g); K–dd (very low/VL < 0.1 me/100 g; low/L= 0.1–0.3 me/100 g; moderate/M = 0.4–0.5 me/100 g; high/H = 0.6–1 me/100 g; very high/VH > 1 me/100 g); Na–dd (very low/VL < 0.1 me/100 g; low/L= 0.1–0.3 me/100 g; moderate/M = 0.4–0.7 me/100 g; high/H = 0.8–1 me/100 g; very high/VH > 1 me/100 g) (Soil Research Institute, 2009)

Table 6. Soil fertility assessment and productivity of *Coffea arabica* based on Soil Map Unit (SMU) in Lintong Nihuta Subdistrict, Humbang Hasundutan District

Soil Orders	Subgroups	SMU	CEC, me/100g	Base Saturation, %	P-total, %	K-total, %	C-organic, %	Soil Fertility Quality	Productivity, kg.ha^{-1}.year^{-1}
Inceptisol	Cumulic Humudept	SMU 8	16.34 (L)	8.03 (VL)	0.02 (VL)	0.40 (VH)	1.68 (L)	VL	773.12
	Fluventic Humudept	SMU 5	18.56 (M)	15.20 (VL)	0.12 (VH)	0.23 (VH)	1.85 (L)	L	906.24
		SMU 9	29.79 (H)	5.34 (VL)	0.08 (H)	0.28 (VH)	2.53 (M)	L	819.20
	Typic Humudept	SMU 1	21.87 (M)	6.87 (VL)	0.11 (VH)	0.36 (VH)	2.45 (M)	L	716.80
		SMU 2	22.24 (M)	9.82 (VL)	0.13 (VH)	0.21 (VH)	1.86 (L)	L	665.60
		SMU 3	14.62 (L)	15.71 (VL)	0.08 (H)	0.18 (H)	1.96 (L)	VL	972.80
		SMU 4	23.03 (M)	4.05 (VL)	0.08 (H)	0.29 (VH)	1.64 (L)	L	952.32
		SMU 13	35.10 (H)	10.75 (VL)	0.05 (L)	0.39 (VH)	0.72 (VL)	VL	870.40
Entisol	Typic Udorthent	SMU 6	19.16 (M)	13.44 (VL)	0.08 (H)	0.40 (VH)	3.00 (M)	L	768.00
		SMU 10	32.01 (H)	7.00 (VL)	0.13 (VH)	0.22 (VH)	1.81 (L)	L	788.48
		SMU 11	32.03 (H)	3.79 (VL)	0.12 (VH)	0.19 (H)	5.31 (VH)	L	983.04
		SMU 12	38.96 (H)	3.21 (VL)	0.16 (VH)	0.13 (H)	2.26 (M)	L	921.60
Ultisol	Typic Haplohumult	SMU 7	12.55 (L)	24.10 (L)	0.06 (L)	0.34 (VH)	1.80 (L)	L	747.52

Note: CEC (very low/VL< 5 me/100 g; low/L = 5–16 me/100 g; moderate/M = 17–24 me/100 g; high/H = 25–40 me/100 me/100 g; very high/VH > 40 me/100 g); base saturation (very low/VL< 20%; low/L= 20–40%; moderate/M = 41–60%; high/H = 61–80%; very high/VH > 80%); P–total (very low/VL < 0.03%; low/L = 0.03–0.06%; moderate/M = 0.06–0.079%; high/H = 0.08–0.10%; very high/VH > 0.10%), K–total (very low/VL < 0.03%; low/L = 0.03–0.06%; moderate/M = 0.07–0.11%; high/H = 0.12–0.20%; very high/VH > 0.20%), C–organic (very low/VL< 1%; low/L= 1–2%; moderate/M = 2.01–3%; high/H = 3.01–5%; very high/VH > 5%) (Soil Research Institute, 2009). Soil fertility quality (very low = VL; low = L) adopted from Dierolf et al. (2001)

year^{-1} and followed by inceptisol and ultisol of 834.56 and 747.52 kg.ha^{-1}.year^{-1}, respectively. It was caused the high C-organic in entisol could be increased the soil pH, CEC and base saturation such as Ca, K, Mg, Na with the result that the nutrients absorbed in soil colloids can available for plants. According to Silva & Mendonca (2007); Tiecher et al. (2012); Zandonadi et al. (2014) stated that the organic matter had the surface charge that contributes to increasing soil cation exchange capacity (CEC) and regulates the availability of several nutrients, especially in Cerrado, Brazil whereas had the high weathering rate. Malavolta et al. (1979); Chaves et al. (1991) stated that the linear relationship and significance between an increase in the Ca-exchangeable content in the soil and an increase in coffee bean yield. Clemente et al. (2013) stated that the K nutrient content had the quadratic response to growth, seed size and bean yield of coffee.

Based on the soil fertility assessment of *Coffea arabica* in Lintong Nihuta Subdistrict, Humbang Hasundutan District, North Sumatra Province, Indonesia were classified as very low until low, with the result that efforts are needed to increase soil fertility through by input program of organic matter such as the giving of manure fertilizer, organic fertilizer, and others. In addition, it was recommended to smallholders of *Coffea arabica* in the location with make the “Rorak” technology in transversely between plants with the size around of 20 cm and mature leaves of coffee plants that can be functioned as organic matter. It is expected that an increase the C-organic caused by the Rorak will slowly affect the increase of the CEC and base saturation, with the result that to increase the absorption of macro- and micro-nutrients for *Coffea arabica* and long-term will affect the process of growth, quality (flavor), and yield of *Coffea arabica*. Therefore, domestic coffee needs could be fulfilled and exported.

Conclusions

The mapping overlay of *Coffea arabica* in Lintong Nihuta Subdistrict, Humbang Hasundutan District, North Sumatra Province, Indonesia were resulted in thirteen Soil Map Unit (SMU) and the widest was found in SMU 6 of 37.55% compared to other SMU. Soil classification resulted the five profiles were included the first profile consisted of SMU 1, 2, 3, 4, 13 with the horizon Ap-A-B-C, the second profile consisted of SMU 5, 9 with the horizon Ap-A-B-C, the third profile consisted of SMU 6, 10, 11, 12 with the horizon Ap-Ah_1-Ah_2-C, the fourth profile consisted of SMU 7 with the horizon Ap-Bt-C, and the fifth profile consisted of SMU 8 with the horizon A-B-C. Three soil orders were observed including inceptisol found in the first, second, and fifth profiles of 37.55%, entisol discovered in the third profile of 54.08%, and ultisol found in the fourth profile of 8.37%. In over all, the chemical characteristics of entisol and inceptisol are greater compared to ultisol. Furthermore, the physical characteristics of the soil profiles showed the granular until angular blocky structure, very soft until hard consistency, 1.04 to 1.42 g.cm^{-3} bulk density, and four types of texture including sandy loam, loamy sand, sandy clay loamy, and sandy. The soil fertility was assessed based on the CEC, C-organic, P-total, and K-total showed that entisol was higher compared to inceptisol and ultisol. A linear relationship with the highest productivity of *Coffea arabica* in sequence were found in entisol of 865.28 kg.ha^{-1}.year^{-1}, inceptisol of 834.56 kg.ha^{-1}.year^{-1} and ultisol of 747.52 kg.ha^{-1}.year^{-1}.

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