CORRELATION OF ELEVATION, SOIL CHEMICAL PROPERTIES AND YIELD OF COFFEE ARABICA GROWN IN SHADED AND UNSHADED CONDITION

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The present study analysed the correlation between altitude, soil chemical properties, and shade on Arabica coffee yields in Humbang Hasundutan Regency, North Sumatra, Indonesia. The research method of purposive sampling was applied. Both topsoil and subsoil samples were analysed for soil acidity (pH), the level of soil carbon (C), total nitrogen (N), P_2O_5, potassium (K), and cation exchange capacity (CEC). The coffee growth variables observed included productive branches, number of bunches, number of fruit/bunches, diameter of canopy and yield. The outcome quality variables were physical quality and taste. Data on soil chemical properties, altitude, yield and coffee quality were analysed using the correlation method. The results showed that under shading, the soil N, P, K contents, CEC and pH of soil were correlated positive with altitude increase, while C-organic content, productive branches, number of fruits per bunch and coffee production were correlated negative. Under unshade condition, the soil N, C-organic, K contents, soil pH, productive branches, the number of fruit per bunch were correlated negative with altitude increase, while CEC, soil P content, number of bunches, diameter of canopy and coffee yield were correlated positive. Under shaded condition, the most significant positive correlation was registered for the number of bunches (0.959), followed by CEC (0.786), soil pH (0.831) and soil P content (0.829), while without shading the canopy diameter showed the highest correlation (0.89). The study revealed that shading affects the taste of Arabica coffee, namely the quality of flavour, body, aftertaste and balance, at all altitudes.

coffee, soil chemical properties, elevation, yield, correlation

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INTRODUCTION

In Indonesia, Arabica coffee (*Coffea arabica* L.) started to be cultivated as long as 120 years ago. North Sumatra is one of the most important producers of Arabica coffee in Indonesia. The world production of Arabica coffee beans was 173 765 t in 2017, with North Sumatra contribution by 50 416 t of green beans (DGEC, 2017). The largest Arabica coffee producing regions (totally 60 285 ha) are located in North Sumatra, representing a source of livelihood for 119 576 coffee farmers. In the current decade, Arabica coffee cultivation has been facing the issue of climate change (Malau, Pandiangan, 2018), especially in the coffee plantations distributed in nine North Sumatra districts situated 800–1 600 m a.s.l. In Humbang Hasundutan Regency, coffee plantations are located at various elevations (1 200–1 500 m a.s.l.).

At all Indonisian plantations and elevations, farmers apply generally almost the same cultivation technologies, such as plants shading, pruning, and fertilization. Nevertheless, the quality of Arabica coffee (both physical and taste quality) may significantly vary in dependence on plantation altitude. Researches on the relationship between elevation, soil properties, coffee production, and quality have been carried out worldwide (Barbosa et al., 2012; Wahyuni et al., 2013; Silva et al., 2015; Qadry et al., 2017).

However, not much research has been done in Humbang Hasundutan, where a specific variety of Arabica coffee called Sigarar Hutang is cultivated.

Elevation influences air temperature and rainfall (Ping et al., 2013; Saeed et al., 2014). Malau et al. (2018) mentioned that climate affects also the performance of Arabica coffee genotypes. The most important factor affecting these phenotypes appeared to be the length of rainy season. According to Karim (1996), the most ideal elevation for Arabica coffee cultivation ranges between 1 200 and 1 400 m a.s.l. However, Arabica coffee grows and produces optimally at an elevation of 900 to 1700 m a.s.l. which is an ideal habitat for its cultivation. The higher situated the location, the lower the temperature, the higher the rainfall and the more fertile the land (Sari et al., 2013; Van Beusekom et al., 2015). The climate condition change impacts the process of soil organic matter (OM) decomposition and chemical composition and the fruit ripening process (Somporn et al., 2012).

Information about soil chemical properties can serve as a guidance for selecting locations suitable for coffee planting and determining the right fertilizer dosage meeting the needs of plants (Nunez et al., 2011; Maro et al., 2013). Thus the coffee growing management can be more efficient and coffee production low-cost (Amaral et al., 2011; Hanisch et al., 2011).

Soil's ability to provide plants with nutrients depends on its chemical properties such as pH, organic carbon and mineral contents (Kufa, 2011). Nutrients available in soil are macronutrients (namely nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na)) and micronutrients (namely boron (B), zinc (Zn), copper (Cu), and iron (Fe)). Each of them plays a role in the growth and production of coffee plants (Nunez et al., 2011).

Coffee belongs to the group of C3 plants tending to thrive at moderate sunlight intensity. So coffee cultivation requires shading to protect the plants against direct sunlight and thus reduce the evapotranspiration process. Coffee plants need lifelong shade for their proper growth and development with reduced sunlight intensity and regular irradiation. Different levels of shading are required with respect to the growing phase of a plant. An unsuitable level of shade in the vegetative and generative phases affects the growth, production, and taste of coffee. However, in some other destinations we can meet also a coffee growing practice without shading. Non-shaded coffee cultivation is being practiced e.g. in Hawaii, Brazil, and Kenya (Panggabean, 2011). In Indonesia, shaded cultivation is generally applied, but under certain conditions, depending on farmers' knowledge, coffee plants are also grown without shade.

This study aims to analyse the correlation between elevation, soil chemical properties and the growth, production and quality of Arabica coffee cultivated in shade/without shading in Humbang Hasundutan, North Sumatra.

MATERIAL AND METHODS

The research was conducted in 2016–2017 in the highlands of Humbang Hasundutan District, North Sumatra Province, Indonesia. We used a research method with a purposive selection of Arabica coffee growing locations and elevation (Fig. 1), and also, random sampling of soil and coffee beans per location. The study sites are situated at altitudes from 1 200 to > 1 500 m a.s.l. and are divided into 4 zones (in m a.s.l.): 1 200–1 300, 1 300–1 400, 1 400–1 500,, and > 1 500. Plants used for shading the coffee trees at

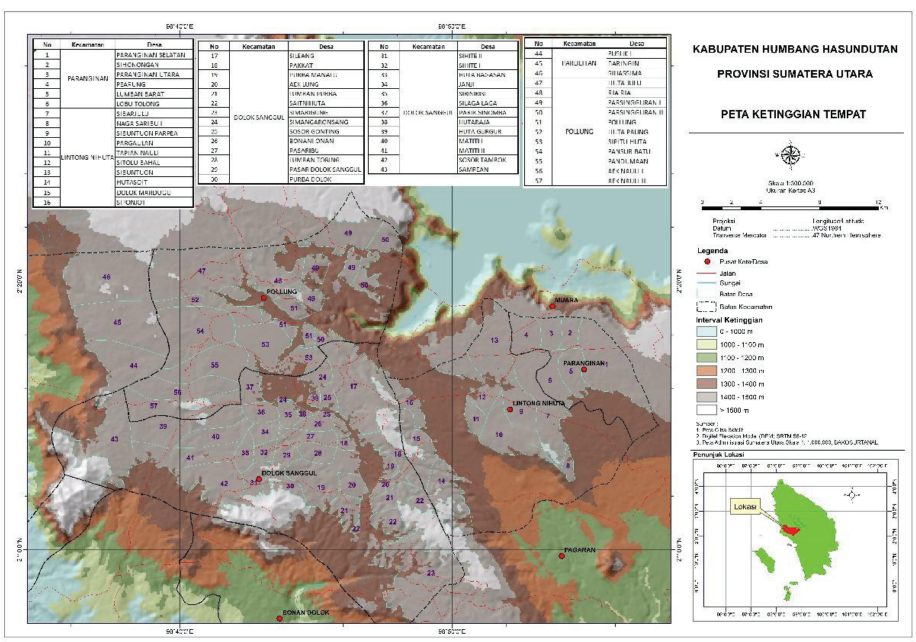

Fig. 1. Regional map of Humbang Hasundutan;

Source: Regional Planning and Development Agency for Humbang Hasundutan Regency (2020)

Table 1. Soil chemical properties in coffee plantations in Humbang Hasundutan are based on altitude

Parameter	Altitude (m a.s.l.)			
	1 200–1 300	1 300–1 400	1 400–1 500	>1 500
N content (%)				
Topsoil	0.7 (H)	0.6 (H)	0.3 (M)	0.7 (H)
Subsoil	0.5 (M)	0.4 (M)	0.3 (M)	0.7 (H)
C-organic content (%)				
Topsoil	11.9 (VH)	8.7 (VH)	4.2 (H)	9.5 (VH)
Subsoil	8.6 (VH)	6.0 (VH)	4.3 (H)	8.9 (VH)
Cation exchange capacity ($cmol_c\ kg^{-1}$)				
Topsoil	19.1 (M)	15.8 (L)	13.2 (L)	21.6 (M)
Subsoil	13.1 (L)	13.1 (L)	14.1 (L)	20.5 (M)
pH				
Topsoil	5.8 (RA)	5.7 (RA)	5.5 (RA)	5.9 (RA)
Subsoil	5.7 (RA)	6.0 (RA)	5.3 (A)	5.9 (RA)
K exchangeable (me/100g)				
Topsoil	1.6 (VH)	0.2 (L)	0.8 (H)	0.6 (H)
Subsoil	0.6 (H)	0.1 (L)	0.4 (M)	0.4 (M)
P total (%)				
Topsoil	1531.3 (VH)	1068.0 (VH)	1481.4 (VH)	3651.8 (VH)
Subsoil	1113.6 (VH)	619.5 (VH)	1141.9 (VH)	3295.9 (VH)
P average (%)				
Topsoil	17.1 (M)	7.3 (VL)	189.8 (VH)	9.3 (VL)
Subsoil	7.0 (VL)	4.3 (VL)	104.0 (VH)	19.6 (M)

H = high, VH = very high, M = medium, L = low, VL = very low, A = acid, RA = rather acid

higher altitudes are Dadap (*Erythrina variegate*), Asan (*Pterocarpus indicus*), and Suren (*Toona sinensis*).

Soil types of the study sites are mostly Inceptisol and Ultisol. Climate is very wet (Schmidt, Ferguson, 1951). At each location, composite soil samples were taken from the depth of 0–10 cm and 10–20 cm below the canopy of the coffee plant. The Arabica coffee varieties cultivated in the study sites are known as Sigarar Hutang.

The soil samples were laboratorily analysed for soil acidity (pH), the content of inorganic carbon (C), total nitrogen (N), P_2O_5 available, potassium (K), and cation exchange capacity (CEC). From each location, the coffee samples were taken randomly and the processed wet coffee beans obtained were dried in the sun to a moisture content of 12 % (Sumirat, 2008). The parental plants of selected farms located in one climate zone originated from the same climate zone in the same district (information provided by the farms' owners). In each of the selected farms, 200–300 plants were grown. Coffee plants were 6–7-year old, performing shoot of bronze-coloured leaves, bearing ripe fruits, with harvest frequency once in two weeks. In each farm, 10 plants were selected randomly to provide source data. The plant variables observed included the weight of production. Data on soil chemical properties, elevation, and coffee production were then analysed using the correlation equation with significant difference ($\alpha = 0.05$) (Gomez, Gomez, 1984).

The observation of coffee flavour quality was carried out on 10 sample plants from each sample plot. Each sample plot was repeated three times. The quality parameters observed were flavour strength/fragrance, acidity, body, flavour, aftertaste, and balance. The organoleptic taste quality measurement referred to the Specialty Coffee Association of America (SCAA) Standard (Yusianto, 2014). Coffee samples with a distinctive taste/unit (specialty) with a score ≥ 6 have only been involved. The organoleptic test was conducted by professional panellists from Gayo Cupper Team, Bener Meriah Aceh Province.

RESULTS

In the study locations, the categories of soil acidity (pH) varied from rather acidic to acid (Table 1). Topsoil from all four elevation zones involved (1 200–1 300, 1 300–1 400, 1 400–1 500, and > 1 500 m a.s.l.) was categorised as rather acidic, subsoil at 1 400 m a.s.l. as sour.

The soil C-organic content at the elevations of 1 200–1 400 m and > 1 500 m a.s.l. was categorised as very high (VH), namely 6.0–11.9 % in topsoil and

Table 2. Correlation between altitude, soil chemical properties, and coffee production in shaded condition

Correlation	Altitude	N	C	CEC	pH	K	P average	Productive branch	Number of bunches	Number of fruit/bunches	Canopy diameter	Yield
Altitude	1	0.067	–0.334	0.786	0.831	0.051	0.829	–0.736	0.959*	–0.495	0.678	–0.211
N		1	0.916	0.666	–0.111	0.960	–0.161	0.626	0.296	0.780	–0.338	0.935
C			1	0.319	–0.406	0.900	–0.454	0.884	–0.112	0.917	–0.554	0.953*
CEC				1	0.588	0.649	0.554	–0.161	0.884	0.091	0.341	0.403
pH					1	0.031	0.999**	–0.713	0.670	–0.707	0.960*	–0.454
K						1	–0.022	0.617	0.225	0.672	–0.158	0.837
P average							1	–0.746	0.659	–0.742	0.969*	–0.498
Productive branch (stem)								1	–0.552	0.910	–0.746	0.794
Number of bunches									1	–0.236	0.458	0.056
Number of fruit/bunches										1	–0.837	0.948
Canopy diameter											1	–0.650
Yield												1

*,** = * and ** significant at 5% and 1% levels respectively, CEC = cation exchange capacity

subsoil layer. At 1 400–1 500 m a.s.l. it was classified as high (H) (4.3 %).

The soil total N content at the elevation of 1 200–1 300 m a.s.l. was in H category and at 1 300–1 400 m a.s.l and 1 400–1 500 m a.s.l. it was in moderate (M) category, at elevations > 1 500 m a.s.l. it was in H category (Table 1).

The soil content of P_2O_5 was at altitudes of 1 200–1 300 m a.s.l. categorised as M in topsoil and as very low (VL) in subsoil. At 1 300–1 400 m a.s.l. it was of VL category in both soil layers. At 1 400–1 500 m a.s.l. the levels of P_2O_5 were identified as VH.

Soil cation exchange capacity (CEC) found at 1 200–1 500 m a.s.l. was of low level (L) category (13.1–19.1 cmol kg^{-1}), while at elevations >1 500 m a.s.l. it was of M category (20.5–21.6 cmol kg^{-1}).

The soil content of alkaline cations (K) decreased with increasing altitude (Table 1).

The correlation analysis of soil C-organic content at the four elevation zones produced slightly negative values (–0.311), where its levels both in topsoil and subsoil tended to decrease at 1 200–1 400 m a.s.l. but to increase at 1 500 m a.s.l. (Table 2). Table 2 also shows that the soil total N content tended to decrease with a very slight negative correlation at 1 300–1 400 m a.s.l. (–0.012), but it increased at elevations > 1 500 m a.s.l.

The correlation analysis of soil P_2O_5 content gave positive values, increasing with rising elevation (0.281) (Table 2).

Oppositely, soil acidity (pH) was slightly negatively correlated with elevation (–0.089), and its value tended to decrease from 1 200–1 400 m a.s.l. altitudes (Table 2). In shaded condition, soil pH was slightly negatively correlated with elevation (–0.089), it tended to increase from 1 200–1 400 m a.s.l. (Table 2). Similarly, in unshaded condition, soil pH had a negative correlation with elevation and tended to decrease (–0.432) (Table 3). Soil acidity seems to be more related to the conditions of high rainfall and low air temperatures in this area. Besides, soil acidity is related to the complex nature of the constituent minerals which have a pH-dependent charge. In this study, the soil pH values are in a slightly acidic category. The results are consistent with those of De Bauw et al. (2016) stating a decrease in pH from over 7.5 at 1 000 m a.s.l. to 4.9 at 2 200 m a.s.l., which is associated with decreased soil K levels.

This condition can be associated with a high soil OM content in almost all experimental units. OM can function as a buffer affecting soil pH. It can minimize soil pH changes so that the soil solution is still able to maintain the pH of the soil no matter if there is an addition of acid or base in the soil.

The soil C-organic content at 1 200–1 400 m a.s.l. and > 1 500 m a.s.l. altitudes was categorised as VH, while at 1 400–1 500 m a.s.l. as H (Table 1). This shows that the coffee growing area is rich in organic material. According to Sari et al. (2013), soils are considered fertile if the C-organic content exceeds 3 %. The main source of OM is litter/topsoil which comes from falling leaves and twigs of coffee and other plants which are quite abundant, including left overs from weeds. According to Ping et al. (2013), higher rainfall and lower temperatures in mountain-

Table 3. Correlation between altitude, soil chemical properties, and coffee production in unshaded condition

Correlation	Altitude	N	C	CEC	pH	K	P average	Productive branch	Number of bunches	Number of fruit/bunches	Canopy diameter	Yield
Altitude	1	–0.012	–0.311	0.546	–0.089	–0.432	0.281	–0.151	0.681	–0.408	0.89	0.457
N		1	0.954*	0.826	0.846*	0.319	–0.835	–0.765	0.628	0.844	0.4	0.882
C			1	0.624	0.820	0.45	–0.868	–0.668	0.386	0.932	0.118	0.702
CEC				1	0.607	0.103	–0.495	–0.663	0.868	0.509	0.846	0.994**
pH					1	–0.143	–0.980*	–0.964*	0.669	0.555	0.165	0.68
K						1	0.023	0.353	–0.402	0.744	–0.09	0.127
P average							1	0.894	–0.512	–0.64	0.002	–0.583
Productive branch (stem)								1	–0.817	–0.357	–0.327	–0.715
Number of bunches									1	0.126	0.796	0.856
Number of fruit/bunches										1	0.052	0.578
Canopy diameter											1	0.783
Yield												1

*, ** = * and ** significant at 5% and 1% levels respectively, CEC = cation exchange capacity

ous areas increase the amount of litter/topsoil which is the main source of OM.

Based on the results of the analysis, soil C-organic content is negatively correlated with elevation, tending to decrease both in topsoil and subsoil at 1 200–1 400 m a.s.l., but increasing at an elevation of 1 500 m a.s.l. In this study, the levels of C-organic in the topsoil layer are higher than those in the subsoil one. This can be attributed to the process of mineralization and nutrient uptake occurring in the lower layers which are closer to plant roots. At higher altitudes, the process of litter decomposition is slow so that C-organic accumulates in soil (Kidanemariam et al., 2012; Charan et al., 2013). Similar results were reported by Kidanemariam et al. (2012) from the Ethiopian region, as well as Sari et al. (2013) and Sipahutar et al. (2014).

Under shaded conditions, the soil total N content is positively correlated with elevation (Table 2). It is closely related to the soil OM content (Rusdiana, Lubis, 2012). Some researchers report that the high organic (C-organic) content can increase the nitrification process, so that the soil N content increases (Kidanemariam et al., 2012; Purwanto et al., 2014; Sipahutar et al., 2014). The soil N is used by microorganisms to decompose materials or soil compounds.

The soil P content is positively correlated with elevation (Tables 2, 3), while the values of P in shaded conditions are higher correlated (0.829) than those in unshaded conditions (0.281). These results indicate that the value of available P increases with increasing elevation. Our results differ from those given in some other studies (Sari et al., 2013; Sipahutar et al., 2014; Vincent et al., 2014).

The values of soil CEC vary, but there is a tendency to increase and positively correlate with elevation. Allegedly, the higher the location altitude, the greater the vegetation density contributing to a greater mass of organic material (Sari et al., 2013). This organic colloid also displays a greater cation absorption than clay colloids so that the OM addition to soil can increase the soil CEC value (Kufa, 2011; Nazari et al., 2012; Kilambo et al., 2015). Soil CEC is an indicator of soil fertility related to the ability of soil colloids to provide nutrients bound in the colloid sorption complex so they cannot be released (washed away) easily (Soewandita, 2008). The CEC scores are included in the L-M category (Table 4) meaning that the soil possesses low ability to absorb and exchange cations. The result points to a very low soil fertility in the study location so additional fertilization input is needed.

The outcomes for the soil K content are similar – it appears that the higher the location altitude, the lower the soil K content, which is negatively correlated with the unshaded condition, but in the shaded condition it shows a weakly positive correlation (0.051). Identical results gave Sari et al. (2013) stating that the soil saturation with bases at higher altitudes tends to get lower. The low accumulation of base cations at higher elevations indicates the presence of base cations in soil.

The results of the analysis show that altitude correlates differently to the vegetative and generative

Table 4. Correlations between coffee flavour parameters with altitude and shade

Altitude and shading	Aroma	Flavour	Aftertaste	Acidity	Body	Balance	Uniform	Clean cup	Sweetness	Overall	Total
1	0.775	0.775	0.447	.[a]	.[a]	–0.258	.[a]	.[a]	.[a]	0	0.674
	1	1.000**	0.577	.[a]	.[a]	–0.333	.[a]	.[a]	.[a]	0.577	0.870
		1	0.577	.[a]	.[a]	–0.333	.[a]	.[a]	.[a]	0.577	0.870
			1	.[a]	.[a]	0.577	.[a]	.[a]	.[a]	0	0.905
				.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
					.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
						1	.[a]	.[a]	.[a]	–0.577	0.174
							.[a]	.[a]	.[a]	.[a]	.[a]
								.[a]	.[a]	.[a]	.[a]
									.[a]	.[a]	.[a]
										1	0.302
											0.698

** = significant at 1% levels respectively; [a]= data not detected

growth (production) of coffee in unshaded and shaded conditions. Under unshaded condition, elevation is negatively correlated to productive branches and the number of fruit/bunches, but positively correlated to the number of bunches, canopy diameter and coffee production. Likewise, in shaded conditions, elevation is negatively correlated with productive branches, number of fruit/bunches and coffee production, but strongly positively correlated with the number of bunches (0.959) and canopy diameter. Our results contradict with Da Silva et al. (2005) reporting that the 100 coffee beans weight increases with increasing elevation. Lower temperatures at higher elevations slow down the ripening process of coffee fruit so that the formation of coffee beans is more perfect and fuller (heavy) (Bertrand et al., 2011; Bote, Struik, 2011; Somporn et al., 2012).

The correlation analysis between the soil chemical properties and the growth of shaded and unshaded coffee plants is also shown in Tables 2, 3. In shaded coffee plants, the soil chemical parameters such as C-organic and N contents, CEC, and soil pH had a positive correlation with the number of bunches, number of fruit/bunches, canopy diameter, and coffee production, but they were negatively correlated to productive branches. The soil K content was positively correlated to productive branches, number of fruit/bunches and coffee production, while the P content was negatively correlated to the number of fruit/bunches and coffee production.

Under shaded condition, the soil chemical parameters like C-organic, N and K contents and CEC were strongly positively correlated to productive branches, number of fruits per bunches, and coffee production, but there were negative correlations to canopy diameter. A negative correlation concerning the three parameters was generated by P; the soil P content was positively correlated to the number of bunches and canopy diameter.

The intensity of sunlight has a very important role in the taste of coffee. Coffee flavour test results at all heights, coffee beans in the presence of shade have a positive effect on forming flavour, body, quality aftertaste, and balance. This implies from the comparison of the four parameters, where the taste of Arabica coffee in shaded conditions has a higher rating scale (Table 4). The relationship between altitude and coffee flavour is quite strong (0.698), although not significantly different (Table 4) – the higher the coffee plantage altitude, the better the coffee flavour. These results are in line with those of Qadry et al. (2017), that Gayo arabica coffee varieties have better chemical physicochemical quality if planted at elevations above 1 500 m a.s.l.

DISCUSSION

The soil acidity (pH) in the four elevation zones (1 200–1 300, 1 300–1 400, 1 400–1 500, and > 1 500 m a.s.l.) of the the study site varied between 5.3–5.9. Soil acidity is one of key soil fertility parameters. Optimum soil pH for coffee growing, production and quality is 5.8–6.2 (Maro et al., 2014), so from this respect the study site is suitable.

Soil pH seems to be more related to high rainfall and low air temperatures in this area. Besides, the rather acidic soil reaction is related to the complex nature of the soil mineral composition which has a pH-dependent charge. In this study, the soil pH value was in a rather acidic category. This result is in line with De Bauw et al. (2016) stating a decrease in soil pH from over 7.5 at 1 000 m a.s.l. to 4.9 at 2 200 m a.s.l. associated with decreased soil K levels.

This condition can be due to a high OM proportion in soil of the study site. The presence of OM may function as a buffer for soil pH directly impacting its level. The buffer from organic material minimizes pH changes so that the soil solution is capable of keeping the pH level no matter if there is an addition of acid or base in the soil. Moreover, the soil in the study site is porous showing good drainage and this property possibly enables the base cations from higher situated places to be washed away to a lower place. Soil pH is an important factor affecting soil fertility because it greatly influences the other soil fertility parameters and enhances the plant nutrient uptake capacity (Marschner, 2012).

The soil organic C content at the elevation of 1 200–1 400 m a.s.l. and > 1 500 m a.s.l. is categorised as very high, while at 1 400–1 500 m a.s.l. as high. This indicates the soil OM richness of the coffee growing area. According to Sari et al. (2013), the land is categorised as fertile if the soil organic C level exceeds 3 %. The main source of OM is litter/humus which comes from avalanches of leaves and twigs of coffee plants and shade as well as other plants which are quite abundant. According to Ping et al. (2013), higher rainfall and lower temperatures in mountainous areas increase the amount of litter/humus.

In this study, the topsoil level of C organic is higher than the subsoil. This can be attributed to the process of mineralization and nutrient absorption occurring in the lower layers which are closer to the roots of plants. In the highlands, the litter decomposition process runs slowly so that there is an accumulation of C organic in the soil (Kidanemariam et al., 2012; Charan et al., 2013). These results accord with those from similar studies by Kidanemariam et al. (2012) in the Ethiopian region, and Sari et al. (2013) and Sipahutar et al. (2014) in Indonesia.

Tables 1, 2 also show that soil total N content tends to decrease and negatively correlate at an elevation of 1 300–1 400 m a.s.l., but to increase again at elevations > 1 500 m a.s.l. The soil total N content is closely related to its OM content (Rusdiana, Lubis, 2012). Some researchers report that the high content of organic (C-organic) ingredients can increase the nitrification process so that the N content increases (Purwanto et al., 2014; Sipahutar et al., 2014). Soil N is used by microorganisms to decompose materials or compounds in the soil. Organic material is one of the N sources for plants. According to Rusdiana, Lubis (2012), the availability of N in the soil is closely related to the soil OM content, especially the decomposition rate (C/N).

The soil content of P_2O_5 in the four elevation zones varies. In our study the value of available P_2O_5 in soil increases with increasing elevation. This result differs from those reported by Sari et al. (2013), Sipahutar et al. (2014) and Vincent et al. (2014). The rising temperature from January to May can stimulate the microbial and uterine activity of soil available P_2O_5 , increase the microbial mineralization and uptake of P_2O_5 by plants so that it can increase the P_2O_5cycle a$_c$celeration and the content of P_2O_5 .

The cation exchange capacity (CEC) of soil tends to increase and positively correlates with altitude (Table 2). Suspectedly, the higher the field elevation, the denser the vegetation, thus providing more OM (Sari et al., 2013). Organic colloids also exhibit a greater cation absorption than clay colloids so that the OM addition to soil can increase the soil CEC value (Kufa, 2011; Nazari et al., 2012; Kilambo et al., 2015). Soil CEC is an indicator of soil fertility that is related to the ability of colloidal soil to provide nutrients bound in colloid absorption complexes so that they cannot be easily reseased/washed away by water (Soewandita, 2008). The CEC value falls in with the L-M category (Table 2) showing that the ability of the soil to absorb and exchange cations is low. The low CEC value reveals that the study location's soil fertility level is very low, therefore additional fertilization is needed.

The analysis of soil alkaline cations (K) yielded similar results. Table 2 shows that the K soil content decreases with rising elevation. Identical results published Sari et al. (2013) stating that the base saturation at high altitudes is lower. The low accumulation of alkaline cations at higher elevations indicates the phenomenon of alkaline cation leaching.

Our results show that altitude has a different correlation with vegetative and generative growth (production) of coffee. Whereas elevation correlated negatively with productive branches, the number of fruit/bunches and coffee production, it strongly positively correlated with the number of bunches (0.959) and canopy diameter. Contradictly, Da Silva et al. (2005) stated that the 100 coffee beans weight increases with rising elevation. Lower temperatures at higher situated places slow down the coffee ripening process so that the formation of coffee beans is more perfect and fuller (heavy) (Bertrand et al., 2011; Bote, Struik, 2011; Somporn et al., 2012). In general, the results of the correlation analysis of soil chemical properties with elevation also indicate that the higher situated the place, the more negatively correlated soil chemical properties (N, C-organic, K contents and pH), the same as CEC and soil P_2O_5 content.

Table 2 presents a mutual correlation between the individual soil chemical properties. Soil pH is closely tied to CEC. This proves that CEC is linearly related to soil pH, i.e., if the CEC level is low, then the base cations are reduced and replaced by H^+ ions. This can lead to soil pH decrease, and *vice versa*. Soil acidity decreases and fertility increases with increasing CEC. The potential release of absorbed cations for plants depends on the level of CEC.

The soil total N is strongly correlated with C organic, soil pH and CEC, weakly correlated with K, and negatively correlated with P. This is because the higher the C organic level, the greater the soil N reserves in the form of organic N (supported during the following mineralization process), as well as the higher the CEC value, the colloidal soil will be more active. Active colloids can absorb NH_4+, and with still more absorbed NH_4+, a lot of ammonium is produced leading to soil nitrification. Damanik et al. (2011) state that the concentration of H+ ions determines the amount of cation exchange charge that depends on pH, and also the charge of anion exchange, and therefore it affects the activity of all exchangeable cations. The solubility of the compounds Fe, Al, and Ca-phosphate increases with increasing pH but, conversely, the solubility of Ca-phosphate decreases.

Table 2 also presents the results of the correlation analysis between the soil chemical properties and the growth of shaded/unshaded coffee plants. In the coffee plantations without shade, soil chemical properties (C and N contents, CEC, pH) have a positive correlation with the number of bunches, number of fruit/bunches, canopy diameter, and coffee production, but they are negatively correlated with productive branches. While the K level has a positive correlation with productive branches, the number of fruits/bunches and coffee production, the P level has a negative correlation with the number of fruit/bunches and coffee production.

Soil chemical properties (soil C, N, K levels, CEC, pH) correlate positive with productive branches, number of fruits/bunches, and coffee production, but negative with canopy diameter parameters. Conversely, negative correlations to all the three parameters are generated by the P level, meaning that P correlates positive with the number of bunches and canopy diameter.

Clemente et al. (2013) and Kilambo et al. (2015) reported that soil pH, beside influenceing productivity and flavour, also determines the quality of Arabica coffee beans. Soil C-organic and N content also positively correlated with coffee production in non-shaded and shaded conditions (Table 2). According to Maro et al. (2014), for optimum coffee plant growth and production, the OM (C-organic) content above 2 % is needed. In the Humbahas area, the soil C-organic content is in accord with coffee growing needs. Likewise, the coffee plants optimum growth and production require the soil N levels exceeding 0.12 % (Maro et al., 2014). Adequate N supply increases the number of plagiotropic branches (branches of production), leaf area, and starch production, and the contents of other carbohydrates that play a role in the formation and growth of coffee beans (Clemente et al., 2013). Moreover, N is a nutrient affecting plant growth and caffeine content in coffee plant tissue.

The intensity of sunlight has a very important role in the taste of coffee (Geeraert et al., 2019). Flavour test results of coffee beans produced at all altitudes with or without shading have been assessed. The presence of shade positively affects the forming of flavour, body, aftertaste and balance quality of coffee beans. This can be seen from the comparison of the values of the four parameters, where the taste of Arabica coffee grown in shaded conditions is rated higher (Table 4). The relationship between the altitude and the coffee flavour is quite strong (0.698), although not significantly different (Table 4) (the more intense the coffee flavour, the better). These results are in line with Qadry et al. (2017), that Gayo arabica coffee varieties have better chemical and physicochemical quality if planted at elevations above 1 500 m a.s.l.

An increase in air temperature under the auspicious condition affects the taste quality due to the effects of various syntheses taking place in the coffee beans during the ripening process. Higher temperatures influence the levels of sucrose, trigonelline, chlorogenic acid, caffeine which are associated with a decrease in organoleptic quality (Ky et. al., 2001; Vaast et al., 2006; Geromel et al., 2008). Furthermore, Bote, Struik (2011) stated that the coffee plants grown in unshaded condition produce beans with lower organoleptic quality (in terms of acidity, body and taste) compared to those grown in shade. Similar to decreasing shade condition, the lower altitude of coffee plantage has also been found to negatively affect the coffee quality because of higher air temperature averages that accelerate the process of fruit ripening and hence, change the biochemical composition of coffee beans.

CONCLUSION

A real correlation exists between altitude and some soil chemical properties and coffee production in Humbang Hasundutan under conditions that are shaded and unshaded.

Under unshaded condition, the soil N, C-organic, K exchangeable and pH were negatively correlated with an increase in the field altitude, while CEC and P were available and coffee crop production was correlated positive. Likewise in shaded conditions, soil N, C, K levels and pH and coffee crop production negatively correlated with an increase in elevation, while the CEC and P available correlated positive.

Shade affects the taste of Arabica coffee at all elevations, namely the quality of flavour, body, aftertaste and balance quality. From the comparison of the values of the four parameters it follows that the relationship between altitude and the coffee flavour is quite strong (0.698), although not significantly different. However, the higher situated the coffee plantage, the better the coffee flavour.

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REFERENCES

Qadry NA, Rasdiansyah R, Abubakar Y (2017): The effect of land altitude and varieties on physical and fisiko-chemical quality of Gayo Arabica coffee. Jurnal Ilmiah Mahasiswa, Teknologi Hasil Pertanian, 2, 279–287. doi: 10.17969/jimfp.v2i1.2256. (in Indonesian)

Amaral JFT, Martinez HEP, Laviola BG, Tomaz MA, Filho EIF, Cruz CD (2011): Productivity and efficiency of nutrient use in coffee crops. Coffee Science, Lavras, 6, 65–74.

Barbosa JN, Borem FM, Cirillo MA, Malta MR, Alvarenga AA, Alver HMR (2012): Coffee quality and its interactions with environmental factors in Minas Gerais, Brazil. Journal of Agricultural Science, 4, 181–190. doi: 10.5539/jas.v4n5p181.

Bertrand B, Alpizar E, Lara L, Santa Creo R, Hidalgo M, Quijano JM, Etienne H (2011): Performance of Coffea arabica F1 hybrids in agroforestry and full-sun cropping systems in comparison with American pure line cultivars. Euphytica, 181, 147–158.

Bote AD, Struik PC (2011): Effects of shade on growth, production and quality of coffee (Coffea arabica) in Ethiopia. Journal of Horticulture and Forestry, 3, 336–341.

Charan G, Bharti VK, Jadhav SE, Kumar S, Acharya S, Kumar P, Srivastava RB (2013): Altitudinal variations in soil physico-chemical properties at cold desert high elevation. Journal of Soil Science and Plant Nutrition, 13, 267–277.

Clemente JM, Martinez HEP, Alves LC, Lara MCR (2013): Effect of N and K doses in nutritive solution on growth, production and coffee bean size. Revista Ceres, 60, 279–285.

Damanik MMB, Bachtiar EH, Fauzi, Sarifuddin, Hamidah H (2011): Soil fertility and fertilization. USU Press, Medan. (in Indonesian)

Da Silva EA, Mazzafera P, Brunini O, Sakai E, Arruda FB, Mattoso LHC, Pires RCM (2005): The influence of water management and environmental conditions on the chemical composition and beverage quality of coffee beans. *Brazilian Journal* of *Plant Physiology*, 17, 229–238.

De Bauw P, Van Asten P, Jassogne L, Merckx (2016): 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 and Environment, 231, 166–175. doi: 10.1016/j.agee.2016.06.036.

DGEC (2018): Tree crop estate statistics of Indonesia 2017–2019, Coffee. Dirjen Perkebunan, Jakarta. Available at https://drive.google.com/file/d/1S8UHnTgSVwKgqEJB5WXFSp6903sRiiWH/view. (in Indonesian)

Geeraert L, Berecha G, Honnay O, Aerts R (2019): Organoleptic quality of Ethiopian Arabica coffee deteriorates with increasing intensity of coffee forest management. Journal of Environmental Management, 231, 282–288. doi: 10.1016/j.jenvman.2018.10.037.

Geromel C, Ferreira LP, Davrieux F, Guyot B, Ribeyre F, Scholz MBD, Luiz FPP, Vaast P, Leroy DT, Androcioli A, Vieira LGE, Mazzafera P, Marraccini P (2008): Effects of shade on the development and sugar metabolism of coffee (Coffea arabica L.) fruits. Plant Physiology and Biochemistry, 46, 569–579.

Gomez KA, Gomez AA (1984): Statistical procedures for agricultural research. John Wiley and Sons.

Hanisch S, Dara Z, Brinkmann K, Buerkert A (2011): Soil fertility and nutrient status of traditional Gayo coffee agroforestry systems in the Takengon region, Aceh Province, Indonesia. Journal of Agriculture and Rural Development in the Tropics and Subtropics, 112, 87–100.

Karim A (1996): Land characteristics valuation of catimor Arabica coffee in Central Aceh. Jurnal Penelitian Pertanian, 1, 19–26. (in Indonesian)

Kidanemariam A, Gebrekidan H, Mamo T, Kibret K (2012): Impact of elevation and land use type on some physical and chemical properties of acidic soils in Tsegede Highlands, Northern Ethiopia. Open Journal of Soil Science, 2, 223–233.

Kilambo DL, Mlwilo BL, Mtenga DJ, Godsteven P (2015): Effect of soils properties on the quality of compact Arabica hybrids in Tanzania. American Journal of Research Communication, 3, 15–19.

Kufa T (2011): Chemical properties of wild coffee forest soils in Ethiopia and management implications. Agricultural Sciences, 2, 443–450.

Ky CL, Louarn J, Dussert S, Guyot B, Hamon S, Noirot M (2001): Caffeine, trigonelline, chlorogenic acids and sucrose diversity in wild Coffea arabica L. and C. canephora P. accessions. Food Chemistry, 75, 223–230.

Malau S, Pandiangan S (2018): Morphological variation in Arabica coffee (Coffea arabica L.) growing in North Sumatra, Indonesia. Jurnal Agronomi Indonesia, 46, 314–321. doi: 10.24831/jai.v46i3.19342. (in Indonesian)

Malau S, Lumbanraja P, Pandiangan S, Tarigan JR, Tindaon F (2018): Performance of Coffea arabica L. in changing climate of North Sumatra of Indonesia. Scientia Agriculturae Bohemica, 49, 340–349. doi: 10.2478/sab-2018-0041.

Maro GP, Mrema JP, Msanya BM, Teri JM (2013): Farmers' perception of soil fertility problems and their attitudes towards integrated soil fertility management for coffee in Northern Tanzania. Journal of Soil Science and Environmental Management, 4, 93–99.

Maro GP, Msanya B, Mrema JP (2014): Soil fertility evaluation for coffee (Coffea arabica) in Hai and Lushoto Districts, Northern Tanzania. International Journal of Plant and Soil Science, 3, 934–947.

Marschner H (2012): Mineral nutrition for higher plants. Academic Press.

Nazari YA, Soemarno, Agustina L (2012): Management of soil fertility in potato planting with the application of organic and inorganic fertilizers. Indonesian Green Technology Journal, 1, 7–12. (in Indonesian)

Nunez PA, Pimentel A, Almonte I, Sotomayor-Ramirez D, Martinez N, Perez A, Cespedes CM (2011): Soil fertility evaluation of coffee (Coffea spp.) production systems and management recommendations for the Barahona Province, Dominican Republic. *Journal of Soil Science* and *Plant Nutrition*, 11, 127–140.

Panggabean E (2011): The smart coffee book. Agromedia Pustaka, Jakarta. (in Indonesian)

Ping CL, Michaelson GJ, Stiles CA, Gonzalez G (2013): Soil characteristics, carbon stores, and nutrient distribution in eight forest types along an elevation gradient, eastern Puerto Rico. Ecological Bulletins, 54, 67–86.

Purwanto P, Hartati S, Istiqomah S (2014): Effect of litter quality and dosage on soil nitrification potential and sweet corn yield. Sains Tanah – Jurnal Ilmu Tanah dan Agroklimatologi, 11, 11–20. (in Indonesian)

We apologize, the source of the map that we used is in the final form produced by the Regional Planning and Development Agency team for Humbang Hasundutan Regency (2020). Map of the elevation of Humbang Hasundutan district. Bappeda Kabupaten Humbang Hasundutan.

Rusdiana O, Lubis RS (2012): Estimation of the correlation between soil characteristics and carbon stocks in secondary forests. Jurnal Silvikultur Tropika, 1, 14–21. (in Indonesian)

Saeed S, Barozai MYK, Ahmed A, Shah SH (2014): Impact of altitude on soil physical and chemical properties in Sra Ghurgai (Takatu mountain range) Quetta, Balochistan. International Journal of Scientific and Engineering Research, 5, 730–735.

Sari NP, Santoso TI, Mawardi S (2013): Distribution of soil fertility levels in Arabica coffee of community plantations in the Ijen-Raung plateau according to altitude and shade plants. Pelita Perkebunan, 29, 93–107. (in Indonesian)

Schmidt FH, Ferguson JHA (1951): Rainfall types based on wet and dry period ratios for Indonesia with Western New Guinea. Djakarta: Kementerian Perhubungan, Djawatan Meteorologi dan Geofisik/Verhandelingen.

Silva SA, de Queiroz DM, Ferreira WPM, Correa PC, Rufino JLS (2015): Mapping the potential beverage quality of coffee produced in the Zona da Mata, Minas Gerais, Brazil. Journal of the Science of Food and Agriculture, 96, 3098–3108. doi: 10.1002/ jsfa.7485.

Sipahutar AH, Marbun P, Fauzi F (2014): Study of C-organic, N and P humitropepts at different altitude in sub-district of Lintong Nihuta. Jurnal Online Agroekoteknologi, 2, 1332–1338. (in Indonesian)

Soewandita H (2008): Soil fertility study and land suitability analysis for plantation crops commodities in Bengkalis district. Jurnal Sains dan Teknologi Indonesia, 10, 128–133. (in Indonesian)

Somporn C, Kamtuo A, Theerakulpisut P, Siriamornpun S (2012): Effect of shading on yield, sugar content, phenolic acids and antioxidant property of coffee beans (Coffea arabica L. cv. Catimor) harvested from north-eastern Thailand. *Journal* of the *Science* of *Food* and *Agriculture*, 92, 1956–1963.

Sumirat U (2008): Impact of long drought on changes in the nature of Robusta coffee beans (Coffea canephora). Pelita Perkebunan, 24, 80–94. (in Indonesian)

Vaast P, Bertrand B, Perriot JJ, Guyot B, Genard M (2006): Fruit thinning and shade improve bean characteristics and beverage quality of Arabica coffee (Coffea arabica L.) under optimal conditions. *Journal* of the *Science* of *Food* and *Agriculture*, 86, 197–204. doi: 10.1002/jsfa.2338.

Van Beusekom AE, Gonzalez G, Rivera MM (2015): Short-term precipitation and temperature trends along an elevation gradient in Northeastern Puerto Rico. Earth Interactions, 19, 1–33.

Vincent AG, Sundqvist MK, Wardle DA, Giesler R (2014): Bioavailable soil phosphorus decreases with increasing elevation in a subarctic tundra landscape. PLoS ONE, 9, 1–11.

Wahyuni E, Karim A, Anhar A (2013): Analysis of organic Arabica coffee flavors at several altitudes and their processing methods in the Gayo High Plain. Jurnal Manajemen Sumberdaya Lahan, 2, 261–269. (in Indonesian)

Yusianto, Nugroho D (2014): Physical and flavor profiles of Arabica coffee as affected by cherry storage before pulping. Pelita Perkebunan, 30, 137–158. (in Indonesian)

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