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The Correlation of Elevation, Soil Chemical Properties and Yield of *Coffea arabica* L. in Shaded Conditions

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Abstract. The research aims to analyze the correlation of altitude, soil chemical properties and shades on Arabica coffee yields in Humbang Hasundutan Regency Sumatera Utara Province. This research was conducted using survey method with purposive sampling approach. Sampling were conducted on altitude varied between 1200 – 1500 m asl. Soil samples in top soil and sub soil were taken in order to analyze pH, C, N, P_2O_5, K and cation exchange capacity (CEC). Coffee plant growth variables observed including productive branches, number of bunches, number of fruit per bunches, diameter of canopy and total yield, whereas the quality variable measured were physical quality and taste. Data on soil chemical properties, elevation, yield and coffee quality were analyzed using the correlation method. The results showed that under shaded condition, N, CEC, pH, K and P were positively correlated with height increase, while C-organic, productive branches, number of fruits per bunch and coffee production were negatively correlated. and whereas in the condition without shade, N, C, pH, K, productive branches, the number of fruit per bunch is negatively correlated with height increase, while CEC, P number of bunches, diameter of canopy and coffee yield are positively correlated. Statistical data shows that under shaded condition, the strongest correlation showed by pH and P average (0.999), whereas in an unshaded condition, yield and CEC showed the strongest correlation (0.994). In addition, shading affects on the taste of Arabica coffee at all elevation, namely the quality of flavour, body, quality after taste and balance.

Keywords: coffee, soil chemical properties, elevation, yield quality

Introduction

Arabica coffee (*Coffea arabica* L.) firstly cultivated in Indonesia documented around 120 years ago. Adaptable in tropical area in Indonesia, one of its most important production center is north Sumatera.In 2017, it was estimated out of 173,765 tons coffee beans produced, north Sumatera contribution were 50,416 tons (Directorate General for National Export Development, 2014). A total of 60,285 ha of Arabica coffee plantation area located in north Sumatra have becomes the source of livelihood of 119,576 coffee farmers, thus, it has significant economic importance. Presently, cultivation of Arabica coffee facing the issue of climate change (Malau and Pandiangan, 2018) including north Sumatera coffee plantations. It spreads across nine districts in north Sumatra, in altitudes varied between 800 -1,600 m above sea level (asl). Humbang Hasundutan regency located in highland with elevation between 1,200-1,500 m asl and has been known as one of north Sumatera's prominent coffee plantation region.

Various cultivation technology applied by farmers, i-e shading, pruning and fertilization, generally similar in various locations and elevation of cultivation in north Sumatera. Nevertheless, the quality of Arabica coffee produced by farmers, both physical and taste quality has been reported to be varied greatly. Researches on the correlation of elevation, soil properties, coffee production and quality have been previously reported (Qadry *et al*., 2017; de Assis Silva *et al*., 2016; Barbosa *et al*., 2012; Lara-Estrada and Philippe, 2007). However, there is no such data available of Arabica coffee produced in Humbang Hasundutan, especially on its specific varieties called Sigarar Hutang.

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Land elevation affects air temperature and rain fall (Saeed *et al*., 2014; Ping *et al*., 2013), while Malau and Pandiangan (2018) reported climate affected the performance of Arabica coffee genotypes. It has been reported that the length of rainy season is mainly affecting the coffee phenotypes. According to Franca and Oliveira (2019), the most ideal elevation for Arabica coffee cultivation is above 1000 m asl. However, Arabica coffee grows and produces optimally at an elevation of 900 to 1700 m asl. The higher the place, the lower the temperature and the higher the rainfall are the more fertile the land (Van Beusekom *et al*., 2015; Sari *et al*, 2013). Changes in climate factors will impacts the process of organic matter decomposition, soil chemical composition and fruit ripening process (Somporn *et al*., 2012).

Information on soil chemical properties can be used as a guideline in selecting coffee planting locations and determining the right dosage of fertilizers which will suit the needs of plants (Maro *et al*., 2013; Núñez *et al*. 2011). Thus, coffee plant management can be more efficient and production costs can be reduced (Putra, 2020).

The ability of the soil to provide nutrients for plants depends on the soil chemical properties such as pH, organic carbon and mineral content (Kufa, 2011). Nutrients available in the soil consist of macro-nutrients namely nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) and micro-nutrients, namely boron (B), zinc (Zn), copper (Cu) and iron (Fe), which plays important role in the growth and production of coffee plants (Núñez *et al*., 2011).

Coffee belong to the group of plants which not require full light (C_3) so, that in its development coffee cultivation requires shade plants as a protection against direct sunlight to reduce the evapotranspiration process. Coffee plant requires different level of shades according to its growth phase. Unsuitable level of shading in the vegetative and generative phase will affect the growth, production and taste of coffee. On the other hand, unshaded cultivation are practiced in Ethiopia, Peru and Brazil (Gomes *et al*., 2020; Jezeer *et al*., 2018). In Indonesia, coffee cultivation is generally carried out by applying shade but in certain conditions due to farmers' knowledge, coffee plants are also found without shade.

Since, various factors contributes to Arabica coffee production and quality, this study aims to analyze the correlation between elevation, soil chemical properties on the growth, production and quality of Arabica coffee in shaded and un-shaded plant conditions in Humbang Hasundutan, north Sumatra, Indonesia.

Material and Method

This research was conducted in the highlands of Humbang Hasundutan district, north Sumatra province, in 2016-2017 research location based on the elevation were divided into 4 groups as follows: 1,200 - 1,300 m asl, 1,300 - 1,400 m asl, 1400 - 1,500 m asl and > 1,500 m asl. Research area splitted between unshaded and shaded; with Dadap (Erythrina variegate), Asan (Pterocarpusindicus) and Suren (Toonasinensis) identified as shading plants. Arabica coffee cultivars found at research sites known as Sigarar Hutang. 35 sampling points were determined on each of sampling area.

Soil types in the study sites are Inceptisol and Ultisol soil, while the climate is very wet climate type. Soil samples were taken from each location by composite at a depth of 0-10 (top soil) and 10–20 cm (sub soil) under the canopy of the coffee plant.

Laboratory analysis of soil samples comprised of soil acidity (pH), inorganic carbon (C), total nitrogen (N), available CEC P_2O_5, potassium (K), cation exchange capacity (CEC).

Parental plants chosen based on information from the farm owner originate from the same climate zone in the same district 200-300 plants were grown in each of selected farm, aged 6-7 years, showing bronze-colored leaves shoots; bearing ripe fruits which harvest in two weeks intervals. As data source 10 plants were selected randomly of each farm.

Coffee beans samples were collected and sun dried to a moisture content of 12% (Sumirat, 2008). The plant variables observed included the productivity.Data on soil chemical properties, elevation and coffee production were then analyzed using the correlation equation with significant difference ($\propto = 0.05$)

Observation of the quality of coffee flavour 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, after taste and balance. Organoleptic tast quality test measurement refers to the Specialty Coffee Association of America (SCAA), the standard which has been translated by (Yusianto and Nugroho, 2014). Mentioned, coffee with a distinctive taste/unit (specialty) if it has a score ≥ 6. Organoleptic test conducted by professional panellistsfrom Gayo Cupper Team, Bener Meriah Aceh Province.

Result and Discussion

The results of the analysis showed that the soil acidity (pH) values in the study locations varied between rather acidic - acid categories (Table 1). Soil acidity on top soil layer at all elevation zone has a rather acidic category, only at an elevation of 1400 m asloin sub soil layer found acid category. The C-organic content recorded mostly at very high (VH) level, varied between 6.0-11.9%; except in 1400-1500 m asl, which were high (H) Table 1.

N-total analysis shows high (H) percentage categories in all catagorized elevation, except at 1,300-1,400 m asl, which is medium (M) Table 1.

The value of P Av (P_2O_5) in top soil and sub soil varied between elevation. It is recorded as VH (1400-1500 m asl) to VL (1300-1400 m asl) in top soil and sub soil. CEC result showed that the value in top soil and sub soil varied between elevation from L (1200-1500 m asl) to M (>1500 m asl).

The measurement of K exc, value varied between elevation and soil layer, in which at the top soil the VH category recorded in 1200 -1300 m asl to L at 1300-1400 m asl, while in the sub soil, H value detected in 1200-1300 m asl, while L value detected in 1300-1400 m asl.

Correlation analysis of C-organic at four-zone elevations produces slightly negative values (-0.311), where levels of C organic in top soil and sub soil tend to decrease at an elevation of 1,200-1,400 m asl but increase at an elevation of 1,500 m in shaded condition (Table 2). Table 2 also shows that in shaded condition, the N-total content tends to decrease with very slight negatively correlate at an elevation of 1,300 - 1,400 m asl (-0.012), but increased at an elevation of > 1,500 m asl. The value of P_2O_5 is produced positively correlated with elevations (Tables 2). These results indicate that P_2O_5 the available value increases with increasing elevation (0.281). Otherwise, soil acidity is slightly negatively correlated with elevation (-0.089), where the pH value tends to decrease from an elevation of 1,200 - 1,400 m asl (Table 2).

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

Parameter	Altitude (m asl)			
	1200-1300	1300-1400	1400-1500	>1500
N (%)				
Top soil	0.7 (H)	0.6 (H)	0.3 (M)	0.7 (H)
Sub soil	0.5 (M)	0.4 (M)	0.3 (M)	0.7 (H)
C-org (%)				
Top soil	11.9 (VH)	8.7 (VH)	4.2 (H)	9.5 (VH)
Sub soil	8.6 (VH)	6.0 (VH)	4.3 (H)	8.9 (VH)
CEC (C mol/Kg)				
Top soil	19.1 (M)	15.8 (L)	13.2 (L)	21.6 (M)
Sub soil	13.1 (L)	13.1 (L)	14.1 (L)	20.5 (M)
pH				
Top soil	5.8 (RA)	5.7 (RA)	5.5 (RA)	5.9 (RA)
Sub soil	5.7 (RA)	6.0 (RA)	5.3 (A)	5.9 (RA)
K exc				
Top soil	1.6 (VH)	0.2 (L)	0.8 (H)	0.6 (H)
Sub soil	0.6 (H)	0.1 (L)	0.4 (M)	0.4 (M)
P Total				
Top soil	1531.3 (VH)	1068.0 (VH)	1481.4) (VH	3651.8 (VH)
Sub soil	1113.6 (VH)	619.5 (VH)	1141.9 (VH)	3295.9 (VH)
P av				
Top soil	17.1 (M)	7.3 (VL)	189.8 (VH)	9.3 (VL)
Sub soil	7.0 (VL)	4.3 (VL)	104.0 (VH)	19.6 (M)

Information= VH (very high); H= (high); M (medium); L= (low); VL= (very low); RA= (rather acid); A= (acid)

Soil acidity (pH) in shaded condition has a slight negative correlation with elevation (-0.089), where the pH tends to increase from an elevation of 1,200-1,400 m asl (Table 2). Similarly, at unshaded condition, soil acidity (pH) has a negative correlation with elevation, where the pH tends to decrease with value is -0.432 (Table 2). The soil acidity (pH) of the soil seems to be more related to the conditions of high rainfall and low air temperatures in this area. Besides, rather acidic of pH is related to the complex nature of the constituent minerals which have a pH-dependent charge. In this study, the soil pH value is in the slightly acidic category. These results are consistent with research by (De Bauw *et al*., 2016) which states that a decrease in pH at an elevation higher than 7.5 at an elevation of 1000 m asl to 4.9 at 2200 m asl, which is associated with decreased K levels.

This condition can be caused because almost all of the experimental units have high organic matter content. The existence of organic matter can function as a buffer of soil pH which affects the pH value of the soil. The

Table 2. Correlation between elevation, soil chemical properties and Coffee production in conditions with shade and unshaded

Correlation	Elevation	N	C	CEC	pH	K	P Av	Productive branch	Number of bunches	number of fruit/ bunches	Diameter of canopy	Yield
Elevation	1	0.067	-0.334	0.786	0.831	0.051	0.829	-0.736	0.959*	-0.495	0.678	-0.211
N	- 0.012	1	0.916	0.666	-0.111	0.960*	-0.161	0.626	0.296	0.78	-0.338	0.935
C	- 0.311	0.954*	1	0.319	-0.406	0.9	-0.454	0.884	-0.112	0.917	-0.554	.953*
CEC	0.546	0.826	0.624	1	0.588	0.649	0.554	-0.161	0.884	0.091	0.341	0.403
pH	- 0.089	0.846*	0.820	0.607	1	0.031	.999**	-0.713	0.67	-0.707	.960*	-0.454
K	- 0.432	0.319	0.45	0.103	- 0.143	1	-0.022	0.617	0.225	0.672	-0.158	0.837
P Av	0.281	- 0.835	- 0.868	- 0.495	0.980*	0.023	1	-0.746	0.659	-0.742	0.969*	-0.498
Productive branch (stem)	- 0.151	- 0.765	- 0.668	- 0.663	- 0.964	-0.353	0.894	1	-0.552	0.91	-0.746	0.794
Number of bunches	0.681	0.628	0.386	0.868	0.669	-0.402	-0.512	-0.817	1	-0.236	0.458	0.056
Number of fruit/ bunches	-0.408	0.844	0.932	0.509	0.555	0.744	-0.64	-0.357	0.126	1	-0.837	0.948
Diameter of canopy	0.89	0.4	0.118	0.846	0.165	-0.09	0.002	-0.327	0.796	0.052	1	-0.65
Yield	0.457	0.882	0.702	0.994**	0.68	0.127	-0.583	-0.715	0.856	0.578	0.783	1

buffer function of organic matter plays a role in minimizing pH changes so that the soil solution will still be able to maintain the pH of the soil if there is an addition of acid or base in the soil.

The C-organic content at an elevation of 1,200-1,400 m asl and > 1,500 m asl are categorized as very high, while at an elevation of 1,400-1,500 m asl as high (Table 1). This shows that the coffee development area is rich in organic material. According to (Sari *et al*., 2013), soils are considered fertile if the C-organic content is greater than 3%. The main source of organic material is litter/top soil which comes from falling leaves and twigs of coffee plants and shade and other plants which are quite abundant, including jug left overs from weeds. According to (Ping *et al*., 2013), higher rainfall and lower temperatures in mountainous areas will increase the amount of litter/top soil which is the main source of organic matter.

Based on the results of the analysis, C-organic content is negatively correlated with elevation, where C-organic content in top soil and sub soil tends to decrease at an elevation of 1,200-1,400 m asl but increasing at an elevation of 1,500 m asl. In this study, the levels of C-organic top soil layer (top soil) is higher than the sub soil layer. This can be attributed to the process of mineralization and nutrient uptake occurring in the lower layer which is closer to plant roots. In high elevation areas, the process of litter decomposition is slow so that the accumulation of C-organic in the soil (Charan *et al*., 2013; Kidanemariam *et al*., 2012). Similar research results were reported by Kidanemariam *et al*. (2012) in the Ethiopia region, as well as (Sipahutar *et al*., 2014; Sari, *et al*., 2013).

Under shaded conditions, total N is positively correlated with elevation (Table 2). The total N content of the soil is closely related to the content of organic matter in the soil (Rusdiana and Lubis, 2012). Some researchers report that high organic (C-organic) content can increase the nitrification process, so that the N content increases (Purwanto *et al*., 2013; Kidanemariam *et al*., 2012; Sipahutar *et al*., 2004). N soil is used by micro-organisms to decompose materials or compounds in the soil.

P-value is positively correlated with elevation (Tables 2-3), where P levels in the shaded conditions are higher correlated (0.829) than in un-shade conditions (0.281). These results indicate that the P-available value increases with increasing elevation. The results of this study differ from those reported by some researcher (Sipahutar *et al*., 2014; Vincent *et al*., 2014).

The value of land cation exchange capacity (CEC) varies but there is a tendency to increase and positively correlate with elevation (Tables 5-6). Allegedly, the

Table 3. Correlations between Coffee flavour parameters with altitude and shade

Elevation & shading	Aroma	Flavour	After taste	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	0.87
		1	0.577	.a	.a	-0.333	.a	.a	.a	0.577	0.87
			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

higher the height of the place, the greater the density of vegetation so that it contributes more organic material (Sari *et al*., 2013). This organic colloid also has greater cation absorption than clay colloids so, that the addition of organic matter to the soil can increase the value of soil CEC (Kilambo *et al*., 2015; Kufa, 2011). Soil CEC is an indicator of soil fertility related to the ability of soil colloids to provide nutrients contained in the colloid sorption complex. So, it is not easily washed out of the water (Silva Aragão *et al*., 2020). Based on Table 3, CEC scores are included in the low moderate category. This shows that the soil's ability to absorb and exchange cations are low. The low CEC is an indication that the research location has a very low level of soil fertility so additional input is needed.

Likewise with the base cation (K), it appears that the higher the place, the K soil will decrease and negatively correlated under the conditions of shelter but in the shaded conditions shows a weak positive correlation (0.051). The results of this study are identical to (Sari, *et al*., 2013) which shows the saturation of bases in high places the tendency is getting lower. The low accumulation of base cations at higher elevations indicates that leaching of base cations occurs in the soil.

The results of the analysis show that the elevation has a different correlation to the growth of vegetative and generative (production) of coffee in the conditions of no shade and shade. Under unshaded conditions, 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, an elevation is negatively correlated with productive branches, number of fruit/bunches and coffee production, but positively correlated strongly with the number of bunches (0.959) and canopy diameter. The results of this study contradict the report of (Da Silva, 2005) that the weight of 100 coffee beans increases with increasing elevation. Lower temperatures at higher elevations will slow the ripening process of coffee fruit so, that the formation of coffee beans is more perfect and fuller (heavy) (Somporn *et al*., 2012; Bertrand *et al*., 2011; Bote and Struik, 2010).

Correlation analysis between the chemical properties of the soil and the growth of the shaded and shaded coffee plants is also shown in Table 2. Consecutively, in shade coffee plants, the chemical properties of the soil such as C-organic, N, CEC and pH have a positive correlation with the parameters number of bunches, the number of fruit/bunches, canopy diameter and coffee production but negatively correlated to productive branches, while K was positively correlated to productive branches, the number of fruit/bunches and coffee production, conversely P is negatively correlated to the number of fruit/bunches and coffee production. Under shaded conditions, the chemical properties of soil C-organic, N, K and CEC yield strong positive correlations to productive branches, the number of fruits per bunches, and coffee production but negatively correlated to canopy diameter, parameters. Instead, a negative correlation is generated by P concerning the three parameters, meaning that P is 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 can be seen from the comparison of the values of the four parameters, where the taste of Arabica coffee in shaded conditions has a higher rating scale (Table 3). The relationship between altitude and coffee flavour is quite strong (0.698), although not significantly different (Table 3), the higher of elevation of cultivation area, coffee flavour more better. These results are in line with research by (Qadry *et al*., 2017), that Gayo arabica coffee varieties have better chemical physico-chemical quality if planted at elevation of >1,500 m asl.

The soil acidity (pH) values in four-zone of elevations were varied between 5.3–5.9. Soil acidity is one of the important factors in soil fertility.Optimum soil acidity (pH) for growth and production and quality of coffee is 5.8–6.2 (Maro *et al*., 2014) so, that in general the land in the research location is suitable for the development of coffee plants.

Soil pH seems to be more related to high rainfall conditions and low air temperatures in this area. Besides, the rather acidic soil reaction is related to the complex nature of the mineral constituent soil 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 the research of (De Bauw *et al*., 2016) which states that the decrease in pH at a height higher than 7.5 at an elevation of 1000 m asl to 4.9 at 2,200 m asl, which is associated with decreased potassium levels.

This can be due to research location contained high organic matter content, which can function as a buffer of soil pH which in turn will impacted on soil pH values. The function of the buffer from organic material play a role in minimizing changes in pH so that the soil solution will still be able to maintain the pH of the soil if there is an addition of acid or base in the soil. Moreover, the soil structure is porous, thus the soil in the study site has good drainage and may caused base cations from higher places being washed to lower place. It is also known that soil pH is an important factor affecting soil fertility because it has a large in fluence on other soil fertility parameters and higher plant nutrient uptake capacity (Marschner and Marschner, 2011).

The organic C content at the elevation of 1,200-1,400 and > 1,500 m asl is a very high category, while at an elevation of 1,400-1,500 m asl is classified as high. This shows that the coffee development area is rich in organic matter. According to (Sari *et al*., 2013), the land is categorized as fertile if the organic C level is more than 3%.The main source of organic material is litter/humus which comes from avalanches of leaves and twigs of coffee plants and shade and other plants which are quite abundant in number.According to (Ping *et al*., 2013), higher rainfall and lower temperatures in mountainous areas will increase the amount of litter/humus which is the main source of organic matter.

In this study, the top soil level of C organic is higher than the sub soil. 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 organic C in the soil (Charan *et al*., 2013; Kidanemariam *et al*., 2012). The results of a similar study were also reported by (Kidanemariam *et al*., 2012) in the Ethiopian region and Sari *et al*. (2013) and (Sipahutar *et al*., 2014) in Indonesia.

Table 1-2 also show that the total N-content tends to decrease and negatively correlate at an elevation of 1,300 - 1,400 m asl, but increase again at an elevation of > 1,500 m asl. The total N content of the soil is closely related to the content of organic matter in the soil (Rusdiana and 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 (Sipahutar *et al*., 2014; Purwanto *et al*., 2014). N soil is used by micro-organisms to decompose materials or compounds in the soil. Organic material is one of the N sources for plants. According to Rusdiana and Lubis (2012), the availability of N in the soil besides being determined by the amount of total-N soil is also closely related to the content of soil organic matter, especially the decomposition rate (C / N).

The content of P_2O_5 in four elevation zones has varying levels. These results indicate that P_2O_5 the available value increases with increasing elevation. The results of this study are different from those reported by (Vincent *et al*., 2014) and (Sipahutar *et al*., 2014). The rising temperature from January to May can stimulate microbial and uterine activity P_2O_5 available in the soil, increasing microbial mineralization and uptake of P_2O_5 by plants so, that it can increase cycle acceleration P_2O_5 and the content of P_2O_5 which is available tends to be higher.

The value of cation exchange capacity (CEC) is a tendency to increase and positively correlate with place height (Tables 2). It is suspected that the higher the elevation of the place, the greater the density of vegetation so that it contributes more organic matter (Sari *et al*., 2013). Organic colloids also have greater cation absorption than clay colloids so, that the addition of organic matter to the soil can increase the CEC value of the soil (Kilambo *et al*., 2015; Kufa, 2011). Soil CEC is an indicator of soil fertility that is related to the ability of colloidal soil to provide nutrients found in colloidal absorption complexes so, that it is not easily washed away by water. Based on Table 2, the CEC value is included in the low moderate category. This shows that the ability of the soil to absorb and exchange cations is low. The low CEC is an indication that the research location has a very low soil fertility level so, additional input from outside is needed.

Likewise with alkaline cations (K), in Tables 2, it can be seen that the higher elevation, the K land will decrease. The results of this study are identical to Sari *et al*. (2013) report which shows that base saturation at a high tendency is lower. The low accumulation of base cations at a higher elevation indicates that there is a washing of alkaline cations in the soil.

The results of the analysis show that the elevation has a different correlation with vegetative and generative growth (production) of coffee, whereas elevation correlated negatively with productive branches, number of fruit/bunches and coffee production but is strongly positively correlated with the number of bunches (0.959) and canopy diameter. The results of this study contradict the reports of (Da Silva *et al*., 2005) that the weight of 100 coffee beans increases with increasing elevation. Lower temperatures at higher places will slow down the coffee ripening process so, that the formation of coffee beans is more perfect and fuller (heavy) (Somporn *et al*., 2012; Bertrand *et al*., 2011; Bote and Struik, 2010). In general, the results of the correlation analysis of soil chemical properties with elevation also indicate that the higher the place, the soil chemical properties (N, C organic, pH and K) are negative, while CEC and P_2O_5 are correlated negatively.

Tables 2 also shown the correlation between the chemical properties of soil with each other and pH is closely tied to CEC. This proves that CEC is linearly related to soil pH, that is, if the CEC level is low then base cations will be reduced and replaced by H^+ ions so. That it can cause the soil pH to decrease and *vice versa*. The acidity will decrease and fertility will increase with increasing CEC. The potential release of absorbed cations for plants depends on the level of CEC.

The N-Total correlation is strongly correlated with organic C, pH and soil CEC, correlated weakly with K and negatively correlated with P. This is because the higher the level of C organic, the N reserves in the form of organic N will be higher and increase after going through mineralization, as well as the high CEC value, the colloidal soil will be more active. Active colloids can absorb NH_4^+ and with more and more NH_4^+ which is absorbed, it will produce a lot of ammonium so, that nitrification occurs in the soil reported by (Hasibuan *et al*., 2014) 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 will affect 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.

Correlation analysis between soil chemical properties and growth of non-shaded and shaded coffee plants is also shown in Table 2. In unshaded coffee plantations, soil chemical properties such as C, N, CEC and pH have a positive correlation with the parameters of the number of bunches, the number of fruit/bunches, canopy diameter and coffee production but negatively correlated with productive branches, while K has a positive correlation with productive branches, the number of fruits/bunches and coffee production, on the contrary P has a negative correlation with the number of fruit/bunches and coffee production.

Soil chemical properties C, N, KTK, pH, K produces a positive correlation with productive branches, number of fruits/bunches and coffee production but negatively correlates with canopy diameter parameters. Conversely, negative correlations are generated by P on all three parameters, it means that P has a positive correlation with the number of bunches and canopy diameter.

The soil pH in addition to influencing productivity and flavour also determines by (Kilambo *et al*., 2015; Clemente *et al*., 2013) the quality of Arabica coffee beans. Soil C-organic and N content also positively correlated with coffee production in non-shaded and shaded conditions explain in Table 2. According to Maro *et al*. (2014) to optimally grow and produce coffee plants need organic matter (C-organic) above 2%. The content of C-organic soil in the Humbang area is also following coffee needs. Likewise, for optimal growth and production of coffee plants, it requires N elements with levels above 0.12% (Maro *et al*., 2014). Adequate N supply will increase the number of plagiotropic branches (branches of production), leaf area and starch production, and other carbohydrates which play a role in the formation and growth of coffee beans (Clemente *et al*., 2013). Also, nutrient N affects plant growth and caffeine content in coffee plant tissue.

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 after taste and balance. This can be seen from the comparison of the values of the four parameters, where the taste of Arabica coffee in shaded conditions has a higher rating scale Table 3. The relationship between altitude and coffee flavour is quite strong (0.698) although not significantly different Table 3, the higher the height of coffee flavour the better. These results are in line with research by (Qadry *et al*., 2017), that Gayo arabica coffee varieties have better chemical physico-chemical quality if planted at elevation of >1,500 m asl.

An increase in air temperature under the auspicious condition affects the quality of taste due to the effects of various syntheses in the coffee beans during the ripening process, such as sucrose, trigonelline, chlorogenic acid, caffeine, which causes a decrease in organoleptic quality (Geromel *et al*., 2008; Vaast *et al*., 2006; Ky *et al*., 2001). Furthermore, according to (Bote and Struik, 2010), coffee beans produced from plants in shaded conditions produce beans with lower organoleptic quality (in terms of acidity, body and taste) compared to coffee grown in shaded conditions. Similar to decreasing shade levels, lower growing heights have been found to have a negative effect on coffee quality because an increase in average air temperature accelerates the process of fruit ripening and hence, changes the biochemical composition of coffee beans.

Conclusion

There are strong correlations between elevation, soil chemical properties and coffee production in Humbang Hasundutan district under shaded and unshaded conditions. Under un-shaded conditions, N, C, pH, and K negatively correlated with an increase in elevation, while CEC and P are available and coffee crop production is positively correlated. Likewise in shaded conditions, N, C, pH, K, and coffee crop production is negatively correlated with an increase in elevation, while the CEC and P available have positive correlation properties.

Shading affects the taste of Arabica coffee at all elevation, namely the quality of flavour, body, quality of after taste and balance. Of the comparison between values of the four parameters, the relationship between altitude and coffee flavour is quite strong (0.698), although not significantly different. However, the higher of elevation of cultivation area, the better the coffee flavour.

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