Association of Arabica Coffee Quality Attributes with Selected Soil Chemical Properties

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Abstract: Coffee (*Coffea arabica* L.) bean quality attributes differ based on the origin of the produce. Several agro-ecological conditions influence coffee bean quality attributes. Soil chemical properties may be some of the factors affecting the quality attributes. However, no study has so far been conducted to elucidate the association of coffee bean qualities with soil chemical properties in both major and minor coffee growing regions of Ethiopia. Thus, this research was conducted with the objective of establishing association of chemical soil properties with coffee cup quality attributes. Coffee beans as well as soil samples from which the beans originated were subjected to chemical analysis. The coffee beans and the corresponding soil samples originated from large scale coffee plantations (Bebeka, Gemadro and Goma), districts from southwestern major coffee growing region (Gore, Jimma, Lemkefa), West (Gimbi), East (Badano, Chiro, Darolebu, Habro and Melkabelo), South (Yirgacheffe) and northwestern minor coffee growing districts (Ankasha, Bure, Mecha and Jabi). The soil samples were collected from the depth of 0 - 50 cm near the coffee trunks and samples of ripe coffee cherries were picked up from the trees during the 2010/11 harvest season. Selected chemical properties of the soil, namely, available potassium, cation exchange capacity, exchangeable acidity, exchangeable bases, available micronutrients, available phosphorus, total nitrogen, soil pH, electrical conductivity, and percent organic carbon were determined from 53 soil samples in Jimma University soil laboratory and Wolkitie Soil Testing and Soil Fertility Improvement Centre using the established procedures. The sampled red coffee cherries were carefully subjected to the dry processing methods and the separated beans tested for quality attributes in accordance with Ethiopian Commodity Exchange (ECX) and Specialty Coffee Association of America (SCAA) coffee quality test procedures and standards. Correlation and stepwise regression analyses were done to establish the association of the selected soil chemical properties with the coffee bean quality attributes. The correlation analysis revealed that coffee quality attributes were positively and significantly associated with CEC (r = 0.36**), available soil Mg content (r = 0.28*), exchangeable acidity (H^+) (r = 0.35*), and soil pH (r = 0.30*). However, the coffee quality attributes were negatively and significantly associated with soil available Cu (r = - 0.35*), available Zn (r = - 0.40**), and total N (r = - 0.40**). The regression analysis showed that coffee quality attributes were more profoundly dependent on available Fe content (R^2 =0.22) and CEC (R^2 = 0.13) in the soil. The soil CEC and available soil iron (Fe) accounted for 13 and 21.9%, respectively of the observed variation in the overall coffee quality attributes that determines the final coffee grade and consumer preferences. Therefore, it could be concluded that coffee quality attributes improved with increase in the levels of soil CEC, Mg, H1+, and pH, while decreasing with increase in the levels of available soil Cu, Zn and total N. However, enhanced soil CEC and available iron content led to improved grade and overall specialty coffee quality attributes whilst enhanced soil available zinc and copper as well as total soil nitrogen led to reduced grade and overall specialty coffee quality attributes.

Keywords: Available soil iron; *Coffea arabica* L.; CEC; Coffee grade; Specialty coffee quality attributes; coffee cup quality

1. Introduction

Arabica coffee (*Coffea rabica* L) grows in Ethiopia, which is the place of its origin. Thus, one understands well the ecological requirements of Arabica coffee when visiting the live progenies in their homeland in the Ethiopian high rainfall natural forests (Wintgens, 2004; Wrigley, 1988). Coffee grows in a wide range of ecologies in its original forest habitat. It occurs in the multi-strata of forest ecosystems in the clay-silicaceous soils of granite as it does on soils of volcanic origin or even on alluvial soils (Wrigley, 1988; Paulos, 1994; Malavolta, 2003; Wintgens, 2004). The plantation crops such as tea, coffee, and rubber have different agro-climatic requirements and are cultivated in diverse soil types (Jessy, 2011).

An effective depth of greater than 150 cm enables the coffee plant to exploit a greater volume of soil for nutrients and water. Highly suitable areas are those with high soil organic matter (SOM) (> 3%) content and slightly acidic soils (between pH 5.3 and 6.5) (Paulos, 1994). The bulk of coffee soils in Ethiopia are classified as *Nitosols*, which are highly weathered, originated from volcanic rocks, deep, well drained and have medium to high contents of most of the essential elements, except nitrogen and phosphors (Paulos, 1994).

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The physical environment including the soil is one of the most important factors that influence coffee quality (Wintgens, 2004; Läderach, 2007)). Avelino *et al.* (2005) showed that the quality of Jamaica Blue Mountain coffee and the Kenya AA type coffee share common properties that could be due to favourable influence of altitude and soil. Other studies revealed that volcanic soils often produce pointed acidity, good body, and a balanced cup (Njorge, 1998; Pinkert, 2004; Bertrand *et al.*, 2006).

In Ethiopia, coffee is not only produced in natural forests where it originated but also it is expanding to other regions that experience full sun to partial shade environment. In both major and minor coffee growing regions, the influence of soil properties on coffee quality is not well studied. Taye (2011) conducted research to determine the status of soil nutrient elements, and characterize the soils on which coffee is grown. The metal composition of coffee bean variations due to their differences in geographical origin was also reported (Abera, 2006). Abera (2006) analysed the metal contents (Ca, Cd, Cr, Co, Cu, Fe, K, Mg, Mn, Ni, Pb and Zn) of raw and roasted coffee beans obtained from five different parts of Ethiopia (Wollega, Sidamo, Harar, Bench-Maji and Kaffa zones), and found that the observed the metal concentrations in roasted coffee beans were relatively higher than their corresponding raw coffee samples. Abebe *et al.* (2008) reported inverse relationships between coffee cup quality and soil nitrogen to phosphorus ratio and soil Zn content at Shako. The authors also found direct associations coffee cup quality with soil K, Ca, CEC, pH, and micronutrients at Yayo forest coffees in Ethiopia.

Nevertheless, the associations of soil chemical properties and coffee beans quality of different origins in Ethiopia require further research considering the changing conditions of climate and farming practices. Thus, the objective of this research was to elucidate associations of coffee quality attributes from major and minor coffee growing regions in Ethiopia with soil chemical properties.

2. Materials and Methods

2.1. Site Selection and Sample Preparation

The study sites were purposely selected considering the natural barriers and/or spatial location and agro climatic situation (Figure1). The study sites included Bebeka, Gemadro, Goma, Gore, Jimma, Lemkefa, (Southwest); Gimbi (West); Yirgacheffe (South); Ankasha, Bure, Mecha, Jabi (Northwest); and Badano, Chiro, Darolabu, Habro, Malkabalo (East) woredas (districts) of coffee growing regions during the 2010/11 harvest season. Soil samples per replication (sub-farm) were collected from three sub-samples from the depth of 0 – 50 cm from the immediate rhizosphere near the coffee trunk, from which ripe coffee cherries were picked up at the same time for studying quality attributes of the coffee beans.

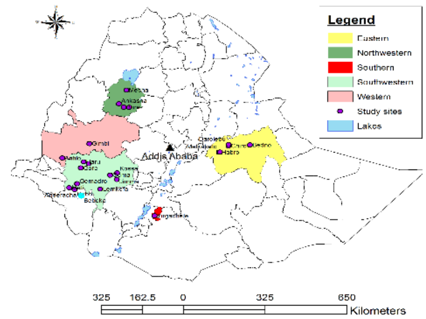

Figure 1. Map of coffee origins from which the green coffee bean and soil samples were collected.

2.2. Laboratory Analysis

Soil sample analysis: A composite of three soil subsamples was taken per replication. Three replications were considered per site. A total of 53 soil samples (Table 1) were collected for laboratory analysis. The soil samples were air-dried in the laboratory and crushed and sieved through a 2 mm sieve for determining the selected soil chemical properties. Soil pH was determined with 1:2.5 soil: water suspension, and measured with a digital pH metre. Organic Carbon was determined by the potassium dichromate oxidation method (Walkley and Black, 1934). Total nitrogen (TN) was measured using the Kjeldahl method (Jackson, 1958), Available phosphorus was determined by Bray II Method followed by quantification in a UV-vis spectrophotometer (Bray and Kurtz, 1945); andEC was determined on the supernatant obtained from a 1:2.5 (soil: water) suspension using a conductivity bridge at the laboratory of Jimma University College of Agriculture and Veterinary Medicine (JUCAVM). The exchangeable bases (Ca and Mg) were measured by extraction with NH_4OAC followed by quantification using a flame photometer. Exchangeable K was extracted by the sodium acetate method. Exchangeable acidity was extracted with 1M KCl, followed by the quantification of Al and H by titration. Available micronutrients iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn) were determined by digesting with nitric-perchloric acid followed by quantification by atomic absorption spectrophotometer. Cation exchange capacity (CEC) was determined by the titration method at Wolkitie Soil Testing and Soil Fertility Improvement Centre.

Coffee quality analysis: Fifty-one coffee samples (Table 2) were carefully prepared by the dry processing method, and handed over to ECX (100 g), Jimma Centre and Efico (50 g) in Belgium. A panel of 3-4 trained, experienced and internationally certified (Q graders) cuppers took 6 to 8 cc of the brew from 5 cups using soupspoons and forcefully slurped it to spread evenly over the entire surface of the tongue and palate and then expectorated on to the spittoon. Cup cleanness, acidity, body, and flavour were evaluated as per the standard method. Finally, the preliminary grade assessment was made based on the scores of the raw and cup quality analyses (ECX, 2009).With regard to specialty assessment by Efico, aroma, acidity, flavour, body, aftertaste, and balance attributes were evaluated. Then, the overall attribute was determined as an average of these six attributes (SCAA, 2009).

2.3. Statistical Analysis

One way ANOVA was conducted for both soil and coffee samples. Moreover, Pearson correlation analysis was conducted to determine the associations between soil chemical properties and coffee quality attributes. Regression analysis was also conducted for soil chemical properties and coffee quality attributes using SPSS 16 v2 software (SPSS Inc.2007). In the regression analysis, the soil chemical properties were considered as independent and coffee quality attributes as dependent (response) factors to assess how much of the variation in the coffee quality attributes could be accounted for by the predictors.

3. Results

3.1. Chemical Properties of Soils and Coffee Quality Attributes

3.1.1. Chemical Properties of Soils

Soil chemical properties showed highly significant variations among the study sites (Table 1).Variation in soil properties at natural state is obvious not only at distant sites even in a neighbourhood because of time, soil forming factors, and human manipulation for agriculture (Jenny, 1994). It is reported that soils vary from place to place because the intensity of the factors is different at different locations (Anonymous, *n.d.*).

3.1.2. Coffee Quality Attributes of Different Regions

Coffee quality attributes including hundred bean weight (HBW), secondary defects, odour, and total points showed significant difference (Table 2A). These attributes dominate the preliminary grade assessment (ECX, 2009). For specialty attributes, bean moisture content and acidity were significantly different and non-significant otherwise (Table 2B). Although the p-value is 0.069 mean separation with Tukey HD showed that coffee samples from Ankasha exceeded as compared to those from Bebeka.

3.2. Association of Soil Chemical Properties with Coffee Quality Attributes

Pearson correlation analysis showed positive and significant correlations between soil CEC and coffee acidity, flavour, total point, and perfumed attributes. Positive and significant ($P < 0.05$) correlations were observed between H^{1+} concentration and hundred bean weight (HBW); between soil available Mg content, balance, aftertaste, and overall coffee quality; and between pH and secondary defects. However, negative and significant ($P < 0.05$) correlations were recorded between Cu and HBW; between Zn and odour; and between total N and body. Other chemical soil properties viz. K, Ca, Fe, Mn, P, EC, and soil organic carbon content did not show significant correlations with all coffee quality attributes. Similarly, moisture content, aroma, and fruity quality attributes did not show significant correlations with any of the soil chemical properties (Table 3).

Table 1. Mean values of soil chemical properties of the study sites.

Farm	No.	**K** (mg/kg)	**CEC** (meq/100g)	**H** (meq/100g)	**Mg** (meq/100g)	**Ca** (meq/100g)	**Fe** (meq/100g)	**Mn** (meq/100g)	**Cu** (meq/100g)	**Zn** (meq/100g)	**P** (ppm)	**N** (%)	**pH** (Water)	**EC** (mS/cm)	**C** (%)
Anderacha	3	17.80^{c}	30.00^{def}	0.97^{bcd}	3.37^{bcde}	27.83^{a}	9.57^{a}	6.37^{k}	2.73^{d}	6.30^{abcd}	1.37^{b}	4.80^{a}	6.37^{abc}	0.02^{c}	3.93^{ab}
Ankesha	3	12.87^{efg}	31.87^{cde}	0.63^{fgh}	4.23^{ab}	11.00^{fg}	5.73^{abcde}	7.53^{j}	3.17^{c}	4.57^{defg}	0.47^{fg}	2.23^{cdef}	6.00^{bc}	0.02^{c}	2.43^{cd}
Bebeka	3	11.37^{g}	21.53^{ghi}	0.63^{fgh}	2.13^{efgh}	11.47^{efg}	4.13^{cde}	9.80^{g}	0.53^{i}	5.67^{bcdef}	0.50^{efg}	2.10^{cdefg}	6.00^{bc}	0.03^{c}	2.97^{bcd}
Badano	3	16.03^{d}	38.57^{abc}	0.23^{j}	3.93^{bc}	29.27^{a}	3.90^{cde}	2.33^{o}	2.27^{e}	4.50^{defgh}	0.70^{de}	1.87^{defg}	6.93^{abc}	0.03^{c}	2.97^{bcd}
Bure	3	22.87^{a}	23.00^{fgh}	0.50^{hi}	4.43^{ab}	16.47^{cd}	6.03^{abcde}	13.90^{c}	3.50^{b}	7.83^{a}	0.63^{def}	2.37^{cdef}	6.40^{abc}	0.03^{c}	3.10^{bc}
Chiro	3	11.70^{g}	39.93^{ab}	0.57^{fgh}	4.53^{ab}	13.93^{def}	2.97^{e}	2.90^{n}	1.93^{f}	3.90^{fghi}	2.80^{a}	1.60^{defg}	6.37^{abc}	0.03^{c}	3.13^{abc}
Darolebu	3	14.20^{e}	35.87^{bcd}	0.33^{ij}	3.63^{bcd}	13.10^{efg}	3.47^{de}	2.53^{no}	1.57^{g}	4.43^{efgh}	0.57^{defg}	3.03^{bc}	6.60^{abc}	0.04^{c}	1.83^{d}
Gemadro	3	9.63^{hi}	14.13^{ij}	0.90^{cde}	0.87^{h}	3.63^{h}	5.50^{abcde}	1.77^{p}	0.90^{h}	2.50^{i}	0.53^{efg}	3.77^{b}	6.53^{abc}	0.04^{c}	3.27^{abc}
Gimbi	3	13.40^{ef}	25.13^{efg}	1.17^{b}	1.93^{fgh}	4.23^{h}	3.70^{cde}	3.50^{lm}	0.50^{i}	2.87^{ghi}	0.47^{fg}	1.50^{efg}	6.27^{abc}	0.04^{c}	3.10^{bc}
Goma	3	21.67^{a}	27.47^{efg}	1.07^{bc}	2.70^{cdef}	17.77^{bc}	7.33^{abcd}	14.67^{b}	0.43^{i}	6.73^{ab}	0.93^{c}	2.23^{cdef}	5.87^{c}	0.05^{c}	4.30^{a}
Gore	3	8.17^{i}	27.57^{efg}	2.33^{a}	1.23^{gh}	6.33^{h}	3.80^{cde}	9.07^{i}	0.43^{i}	2.70^{hi}	0.53^{efg}	2.23^{cdef}	6.30^{abc}	0.05^{c}	3.97^{ab}
Habro	3	19.73^{b}	30.70^{de}	0.73^{efg}	2.43^{defg}	10.30^{g}	4.70^{bcde}	3.80^{l}	0.97^{h}	5.70^{bcdef}	0.57^{defg}	2.43^{cde}	7.00^{ab}	0.05^{c}	2.33^{cd}
Jabi	3	12.10^{fg}	31.37^{cde}	0.67^{fgh}	5.47^{a}	19.87^{b}	4.70^{bcde}	9.07^{h}	2.70^{d}	4.77^{def}	0.50^{efg}	2.57^{cd}	6.53^{abc}	0.05^{c}	2.43^{cd}
Jimma	3	22.50^{a}	15.70^{hij}	0.57^{fgh}	2.47^{defg}	12.63^{efg}	5.10^{bcde}	11.63^{e}	0.40^{i}	5.43^{bcdef}	0.40^{g}	1.40^{fg}	6.40^{abc}	0.06^{bc}	3.50^{abc}
Lem	3	9.67^{hi}	28.63^{defg}	0.77^{def}	2.70^{cdef}	13.33^{efg}	7.70^{abc}	16.90^{a}	0.40^{i}	6.67^{abc}	0.40^{g}	2.57^{cd}	6.17^{abc}	0.06^{bc}	3.93^{ab}
Mecha	3	16.47^{cd}	45.85^{a}	0.53^{ghi}	4.63^{ab}	14.17^{de}	6.00^{abcde}	12.77^{d}	3.80^{a}	6.13^{abcde}	0.77^{cd}	2.07^{cdefg}	5.97^{bc}	0.06^{bc}	2.97^{bcd}
Melkabelo	2	19.80^{b}	38.33^{bc}	0.90^{cde}	4.60^{ab}	20.10^{b}	2.65^{e}	2.90^{n}	2.20^{e}	4.90^{cdef}	0.45^{fg}	2.45^{cde}	7.15^{a}	0.11^{ab}	3.85^{ab}
Yirgachafe	3	9.83^{h}	11.00	0.63^{fgh}	3.37^{bcde}	11.33^{efg}	8.63^{ab}	10.43^{f}	0.40^{i}	5.60^{bcdef}	0.40^{g}	1.13^{g}	6.20^{abc}	0.13^{a}	3.70^{ab}
P-value		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.006	<0.001	<0.001
Mean		14.90	28.38	0.78	3.23	14.16	5.36	7.98	1.59	5.07	0.73	2.35	6.38	0.05	3.19
SD		4.71	9.13	0.45	1.31	6.86	2.20	4.75	1.19	1.52	0.57	0.90		0.03	0.73
CV%		31.63	32.18	57.92	40.42	48.47	41.08	59.56	74.81	30.06	77.98	38.13	7.08	63.50	22.83

Note: Means followed by the same letter in the column are not significantly different at P ≤ 0.05

Table 2. Coffee quality attributes.
A. Preliminary grade attributes.

Farm	No.	HBW	Preliminary defects	Secondary defects	Odour	Acidity	Body	Flavour	Total points
Bebeka	3	16.04 abc	15 a	14 a	9.33 ab	11 a	11 a	9 a	84.3 a
Anderacha	3	15.39 abc	15 a	14 a	10 a	10 a	9 a	9 a	82.0 a
Gemadro	3	15.02 abc	15 a	9 ab	10 a	12 a	10 a	9 a	80.0 ab
Lem	3	15.64 abc	9.5 a	5 b	10 a	10 a	9 a	9 a	67.5 b
Jimma	3	15.03 abc	15 a	9 ab	10 a	12 a	12 a	11 a	84.0 a
Goma	3	15.44 abc	15 a	9 ab	10 a	12 a	10 a	12 a	83.0 a
Gore	3	18.60 a	15 a	14 a	10 a	12 a	11 a	11 a	88.0 a
Gimbi	3	16.16 abc	14 a	10 ab	10 a	10 a	9 a	10 a	78.0 ab
Yirgachafe	3	14.94 abc	15 a	15 a	10 a	12 a	10 a	10 a	87.0 a
Jabi	3	13.94 bc	15 a	15 a	10 a	10 a	9 a	10 a	84.0 a
Bure	3	14.71 abc	15 a	11 ab	8.67 b	12 a	10 a	10 a	81.7 a
Ankesha	3	13.57 c	15 a	6.5 ab	10 a	11 a	10 a	12 a	79.5 ab
Mecha	3	13.99 bc	14 a	12 ab	10 a	11 a	10 a	10 a	82.0 a
Chiro	2	17.60 abc	15 a	13.5 ab	10 a	12 a	12 a	12 a	89.5 a
Habro	3	16.59 abc	15 a	12 ab	10 a	11 a	10 a	11 a	84.0 a
Darolebu	2	18.08 ab	15 a	15 a	10 a	10 a	10 a	8 a	83.0 a
Melkabelo	2	16.72 abc	15 a	10.5 ab	10 a	12 a	10.5 a	10.5 a	83.5 a
Badano	3	15.21 abc	15 a	14 a	10 a	11 a	10 a	10 a	85.0 a
P-value		.003	.136	.001	.022	.314	.411	.133	.001
mean		15.60	14.57	11.57	9.88	11.13	10.10	10.15	82.40
sd		1.70	1.98	3.74	0.47	1.37	1.46	1.70	5.83
CV		10.9	13.6	32.3	4.8	12.3	14.4	16.7	7.1

Note: Means followed by the same letter in the column are not significantly different at P ≤ 0.05; HBW = Hundred bean weight

B. Specialty grade attributes.

Farm	No.	Water content	Aroma	Body	Acidity	Balance	Fruity	Perfumed	Flavour	Aftertaste	Overall	Specialty Grade
Bebeka	3	9.13 c	4.67 a	5.00 a	5.67 ab	4.17 b	5.00 a	3.00 a	4.00 a	4.67 a	4.52 a	1.67 a
Anderacha	3	9.43 bc	5.00 a	5.00 a	5.33 b	5.00 ab	3.67 a	4.17 a	4.00 a	5.00 a	4.65 a	1.67 a
Gemadro	3	9.63 abc	5.67 a	5.33 a	6.33 ab	5.67 ab	5.67 a	5.67 a	5.67 a	6.00 a	5.75 a	1.00 a
Lem	3	9.13 c	6.00 a	5.33 a	7.50 ab	6.17 ab	5.33 a	4.83 a	5.17 a	5.83 a	5.77 a	1.00 a
Jimma	3	9.03 c	6.33 a	5.83 a	8.00 a	6.17 ab	6.67 a	6.00 a	6.17 a	6.00 a	6.40 a	1.00 a
Goma	3	8.53 c	5.00 a	5.33 a	5.67 ab	5.17 ab	6.00 a	4.33 a	5.17 a	5.67 a	5.29 a	1.33 a
Gore	3	8.87 c	5.67 a	5.33 a	6.67 ab	5.83 ab	4.67 a	3.67 a	3.33 a	4.67 a	4.98 a	2.00 a
Gimbi	3	9.57 bc	6.00 a	6.00 a	5.67 ab	6.00 ab	6.67 a	4.67 a	5.83 a	6.00 a	5.85 a	1.00 a
Yirgachafe	3	8.77 c	5.67 a	5.67 a	5.50 b	5.33 ab	6.33 a	5.67 a	5.67 a	6.17 a	5.75 a	1.67 a
Jabi	3	6 a	6.00 a	6.33 a	6.67 ab	6.17 ab	3.33 a	5.00 a	5.50 a	6.00 a	5.63 a	1.33 a
Bure	3	8.83 c	6.17 a	6.33 a	6.50 ab	5.83 ab	6.50 a	6.00 a	6.00 a	6.00 a	6.17 a	1.00 a
Ankesha	3	10.77 ab	7.33 a	6.67 a	7.50 ab	6.83 a	4.33 a	6.67 a	7.17 a	7.17 a	6.71 a	1.00 a
Mecha	3	9.23 c	5.67 a	5.83 a	6.33 ab	6.00 ab	6.17 a	4.33 a	5.50 a	6.00 a	5.73 a	1.00 a
Chiro	2	8.20 c	6.00 a	6.50 a	6.50 ab	6.00 ab	7.00 a	5.50 a	5.00 a	6.00 a	6.06 a	1.00 a
Habro	3	9.30 bc	5.00 a	5.00 a	5.33 b	5.00 ab	6.33 a	4.33 a	4.00 a	4.33 a	4.92 a	1.33 a
Darolabu	2	8.97 c	6.00 a	6.50 a	7.17 ab	6.00 ab	5.00 a	4.17 a	4.67 a	5.83 a	5.67 a	1.00 a
Melkabelo	2	9.00 c	6.00 a	6.00 a	6.50 ab	6.00 ab	6.50 a	6.00 a	7.00 a	7.00 a	6.38 a	1.00 a
Badano	3	9.20 c	6.50 a	6.67 a	7.50 ab	6.50 ab	5.67 a	6.17 a	6.00 a	5.83 a	6.35 a	1.00 a
P-value		.000	.305	.160	.001	.069	.715	.545	.275	.650	.358	.477
mean		9.29	5.81	5.80	6.46	5.76	5.56	4.98	5.30	5.76	5.68	1.24
sd		0.79	1.02	0.89	1.04	0.91	1.99	1.75	1.62	1.31	1.02	0.55
CV%		8.5	17.6	15.4	16.1	15.8	35.7	35.1	30.6	22.8	17.9	44.6

Note: Means followed by the same letter in the column are not significantly different at P≤0.05

Table 3. Pearson correlation coefficients (r) between chemical properties of soils and coffee quality attributes.

	HBW	Secondary defects	Odour	Acidity	Body	Flavour	Total point	MC	Aroma	Balance	Fruity	Perfumed	After taste	Overall
K	-0.06	-0.03	-0.06	-0.01	0.22	0.06	0.09	-0.10	-0.05	-0.02	0.13	0.07	0.08	0.06
CEC	-0.05	0.08	0.13	0.32*	0.22	0.34*	0.36**	0.04	0.13	0.03	0.12	0.29*	0.18	0.18
H	0.35	0.05	0.01	0.03	0.09	0.09	0.12	-0.06	-0.06	-0.07	-0.09	-0.10	-0.07	-0.14
Mg	-0.17	0.09	-0.05	0.06	0.10	0.20	0.15	0.14	0.27	0.32*	-0.03	0.26	0.28*	0.28*
Ca	-0.20	0.05	0.02	-0.06	-0.01	0.02	0.02	0.03	-0.01	0.04	-0.12	-0.01	-0.05	-0.02
Fe	-0.26	-0.15	0.00	-0.02	-0.26	-0.08	-0.27	-0.04	-0.09	-0.12	-0.02	0.07	0.03	-0.06
Mn	-0.18	-0.21	-0.27	0.13	-0.11	0.03	-0.25	-0.13	-0.03	-0.03	0.10	-0.06	-0.02	-0.01
Cu	-0.35*	0.05	-0.08	-0.01	-0.22	-0.14	-0.02	0.22	0.17	0.23	-0.12	0.10	0.11	0.15
Zn	-0.21	-0.05	-0.40**	0.15	-0.13	0.02	-0.06	-0.11	0.04	0.00	0.16	0.16	0.18	0.15
P	0.21	0.17	0.03	0.04	-0.01	0.07	0.16	-0.14	-0.12	-0.07	0.02	-0.02	0.02	-0.07
N	0.04	-0.02	0.08	-0.14	-0.40**	-0.22	-0.19	0.11	-0.14	-0.14	-0.22	-0.11	-0.06	-0.19
pH	0.15	0.3*	0.05	-0.08	0.05	-0.10	0.24	0.00	0.11	0.06	0.01	0.17	0.10	0.11
EC	0.17	0.12	-0.03	0.00	0.20	-0.25	0.06	-0.18	-0.04	0.01	0.05	0.01	0.05	0.03
%OC	0.03	-0.24	0.03	0.23	0.12	0.19	-0.02	-0.19	-0.07	-0.12	0.04	-0.04	-0.08	-0.08

Note: * and **, significant at $P < 0.05$ and 0.01, respectively; HBW = hundred bean weight (g); MC = green coffee bean moisture content (%), K =available potassium, CEC= cation exchange capacity, Mg = magnesium, Ca =calcium, Fe =iron, Mn = manganese, Cu =copper, Zn =zinc, P =available phosphorus, N = total nitrogen, pH =soil acidity, EC =electrical conductivity, %OC =percent organic carbon.

Preliminary coffee quality attributes: The preliminary grade assessment was made based on the scores of the raw and cup quality analyses of the arrivals in this case of the supplied samples (ECX, 2009). The results of the regression analysis revealed that the variation in hundred beans weight was accounted for/expressed 12, 18.5 and 26.7% by Cu, P and Fe, respectively, while 30.2 and 33.8% was by EC, and H, respectively. Soil pH accounted for 8.5% of the variation in secondary defect. Zinc (Zn) and Fe accounted for 16.1 and 20.3% of the variation in odour, respectively. Regarding the acidity and perfumed attributes, CEC accounted for 8.6 and 8.0% of the variations, respectively. Total N and EC accounted for 16.2 and 25.2%, while K, CEC and Cu accounted for 30.5, 35.1 and 38.6% of the variation in body, respectively. The coffee flavour variation was accounted for by CEC, EC, Mg, and Cu by about 10.7, 15.5, 21.1 and 25%, respectively. Soil magnesium (Mg) accounted for 7.5, 9.6 and 7.7% of the variation in coffee aroma, balance, and overall attributes, respectively. For the total point attribute, which is the basis for the final grading, 13 and 21.9% of the variation was accounted for by soil CEC and available soil iron (Fe), respectively (Table 4).

Specialty coffee quality attributes: Specialty analysis was conducted using the same samples that scored a preliminary grade of 1, 2, and 3. Specialty assessment was made by Efico, based on aroma, acidity, flavour, body, aftertaste, and balance attributes. Then, the overall score was calculated as an average of these six attributes (SCAA, 2009). Copper (Cu) and EC accounted for 4.94 and 4.19% of the variation in moisture content of the green coffee beans, respectively. The variations in coffee aroma, balance, overall, and aftertaste were contributed by Mg to the extent of 7.48, 9.63, 7.67, and 7.44%, respectively. Moreover, 5.36% of the variation in coffee aftertaste was contributed by soil Ca. The variations in fruity and perfumed attributes of 4.7 and 7.98% were accounted for by total N and CEC, respectively (Table 2).

Table 4. Regression coefficients (R^2) between soil chemical properties and coffee quality attributes.

Quality attributes	Variable	Partial R2	Model R2	C(p)	F-Value	Pr > F
Hundred bean weight (g)	Cu	0.1197	0.1197	3.0481	6.66	0.0129
	P	0.0650	0.1847	1.3504	1.3504	0.0562
	Fe	0.0818	0.2665	-1.2987	-1.2987	0.0266
	EC	0.0356	0.3021	-1.3199	-1.3199	0.1327
	H	0.0356	0.3376	-1.3426	-1.3426	0.1270
Secondary defect	pH	0.0850	0.0850	-2.4751	4.55	0.0379
Odour	Zn	0.1606	0.1606	-6.1563	9.38	0.0036
	Fe	0.0420	0.2027	-6.2014	2.53	0.1183
Acidity	CEC	0.0863	0.0863	-1.3228	4.63	0.0364
Body	N	0.1617	0.1617	8.6517	9.45	0.0034
	EC	0.0901	0.2518	4.6694	5.78	0.0201
	K	0.0533	0.3051	3.1318	3.60	0.0638
	CEC	0.0460	0.3511	2.0776	3.26	0.0775
	Cu	0.0345	0.3856	1.7879	2.53	0.1190
Flavor	CEC	0.1071	0.1071	3.6314	5.88	0.0190
	EC	0.0481	0.1552	2.9066	2.73	0.1050
	Mg	0.0556	0.2108	1.7545	3.31	0.0752
	Cu	0.0394	0.2502	1.5212	2.42	0.1269
Total points	CEC	0.1303	0.1303	1.9497	7.34	0.0093
	Fe	0.0888	0.2191	-1.0457	5.46	0.0237
Moisture content (%)	Cu	0.0494	0.0494	-0.5066	2.54	0.1171
	EC	0.0419	0.0913	-0.5578	2.22	0.1432
Aroma	Mg	0.0748	0.0748	-4.2584	3.96	0.0522
Balance	Mg	0.0963	0.0963	-5.7675	5.22	0.0267
Fruity	N	0.0468	0.0468	-2.1582	2.40	0.1274
Perfumed	CEC	0.0798	0.0798	0.8768	4.25	0.0446
Aftertaste	Mg	0.0744	0.0744	-2.4590	3.94	0.0528
	Ca	0.0536	0.1280	-3.0370	2.95	0.0924
Overall	Mg	0.0767	0.0767	-2.5639	4.07	0.0491

4. Discussion

The coffee quality attributes increased with increase in the levels of soil CEC, Mg, H1+, and pH, while decreasing with the increase in the levels of soil Cu, Zn and total N. Consistent with the results of this study, the best soils of good quality coffee are lava, volcanic ash soils, basic rocks and alluvial deposits that exhibit a high cation-exchange capacity and a favourable soil organic matter status (Anonymous, n.d). Soils with a high percentage of organic material are more fertile, less liable to erosion and have a better water and nutrient retention capacity (Mitchell, 1988). The acidity level of the soil is also reported to produce a good quality coffee (Avelino et al., 2005).

The finding of this research particularly related to the associations of soil N and Mg with coffee quality is in agreement with the report of Yara (2010), who reported that increased level of soil Mg improved coffee quality while increased levels of soil N decreased it. The study further revealed that flowering and berry set were favoured by soil N, P, S, B and Zn. Bean size was favoured by soil N, P, B and Z while yield was improved by N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn. Soil N was helpful for disease tolerance. Caffeine content increased with increase in soil Mg and S levels (Yara, 2010).

The results of this study are in agreement with the findings of Abebe et al. (2008) who reported that CEC and pH had positive correlation with coffee quality at Yayo and Shako (both Southwest Ethiopia). However, contrasting the results of this study, Abebe et al. (2008) found positive associations between soil N and Zn and coffee quality. On the other hand, the results of this study showed no associations between soil available P, K, and Ca contents and coffee quality attributes, which is in contrast to the findings of the above-mentioned author, who reported positive associations between these nutrients in the soil and coffee quality attributes. Available soil magnesium, calcium, nitrogen, phosphorus, and soil pH were negatively associated with coffee quality attributes (Mekonen 2009), which is inconsistent with the results of this study. The contrasts between certain results of this study and that of the other authors may be ascribed to environmental and climatic factors as well as the coffee processing methods employed during the study. However, it was reported that soil properties are problematic to map for a number of reasons (Läderach, 2007). Thus, soil characteristics maps do not exist at a large scale for the study areas.

The observed wide variations in the soil chemical properties of the five different coffee growing regions could be ascribed to the variability in the parent material and the climatic factors that affect soil formation. Accordingly, warmer and wetter south and south-western and northern regions have generally acidic soils whilst the cooler and drier eastern region has neutral to alkaline soils. Similarly, that nutrient and soil organic matter contents varied across the regions as well as districts within the regions could be attributed to differences in the soil forming processes as well as the variations in anthropogenic activities (Jonasson, 1933; Sylvain, 1955). As reported by Oberthür et al. (n.d.), accurate information on the location and associated environmental conditions is needed for improved quality, traceability and transparency with respect to both origin and production processes. Readily available descriptions of coffee growing areas have until now been generalized over a wide range of sites and with only a limited number of descriptors. Soil is usually quoted as a basic factor impacting on coffee quality (Cofenac, 2003; Illy, 2001). It is generally accepted that volcanic soils produce the best quality coffee especially with regard to the attributes of acidity and body (Griffin, 2001). Illy (2001) quotes that micronutrients frequently show a non-linear correlation between their concentration in the soil and cup quality. Another study (Foote, 1963 cited by Läderach (2007)) has shown that nutrient deficiencies may decrease cup flavour. On the other hand, there is a very clear and positive link between gustative qualities and low soil fertility (Pochet, 1990). Griffin (2001) states that potassium also augments the body of a coffee and increases the weight of the bean. Avelino et al. (2002) showed that low contents of calcium affect coffee quality, Cofenac (2003) states that magnesium content favours the characteristics of aroma and flavour. Cofenac (2003) also showed that high contents of nitrogen and iron in coffee soils contribute directly to improved acidity of the brew. Avelino et al. (2002) found that excess aluminium affects coffee quality negatively, while Cofenac (2003) states that high contents of copper negatively affects aroma, flavour and body characteristics.

5. Conclusion

This study has demonstrated that soil chemical properties have both negative and positive associations with coffee quality attributes. The correlation analysis signified that factors that lead to increased soil CEC, available magnesium, exchangeable acidity, and soil pH may lead to enhanced coffee quality attributes whereas factors that lead to enhanced contents of available copper, zinc, and total nitrogen in the soil may reduce coffee quality attributes. The regression analysis further indicated that increased soil CEC and available iron (Fe) content had a direct positive influence on the overall coffee quality attributes, which is the basis for the final grading of coffee beans. It could, thus, be concluded that increasing the cation exchange capacity of and available iron content of soils leads to significantly enhanced overall coffee quality attributes and consumer preferences. Therefore, it may be tentatively recommended that coffee farmers in Ethiopia should particularly improve the soil towards enhanced cation exchange capacity and available iron content to improve quality attributes of coffee beans. However, the results of this study need to be verified by repeating the experiment by involving additional soil chemical properties and weather variables as well as farm management practices.

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