Influence of Soil Properties on Cup Quality of Wild Arabica Coffee in the Coffee Forest Ecosystem of SW Ethiopia*

A. YADESSA[1*], J. BURKHARDT[2], M. DENICH[1], T. WOLDEMARIAM[3], E. BEKELE[3], H. GOLDBACH[2]

[1]University of Bonn, ZEF Bonn, Walter-Flex-Str. 3, D-53113, Bonn, Germany.
*Ethiopian Institute of Agricultural Research, Forestry Research Center, P.O. Box 30708, Addis Ababa, Ethiopia. Email: abebeyadessa@hotmail.com or ay.tarfa@gmail.com
[2]University of Bonn, INRES-PE, Karlrobert-Kreiten-Straße 13, 53115 Bonn, Germany.
[3]Addis Ababa University, P.O. Box 28513, Addis Ababa, Ethiopia.

Summary

A study to establish a relationship between cup quality of coffee and soil properties was conducted in the coffee forest ecosystem of south western Ethiopia, the home of wild Arabica coffee. Cup quality of coffee depends on different factors such as the type of coffee, soil conditions, climatic conditions, processing methods etc. The present paper assessed the influence of soil conditions of the Afromontane rainforests in SW Ethiopia on cup quality of wild Arabica coffee. The study was based on 74 sample plots collected from Sheko (40 samples) and Yayu (34 samples) forests. From each plot, red cherries were hand picked and dry processed, and soil samples (0-20 cm depth) were also collected. Soil texture, cation exchange capacity (CEC), pH, major-nutrients and micro-nutrients were analyzed following the standard procedures. The sensorial analysis was made in Ethiopia by 5 professional tasters (3 from Ethiopia and 2 from Germany). Results showed that the overall cup quality of wild arabica coffee was not correlated with total N and available P levels of the soil at Sheko, but significantly and inversely correlated with N: P ratio. At Yayu, however, it was neither correlated with N or P and nor with N: P ratio, but rather significantly correlated with K, Ca, CEC and pH values. The effect of micronutrients on coffee quality was more of site-specific. Soil Zn content was negatively correlated with cup quality at Sheko, but positively correlated at Yayu; that is, higher Zn concentration was associated with poor coffee quality at Sheko but with better quality at Yayu. Although the influence of soil properties varied according to the criteria and from site to site, generally coffees with better cup quality were those collected from plots with higher levels of available P, K, clay and silt, but inversely correlated with sand content. Higher levels of soil pH, Mg, Mn and Zn were also associated with improved coffee aroma. This indicates that the quality of the soil is a very important factor for the production of quality coffee, and specifically the balance between the different nutrients is of paramount importance for the cup quality of coffee.

Introduction

The composition and productivity of an ecosystem including the coffee forest ecosystem is markedly affected by the physical and chemical properties of its soil (Raghunbanshi, 1992. The coffee forest ecosystem in Ethiopia is the home of wild Arabica coffee, which may have distinct ecological conditions that have favored the growth of wild Arabica coffee. Coffee is a tropical plant which grows between the latitudes of 25° N and 25° S (ICO, 2008), but requires very specific environmental conditions for production of quality coffee. The beverage quality of coffee depends on the type of coffee, soil conditions, climatic conditions, processing

methods, etc. (CRI, 2001; Pinkert, 2004; Bertrand *et al*., 2006). Among these factors, the influence of soil conditions on the cup quality of coffee is the focus of the present study. It is hypothesized that coffee plots differ considerably in their soil characteristics and these differences would impart differences in cup quality of coffee. Soils usually vary in their nutrient concentrations based on the parent material and other soil-forming factors. Thus, the concentrations of nutrients in the soil are associated with its biological and geochemical cycles (Slagle *et al*., 2004), and they are also influenced by anthropogenic factors such as deforestation and land management.

Soil consists of both mineral particles and organic matter, and the nature and amount of these components in the soil influences its characteristics. Soil nutrients may be inherited from the parent materials or added through the use of external inputs (organic and inorganic fertilizers, rain, etc.) (Pastor and Post, 1986; Castrignano *et al*., 2000). In the natural habitat of coffee, soils are acidic to slightly acidic with limited phosphorus availability (Senbeta, 2006; Kufa, 2006). Ideal soils for coffee should be deep, permeable, slightly acidic and porous (D'Souza and Jayarama, 2006). To achieve the optimum yield and quality of coffee, the nature and properties of the soil are of paramount importance. Nutrients are required for both vegetative growth of coffee trees and production of high quality beans and hence nutrient imbalances can affect coffee quality (Njorge, 1998). Deficiencies in nutrients lead to lower quality coffees (Feria-Morales, 1990 cited in Feria-Morales, 2002).

Many studies have identified soil nutrient availability to be an important factor controlling net primary productivity (Pastor & Post, 1986) and biochemical contents of plants (Mazzafera, 1999), and hence quality of the product. Some works on the influence of soil properties on coffee quality has been reported, especially in coffee plantations (Njorge, 1998; Pinkert, 2004). Literature show that volcanic soils often produce a potent acidity and a good body, and such soils can lead to a more balanced cup (CRI, 2001; Bertrand *et al*., 2006). But the influence of soil properties on the quality of wild Arabica coffee in general and on its cup quality in particular has not so far reported to the best of our knowledge under its natural habitat. Therefore, the objective of the study was to assess the correlation between the soil properties and cup quality of wild Arabica coffee in the coffee forest ecosystem of SW Ethiopia.

Materials and methods

Study sites

The study was carried out in Sheko and Yayu Afromontane rainforests of SW Ethiopia, where wild populations of Arabica coffee are the common features of the forest ecosystem.

Sheko (also known as Berhane-kontir) forest

It is located in Sheko district of Bench-Maji zone, South Nations, Nationalities and Peoples Regional State. The name of Sheko forest is inherited from the Sheko ethnic group living in the area. Sheko and Mejenger are the major ethnic groups, and Menit, Bench, Amhara and Kaffa are also living in the area. The altitude in Sheko forest ranges from 950-1800 m above sea level. The total rainfall is 2200 mm per annum and the mean annual temperature 22°C. It represents the transition between the Afromontane moist forest and the lowland dry forest, located west of the Great Rift Valley (Senbeta *et al.*, 2006; Kufa, 2006).

Yayu forest

It is located in the Yayo district of Illubabor Zone, Oromia Regional State, Ethiopia. Yayu has got its name from the word Yayo, the name of the Oromo sub-clan living in the Yayo district of Illubabor Zone. The soils of the area are red or brownish Ferrisols derived from volcanic parent material. The forest area is characterized by a rolling topography, and is highly dissected by small streams and two major rivers (Geba and Dogi rivers). The altitude in Yayu forest ranges from 1200-2150 m above sea level. The area has warm and humid climate. The mean annual temperature is about 20°C, with mean minimum and mean maximum values of about 12.7°C and 26.1°C, respectively. The rainfall pattern is unimodal with mean annual rainfall of 2100 mm/annum (Gole, 2003).

Coffee sampling and Sensory analysis

Coffee cherries were harvested at full maturity, between October and December 2006 in Ethiopia, which is usually when the coffee is good quality. Red cherries were hand picked and dry processed. The dried cherries were depulped and the beans were made ready for cup tasting. Cup tasting was done at Coffee Quality Inspection and Auction Center, commonly known as Coffee Liquoring Unit (CLU) under the then Ministry of Coffee and Tea Development, now under the Ministry of Agriculture and Rural development, in Addis Ababa, Ethiopia. Sensory evaluation was done using the major quality criteria: fragrance, aroma, flavour, acidity, body, aftertaste and overall quality; and scoring was based on a scale of 1-10, corresponding to the total absence (or presence) of the criterion in the coffee. The coffee samples were medium roasted and medium ground. The beverage was prepared by brewing 12 g roasted coffee in 250 millilitres of hot water, which is usually used at CLU. The coffee brews were evaluated by a panel of five experienced tasters (3 from Ethiopia and 2 from Germany).

Soil sampling and analysis

Soil samples were collected from the top soil layers (0-20cm depth). Five samples were collected per each plot and then bulked together to get the representative sample per plot. Since most of the root system of the coffee tree develops in the upper soil layer, the properties of the top soil are more crucial to the coffee plants than those of the deeper subsoil (D'Souza and Jayarama, 2006). Kufa (2006) also reported that most of the root hairs for coffee concentrate on the first 0-20 cm or 0-30 cm soil layers. The soil samples were analyzed following the standard procedures at International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia.

Data analysis

The soil data from the soil analytical laboratory and the sensory data from the panel of experienced tasters were analyzed by using SPSS computer software. The associations between cup quality traits and the soil characteristics were examined by using correlation and regression analyses.

Results and Discussion

Results showed that soil organic matter was not significantly correlated with the cup quality of wild Arabica coffee at both sites and for all the quality traits except that it was positively and significantly correlated with coffee aroma ($r = 0.389$, $p = 0.034$) at Yayu. At Sheko site, the overall cup quality of wild Arabica coffee was not significantly correlated with total N

and available P levels, but significantly and inversely correlated with N: P ratio (Table 1), indicating that an increase in soil total N without commensurate increase in available P may not improve coffee quality. Thus, the balance between them is very essential to have a fine quality coffee. At Yayu, overall cup quality was neither correlated with N or P and nor with N: P or P: N ratios, but rather significantly correlated with K and Ca levels of the soil. The effects of soil Ca, CEC, pH and micronutrients were more of site-specific. Higher Ca, CEC and pH values were associated with better cup quality of coffee at Yayu, but no significant correlation between these soil properties and cup quality at Sheko. This could be due to the fact that Sheko soil is relatively more weathered as compared to that of Yayu as evidenced by significantly lower silt-to-clay ratio, 0.95 and 1.06, respectively. Advanced weathering is commensurate with a low silt-to-clay ratio as compared to normal less weathered soils (FAO, 2001). Moreover, Sheko is characterized by higher mean temperature and rainfall as compared to Yayu, which are important factors of soil weathering.

Although the influence of soil properties varied from site to site, generally cup quality was positively correlated with available P, K, clay and silt, but negatively correlated with sand content. This indicates that the role of soil P and texture in influencing the cup quality of wild coffee, which are related to the nature of parent material of the soil and stage of weathering.

When compared across both sites, except for acidity the cup quality traits of the coffee beverage were positively correlated with soil available P and P: N ratio, but not significantly correlated with soil total N, organic matter and C:N ratio (Table 3).

Table 1. Pearson correlation coefficients between soil properties and overall cup quality of wild arabica coffee from Sheko and Yayu Afromontane rain forests in SW Ethiopia

Soil parameter	Overall cup quality			Remarks
	Sheko (n = 40)	Yayu (n = 34)	Both (n = 74)	
OM, % DM	-0.043	0.291	-0.065	
Total N, % DM	-0.203	0.269	-0.031	
Available P, ppm	0.136	0.277	0.289*	
C: N ratio	0.250	0.021	-0.084	
P:N ratio	0.194	0.303	0.310*	
N:P ratio	-0.339*	-0.167	-0.295*	
Na, meq/100g	-0.022	0.043	0.055	
K, meq/100g	-0.036	0.412*	0.242*	
Ca, meq/100g	-0.100	0.373*	0.125	Site specific
Mg, meq/100g	-0.112	0.263	0.141	
CEC, meq/100g	-0.177	0.410*	0.149	Site specific
pH	-0.206	0.525**	0.221	Site specific
Sand, % DM	0.018	-0.297	-0.367**	
Silt, % DM	-0.059	0.385*	0.387**	
Clay, % DM	0.014	0.067	0.276*	
Fe, ppm	-0.268	-0.167	-0.157	
Mn, ppm	-0.324*	0.198	0.172	Site specific
Zn, ppm ppm	-0.321*	0.370*	0.107	Site specific

**, * = Correlation significant at 1% and 5% level of significance; n = number of observations

Soil Zn was negatively correlated with cup quality at Sheko, but positively correlated at Yayu (Table 1 and Figure 1). This may be because micronutrients are required in small quantities, but Zn concentration was considerably higher at Sheko as compared to that of Yayu. Soil Zn

concentration ranged from 0.66-7.22 ppm (mean 2.97 ppm, range 6.56 ppm) in Sheko area, and from 0.52-3.04 ppm (mean 1.41 ppm, range 2.52 ppm) in Yayu area. In most cases, the soil micronutrients studied had positive correlations with cup quality at Yayu, but an inverse relationship at Sheko, which might be related to the nature of parent material and environmental conditions. The natural content of soil microelements is mainly determined by parent materials and by the soil-forming environment (Liu *et al*., 1996).

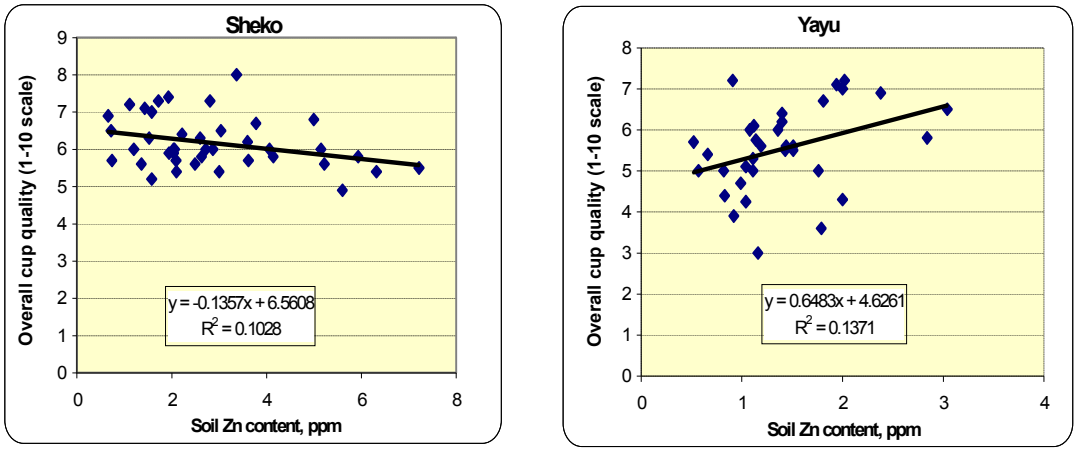

Figure 1. Overall cup quality of wild Arabica coffee as influenced by soil Zn content in Sheko and Yayu Afromontane rainforests in SW Ethiopia.

Table 2. Pearson correlation coefficients between ratios of different cations and cup quality of wild arabica coffee from Sheko and Yayu Afromontane rainforests in SW Ethiopia.

Trait	Ca:K ratio	Mg:K ratio	Mg:Ca ratio	Ca+Mg:K ratio
Fragrance	-0.101	-0.202	-0.006	-0.129
Aroma	-0.254*	-0.346**	0.054	-0.284*
Acidity	-0.036	-0.153	0.003	-0.065
Flavour	-0.202	-0.332**	0.067	-0.240*
Body	-0.159	-0.261*	-0.008	-0.188
Aftertaste	-0.214	-0.350**	0.069	-0.253*
Overall	-0.165	-0.299**	0.01	-0.202

**, * = Correlation significant at 1% and 5% level of significance, respectively.

As clearly indicated in Table 2, the balance between the different soil nutrients, especially the balance between cations of different valency (between monovalents and bivalents) also matters for cup quality rather than differences within the same valency number. The relative proportion between Mg and K was the most important factor in this case; it was inversely related with most of the organoleptic properties of coffee assessed except for acidity. The ratio between Ca and Mg was of no or little importance for coffee cup quality. The ratio between the cations is very important for coffee because K is antagonistic to Mg and Ca (Snoeck and Lambot, 2004). K and Mg promoted the aroma of the coffee brew (Table 4), and thus Mg: K ratio is very important parameter for coffee quality. Potassium augments the body of a coffee (CRI, 2001), and the present study also confirmed this fact.

Table 3. Pearson correlation coefficients between soil OM, total N, available P, C:N and P:N rations versus cup quality of wild Arabica coffee from Sheko and Yayu Afromontane rainforests in SW Ethiopia

	Fragrance	Aroma	Acidity	Flavour	Body	Aftertaste	Overall	OM	Total N	Avail. P	C:N ratio	P:N ratio
Fragrance	-											
Aroma	0.814**	-										
Acidity	0.633**	0.709**	-									
Flavour	0.684**	0.781**	0.891**	-								
Body	0.641**	0.699**	0.840**	0.839**	-							
Aftertaste	0.638**	0.754**	0.847**	0.947**	.853**	-						
Overall	0.702**	0.803**	0.913**	0 .946**	0.893**	0.928**	-					
OM	-0.112	-0.087	0.013	-0.130	-0.074	-0.158	-0.065	-				
Total N	-0.121	-0.074	0.067	-0.107	-0.025	-0.115	-0.031	0.774**	-			
Avail. P	0.242*	0.327**	0.188	0.343**	0.229*	0.356**	0 .289*	-0.207	-0.171	-		
C:N ratio	-0.025	-0.092	-0.089	-0.094	-0.068	-0.127	-0.084	0.510**	-0.100	-0.124	-	
P:N ratio	0.252*	0.302**	0.195	0.364**	0.256*	0.375**	0.310**	-0.341**	-0.348**	0.942**	-0.094	-
	Fragrance	Aroma	Acidity	Flavour	Body	Aftertaste	Overall	OM	Total N	Avail. P	C:N ratio	P:N ratio

**, * = Correlation significant at 1% and 5% level of significance, respectively

Table 4. Pearson correlation coefficients between soil cations, pH, CEC and micro-nutrients versus cup quality of wild Arabica coffee from Sheko and Yayu Afromontane rainforests in SW Ethiopia.

	Fragrance	Aroma	Acidity	Flavour	Body	Aftertaste	Overall	Na	K	Ca	Mg	CEC	pH	Fe	Mn	Zn
Fragrance	-															
Aroma	0.814**	-														
Acidity	0.633**	0.709**	-													
Flavour	0.684**	0.781**	0.891**	-												
Body	0.641**	0.699**	0.840**	0.839**	-											
Aftertaste	0.638**	0.754**	0.847**	0.947**	0.853**	-										
Overall	0.702**	0.803**	0.913**	0.946**	0.893**	0.928**	-									
Na	0.073	0.101	0.053	0.083	0.096	0.107	0.055	-								
K	0.108	0.322**	0.143	0.200	0.246*	0.225	0.242*	-0.130	-							
Ca	0.012	0.159	0.133	0.074	0.161	0.099	0.125	-0.198	0.640**	-						
Mg	0.059	0.233*	0.135	0.122	0.127	0.141	0.141	-0.179	0.643**	0.689**	-					
CEC	-0.011	0.165	0.159	0.125	0.176	0.122	0.149	-0.208	0.591**	0.829**	0.631**	-				
pH	0.092	0.269*	0.176	0.185	0.155	0.242*	0.221	-0.105	0.467**	0.460**	0.369**	0.365**	-			
Fe	0.000	-0.139	-0.119	-0.158	-0.052	-0.140	-0.157	-0.077	0.065	0.106	0.312**	0.140	-0.369**	-		
Mn	0.206	0.285*	0.105	0.239*	0.131	0.262*	0.172	0.135	0.104	-0.040	0.208	-0.057	0.324**	0.057	-	
Zn	0.141	0.247*	0.079	0.125	0.051	0.160	0.107	-0.091	0.400**	0.166	0.269*	0.172	0.494**	0.187	0.628**	-
	Fragrance	Aroma	Acidity	Flavour	Body	Aftertaste	Overall	Na	K	Ca	Mg	CEC	pH	Fe	Mn	Zn

**, * = Correlation significant at 1% and 5% level of significance, respectively

Table 5. Pearson correlation coefficients between soil texture and cup quality of wild arabica coffee from Sheko and Yayu Afromontane rainforests in SW Ethiopia.

	Fragrance	Aroma	Acidity	Flavour	Body	Aftertaste	Overall	Sand	Silt	Clay
Fragrance	-									
Aroma	0.814**	-								
Acidity	0.633**	0.709**	-							
Flavour	0.684**	0.781**	0.891**	-						
Body	0.641**	0.699**	0.840**	0.839**	-					
Aftertaste	0.638**	0754**	0.847**	0.947**	0.853**	-				
Overall	0.702**	0.803**	0.913**	0.946**	0.893**	0.928**	-			
Sand	-0.329**	-0.494**	-0.307**	-0.438**	-0.331**	-0.461**	-0.367**	-		
Silt	0.358**	0.521**	0.369**	0.400**	0.348**	0.419**	0.387**	-0.850**	-	
Clay	0.238*	0.371**	0.195	0.377**	0.249*	0.398**	0.276*	-0.911**	0.557**	-
	Fragrance	Aroma	Acidity	Flavour	Body	Aftertaste	Overall	Sand	Silt	Clay

**, * = Correlation significant at 1% and 5% level of significance, respectively

At Sheko, coffee cup quality was not significantly correlated with soil texture except that fragrance was positively correlated with sand (r=0.351, p=0.026) but inversely correlated with clay (r=-0.329, p=-0.038). At Yayu, however, sand content was negatively correlated with coffee aroma (r= -0.341, p=0.049) and acidity (r=-0.342, p=0.047), but silt content and silt-to-clay ratio were positively correlated with most cup quality traits except for fragrance. Generally across both sites, in most cases cup quality was positively correlated with silt and clay content, but negatively with sand content (Tables 1 and 5).

Conclusions

The present study demonstrated that soil properties considerably influenced the cup quality of wild Arabica coffee in its natural habitat. Among the organoleptic properties of the coffee assessed, aroma was the most affected attribute of coffee by soil properties. And among the major soil nutrients, available P, K and soil texture and also the proportions between Mg and K were the most important parameters for the cup quality of coffee. The effects of micronutrients were more of site-specific. Sodium and total N had no or little influence on the cup quality at all sites and for all cup quality attributes. Generally, coffees with better cup quality were those collected from plots with higher levels of available P, K, clay and silt, but inversely correlated with sand content. Higher levels of soil pH, Mg, Mn and Zn were also associated with improved coffee aroma. This indicates that the quality of the soil is a very important factor for the production of quality coffee, and specifically the balance between the different nutrients is of paramount importance for the cup quality of coffee. Above all, the balance between P and N and the balance between Mg and K are very essential to have fine quality coffee.

This finding adds evidence to the importance of soil factors for coffee quality and verifies the hypothesis that the distinct coffee varies depending on the soil characteristics of the farm where the coffee is grown. Thus, the coffee forest ecosystem in south west Ethiopia as a home of wild Arabica coffee with distinct soil conditions can be used a model for simulating suitable soil conditions for commercial production of Arabica coffee in other parts of the country or elsewhere.

Acknowledgement

The research was sponsored by German Federal Ministry of Education and Research (BMBF). We also acknowledge Center for Development Research (ZEF) and Ethiopian Coffee Forest Forum (ECFF) for hosting and supporting the activities, Forestry Research Center and Jimma Research Center for provision of vehicles and other assistance, Addis Ababa University for different assistances, the Ethiopian Coffee Quality Inspection and Auction Center (CLU) for assistance during the cup tasting, the panel of cup tasters and ASIC for supporting my participation in the conference.

References

Bertrand, B., Vaast, P., Alpizar, E., Etienne, H., Davrieux, F., and Charmetant, P. 2006. Comparison of bean biochemical composition and beverage quality of Arabica hybrids involving Sudanese-Ethiopian origins with Traditional varieties at various elevations in Central America. *Tree physiology*, 26: 1239-1248.

Castrignano, A., Giugliarini, L., Risaliti, R., Martinelli, N. 2000. Study of spatial relationships among some soil physico-chemical properties of a field in central Italy using multivariate geostatistics. *Geoderma*, 97: 39–60.

CRI (Coffee Research Institute). 2001. Coffee quality and environmental conditions. Coffee Research Newsletter, 1(3): 4-6. Accessed online from: http://www.coffeeresearch.org/Newsletters/newsletter%203.pdf

D'Souza, M.V. and Jayarama. 2006. Soil analysis to maintain the productivity in coffee plantations. March 2006 issue of *Indian Coffee*: the monthly Magazine of Coffee Board.

FAO (Food and Agriculture of United Nations). 2001. Lecture notes on the major soils of the world. http://www.fao.org/DOCREP/003/Y1899E/y1899e08a.htm

Feria-Morales, A.M. 2002. Examining the case of green coffee to illustrate the limitations of grading systems/expert tasters in sensory evaluation for quality control. *Food Quality and Preference*, 13: 355–367

Gole, T.W. 2003. Vegetation of the Yayu forest in SW Ethiopia: impacts of human use and implications for *in situ* conservation of wild *Coffea arabica* L. populations. Ecology and Development 10.

ICO (International Coffee Organization). 2008. Ecology. http://www.ico.org/ecology.asp accessed on 11/07/2008.

Kufa, T. 2006. Ecophysiological diversity of wild Arabica coffee populations in Ethiopia: Growth, water relations and hydraulic characteristics along a climatic gradient. Ecology and Development Series No. 46.

Liu, Z., Cai, Z.C., and Wang, J.F., 1996. Microelements of soils in China: Nanjing, Jiangsu Science and Technology Press, 329 p.

Mazzafera, P. 1999. Mineral nutrition and caffeine content in coffee leaves. *Bragantia, Campinas*, 58: 387-391.

Njorge, J.M. 1998. Agronomic and processing factors affecting coffee quality. *Outlook on Agriculture*, 27: 163-166.

Pastor, J. and Post, W.M. 1986. Influence of climate, soil moisture and succession on forest carbon nitrogen cycles. *Biogeochemistry*, **2**: 3-27.

Pinkert, C. 2004. Nutrient and quality analysis of coffee cherries in Huong Hoa district, Vietnam. Plant Research International B.V. Wageningen, Note 280.

Raghubanshi A.S. 1992. Effect of topography on selected soil properties and nitrogen mineralization in a dry tropical forest *Soil Biology and Biochemistry,* 24: 145-150.

Senbeta, F. 2006. Biodiversity and ecology of Afromontane rainforests with wild *Coffea arabica* L. populations in Ethiopia. Ecology and Development Series No. 38, 2006.

Slagle, A., Skousen, J., Bhumbla, D., Sencindiver, J., and McDonald, L. 2004. Trace element concentrations of three soils in central Appalachia. Soil Survey Horizons, 45: 73-85.

Snoeck, J; Lambot, C. 2004. Crop maintenance. *In*: J, N., Wintgens. Eds. Coffee: Growing, Processing, Sustainable Production. WileyVCH. p 246-323.

Yadessa, A., Itanna, F., and Olsson, M. 2001. Contribution of indigenous trees to soil properties: the case of scattered trees of *Cordia africana* Lam. in croplands of western Oromia. *Ethiopian Journal of Natural Resources*, 3: 245-270.

---

*__Citation__:

Abebe Yadessa, Burkhardt, J., Denich, M., Gole, T. W., Bekele, E., Goldbach, H. 2008. Influence of soil properties on cup quality of wild Arabica coffee in coffee forest ecosystem of SW Ethiopia. Paper presented at 22nd International Conference on Coffee Science (ASIC), held between 14-19 September 2008, Campinas, SP, Brazil.

(See abstract http://www.asic-cafe.org/pdf/abstract/A102_2008.pdf)