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Full Length Research Paper

Characterizing major soil physical properties of coffee forest ecosystems in Ethiopia

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The study focused on assessing soil physical properties under natural coffee forest ecosystems in southeast and southwest Ethiopia. For this, the Harenna, Berhane-Kontir, Bonga and Yayu forest coffee soils were collected from three sub-sites and two soil depth ranges at each area. Hence, a total of 24 soil samples were analyzed for major soil physical properties using the standard procedures. The results depicted significant differences among the coffee forests in soil texture particles (silt and sand), bulk density, soil moisture content, water holding capacity, permanent wilting point and available water holding capacity. The proportions of silt followed the order of Berhane-Kontir,Bonga, Yayu and Harenna soils. In contrast, the highest sand and clay contents were from Yayu and Harenna soils, respectively, possibly reflecting their variations in soil weathering process and parent materials, among others. Likewise, there were significant differences between soil depths in most soil physical parameters. In contrast to the increased clay and available water content, the silt and sand particles declined with the decrease in depth, indicating the more vulnerability of forest soils to erosion loss. The results also depicted that clay was negatively correlated with silt particles at all study areas. In contrast, the association between soil water contents at field capacity and permanent wilting point was direct and highly significant at most locations. In conclusions, the findings showed considerable site-specific variations in major soil physical properties and provided soil quality evidences for knowing and promoting natural coffee forest habitats in Ethiopia and elsewhere.

Key words: Certification, correlation, forest habitat, I*n-situ* conservation, montane rainforest, soil properties, wild Ethiopian coffee.

INTRODUCTION

The montane rainforest areas in Ethiopia are the only known center of origin and genetic diversity for the highland arabica coffee (*Coffea arabica L*). In its original forest habitat, arabica coffee occurs in the multi-strata of forest ecosystems and thus it is a shade- loving plant. Since time immemorial, it has been grown in the humid montane rainforests of southwestern Ethiopia (Coste, 1992; Wintgens, 2004). As to its adaptation, coffee grows in wide ecology and it does not appear to have very specific soil requirements. In fact, it performs just as well in the clay-silcaceous soils of granite as it does on soils of volcanic origin with diverse characteristics or even on alluvial soils (Wrigley, 1988; Mesfin, 1998). Water-logging will reduce yield by a substantial amount and kill coffee trees if it is prolonged. Hence, texture and depth of the soil are, therefore, extremely important soil factors. Coffee tree is capable of extending its root system considerably. It requires an effective depth of greater than 150 cm. This characteristic enables it to exploit a considerable volume of land and to thus offset a relative lack of fertility. Highly suitable coffee areas has high soil organic matter (SOM > 3%) content with ideal soil conditions (Coste, 1992; Paulos, 1994).

In Ethiopia, the coffee forest areas which have conserved the sustainable ecosystem and unique biodiversity, including the wild *Coffea arabica* gene pools, are owned and managed by the local people for their livelihoods and approved as UNESCO biosphere reserves for *in situ* conservation and management of natural forest resources. Nonetheless, they are often seriously threatened by several factors, including increasing population pressure, expansion of farmlands, forest land-use conflicts, priority for other food and cash crops and other socio-economic factors (Francis et al.2000; Paulos and Demel, 2000; Tadesse, 2003). In Ethiopia, the natural coffee forest ecosystem occupies

Table 1. Characteristics of the study natural coffee forests in Ethiopia.

Variable	Harenna	Bonga	Berhane-Kontir	Yayu
Wereda/district	Mena-Angetu	Gimbo	Sheko	Yayu-Hurumu
Latitude (N)	6°23´-6°29´	7°17´-7°19´	7°04´-7°07´	8°23´
Longitude (E)	39°44´-39°45´	36°03´-36°13´	35°25´-35°26´	35°47´
Altitude (m a.s.l)	1420-1490	1520-1780	1040-1180	1400
Slope (%)	2-3	3-6	4-18	1-8
Rainfall (mm/year)	950	1700	2100	1900
Max temperature (^{o}C)	34.4	29.9	31.4	34.7
Min temperature (^{o}C)	10.4	8.7	13.8	7.6
Mean temperature (^{o}C)	22.2	18.2	20.3	19.7
Minimum RH (%)	37.9	45.0	50.8	41.8
Maximum RH (%)	84.3	95.2	85.4	98.5
Mean RH (%)	63.2	80.4	68.9	80.9
Wind speed (m/h)	0.93	0.64	0.43	0.35

nearly 33 % of land used for coffee production and contributes 25 % of national coffee production. In this regard, the importance of rainforest conservation can be viewed against the background of man-made destruction or change in about 60 % of the Ethiopian forests during the last thirty years. This is a serious challenge to the remaining and fragmented forest areas (2.6%, about 2,000 km^2) with wild coffee populations (Tadesse et al.2001). Much of the remaining coffee forested area is located in less accessible and/or relatively less populated areas of the south and southwest parts of the country (Paulos and Demel, 2000).

Taye (2010) also pointed out the challenges from forest deforestation, land degradation and declining soil quality coupled with the possible impacts of climate change on environmental sustainability and coffee genetic resources and the need for urgent conservation measures before the status is irreversible. This requires strong collaborations between national and international partners.

The unique poly-culture and forest dominated coffee production systems broadly include forest, semi-forest, garden and plantation (Workafes and Kassu, 2000). These are characterized by various plant composition and species diversity, though detail scientific information on soil conditions is lacking under each coffee production system and zone in the country.

Understanding soil conditions is imperative, *inter alias*, for designing and implementing appropriate soil-test based management options, while at the same time maintaining friendly ecosystem goods and services for global benefits. Hence, assessing soil conditions in general and soil physical aspects in particular are of paramount importance in amending soil fertility status and promoting natural forest resources through sound incentive mechanisms like coffee certification schemes. Therefore, the study was carried out to provide information on characterizing major soil physical properties and to know the extent of variations and associations between soil parameters under natural coffee forest ecosystems of southeast and southwest Ethiopia.

MATERIALS AND METHODS

The study areas are geographically distant and represent the climate gradients of the remaining fragmented montane rainforests in southeast and southwest Ethiopia, hosting the wild arabica coffee genetic resources. These include Harenna, Bonga, Berhane-Kontir and Yayu. Except Harenna in the southeast, the other forests are located in the southwest Ethiopia. They are separated by the Great East African Rift Valley, which dissects the country into southeast and northwest highlands and represent climate gradients of Ethiopia. These forests are fragmented and differ in area coverage (Harenna 15,000 ha, Bonga 5,000 ha, Berhane-Kontir 1,000 ha and Yayu 1,000 ha), physical characteristics and forest vegetation (Paulos and Demel, 2000). The study forest areas also vary in seasonal climate patterns with annual rainfall gradients following the decreasing order of Berhane-Kontir, Yayu, Bonga , Harenna (Table 1).

Soil sampling and laboratory analyses

Soil samples were collected from three sub-sites within each study montane rainforest in Ethiopia. About 500 g soil samples were collected from two depths: surface (0-20 cm) And sub-surface (20-40cm). Hence, a total of 24-soil samples were used for laboratory analyses on the

Table 2. Physical properties (means ± SD) of forest soils at the study coffee forests.

Property	Harenna	Bonga	B-Kontir	Yayu	F-test
BD (g cm^{-3})	1.42±0.06a	1.01± 0.06b	1.07±0.05b	1.23±0.11ab	**
Sand (%)	21.61±2.52b	23.95±7.37ab	15.35±3.02b	38.56±5.57a	**
Silt (%)	14.95±1.15b	22.28±4.36ab	29.61±6.11a	16.28±2.00b	**
Clay (%)	63.44±1.73	53.77±11.02	55.04±5.50	45.16±7.55	Ns
SMC (% dry wt)	33.06±1.10	48.36±5.49	37.76±9.21	34.54±4.45	Ns
SMC (% vol.)	14.01±1.40b	31.88±1.84a	27.94±5.48a	28.09±3.65a	**
WHC (% dry wt.)	61.47±3.37a	60.38±5.53ab	53.65±0.87ab	51.86±1.91b	*
PR (cm^{3} min^{-1})	8.75±1.81	9.63±6.64	5.87±3.94	5.43±4.76	Ns
SHC (cm min^{-1})	1.44±0.30	1.59±1.10	0.97±0.65	0.90±0.79	Ns
FC (0.33 bar)	37.98±1.95	42.54±4.76	39.31±3.84	33.70±3.45	Ns
PWP (15 bar)	26.73±0.70ab	27.79±3.43a	23.34±4.12bc	18.72±2.84c	*
AWHC (cm)	4.81±0.59bc	4.46±0.59c	5.35±0.55ab	5.73±0.45a	*

Ns = Not significant ($P>0.05$); *$P\leq0.05$ and ** $P\leq 0.01$. Means with the same letter within a row are not significantly different (Tukey test at P = 0.05 probability level). Abbreviations: BD = Bulk density, SMC = soil moisture content, WHC = water holding capacity, PR = percolation rate, SHC = saturated hydraulic conductance, FC = field capacity, AWHC = available water holding capacity.

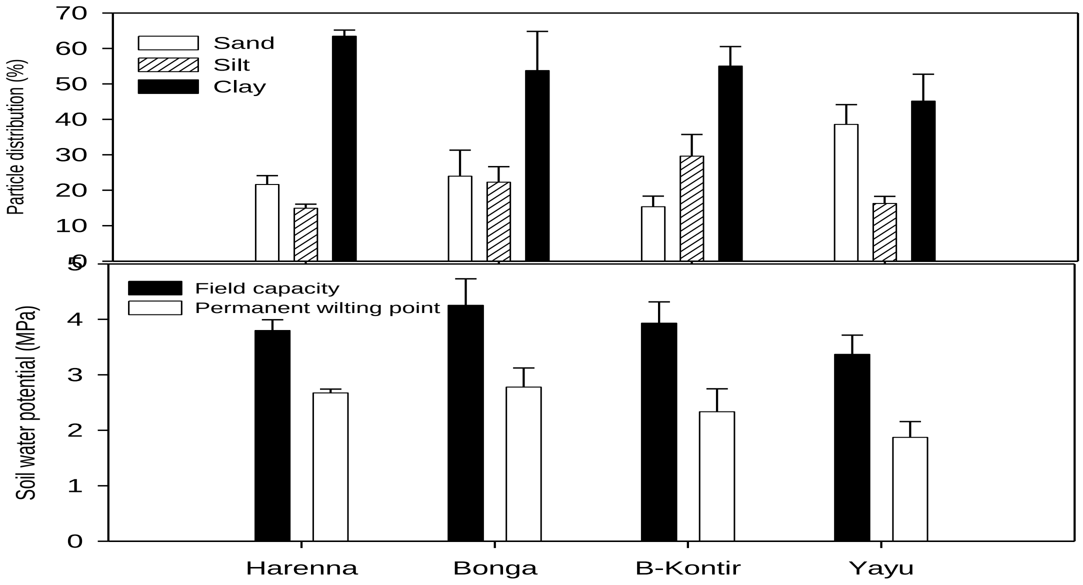

Figure 1. Particle distribution and water content (field capacity and permanent wilting point) of soils from the four montane rainforests.

major soil physical properties. These included bulk density, soil texture and soil water status at field capacity (FC), permanent wilting point (PWP), water storage (WS), available water holding capacity (AWHC), saturated water holding capacity (WHC), percolation rate (PR) and saturated hydraulic conductivity (SHC). The analyses were undertaken in soil laboratory of the International Livestock Research Institute and the Jimma Agricultural Research Center, Ethiopia, using the standard procedures described by Tekalign et al. (1991) and Okalebo et al.(1993).

DATA ANALYSIS

Analysis of variance in a nested design was performed to compare the variations in soil physical properties among and within the wild coffee forest areas. In this case, the

Table 3. Soil physical properties (means ± SD) for surface and deep profile depths at the study montane rainforests of Ethiopia.

Site/depth (cm)	BD (g cm^{-3})	Sand (%)	Silt (%)	Clay (%)	FC (0.33 bar)	PWP (15 bar)	AWC (cm)	FMC (% dry wt)	WHC (% dry wt)	PR (ml/min)	Ksat (cm/ml)
Harenna	*****	**Ns**	**Ns**	**Ns**	******	**Ns**	******	**Ns**	*****	**Ns**	**Ns**
0-20	1.32±0.04b	24.61±1.15	17.95±7.57	57.44±7.21	39.75±2.14a	27.94±1.20	3.12±0.37b	33.55±3.67	65.99±2.87a	10.67±0.71	1.76±0.12
20-40	1.52±0.08a	18.61±4.16	11.95±7.02	69.44±5.29	36.19±1.77b	25.52±0.20	6.48±0.82a	32.57±1.58	56.95±4.30b	6.83±3.18	1.12±0.52
Bonga	Ns	Ns	*	Ns	Ns	*	*	*	Ns	Ns	Ns
0-20	0.92±0.14	26.61±5.03	27.28±5.29a	46.11±9.87	42.72±4.37	26.97±3.53b	2.88±0.41b	53.06±4.45a	57.81±5.18	8.60±5.58	1.42±0.92
20-40	1.10±0.03	21.28±10.39	17.28±4.00b	61.44±14.00	42.36±5.23	28.60±3.35a	6.03±1.02a	43.65±6.56b	62.95±6.07	10.65±7.80	1.75±1.29
B-Kontir	Ns	Ns	Ns	Ns	Ns	Ns	*	Ns	Ns	Ns	Ns
0-20	0.94±0.06	16.80±2.04	27.28±9.17	55.92±8.36	39.57±4.27	23.90±4.92	2.95±0.16b	42.04±12.00	52.36±4.61	8.10±5.57	1.34±0.92
20-40	1.19±0.13	13.89±4.16	31.95±5.03	54.16±6.93	39.06±3.44	22.77±3.39	7.75±1.07a	33.47±6.44	54.93±2.87	3.63±2.36	0.60±0.39
Yayu	*	Ns	***	*	Ns	Ns	**	Ns	Ns	Ns	Ns
0-20	1.10±0.13b	40.56±4.00	19.28±2.00a	40.16±6.00b	33.23±3.36	18.57±2.44	3.23±0.31b	39.29±6.78	51.95±2.41	3.13±1.66	0.52±0.28
20-40	1.34±0.10a	36.56±7.21	13.28±2.00b	50.16±9.17a	34.16±3.71	18.86±3.38	8.21±0.63a	29.79±3.53	51.76±1.71	7.73±7.92	1.27±1.31

Ns = Not significant (P>0.05), *P≤0.05, ** P≤ 0.01 and *** P≤0.001. Means with the same letter within a column are not significantly different according to Tukey test at P =0.05 probability level. Abbreviations: BD = bulk density, FC = field capacity, PWP = permanent wilting point, AWC = available water content, FMC = field moisture content, WHC = water holding capacity, PR = percolation rate, Ksat = saturated hydraulic conductivity.

soil samples from sub-sites and profile depths were nested under the four coffee forests. Comparison between means was carried out according to Tukey test at P = 0.05, whenever the F-test declared significant differences. Moreover, the relationship between soil physical parameters was determined for each coffee forest area from Pearson correlations with the SAS system for Windows-v8 (SAS Institute Inc. Cary NC, USA), and graphs were prepared with Sigma Plot SPW9.0 (SYSTAT Software, Inc).

RESULTS

Soil physical properties

Highly significant variations were found among the four natural coffee forests in soil bulk density, silt and sand particles. Consequently, the lowest and highest soil bulk density values were measured for the Bonga and Harenna soils, respectively (Table 2). Yayu soils had significantly the highest sand content compared to the other sites, except for the Bonga soils. In addition, highly significant differences in silt content were recorded; the mean values ranged from 16.3 to 29.6% for the Yayu and Berhane-Kontir soils, respectively. In contrast, the clay contents did not show significant differences, though the average values decreased in the order of Harenna, Berhane-Kontir, Bonga, Yayu soils. Similarly, significant variations in soil moisture content and water holding capacity were found among the study areas with the highest and lowest values of water retention capacity measured from the Harenna and Yayu soils, respectively. There were also significant variations in the available water holding capacity of the soils. Accordingly, the respectively highest and lowest results were obtained from Yayu and Bonga soils. By contrast, the highly significant lowest field soil water content was recorded at the drier Harenna forests in southeast as compared to the southwest moist coffee forest areas (Table 2). The results depicted that the studied coffee forest soils were determined to have a clay texture, though Yayu soils had significantly the highest proportion of sand and the lowest permanent wilting point as compared to the other forest soils (Figure 1).

The results of the soil physical properties along depths were inconsistent

Table 4. Correlation matrix values between soil physical properties at each study coffee forest.

Coffee forest	Variable	Sand	Silt	Clay	FC	PWP	SAW	BD
	Silt	0.06						
	Clay	-0.54	-0.87*					
	FC	0.36	0.28	-0.41				
	PWP	0.70	0.11	-0.43	0.90*			
	SAW	-0.09	0.40	-0.29	0.88*	0.57		
	BD	-0.68	-0.54	0.79	-0.80	-0.86*	-0.54	
	WHC	0.44	0.45	-0.60	0.95**	0.90*	0.78	-0.92**
Harenna	PR	0.34	0.66	-0.73	0.83*	0.72	0.75	-0.92**
	Silt	0.72						
	Clay	-0.94**	-0.92**					
	FC	-0.80	-0.27	0.60				
	PWP	-0.75	-0.33	0.60	0.88*			
	SAW	-0.48	-0.04	0.30	0.70	0.27		
	BD	-0.21	-0.65	0.45	-0.41	-0.20	-0.52	
	WHC	-0.84*	-0.55	0.76	0.83*	0.96**	0.23	0.02
Bonga	PR	-0.47	-0.64	0.59	0.24	-0.07	0.59	0.21
	Silt	-0.28						
	Clay	-0.19	-0.89*					
	FC	-0.64	0.62	-0.33				
	PWP	-0.60	0.53	-0.25	0.98**			
	SAW	0.10	0.15	-0.20	-0.30	-0.50		
	BD	-0.10	0.34	-0.30	-0.36	-0.41	0.37	
	WHC	-0.24	0.38	-0.27	0.01	0.03	-0.10	0.69
Birhane-Kontir	PR	-0.05	0.54	-0.53	0.80	0.79	-0.30	-0.58
	Silt	0.76						
	Clay	-0.96**	-0.91*					
	FC	-0.94**	-0.60	0.86*				
	PWP	-0.93**	-0.51	0.81	0.98**			
	SAW	-0.71	-0.69	0.75	0.76	0.61		
	BD	0.15	-0.43	0.08	-0.40	-0.51	0.07	
	WHC	0.75	0.46	-0.68	-0.78	-0.73	-0.70	0.28
Yayu	PR	0.61	-0.05	-0.37	-0.69	-0.77	-0.22	0.70

Correlations are significant at *P≤0.05 and **P≤ 0.01 (2-tailed). For abbreviations see Table 2.

among the four coffee forests. Soil bulk density was significantly influenced by profile depth at Harenna and Yayu, but not at Bonga and Berhane-Kontir. However, lower bulk densities were obtained for the surface than for the deeper soil samples, with the highest and lowest reductions at Berhane-Kontir and Harenna, respectively (Table 3). Likewise, at Harenna, profile depth had highly significant influence on soil water contents at field capacity, available soil water depth and water holding capacity. Hence, significantly lower soil available water, higher field capacity and water holding capacity were measured in the surface and deeper soils, respectively. But, soil water conditions (permanent wilting point, field soil water content, percolation rate and hydraulic conductivity) were comparable between depth ranges with relatively higher values for the surface than for sub-surface soils. Similarly, unlike clay, sand and silt were higher in the topsoil except the silt and clay patterns at

Berhane-Kontir. At Bonga and Yayu, soil depth had a significant effect on silt particle. The results revealed a lower proportion of silt and increased soil water content at permanent wilting point and available soil water in the deeper soil than that of surface soil. In contrast, the field soil moisture status was significantly higher in the surface soils only at Bonga. This is in line with the highly significantly higher silt and significantly lower clay contents in the shallow soils than in the sub-surface soils. In contrast to the comparable percolation rate and saturated hydraulic conductivity, significantly more available soil water was calculated for deeper soils at all locations (Table 3).

Correlation matrix

The correlations between the soil physical parameters were different among the coffee forests (Table 4). Field capacity was significantly and directly correlated with soil available water (r = 0.88*), water holding capacity (dry weight basis, r = 0.95**), rate of percolation and hydraulic conductivity (r = 0.83*). In contrast, bulk density has a significant indirect association (r = -0.92**) with water holding capacity of Harenna soils. In the Bonga forest, the clay content of the soil was negatively and significantly correlated with the sand (r = -0.94**) and silt (r = -0.92**) content. There were indirect relationship between sand content and soil water retention, and this was significant for the water holding capacity on a dry weight basis (r = -0.84*). Only at Bonga, the amount of soil water (% dry weight) was directly and significantly correlated with the soil moisture content at field capacity (r = 0.83*) and permanent wilting point (r = 0.96**).

In the Yayu soils, clay was significantly and inversely correlated with sand (r = -0.96**) and silt (r = -0.91*). As a consequence, the level of sand was inversely and significantly correlated with soil water at field capacity (r = -0.94**) and permanent wilting point (r = -0.93**). In addition, the influence of clay was positive and significant on soil water content at field capacity (r = 0.86*). In general, clay was inversely correlated with silt for all forest soils at different significance levels. However, the association between field capacity and permanent wilting point was direct and highly significant at most study sites (Table 4).

DISCUSSION

The current investigation depicted considerable variations in some soil physical parameters among and within the natural coffee forests. The studied coffee soils had clayey texture and site-specific variations in soil physical properties. The significant variations in soil particle distributions (silt and clay) and thus water relations could be associated with the influence of climatic variables on weathering processes as evidenced from the low soil silt contents at Harenna and Yayu coffee forests. The significant difference in bulk density and proportions of sand could also demonstrate the effects of soil parent materials and site physical characteristics presented in Table 1. This could be primarily attributed to the high soil organic matter, enhanced slow mineralization and plant nutrients from litter fall of indigenous leguminous and deciduous coffee shade trees (Wrigley, 1988; Wintgens, 2004). Despite the steep slope landscape, the high vegetation cover from coffee forest can also reduce the risks of run-off (Muschler, 2004; Saito, 2004).

There was a considerable variation among coffee forests in soil moisture content, water holding capacity, permanent wilting point and available water holding capacity, possibly due to variations in the proportions of soil texture, vegetation cover and climate gradients. According to Brady and Weil (2002), in compacted soils, plant water use may be restricted by poor aeration at high water contents and by soil strength at low water contents. Nonetheless, the field soil water content and soil permeability were comparable between soil depths, mostly due to reduced rainfall during the measurements. The friable structure of the coffee soils and high SOM content under forest habitats could also be among the possible reasons for the absence of significant differences in some soil moisture parameters under field conditions. Soils with high organic matter constituents markedly improve soil structures with an ultimate increased nutrient retention and improved plant productivity (Franco and Munns, 1982). This supports the work of Taye et al.(2003), who found increased soil water contents with increased proportion of decomposed organic resources in potting media blends. They associated this with the beneficial direct or indirect effects of the organic matter to form a stable structure that can facilitate the movement of water as reported by other authors (Murphy, 1968; Hofner and Schmitz, 1984) for coffee soils in Ethiopia. At Harenna, soil water contents were inversely and highly significantly influenced by bulk density, which is site-specific response perhaps due to its peculiar bimodal rainfall pattern and seasonal climate variations. This is in agreement with the spatial variability in water relations of these sites (Kufa and Burkhardt, 2011). Since both the volume of pore spaces and soil solids determine the bulk density of a given soil medium, soils with a high proportion of pore space to solids have lower bulk densities as compared to more compact soil with less pore spaces. The present results of soil water movement can be categories in moderate to moderately rapid flow classes according to Brady (1990) who recognized reduced bulk density of soils with increased humus status.

Unlike the other forest sites, at Berhane-Kontir, surface soils had slightly lower silt and higher clay contents than deeper soils, perhaps reflecting the extent of soil weathering with increasing temperature and rainfall, influence of run-off with increased slope and risks of soil exposure to erosion loss at the study sites. Consequently, the comparable and relatively higher percolation rate and hydraulic conductivity of the surface soils could partly be associated to the reduced bulk density and increased sand contents.

In contrast, the field soil moisture status was significantly higher in the surface soil, indicating the role of increased silt content in reducing soil bulk density and thus enhancing soil water holding capacity. The results are quite in line with soil chemical properties observed under forest environments (Taye, 2011).

This could be explained in terms of both texture and structure of the soil that can detect the release of soil water. FAO (1984) report indicated similar finding where the fibrous portion of organic matter promoted soil aggregation and improve the permeability and aeration of clayey soils.

In addition, according to Kolay (1991), such high percolation rates are obtained only at the expense of reduced water retention and thus, could be improved by amending the soil with coarse components.

According to Taye and Tesfaye (2002), the forest-based Ethiopian coffee systems with ideal soil fertility was pointed out among the reasons for sustainable production and supply of the finest quality organic coffees. This could primarily be related to the ideal soil and climate conditions and reduced use of external inputs including agro-chemicals.

The results support Hsieh and Hsieh (1990) who have described the contribution of soil organic matter for crop productivity and thus, the high soil organic matter content has to be maintained for sustainable functioning of the coffee forest ecosystem.

Hence, shade is one of the field management practices essential for establishment and sustainable production of shade-grown coffee plantation as reported by Tesfaye et al.(2002).

In contrast to open field, shade can be used to ensure soil conservation, stability, biodiversity, organic production and additional products. Moreover, shade composition, shade cover, structure of coffee system and management are used as tree-related criteria for the certification of coffee fields as bird friendly or eco-ok (Muschler, 2004; Saito, 2004).

To this effect, Yadessa et al. (2009) have reported improved coffee quality from soils with high soil clay and silt contents as opposed to the inverse correlation between cup quality and sand contents.

Likewise, most soil physical parameters were noted to decline with the increase in soil depth at some study forests, suggesting the high risks of soil erosion loss due to deforestation and land degradation as well as changing patterns of climate.

Despite the physical characteristics of the land and the high rainfall patterns at the study sites, the inherent fertility of the soil and thus quality of the land is maintained due to the high vegetation cover (Paulos, 1994; Taye and Burkhardt, 2011).

This supports the findings on the spatial variability of soil organic carbon (Law et al.2009), soil nutrients (Sokouti and Mahdian, 2011) and water relations (Kufa and Burkhardt, 2011).

In general, the coffee forest soils were characterized by good physical properties: friable, well-drained, high moisture storage capacity and deep rooting depth, but with high risks of erosion and moisture stress, suggesting the need for proper soil fertility amendments (Wrigley, 1988).

The correlation values were found to be comparable between most soil physical paramters with location specific patterns. There was signficant indirect relationship between silt and clay at all study locations as reported by Yadessa et al. (2009).

Moreover, soil bulk density was significantly and indirectly related to saturated water-holding capacity, percolation rates and hydraulic conductivity of the soil as it has been reported by Kufa and Burkhardt (2011). This indicates the compactness of the soil with reduced pore spaces and decreased soil water content at field capacity. Similar pattern of soil relationship has been reported by Jayaganesh et al.(2011) and Taye (2011).

From the present study, it can be concluded that the natural coffee forest ecosystems had kept ideal soil physical conditions, with varying influence of site and climate associated factors.

Consequently, Berhane-Kontir and Harenna soils had the respetive higher values of silt and clay contents as opposed to the highest sand in Yayu soils, perhaps indicating the influence of soil forming factors.

This corroborates with site-specific soil chemical properties of forest soils as reported by Taye (2011) who underscored the need for supporting *in situ* conservation and management of natural coffee forest biosphere reserves for global direct and indirect benefits.

In this regard, promotion of sustainable forest dominated and shade-grown specialty coffee production in Ethiopia, among others, through sound certification and branding schemes awaits for integrated and comprehensive studies on the relationships between ecological factors (climate and soil variables) and coffee cup quality attributes.

This would contribute to ensure traceable supply of high quality coffee profile with known geographical indicators and premium prices.

However, as to what extent coffee forest management levels, composition of plant species, soil parent materials, soil microorganism and biochemical processes, singly or in combinations, can dictate soil quality status and coffee quality profile mapping remain for future detail studies under diverse arabica coffee growing zones and production systems in Ethiopia and elsewhere.

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