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# Spatial Variability in Water Relations of Wild *Coffea arabica* Populations in the Montane Rainforests of Ethiopia

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## ABSTRACT

In Ethiopia, the fragmented montane rainforests with the occurrence of diverse flora and fauna, including the wild arabica coffee genetic resources, are under continuous threats of genetic erosion largely due to human induced disturbance of original forest ecology coupled with climate changes. This study was undertaken to evaluate and compare the spatial variability in soil-plant-water relations of wild Arabica coffee populations in the montane rainforests of Ethiopia. For this, seasonal soil and plant moisture status were measured at four coffee forest environments. The results depicted that the changes in soil-plant moisture status was significantly different over seasons and among the wild arabica coffee populations. In the southwestern coffee forests, the patterns followed the order of spring>winter>autumn. In contrast, higher moisture status was measured in winter when compared to summer season at the drier Harenna forest. Likewise, Leaf Water Potential (LWP) revealed significant variations over seasons and locations. Accordingly, the Harenna coffee populations showed the highest predawn LWP and diurnal changes in LWP during the winter season as compared to other populations. Moreover, the Harenna and Bonga trees had the lowest leaf water contents in dry seasons. The Yayu coffee trees maintained high leaf water as compared to others under increased soil moisture availability. There was a significant positive relationship between soil and leaf water contents in the forest grown coffee trees. Present findings demonstrate differences in spatial soil-plant moisture dynamics among the wild arabica coffee populations and underline the roles of forest ecology as potential natural coffee gene pools for future selection and breeding program. This underlines the need for a multi-site *in-situ* management and utilization of forest genetic resources at their original forest habitats in Ethiopia.

**Key words:** Coffee diversity, climate gradient, forest ecology, soil-plant-water relations, wild coffee management and conservation

## INTRODUCTION

Arabica coffee (*Coffea arabica* L.) is indigenous to the montane rainforests of Ethiopia and hence it has inherent characteristics to adapt shade conditions to thrive best and remain sustainability productive (Coste, 1992; Wintgens, 2004). In Ethiopia, coffee is produced under shade trees in four broad production systems (forest, semi-forest, garden and plantation) (Workafes and Kassu, 2000), predominantly by smallholdings who followed traditional management systems to produce the finest specialty and by *de facto* organic arabica coffees

(Taye and Tesfaye, 2002). The national average coffee yield, however, remains low (hardly exceeding 600 kg $ha^{-1}$ clean coffee) as compared to other coffee producing countries. In an attempt to improve the production of forest grown coffee, the magnitude of forest coffee intervention has considerably affected the diversity, composition and structure of plant species (Senenbeta and Denich, 2006). Similarly, Beer *et al.* (1998) pointed out important aspects of coffee production limitations and coffee shade interactions. According to Chaves *et al.* (2008), excessive evapo-transpiration and severe drought stress, death of actively growing shoot parts, seasonal crinkling of leaves, frost damage and subsequent yield reduction are some of the common problems in unshaded coffee orchards. Hence, intensive coffee production can hamper efforts to protect, maintain and enhance habitats and species.

In Ethiopia, human-induced disturbance is one of the major threats to the world forest resources, including coffee environments and coffee genetic diversity (Paulos and Demel, 2000). The main driving forces behind deforestation are increasing population pressure, the expansion of agricultural land, urbanization, uncontrolled exploitation of forest resources, overgrazing, seasonal fire, non-forestry investment, mining and establishment of new settlements in the forested lands (Gole, 2003). The regional climatic change and recurrent drought is becoming one of the major problems to coffee cultivation and existence of coffee gene pools, particularly in marginal areas and monoculture coffee stands under open sunlight environments. According to Tesfaye (2006), drought stress especially at the critical growth stages can result in poor growth and development, reducing the life span or completely drying the coffee trees, aggravating coffee genetic erosion. Taye (2010) has also described that it is not uncommon to see drying coffee trees, possibly due to physiological disorders between the sink and source relationships under full sunlight conditions. This could be associated to continues flowering and heavy crop loads as a result of changes in weather patterns with the occurance of frequent and erratic rainfalls. The situation seems to predispose coffee plants to insect pests and diseases, requiring urgent measures to develop new corrective mitigation practices and preserve arabica gene pools from the possible fast and irreversible losses.

In Ethiopia, there are still immense genetic potentials among and within the wild types, local landraces and released arabica coffee varieties with great diversity for any desirable traits (yield, quality, disease resistance, drought tolerance, low caffeine content, etc) and wider ecological growing conditions. Based on the interdisciplinary research findings and recommendations of the project on the conservation and utilization of wild *Coffea arabica* populations in the montane rainforests of Ethiopia, CoCE (www.coffee.uni-bonn.de), the Yayu and Kafa forest sites were identified and approved as UNESCO Coffee Forest Biospheres. According to Bellachew and Labouisse (2006), there are about 21407 coffee germplasm in the different field gene banks of few African countries, of which around 89.85% is arabica coffee, which is found in Ethiopia. This corroborates with Surendra (2008), who also indicated that Ethiopia alone possesses around 99.8% of the world total arabica's genetic diversity. Currently, a total of around 11691 arabica coffee germplasm have been collected from the different areas and conserved *ex-situ* at different field gene banks in Ethiopia (Taye, 2010), though information is scanty on their soil-plant relations along rainfall gradients and changing environmental conditions.

Yacob *et al.* (1996) reported that arabica coffee materials can be broadly grouped into three canopy classes of open, intermediate and compact types. These could be bourbon or typical cultivars as they are quite different in shoot and root growth systems as well as performances to management practices. The frequency of occurrence in cultivated local coffee landraces was found to be different along rainfall gradients and soil profile depths (Taye *et al.*, 2004), indicating their inherent capacity to exploite below-and above-ground natuarl resources. Similarly, Tyree *et al.* (1998) found maximum water loss rates and whole-plant hydraulic conductance in pioneer as compared to succession forest species which had low hydraulic conductance accompanied by better control over water use.

In spite this, there is a lack of adequate information and knowledge on the reactions of coffee diversity to seasonally changing environments under various agro-ecological zones and production systems. Thus, investigations on coffee germplasm conservation and identification of suitable coffee genotypes and field management practices are amongst the identified high priority research areas in the country (Girma *et al.*, 2008). This would contribute, inter alia, in designing and implementing sustainable management, utilization and conservation of the natural coffee forest resources. This requires, above all, continuous evaluations and identifications of suitable genotype-environment fitness for specific coffee growing geographical areas. This study was conducted to evaluate and compare the spatial variability of soil-plant water relations in four wild *Coffea arabica* populations in the montane rainforests of Ethiopia.

## MATERIALS AND METHODS

**The study site:** The study was undertaken between 2002 and 2006 in four rainforests of southeastern and southwestern Ethiopia viz, Harenna, Bonga, Berhane-Kontir and Yayu with the occurrence of wild *Coffea arabica* populations. They are separated by the Great East African Rift Valley which dissects the country into southeast and northwest highlands. The study areas differ in the area of agro-ecological zones: highland, medium altitude and lowland as well as rainfall gradients (Fig. 1). Except the Harenna area with a bimodal rainfall in the southeast, the other forests are situated in the southwestern part characterized by a monomodal rainfall pattern.

According to Paulos and Demel (2000), these forests are different in area coverage (Harenna 15,000 ha, Bonga 5,000 ha, Berhane-Kontir 1,000 ha and Yayu 1,000 ha), agro-ecological zones, physical characteristics and forest vegetation, among others. The rainfall gradients followed the decreasing order of Berhane-Kontir>Yayu>Bonga>Harenna with varied other micro-climatic

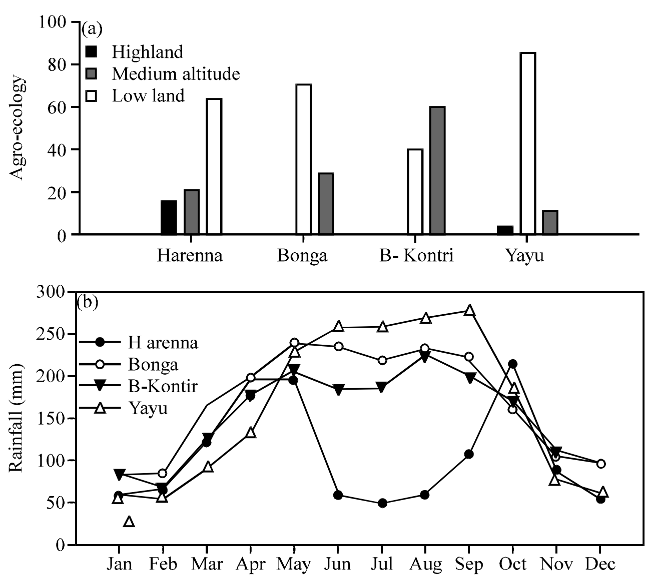


Fig. 1: (a) Agro-ecological area coverage and (b) long-term rainfall patterns at the study montane rainforests of Ethiopia

Table 1: Characteristics of the fourwild *Coffea arabica* populations in Ethiopia

| Variable | Harenna | Bonga | Berhane-Kontir | Yayu |
|---|---|---|---|---|
| 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 (ma.s.l) | 1420-1490 | 1520-1780 | 1040-1180 | 1400 |
| Slope (%) | 2-3 | 3-6 | 4-18 | 1-8 |
| Rainfall (mmyear$^{-1}$) | 950 | 1700 | 2100 | 1900 |
| Maxtemperature (°C) | 34.4 | 29.9 | 31.4 | 34.7 |
| Mintemperature (°C) | 10.4 | 8.7 | 13.8 | 7.6 |
| Meantemperature (°C) | 22.2 | 18.2 | 20.3 | 19.7 |
| MinimumRH (%) | 37.9 | 45.0 | 50.8 | 41.8 |
| MaximumRH (%) | 84.3 | 95.2 | 85.4 | 98.5 |
| MeanRH (%) | 63.2 | 80.4 | 68.9 | 80.9 |
| Windspeed (mh$^{-1}$) | 0.93 | 0.64 | 0.43 | 0.35 |

elements (Table 1). The study forests also differ in soil properties. The distribution of silt and soil bulk density as well as permanent wilting points and available water holding capacity were significantly ($p<0.01$) varied among the forests. The soil clay content was comparable and followed the order of Harenna>Berhane-Kontir>Bonga>Yayu (Taye, 2006).

**Moisture measurements:** Seasonal and diurnal soil-plant water dynamics were monitored under field conditions during dry and wet seasons of 2003 and 2005. This was measured using a Theta probe type ML2 (Delta-T Devices Ltd., Cambridge, UK). In addition, about 500 g of soil samples were collected and immediately weighted using a sensitive balance (KERN 440-33, Kern and Sohn GmbH, Germany). Then oven-dried dry weight was recorded to calculate volumetric field soil moisture content (% dry wt. basis). Simultaneously, a portable pump-up pressure chamber (PMS Instrument Co., Corvallis, USA) was used to measure seasonal and daily leaf water potential (LWP, $\Psi_L$) in wild coffee trees, following the method of (Scholander *et al.*, 1965). The maximum capacity of the chamber is $\Psi_L$ of -2.1 MPa. This is below the level where plants, including Arabica coffee can show typical drought symptoms such as closed stomata, stop in shoot growth and declining overall growth rate (PMS Instrument Co.). LWP was monitored at each site in summer and winter seasons twice a day (predawn and midday). For this, the tip of a lateral branch with two pairs of healthy leaves was removed from the upper canopy of nine representative sample wild coffee trees at each site, which makes a total of 36 coffee trees. The leaf sample was carefully cut and immediately enclosed in a steel pressure chamber. The pressure inside was increased gradually until small sap droplets appeared at the position of the xylem vessels on the cut surface. The pressure reading at this point represents the plant water potential in the field.

Moreover, fully expanded and healthy coffee leaf samples were collected (before sunrise) from the third to fourth nodes on primary branches and leaf fresh weight was immediately measured using a pocket balance (KERN CM 320-1, Kern and Sohn GmbH, Germany). These leaves were oven dried at 70°C for 24 h and dry weight was recorded to calculate the osmotic leaf water content (% dry wt. basis). The soil-plant-water relation was evaluated over seasons: summer (August 2003), autumn (December 2003), winter (March 2004) and spring (September 2004). At Harenna, the last data were collected in the first week of August 2004. The last data on soil-plant moisture contents were determined between August and September 2005. Unlike Harenna of the southeast, this is the main rainy season at the three study forest areas. Hence, the summer and winter seasons representing the driest months in southeast and southwestern Ethiopia, respectively (Fig. 1).

**Statistical analysis:** Analysis of variance (ANOVA) was computed using a nested design of three replications to evaluate spatial variations in soil-plant moisture status among and within the wild Arabica coffee populations under natural forest conditions. For significant differences, mean compassion was accomplished according to Tukey's test at p = 0.05 probability level. Furthermore, regression analysis was analyzed with the SAS system for Windows-v8 (SAS Institute Inc. Cary NC, USA) and graphs were prepared with SigmaPlot SPW9.0 (SYSTAT Software, Inc.).

## RESULTS

**Soil moisture status:** The spatial soil moisture dynamics were significantly different at three of the four studied rainforests. In the southwest sites of the Bonga, Berhane-Kontir and Yayu forests, the average results follow the order spring>winter>autumn. Accordingly, the highest (at Bonga = 39% vol.) and the lowest (at Sheko = 10% vol.) were obtained in May/June 04 and February/March 04, respectively. In contrast, at the southeast Harenna sites, soil moisture content increased from spring (13.3% vol.) to winter season (16.0% vol.) which is in line with the rainfall patterns between the southwest and southeast of the country. In contrast, the values at Harenna were higher in winter than in summer. As a result, significant differences among the forest sites were recorded in autumn ($p<0.05$) and spring ($p<0.001$), when Harenna had the lowest soil moisture of 14.7 and 13.3% vol., respectively. However, significantly maximum soil moisture contents were measured at Berhane-Kontir (28.4%) and Bonga (37.4%) soils in autumn and spring, respectively. In winter, soil moisture contents in the four rainforests were not significantly different, with values ranging from 12.8 to 17.1% in Berhane-Kontir and Bonga, respectively (Fig. 2).

From the soil moisture reading and volumetric determination at Harenna, the significantly highest values were obtained in winter, spring/summer and autumn in that order. At Yayu, significantly lowest (13.7% vol.) and highest (36.5% vol.) soil moistures were measured in spring and winter, respectively. The gradient of the plot was also noticed to slightly influence soil moisture, particularly in the drier Harenna forest. And, the moisture was higher at the bottom of the slope than at the top. This was not the case in the southwest forests where moisture was adequate (Fig. 3).

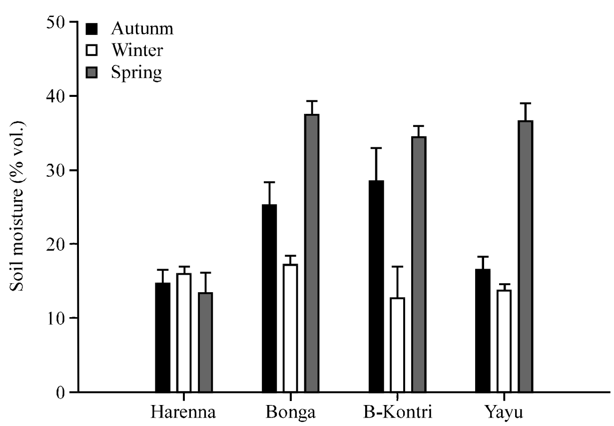


Fig. 2: Seasonal soil moisture dynamics at the four montane rainforests of Ethiopia

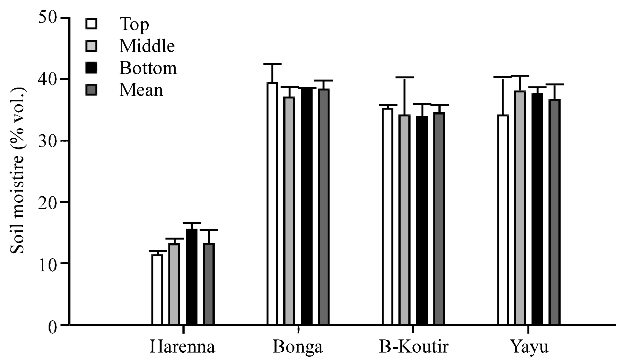


Fig. 3: Soil moisture as influenced by land gradients in the four montane rainforests of Ethiopia

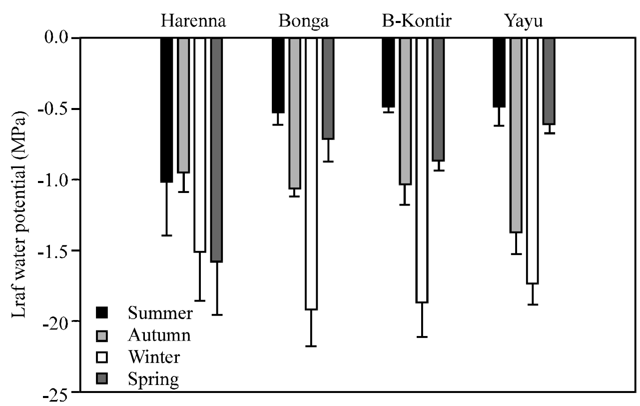


Fig. 4: Seasonal changes in midday leaf water potential of wild coffee trees at the four montane rainforests of Ethiopia

**Leaf water content:** The results of midday leaf water potential (LWP) revealed significant differences due to seasons and forest sites. At the southwest sites, the diurnal LWP values were much lower in winter than in spring. Thus, the lowest LWP at Bonga and Berhane-Kontir were measured during the dry winter season when the diurnal range was also low (Fig. 4). Conversely, coffee trees at the Harenna sites had significantly lower LWP values in August (summer), when the diurnal LWP changes were also minimal as compared to the other seasons. Except at Harenna and Berhane-Kontir, significant predawn LWP variations were detected between the winter and summer seasons. Accordingly, maximum predawn LWP values were measured in the summer season at the southwestern sites as opposed to lower values at Harenna in this season (Fig. 4). At each site, the diurnal LWP patterns fluctuated over seasons. Accordingly, the maximum midday LWP results showed highly significant seasonal variations at most sites. At Harenna, the values showed a decreasing trend from autumn to summer. Conversely, there was a highly significant change in midday LWP across seasons at the other sites, where lowest and highest values were measured in winter and summer seasons, respectively (Fig. 4). This is similar to the status of seasonal soil moisture dynamics (Fig. 3). However, at Bonga the midday LWP was comparable between the dry and wet seasons. The range in LWP between autumn and spring was minimum at Harenna as compared to the southwest sites, where high seasonal ranges in the order of Yayu > Berhane-Kontir > Bonga were determined (Fig. 4).

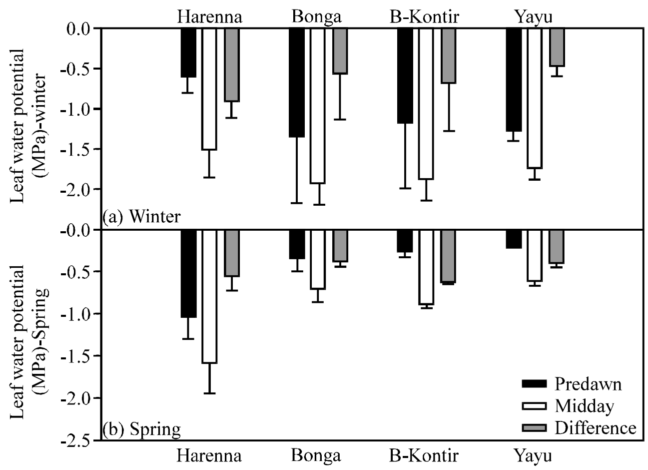


Fig. 5: Diurnal changes in leaf water potentials of wild coffee trees at the four montane rainforests in a) winter (dry) and b) spring (wet) seasons

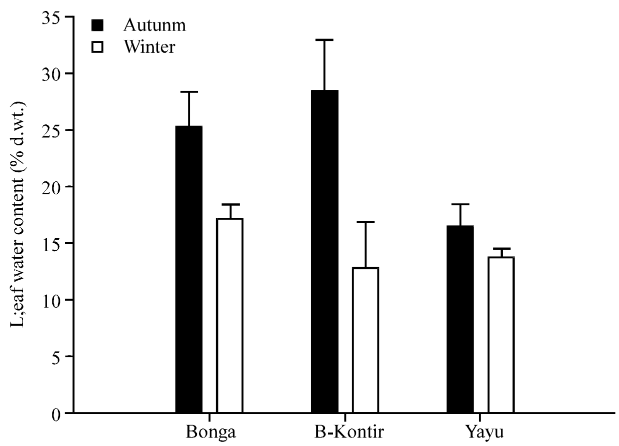


Fig. 6: Leaf water content determined for autumn (wet) and winter (dry) months at the southwest studied montane rainforests of Ethiopia

Meanwhile, midday leaf water potential was significantly low at Bonga, Berhane-Kontir, Yayu and Harenna in that sequence. Predawn and midday LWP were significantly ($p<0.001$) lower in the dry winter as compared to wet spring season in the moist southwest sites. The Harenna coffee wild coffee populations exhibited the highest predawn LWP and maximum diurnal LWP differences in winter as compared to the southwest sites, particularly the Yayu and Bonga trees. The osmotic leaf water content also reveal slight variations between autumn and spring/summer seasons, particularly at Harenna and Yayu (Fig. 5).

Similar to LWP, higher leaf water content was determined in autumn (December) compared to winter (March) at the three wild coffee populations in the southwest (Fig. 6). Despite the high soil moisture content, the Bonga coffee trees showed reduced leaf moisture content on dry weight bases. The regression results depicted that soil moisture was positively and significantly correlated with leaf water contents. Thus, the Harenna and Bonga trees had low leaf moisture content under limited availability of soil moisture. In contrast, the Yayu trees showed relatively high leaf water content with increased soil moisture (Fig. 7).

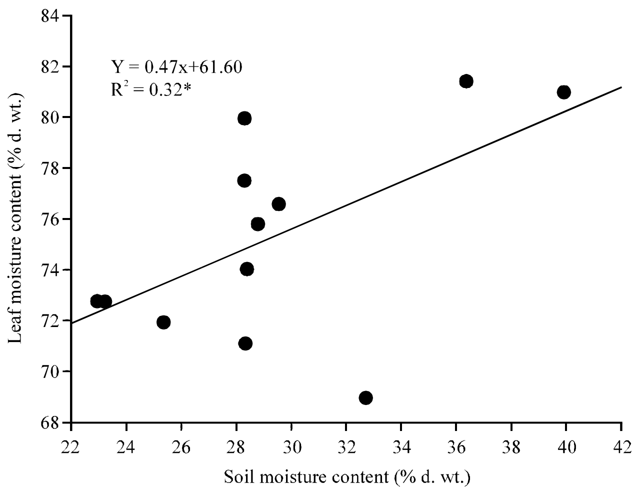


Fig. 7: Relationships between soil and leaf moisture contents for the pooled data of the study sites (n = 12, *Significant regression coefficient at p = 0.05) in the montane rainforests of Ethiopia

## DISCUSSION

**Soil moisture dynamics:** It is needless to mention the importance of natural forests as Arabica coffee gene pools for breeding program 1 and development of the global coffee sector. There are, however, interventions by the local communities to improve forest production and productivity. The results indicated spatial variations in soil and plant water relations under the studied forest conditions. The soil was found to be drier at Harenna as opposed to the moist soils of the southwestern forest sites. At Harenna, the high soil moisture status in spring and autumn may be related to the bimodal rainfall distribution pattern in south and southeastern Ethiopia, including the study Harenna area. Whereas, though the difference between spring and autumn was high at Yayu, the three forests in southwest showed similar pattern in rainfall distribution (Table 1). This demonstrates the dissimilarity in climatic variables between the southwestern and southeastern coffee growing areas (Paulos and Demel, 2000), enabling the country to produce throughout a year and supply the demanded coffees. The significant differences within sites during the dry season could also be associated to the variations in site factors such as shade levels, slope and soil conditions (Paulos and Demel, 2000; Wintgens, 2004). Taye *et al.* (2004) also mentioned site specific variations in the adaptation of coffee landraces along moisture gradients in southern Ethiopia (Table 1). Similar finding was reported by Galal (2010) in that the size distribution and density of most woody perennials was found to decrease with decreased elevations. The results may in part suggest soil moisture competition by the closely spaced coffee trees and associated plant species (Senenbeta and Denich, 2006; Taye, 2006), particularly at the lowland drier Harenna areas. The high soil moisture at Bonga could be due to the moderate over-shading reducing soil-moisture tensions in the soil-plant-atmosphere continuum of forest ecology (Taye, 2006). Tesfaye (2006) also found the occurrences and risks of intermittent drought at the critical growth stages of the coffee plants, suggesting the need to develop technologies on small-scale supplementary irrigation schemes.

Moreover, the results revealed significant seasonal variations among and within the forest sites. The lowest values were recorded during the dry season at most sites which could be mainly associated to reduced plant density, low shade cover, shallow soil depth and loose soil texture at the study forest, among others (Workafes and Kassu, 2000). Vaast *et al.* (2008) also found that the biophysical interactions between timber and coffee trees in ideal agroforestry system. Hence, ecological suitability, farmer's decision and the level of management inputs could be among the possible reasons for the changes in the dominance of different plant species and stand structure in forest ecosystem (Senenbeta and Denich, 2006). This is in consistent with Rajdeep *et al.* (2010) who described the impact of interventions on the floristic composition and species diversity of natural forests in India.

The variations in soil moisture potential may indicate the magnitude of soil moisture removed by the roots and lost through transpiration. There were little differences in soil moisture along the land gradients (top, middle and bottom), indicating the contributions of forest canopy cover to control the adverse effects of erosion due to rainfall. Soil cover especially through broad-leaved weeds and litter fall mainly from the deciduous trees could help to conserve soil moisture and build up fertility status. Nonetheless, there is the possibility of rainwater interception with the upper canopy which is lost by evaporation. Larcher (2003) showed this notion particularly with increasing density of plant cover. Hence, the present slight variations in soil moisture among and within the forest sites could be attributed to human interventions in disturbing the natural forest habitats in Ethiopia (Gole, 2003; Senenbeta and Denich, 2006). The results suggest that stand structures can be used to detect spatial changes in soil moisture and plant nutrients as mentioned by Sokouti and Mahadian (2011). This could be explained due to the impact of shading to increase air humidity and reduce the vapor pressure gradients between the atmosphere and the leaf, which can ultimately reduce the evaporative soil moisture demands. On the other hand, coffee cultivation in full sunlight can able to out-yield shade-grown plants. This leads to an inequality, as fruit production in the sun is higher and photosynthesis of leaves in full sun is reduced, leading to critical imbalances within the distribution of assimilates. This may lead to early dieback of entire coffee plantations and the overbearing syndrome (Wrigley, 1988; Wintgens, 2004).

**Plant water status:** Knowledge on the adaptation mechanisms of plants species are important to understand their ecological success and growth conditions. There were little changes in leaf water status between the dry and wet seasons at Bonga as opposed to the other wild coffee populations. This could indicate the diversity in the inherent among and within the wild coffee populations. This also suggests the extent of vegetation cover and plant density, largely due to the varying magnitudes of forest interventions by the local communities for their livelihoods. The physical conditions of the soil may also enhance more percolation and maintain residual soil moisture for plant use (Taye, 2006). This corroborates with Chaves *et al.* (2008) who found varaiations in seasonal growth changes in Arabica coffee trees. The recovery of the leaf water status depends upon the ability of the soil to supply water to the plant in sufficient quantities to recharge the dehydrated plant tissues (Larcher, 2003). At all sites, no severe leaf-wilting symptoms were observed on the forest grown coffee trees during the study periods, largely indicating the contributions of ideal site fertility with improved moisture retention capacity.

The range of diurnal fluctuation in leaf water status is important in plant growth and development. The difference in LWP permits rapid characterization of plant species in drought-stress environments. This is because plant water potential indicates the suction force, which a plant actually develops or can develop to extract water from the soil. The LWP fluctuates throughout the day and changes can be considered as the difference between predawn and midday water potential.

In this study, the coffee trees showed little diurnal LWP variations during the relatively dry season. At all sites, the minimum change in midday LWP was observed in the dry season which may reflect variations in the ecological functioning and physiological plasticity of Arabica coffee trees as described by Burkhardt *et al.* (2006).

The four wild coffee populations were comparable in terms of the diurnal differences in LWP, indicating the importance of forests in maintaining adequate soil moisture but reducing the photosynthetic capacity of coffee trees. This reflects a trade-off between hydraulic capacity and water-use efficiency in forest grown trees (Sobrado, 2003). Nonetheless, the difference between predawn and midday LWP was higher at Harenna and Berhane-Kontir as opposed to Yayu and Bonga in that order. This concurs with the shoot and root growth characteristics (Taye *et al.*, 2004) and with the LWP in seedlings of wild coffee germplasm accessions (Kufa and Burkhardt, 2011). Again, Harenna and Berhane-Kontir populations showed higher leaf water recovery, suggesting their capacity to withstand wider change in water dynamics under field conditions. By contrast, the Yayu and Bonga trees exhibited low diurnal ranges in LWP, perhaps indicative of increased xylem resistance and stomatal closure to prevent water loss as pointed out by Burkhardt *et al.* (2006) and Tausend *et al.* (2000a, b). This may particularly suggest the effects of low light intensity, reduced net photosynthetic rate, and constrained reproductive performance of coffee plants in forest ecology (Silva *et al.*, 2004; Vaast *et al.*, 2005). This reveals a trade-offs between water transport and leaf water-use as reported by Sobrado (1993) in pioneer and forest tree species.

In Ethiopia, previous reports of Yacob *et al.* (1996) and Taye *et al.* (2004) showed that compact and shallow rooted coffee types flourish ideally on moist flat top and bottom soils, while intermediate and open canopy types adapt and perform well on eroded lands, drier soils and steep slopes besides top and bottom lands. This is in line with that of Siddiqui *et al.* (2007) which reported variations in the response of cotton cultivars to varying moisture regimes. The normal diurnal range in drought-adapted species is large and the longer the predawn values stay close to the midday values, the smaller the re-saturation opportunity of the plant. According to Whitlow *et al.* (1992), the failure of the plant to recover to its predawn values has been recognized as evidence of water deficit for that particular species. In those accessions where stomata have the capacity to close rapidly, evaporation is better regulated and therefore, thus enabling the plant to maintain maximum LWP through which resistance to drought is higher. The value of LWP is likely to decrease with decreasing leaf conductance and flow restrictions in the hydraulic system of root and shoot (Taye, 2006). The result also depicted significantly direct relationships between soil and leaf water contents, reflecting the variations in the rainfall distribution patterns at the study areas (Fig. 1). Understanding and knowledge on the prevailing moisture dynamics would help for continuous production and export of the Arabica coffee according to the market demand. The present results are quite in line with the finding obtained in wild coffee accessions evaluated under controlled nursery environments (Kufa and Burkhardt, 2011), demonstrating the stability of genetic factors in detecting water relations in coffee genotypes under changing environments. A similar soil-plant-water interaction was reported by White and Harper (1970).

## CONCLUSION

The study demonstrated differences among the wild arabica coffee populations in soil-plant-water relations, largely due to variations in climatic gradients and site factors (Table 1). The wild coffee trees displayed significant performances in LWP along seasonal soil moisture regimes under *in situ* field conditions. The findings revealed the unique features of each forest population with regard to seasonal and diurnal changes in water relations, demonstrating the importance of hydraulic properties in future selection and improvement of drought tolerant coffee genotypes. Thus, understanding the diurnal and seasonal variations in leaf water status could provide insight into identifying stress tolerant arabica coffee genotypes. In effect, a multi-site *in-situ*/on-farm management and utilization of coffee forest environments seems to be the viable options in planning sustainable conservation measures of coffee gene pools in their place of origin and genetic diversity as described by Bellachew and Sacko (2009). The variability in the ability of the wild coffee trees might reflect their strategies for coping with fluctuating soil moisture and associated environmental stresses. The findings have a great importance for further ecological studies in restoring open up sites and assessing carbon sequestration capacity of each natural forest. However, further investigations on the levels of forest management, identification of suitable coffee genotypes with desirable traits, including low caffeine, disease resistant, drought tolerant and urgent implementation of sound incentive mechanisms (forest certification) are crucial to benefit from the potential forest genetic resources and ecosystem services.

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