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Diversity of traditional coffee production systems in Ethiopia and their contribution to the conservation of coffee genetic diversity

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Abstract
Being the center of origin and diversification of coffee, *Coffea arabica* L., Ethiopia possesses diverse genetic resources of the crop. This is partly due to the diversity of traditional coffee production systems employed by the Ethiopian farmers for over 2000 years. Coffee production systems in Ethiopia can be grouped into four broad categories as: forest coffee, semi-forest coffee, garden coffee and coffee plantations. The first three are traditional production systems by small-scale subsistent farmers. The three traditional systems, i.e., forest, semi-forest and garden coffee production systems account for 5-6%, 20%, and 68-69% of the total coffee production in Ethiopia respectively, summing up to 94% of the national produce. A large diversity of coffee germplasm is maintained in farm genepools in Ethiopia. Around 130 coffee landraces are cultivated by farmers, of which 55 are from coffee growing regions east of the Great Rift Valley while 75 are from the western part. Through the Ethiopian National Coffee Collection Program, more than 600 coffee types were collected and documented between 1966 and 1984. More than 4500 accessions of coffee collected from the main coffee growing regions in Ethiopia are held in the Chochie field genebank. The maintenance of coffee genetic diversity in the traditional production systems is affected by several socio-economic problems like increased population, price fluctuation, and other competitive cash crops. The fate of coffee genetic resources conservation in such traditional systems depends on a mechanism which guarantees production under economically feasible conditions. A possibility is also to investigate how yield of traditionally used landraces can be improved. Conservation measures and mechanisms to sustainably manage the systems are recommended.

Introduction
Ethiopia is one of the eight regions in the world considered to have a strikingly high level of diversity in cultivated crop plants (Vavilov 1951). Arabica coffee (*Coffea arabica* L.) is one of the crops which have their origin and centre of diversification in Ethiopia. The domestication and use of coffee in Ethiopia dates back some 2000 years ago (Luxner 2001). During the early period of domestication, coffee was only used as food by native people. 'Buna Qalaa'(coffee berries roasted with butter and made up into a ball) is one of the earliest kinds of food made of coffee by the Oromo people in Ethiopia. For Oromos, 'Buna Qalaa' is still used as a special traditional food served at different cultural ceremonies and rituals.

Coffee was known to the rest of the world only during the beginning of the last millennium. It was first introduced by Arabs to Yemen in the 13th century (Haarer 1962). The Arabs developed its present use as liquor in the 15th century. This habit of drinking coffee gradually spread to the rest of the world, leading to an increased interest in producing it as a commodity on a large scale. The Dutch first introduced coffee plantations to Java in 1690 (Figure 1.), and it gradually spread to other parts of the word, especially Latin America. Today, Latin American countries are the major producers of Arabica coffee.

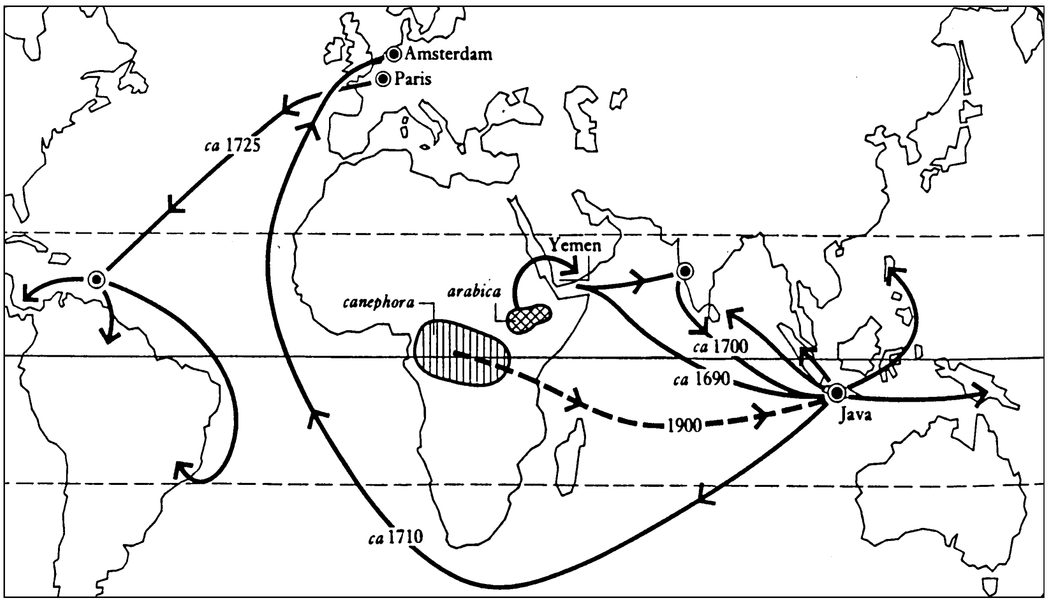

Figure 1. Distribution routes for the cultivated coffee crop in the tropics: the continuous line shows the routes of *C. arabica.* The numbers are approximate years of introduction (Ferwerda 1976).

Coffee is an important commodity in international trade. It is the second most important exported commodity in the world after oil (Pendergrast 1999). More than 80 developing countries mainly earn their foreign currency from coffee. *Coffea arabica* is the most important of three commercially used coffee species (the others are *C. canephora* and *C. Liberica*), accounting for 70% of total production and 90% of the world coffee market (Raina et al. 1998; Pendergrast 1999). For Ethiopia, coffee is 4-5% of the GDP, 20% of the government revenue, 60% of the total foreign exchange earnings up to the year 2000 and a livelihood for more than 25% of its population (Tafesse 1996). The share of coffee to the Ethiopian economy is declining during the last year due to a fall in the coffee price on the global market.

The spread of coffee all over the world was based on seeds from a single tree or few trees introduced to Yemen, thus, cultivated coffee varieties have a very narrow genetic base. The best hope for crop improvement lies in the progenitors or wild relatives of the cultivated plants that harbor rich genetic resources for tolerance against abiotic (drought, cold, heat, salt, solar radiation), and biotic (pathogens, parasites, competitors) stresses (Nevo 1998; Schoen and Brown 1993). In this regard, the Ethiopian Arabica coffee genepool represents the most important and diversified genepool of this species. The natural genetic diversity or genepool of economic plants has three distinct categories, namely: a) the primitive cultivars or landraces of traditional agriculture, b) the advanced cultivars produced by plant breeders in the last 100 years, and c) the wild or weedy species related to domesticated cultivars (Frankel 1982 as cited in Demel and

Assefa 1994)). Ethiopia possesses all three categories of the genepool for *C. arabica* (Tewolde 1990). Sylvian (1958) witnessed the existence of a great variation among the wild coffee plants in Ethiopia. This high level of diversity is partly attributed to the presence of indigenous traditional production systems of coffee in the country. There are four major categories of production systems namely: forest, semi-forest, garden and plantation coffee production systems. The first three are traditional systems by small-scale subsistent farmers, and account for over 95% of the coffee produced in Ethiopia. This paper aims at describing management practices found in the different traditional coffee production systems, characterization of the vascular plant diversity other than coffee and the diversity of landraces maintained by the systems. Based on these data, the potentials and constraints of the systems for the conservation and uses the coffee genetic resources in the future are discussed.

Materials and methods

The study area
For the forest and semi-forest systems, a case study was carried out at Yayu forest ($08^0$15'-$08^0$37'N/$35^0$45'-$36^0$05'E) in Illubabor zone of the Oromia state in southewstern Ethiopia. The data on garden coffee system and land cover by different systems is based on survery conducted in all major coffee growing regions in the eastern, southern, western asn southwestern parts of the country.

Survey methods and sources of data

The data used in this study are from primary sources of recent field surveys and secondary sources of previous surveys and documentations of institutions. In Yayu forest and semi-forest system, the species composition, vegetation structure and the coffee population from 10 quadrats of 400 m^2 in both forest types were studied. In each quadrat, all canopy trees with diameter at breast height (dbh) greater or equal to 10 cm were identified, and their heights and diameters were measured. Small trees and shrubs with dbh <10 cm were identified and counted and their heights measured within five subplots of 9 m^2 in each quadrat. Management practices by farmers in each system were obtained by interviewing farmers owning the coffee plots and development agents of the ministry of agriculture in the area. The density of the canopy cover was estimated using a spherical densiometer (Lemmon 1956; Lemmon 1957). Data on the garden coffee systems and the distribution and diversity of traditional coffee land races or farmers' varieties are based on a previous surveys by Demel Teketay and some unpublished reports (IAR 1986; Admasu et al. 1989). The field genebank at Chochie near Jimma and live collections at Jimma Agricultural Research Center (*ex situ* conservation) were also visited.

Results

The forest coffee system
In this system, coffee is harvested directly from spontaneously regenerating natural population of coffee in the mountain rainforests of west and southwest Ethiopia. The forest coffee production system represents about 9% of the land covered by coffee, and contributes 5-6% of the total coffee produced in the country. The only management practice in the forest system is access clearing to allow movement in the forest during harvesting time. There is a high density of trees (Table 1), small trees, and shrubs in this

system (Figure 2). The average number of canopy trees with dbh > 10 cm is about 460 stems/ha.

Table 1. Some vegetation characteristics of forest and semi-forest coffee systems of Yayu area (Only trees with dbh≥10 cm and matured coffee trees are considered).

System	Canopy cover (%)	Trees per ha	Number of canopy tree species	Coffee plants per ha
Forest	84	460	32	3600
Semi-forest	69	155	19	5800

The major canopy tree species are *Albizia grandibracteata*, *Antiaris toxicaria*, *Blighia unijugata*, *Bridelia micrantha*, *Celtis africana*, *Cordia africana*, *Diospyros abyssinica*, *Ficus exasperata*, *Ficus lutea*, *Ficus sur*, *Ficus thonningii*, *Millettia ferruginea*, *Mimusops kummel*, *Morus mesosygia*, *Olea capensis* subsp. *welwitschi*, *Sapium ellipticum*, *Trichilia dregeana* and *Trilepisium madagascariense*. The major small trees and shrubs making up the middle strata are *Canthium giordanii*, *Dracaena steudneri*, *Ehretia cymosa*, *Maesa lanceolata*, *Maytenus gracilipes*, *Pittosporum viridiflorum*, *Ritchiea albersii* and *Vepris dainelli*.

The average density of coffee is about 3,600 stems/ha. Coffee grows spontaneously like another plant community. The seedling density of coffee is very high, ranging from 10,000 to over 30,000 per hectare. The wild coffee trees tends to be taller with few side branches, growing up to 12 m. This system is the lowest in coffee yield, with an average of around 200-250 kg/ha.

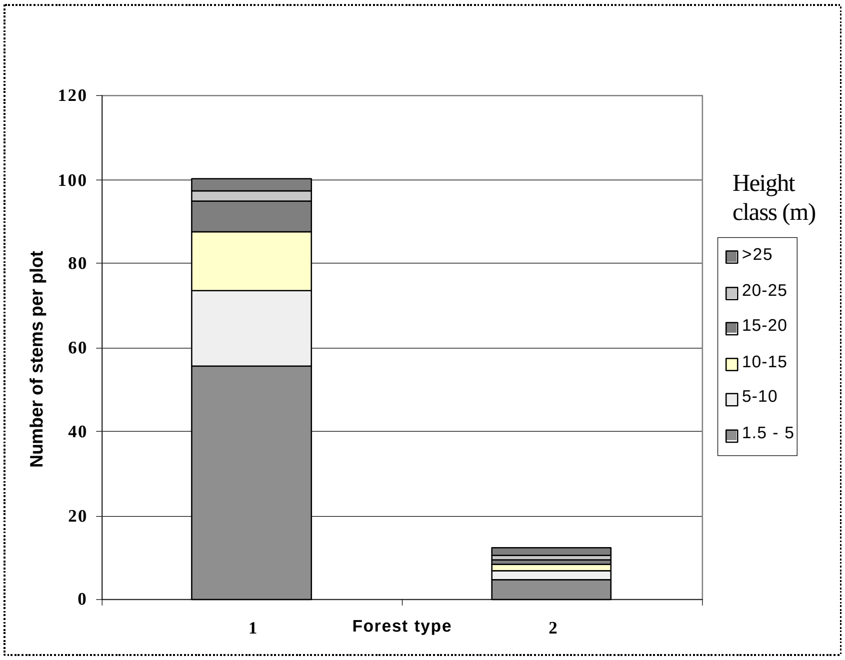

Figure 2. Distribution of plants (excluding coffee and seedlings) in different height classes by different vegetation categories (Forest type 1 is the 'forest system' while type 2 is the 'semi-forest system').

The semi-forest coffee system

Semi-forest coffee represents a system in which the forest is managed or manipulated mainly for coffee production. This system represents 24% of the total land covered with coffee and 20% of the coffee produced in Ethiopia. In this system, small trees and shrubs competing with coffee are cleared. Clearing is twice a year, one before harvesting season and another after harvesting, before the main rainy season starts. The number of large canopy trees is highly reduced in order to open up the canopy to enhance the potential of coffee trees to bear more berries. Coffe yield is directly proportional to current growth of primary and secondary branches (Tewolde 1978), among other yield parameters. Opening up canopy and clearing of competing lower strata vegetation enhance the vegetative growth in side branching, and hence increase yield. Preference as shade trees is mainly given to legumes. Broad-leaved and deciduous trees are considered as "undesirable" for use as coffee shade unless there are no legumes or other 'desirable' tree species in a plot. There is a considerable change in vegetation structure and species composition when the forest system is a converted to semi-forest system (Table 1, Figure 2). This change in forest structure is highly significant in the lower height classes representing shrubs, and small trees.

The major canopy trees are *Albizia grandibracteata, Albizia schimperiana, Antiaris toxicaria, Blighia unijugata, Celtis africana, Cordia africana, Elaeodendron buchannani, Ficus exasperata, Ficus lutea, Ficus sur, Ficus vasta, Millettia ferruginea, Morus mesosygia, Olea capensis subsp. welwitschi, Sapium ellipticum,* and *Trichilia dregeana* while the lower canopy class is composed of few trees like *Ehretia cymosa, Maesa lanceolata* and *Pittosporum viridiflorum*.

In this system too, coffee population is mainly from the spontaneously growing wild population. Farmers simple avoid copetetion from other plants by clearing. To make the distribution of coffee even, farmers collect wild seedlings from densely populated areas and plant in sparsely populated areas. This is almost natural condition except that competition with other species is minimized, but completion among coffee plants is increase due to increase in coffee population. The average yield of the semi-forest coffee is estimated to be around 300-400 kg/ha.

The garden coffee

The garden coffee production system is the major production system in the country, representing 62% of the total land under coffee production and 68-69% of the coffee produced in the country. The size of a garden coffee farm and management varies from region to region and from one farmer to another. It can be as small as very few trees around a homestead up to about 3 ha. The average size is 0.35 in Hararghe, 0.4 in southern parts east of the Great Rift Valley (GRV) and 0.6 ha per household in the southwestern coffee growing region. Management is intensive in traditional garden coffee farms. Weeding 2-3 times per year, fertilizing with farmyard manure and crop residue and hoeing are commonly practiced.

Shade trees densities are lower, about 60 trees/ha. The major trees commonly used as shade trees in garden coffee include *Acacia abyssinica, A. sieberiana, Albizia gummifera, Bersama abyssinica, Celtis africana, Cordia africana, Croton macrostachyus, Ekebergia capensis, Entada abyssinica, Erythrina abyssinica, E. burana, Faidherbia albida, Ficus sur, F. sycomorus, F. vasta, Milletia ferruginea, Pygeum africanum, Olea capensis* subsp. *welwitschii,* and *Syzygium guineense*.

The density of coffee trees varies from one coffee growing region to another, ranging from 1000 to 3500 trees/ha. Lower density is found in Hararghe where coffee is intercropped with several other crops such as sorghum, beans, sweet potato and chat (*Catha edulis*). In south and southwestern parts of the country higher density is used since there is low intensity of intercropping. In these regions, when intercropped, the major mix is ensete (*Ensete ventricosum*), which is an important staple food. Coffee population is of traditional cultivated landraces, mostly a mixture of different types. The average yield of the garden coffee system is between 400-500 kg/ha, but can be as high as 750 kg/ha under intensive management (Demel and Asseffa 1994; Workafes and Kassu 2000).

Diversity of coffee landraces

Surveys in main coffee growing regions of the country showed that there is a high diversity of coffee landraces. A total of 130 landraces known by local names in different localities were recorded in the areas covered by the surveys (see Box 1). Twenty-two were recorded in the Hararghe region in the east (Demel and Assefa 1994), 33 in Borana and Sidama in the southern part, and 75 in Jimma, Illubabor, Wollega, Gambella and Assosa coffee growing regions in western and southwestern parts of the country (Admasu et al. 1989). The list is not exhaustive since many coffee growing areas are still not surveyed. For instance, the major coffee areas such as Kaffa, Mizan –Teferi, Tepi, and Maji in the southwest, and the minor coffee areas such as Shoa, Arsi, Bale, North and South Omo, and Wollo were not covered by the surveys.

Box 1 Traditional landraces in different coffee growing regions

Hararghe	**Borana and Sidama**	**Jimma, Illubabor, Wollega, Gambella and Asossa**
Abadiro, Bale Tino, Bukuri (Enkure), Buna Adi, Buna Guracha A, Buna Guracha B, Buna Jima, Buna Kella, Cherchero, Denga, Fendisha, Gamu, Ittu, Kabnya, Muyra, Olaha, Shekhussieno, Shenkuyi, Shimbure, Torbi, Tujar, Wogere	Walancho,Kolisho, Buna Buncha, Legumami, Kurumei, Dega, Setamo, Tils, Gidicho, Dumancho, Terako, Sewa, Wecincho, Gugudamei, Kudume, Galo, Wolisho, Bedesa, Guto, Meke, Welencho, Kolinsho, Deracicho, Ado, Awicho, Shamilei, Bula Bunchu, Wojo, Danchei, Damu, Kunkuwranachei, Amoler, Ganticho	Mello,Chercherei, Chochie, Mito, Alga, Orommie, Fesfus, Dalecha, Selalei 1, Selalei 2, Shayta, Setea, Wendie, Gota, Kereso, Dirbu, Gedjo, Oshiro (Oromie), Miro, Chakayie, Kabiso, Inaria, Buna guracha, Guna gura, Buna albu, Kubri, Nole Buna, Bokoji, Buna Liketi, Buna Babu, Darimu Buna, Tikur Buna, Yabeshe Buna, Buna adi, Hiromie, Kubri Deme, Buna Bilo, Ale Buna, Chora Buna, Buna Goromiti, Araba, Yeleku Buna, Bisle Buba, Dureni Buna, Kombu, Awer, Buna Saki, Yegeba Buna, Cholu Buna, Buna Birbirso, Goma Buna , Bedesa, Chobo Buna, Geleb Buna, Sardo Buna, Urgoftu, Sor Buna, Yeboto Buna, Yembo Darma Buna, Geri Buna, Yembo Buna, Yekurundusie Buna, Haya Buna, Toluma Buna, Senbo Buna, Kubur, Syndi, Harar Buna, Bedesa, Yawane, Aba Bapasa, Gufaro, Mito, Keda Buna, Gadafa

Note: The headers in bold are names of the coffee growing regions and the list below each column are the local names of the traditional landraces, separated from each other by commas, as recorded in respective regions. Hararghe, Borana and Sidama are found east of the GRV those in the 3rd column are in the western part

Farmers identify their traditional coffee landraces by color of leaves, gross morphology of trees, weight and shape of fruits and beans, presence or absence of aroma during roasting of beans, etc. They give names to the landraces based on the different attributes of the landrace (Demel and Assefa 1994).

The presence of high genetic variation in natural coffee populations in the forest and semi-forest systems could be mainly due to the wide ecological variation, ranging from 1000 m to 1800 m or even up to 2000 m in altitude, with highly dissected and rolling topography. The average temperature and rainfall also varies with a similar magnitude. In garden coffee systems, farmers choose the coffee types of their preferences and often mix more than one landraces. Some farmers plant up to 5 landraces in their garden. Each has its own advantages. Some are high yielding, some have good aroma and flavor, some are resistant to diseases.

Discussion

Several scientists have reported the existence of a great diversity in the Ethiopian coffee genepools (Sylvain 1955; Sylvain 1958; Meyer 1965; Monaco 1968; Charrier and Berthaud 1990; Tewolde 1990; Demel 1999). The existence of such a great natural diversity in Ethiopian coffee genepool is mainly due to 1) maintenance of diverse landraces by local farmers, and 2) the presence of wild populations in the mountain forests. Maintenance of diversity on farm is one kind of effective strategy whereby resource-poor farmers practice low-input agriculture in marginal environments to create stable systems (Melaku et al. 2000). Farmers purposely maintain diverse landraces on their farm to overcome environmental stresses like diseases, pests, drought and also conserve varieties that have specific qualities and are high yielding. The fact that coffee is a valuable commodity crop itself has motivated farmers to select and maintain such diversity over time. The diversity in traditional landraces is higher (75 out of the 130 types) in the coffee regions west of the Great Rift Valley. Studies based on genetic diversity using molecular markers (Lashermes et al. 1996) and agromorphological variations (Montagnon and Bouharmont 1996) also support the pattern of diversity in coffee similar to the traditional landraces distribution. The accessions from the eastern part of the GRV are more similar to the coffee cultivars in other parts of the world outside of Ethiopia.

Sylvain (1955; 1958) categorized the Ethiopian coffee into 12 major types based on several morphological character. Again, the majority (7) of these fall within the regions west of the GRV. Sylvain notes that the list was not complete due to inability to cover all regions. Thus, it is believed that further botanical investigations may reveal more varieties.

The presence of high diversity in the coffee populations can be due to: a) the presence of large areas with wild coffee populations in the forest and semi-forest systems of the western regions (Tadesse et al. in press), b) the fact that in the forest and semi-forest production systems farmers mainly manage the existing natural diversity rather than selectively promoting only a few, c) the presence of greater ecological diversity and larger areas under coffee(Workafes and Kassu 2000), and d) gene flow from the wild to cultivated population in the garden system. Moreover, coffee plants exhibit high phenotypic plasticity dependent on environmental factors such as rainfall and density of shade (Demel and Assefa 1994).

Arabica coffee has two infraspecific taxa of *Coffea arabica* L. var. *arabica* (including var. *typica* of Cramer and var. *abyssinica* A. Chev.) and var. *bourbon* Choussy (including var. *culta* A. Chev.) (Bridson and Verdcourt 1988). However, the infraspecific taxonomy of *C. arabica* is very complex, and several other varieties and forms have been described, the status of which have never been studied with modern phylogenetic methods.

Conservation and utilization of the Ethiopian coffee germplasm has been a concern for decades. The attempt to conserve coffee germplasm *ex situ* in field gene banks was successful on its own right and it was possible for the FAO and the French OSTROM coffee missions to collect large numbers of accessions from Ethiopia in the 1960s (FAO 1968, Berthaud and Charrier 1988). These accessions are found in field genebanks in several tropical and sub-tropical countries (Tadesse et al*.* in press). Ethiopia has the largest collection of Arabica coffee in field genebanks.

Ex situ alone is not enough as conservation measure since conservation is both preservation and evolution (Swaminathan in press). *Ex situ* cuts off the evolutionary process that occurs under the natural environment. Hence, different complementary conservation techniques like *in situ* in forests and on-farms have to be considered for a full range of genetic diversity conservation (Maxted et al. 1997). *In situ* conservation keeps the genetic structure of a population intact in a dynamic process, while allowing the evolutionary processes to continue as plants adapt to changes in environmental conditions (Eriksson et al. 1993). This involves conservation at the ecosystem level, the highest and most complex level of biodiversity. Ecosystem conservation unites the abiotic and biotic worlds, including their processes and entities (Noss 1996). *In situ* conservation of coffee genetic resources offers an interesting approach in biodiversity research: the conservation of genetic diversity in connection with the conservation of species and ecosystem diversity. Through linking the species and ecosystem diversity of montane rain forest with the genetic diversity of wild coffee populations, rainforest protection becomes protection for coffee genepools and vice versa. As, however, in forest coffee systems wild coffee populations are used, the coffee genetic resources are in fact being protected by using them. This kind of protection concept, however, can only be implemented on the basis of appropriate land-use planning considering areas with strict protection as well as use and buffer zones. Traditional coffee production in gardens also allows the conservation of many tree species used as shade on farm, besides the conservation of the genetic diversity of coffee landraces.

The traditions of Ethiopian farmers and the existence of a large diversity of the coffee landraces in agro-ecosystems and forest ecosystems provide good opportunities for the genetic conservation of coffee as well as for the diversity of other species and the ecosystems. But these opportunities have their own challenges. Today, we are at a crossroad: use of the resources to overcome rural poverty and food insecurity, and conservation. Both are attainable if we can manage to overcome relevant socio-economic problems and technical constraints. The main challenges are conversion of the forest coffee ecosystem to farmlands in order to feed the growing population, basic constraints (technical/scientific capacity, policy and finance) to implement conservation programs and the declining trends of coffee prices in the world coffee market. The first two were already discussed elsewhere in detail (Tadesse et al. in press). We elaborate more on the third case. Farmers maintain traditional landraces at their personal cost (Swaminathan in press). But for subsistent small-scale coffee farmers, decline in price below an affordable level to make their livelihoods can affect their decisions to continue producing the traditional coffee varieties or to shift to another crop with comparative economic advantages. For decades, coffee was the major foreign currency earner for Ethiopia, accounting for over 60%. By 2000, this figure has fallen to the record low of 41% and that of the 2001 is expected to be even lower. If this development continues, most farmers may abandon their coffee farms to replace coffee with other economically important crops. Chat has already been out-competing coffee in eastern parts of the country since some time ago (Amare and Krikorian 1973). This made the coffee germplasms of the Hararghe region threatened of all in the country (Tewolde 1990), demanding urgent action for on-farm conservation. Most coffee growing areas east of the GRV have a better infrastructure, market access and potential for growing several vegetables and horticultural crops for commercial purpose. The low yield of the forest and semi-forest system will also enhance the already raging deforestation process for agricultural purposes in western and southwestern parts of the country.

Conclusions and recommendations

Coffee being an important commodity crop, the farming community maintained the diverse landraces to make their livelihoods at marginal economic return. The traditional landraces of coffee managed by farmers are low yielding. Managing coffee diversity enabled them to minimize risks of loss due to biotic and abiotic stresses. On the other hand, unlike the occurrence of a disproportionately high level of genetic diversity of the crop in Ethiopia, most of the coffee in the world market comes from high yielding advanced cultivars in other countries. This is currently increasing in the major producer countries, though production has already exceeded the market demand. Increasing production overseas and the subsequent fall in coffee price on the world market may have a devastating effect on the on farm and in forest coffee genepools, since farmers shift to food and other agricultural crop production to make a living.

The diverse traditional coffee production systems and the existence of a wide genetic diversity of the species in different genepools provide a good opportunity for conservation, utilization and research on this valuable crop species, provided that appropriate measures are taken to address the existing problems within the systems. The measures may include: establishment of gene reserves in the forest coffee ecosystems (Tadesse et al in press), evaluation and enhancement of the traditional landraces to improve yield, establishment of local *ex situ* field genebanks in different coffee growing areas representative of the different agro-climatic zones, and creation economic incentives to compensate losses in yield to the farmers managing the traditional landraces. The last measure is the most important to guarantee long-term on-farm conservation since it addresses the economic problems of the community. Compensation for yield losses can be in a form of improved marketing of the crop as organic products or fair-traded products on a global market. Coffee is mainly consumed in developed nations where the consumer group can afford to pay extra cents for the products originating from farms maintaining diversity in order to encourage genetic conservation on farm.

The FAO Global Plan of Action developed at Leipzig (The Leipzig Declaration) provides an excellent blueprint for plant genetic resources conservation in this regard. It emphasizes developing new markets for “diversity rich” products. It also called for a new and productive partnerships between scientists and farmers to build up on the ongoing efforts of farmers to manage and improve their plant genetic resources, especially in marginal areas. This will enable to address the twin needs: genetic conservation *in situ* and the creation of economic incentives systems to compensate yield loss and reward for contributions to conservation (Swaminathan in press). Coffee genepool conservation in Ethiopia can be one of the best models to implement such a Global Plan of Action.

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