ETHNOBOTANY OF SHADE TREES IN COFFEE PLANTATION SYSTEM IN ANFILLO DISTRICT, KELEM WOLLEGA ZONE, WESTERN ETHIOPIA

ABOMA BULCHA

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This is to certify that the thesis prepared by Aboma Bulcha entitled: *''Ethnobotany of shade trees in coffee plantation system in Anfillo District, Kelem Wollega Zone, Western Ethiopia''* and submitted in partial fulfillment of the requirements for the degree of master of science in Biology complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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ABSTRACT

Farmers have a good understanding of the positive and negative interactions between the shade canopy and the coffee crop. *Coffea arabica* L. is extensively cultivated by households under a variety of shade trees in Anfillo District of Kelem Wollega Zone. This study was conducted in Anfillo District of Kelem Wollega Zone, Oromia Regional State. The aim of this study is to identify the most important shade tree species and to document farmers' knowledge on the environmental and socioeconomic benefits of the shade trees in coffee production systems. Ethnobotanical data were collected through structured and semi-structured interview, guided field walk and field observation. Data analyzed using the standard ethnobotanical methods. A total of sixty five informants which are between the age of 25-70 were involved in this research, of which eight were selected as key informants**.** of which, eight were selected as key informants. A total of twelve coffee shade tree species that have more than 10 major use categories were recorded. The ranking analyses showed that *Albizia gummifera,* and *Millettia ferruginea* as the most preferred coffee shade trees. Leguminous trees (Fabaceae) are the most diverse group in both semi-forest and semi-plantation coffee system. Farmers preferred these species in their coffee plantation due to their soil fertility improvement. In addition to shade provision, coffee shade trees are important in improving soil fertility (leaf fall provide mulch), increasing the yield and size of coffee beans, and others. However, denser shading resulted in lower yields and under full sun, cup quality and coffee bean size decrease. There is a need to determine the appropriate density of shade trees to maximize the productivity of coffee plants.

Keywords: Ethnobotany, leguminous trees; shaded coffee systems

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CHAPTER ONE

1. INTRODUCTION

1.1 Background of the study

Ethnobotany is the study of how people make use of indigenous (native) plants. Indigenous people have local knowledge on plant resource and their uses. Coffee naturally occurs as an understorey shrub or small tree in the Afromontane rainforests. Hence, coffee production is associated with other plant species which serve as shade trees. This nature of coffee has contributed for the survival of most remnant forests in Ethiopia (Tadesse and Feyera 2008).

In the coffee management systems, farmers select certain species of trees as coffee shade tree and remove others which they believe have adverse impacts on the growth and productivity of the coffee shrub. Coffee yield was highly correlated with the number and size of the branches of coffee shade trees (Adugna *et al* 2011). This in turn is related to the amount of solar radiation reaching the lower strata and the presence or absence of small trees and shrubs competing with coffee. Shaded coffee production system has received considerable attention from conservation organizations in recent years since it promotes biodiversity conservation while enhancing income generation from the sale of both timber and non-timber forest products.

Shade is more essential to *Coffea arabica* L. since the growth of coffee is affected by high light intensity, high temperature and low soil moisture (Ashenfi *et al* 2014). Shade trees have positive effects on microclimate and soil biological properties which are the key to long term sustainability of coffee ecosystem. Furthermore, most common coffee shade trees are also acknowledged for their good capacity in formation of symbiotic associations with certain soil bacteria, rhizobia (Grossman *et al*., 2006) and arbuscular mycorrhizal fungi (Wubet *et al*., 2003), all of which play a pivotal role in improvement of soil fertility and boost yields of associated crops. Adequate shade also improves soil fertility by way of returning large amounts of leaf litter to the underneath soil, enhancing nitrogen fixation and retains soil moisture**.** Various studies indicate that *Coffea arabica* has the highest yields under 50 to 60% of shade (Ashenfi *et al* 2014). Shade trees are recommended as a protective measure when environmental conditions can be difficult for coffee, particularly in areas which are exposed to high temperature, long drought, heavy rain fall and chance of hail**.**

Shading buffers the extreme temperature variations and provides a microclimate which attenuates extreme temperatures of air and soil and preserves surface soil humidity. Photosynthetic rate of coffee plants that are grown exposed to direct sun light is limited by stomata closure, high leaf temperature and low internal carbon dioxide concentration. Similarly, (Sethar *et al*., 2002) indicated that the physiological processes of plants are temperature dependent, and under high temperature crops have great difficulty in maintaining photosynthetic activities and growth.

The production of heavier and larger coffee beans is mainly caused by the effect of temperature and the duration of the ripening period, which is also induced by shade. Muschler (2001), who found comparable results, indicated that coffee bean size significantly and consistently increases even with increasing shade levels. Similarly, the shade effect on liquor taste was also the result of delayed fruit maturation and ripening. Coffee can be cultivated within the range of 800 m to 2500 m above sea level, mean annual rainfall of 900 – 2000 mm and temperature range of 15-32^{O}C.

1.2 Statements of the problem

The livelihood of the communities living inside and around the forests depends, in various ways, on the products and services provided by a diversity of trees. There has been increasing encroachment on the shade trees and the forest reserve due to this high demand and the forest is threatened due to unsustainable harvesting of these forest products. This research explored farmers' knowledge regarding how these trees affect coffee productivity and ecosystem services in Anfilo District. So the study tried to find the following questions. 1) What type of shade tree species occurred along with coffee and how abundant are these species? 2) What are the effects of shade trees on growth and productivity of coffee shrubs? 3) How did farmers manage shade trees in their coffee plantation system in this area? 4) Which plant communities were important for conservation?

1.3 Hypotheses

The primary objective of the research reported here was to acquire coffee farmers' knowledge regarding how the trees present in their coffee plantation impact a range of ecosystem services, including biodiversity conservation and coffee production and how management can influence these impacts. In accordance with the concepts introduced above, I propose the following hypotheses for the coffee-shade system under this study.

1. Understanding the local knowledge of plant species will have high importance in the framework of sustainable management of vegetation cover in coffee plantation system.
2. Continuous or more intensive management in coffee plantation system will suppress tree regeneration and reduces tree density.

3. Shaded coffee systems particularly those dominated by tree legumes will provide higher return value and better coffee attributes.
4. It is important for the community to embrace agro-forestry to increase tree diversity for provision of tree products as well as improve soil fertility and coffee quality.

1.4 Research Objectives

1.4.1 General objective

The study was conducted with the aim to assess the local knowledge about tree species common in coffee farms to identify the major shade tree species, to see their diversity and use categories as well as to document the traditional management and the associated indigenous knowledge for conservation and sustainable utilization of plants in Anfillo District.

1.4.2 Specific objectives

This study intended-

1) to identify suitable coffee shade trees resulting in coffee beans with best quality attributes.
2) to describe the socioeconomic benefits of various shade trees in coffee production systems.
3) to identify the most important and preferred shade tree species for conservation.
4) to assess the status of coffee production under various shade trees and unshaded areas.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Farmers' knowledge of coffee productivity

Ethnobotanical knowledge has been shown to be a relatively accessible and reliable source of information on vegetation dynamics. It can also provide valuable information about single species, which can be directly applied to local resource management. According to (Kremen *et al*.,2008), although there is no consensus as to whether local communities are actually aware of the importance ecosystem services, local people from different regions in Africa and Asia recognize the multifunctional values of forests and agroforests including income and ecosystem services.

Shade coffee agro-ecosystems have a high potential for strengthening ecological processes. This is partly due to the similarity between the structure of shaded coffee farms, and the natural forest ecosystems that they have displaced. In addition, (Beer *et al*., 1998) indicated that growing coffee under shade trees is one of the fundamental principles in traditional organic coffee growing systems. Species losses or declines affect the quality of life of local people, including their health, nutrition and household income. Thus, knowing the preferences of local people helps to implement management solutions for natural resources that are locally accepted and better match their needs.

2.2 Uses of coffee shade trees

2.2.1 Shade trees mitigate climate change effect

Coffee yield is related to climatic suitability and so shading could increase resilience of coffee production in current areas. In the semi-plantation coffee system, reduction of shade mainly happens through removal of big canopy trees (Senbeta and Denich, 2006) which may cause changes in microclimate, as gaps in the canopy may bring about rising air temperature and decreasing air humidity. Shading buffers the extreme temperature variations and provides a microclimate which attenuates extreme temperatures of air and soil and preserves surface soil humidity.

Coffee yield is related to climatic suitability and so shading could increase resilience of coffee production in current areas. Transpiration rates of coffee grown in full sun were higher than coffee under shade trees. Shade species can act as a buffer against rain, wind, and temperature extremes, which can harm the coffee crop. This is in line with (Bote and Struik, 2011), who showed that shade trees provide a range of benefits to coffee plants including reduction of air and soil temperature extremes and reduction in the quantity and quality of transmitted light and hence avoidance of over-bearing.

Shade canopy intercepts solar radiation, wind, and rain, creating a more stable physical environment for the coffee crop. (Philpott *et al*., 2007) indicated that shade trees, however, can mitigate temperatures and precipitation extremes as well as wind and storm events, thereby limiting potential income losses. Large-scale removal of rainforests is likely to cause a warmer and drier climate, leading to reduced cloud formation and upward shifts of cloud condensation layers.

2.2.2 Conservation of Biodiversity

Numerous studies on shade coffee have shown that a diversified and abundant canopy of shade trees enhances associated biodiversity of other plants and animals, including insects and birds, and herbaceous plants and epiphytes. Similarly (Perfecto *et al*.1996, 2003) showed that shade coffee systems may have exceptional potential for biodiversity conservation of tropical plant and animal species. Shade grown coffee has been promoted as means of preserving biodiversity even though expansion of coffee cultivation has been seen as contributing factor to deforestation and erosion of biodiversity. Shade coffee plantations support a high diversity of other vertebrate groups as well as birds. Trees in shaded coffee systems often harbor epiphytes the presence of which enhances bird diversity. Epiphytes can harbor lots of insects as a food source for birds, as well as provide nesting material for resident birds. (Beer *et al*., 1998) indicated that shade trees reduce excessive light, mulch the soil with their litter, create hostile conditions for pests and diseases, and harbor a variety of predatory animals. In a study of the role of coffee plantations for a variety of bird species in the Western Ghats, India, Shahabuddin (1997) has shown that coffee plantations appear to be valuable refuges for many forest-dwelling species.

The conversion of a multi-species forest ecosystem to a monoculture coffee plantation resulted in several microhabitat changes and a significant decrease in species composition between forest and plantation habitats. In addition, (Nestel 1995) indicated that a diverse shade forest creates more habitats for macro-fauna and micro-fauna. The loss of the shade in coffee plantations also means the loss of resources for many species in the detritivore food chain. The coffee forests are rich in regional endemic species. Besides, they are also habitats for economically important crop genetic resources, like *Coffea arabica*, food crops like ENSET and different root crops, spices like *Aframomum corrorima* (Braun) P.C.M.Jansen and *Piper capense* L.f. Numerous studies on shade coffee have shown that a diversified and abundant canopy of shade trees enhances associated biodiversity of other plants and animals, including insects and birds (Perfecto *et al*., 1996, 2003), and herbaceous plants and epiphytes.

2.2.3 Provision of different products and services vital for livelihoods

The traditional coffee production systems provide a variety of ecosystem services that humankind relies on, including: provisioning, regulating, aesthetic, spiritual, educational, and recreational, and supporting. This agrees with (Beer *et al*., 1998), indicated that the retaining or planting of trees in the coffee farms is based on the understanding that it provides better condition for coffee plants in reducing excessive light, mulch the soil with litter, reducing periodic over-bearing and subsequent die-back of coffee branches (Bote and Struik, 2011), fodder, timber and other products.

Coffee shade trees are also providing regulating services such as carbon sequestration and climate regulation, waste decomposition and detoxification, nutrient dispersal and cycling. As these systems are located on the mountains, they are important in watershed management and as water catchments and erosion barriers, including a role in the capture and transport of water and protection of soils against erosion. (Senbeta *et al*., 2013), stated that these systems are providing many non-timber forest products like spices, honey, food in addition to coffee for local community living in and around the forest.

2.2.4 Ecological uses and services

The extensive root system of shade trees stabilizes soil particles, reducing soil erosion during torrential rains. Shade trees help promote the activity of beneficial soil organisms, such as nitrogen fixers, and material decomposers. In addition to their apparent roles in soil fertility enhancement, moisture conservation, weed suppression and modulation of light (Yacob *et al*., 1996), leguminous shade trees have tremendous use in promoting organic coffee production in the country. Increased litter from shade trees promotes a diversity of decomposer organisms and other species that can provide ecosystem services such as pest control. In addition, (Beer *et al*., 1998) indicated that shade trees reduce excessive light, mulch the soil with their litter, create hostile conditions for pests and diseases, and harbor a variety of predatory animals. Shaded coffee systems possess intrinsic mechanisms for the recycling of nutrients, reducing the dependency of the system on and external supply of nutrients.

Shade trees create more habitats for birds and soil insects, increasing the species and trophic diversity in the ecosystem. (Grossman *et al*., 2006) expressed the good capacity of coffee shade trees in formation of symbiotic associations with certain soil bacteria, rhizobia and arbuscular mycorrhizal fungi, (Wubet *et al*., 2003) all of which play a pivotal role in improvement of soil fertility and boosting of yields of associated crops. Additionally, Muschler (2001) has verified the main benefits obtained from shading in terms of improved coffee attributes compared to unshaded ones. The humus layer is also enhanced in shaded systems, resulting in greater diversity and abundance of the detritivorous fauna. The high structural complexity of the traditional coffee plantation is a result of the various vegetative layers in the agro-ecosystem. This structural complexity offers living and nesting sites for a variety of organisms.

2.2.5 Pest and disease control

Farmers mentioned that pests and diseases as the main factor affecting coffee productivity in relation to trees. Excessive shade increases the incidence of other economically important fungal diseases especially in very moist situations such as river side or valley bottoms. (Le-Pelley 1973), expressed that although many herbivores can potentially damage coffee plants, only a few are economically important. As with birds, a large proportion of individuals and species were partially frugivorous and nectarivorous, feeding on the flowering and fruiting trees of the canopy.

2.3 Coffee and shade tree management

Under undisturbed natural forests, coffee plants tend to grow taller in height, with few branches and produces only very few cherries due to high canopy cover and competition with small trees and shrubs in the under-storey. This agrees with (Gole *et al*. 2002), who stated that the traditional coffee production and management was practiced for centuries in Ethiopia through selective removal of some species and purposefully retaining others they believe have an impact on productivity. Hence, farmers open up the canopy by thinning shade trees, and clear the under storey vegetation to increase coffee yield.

2.4 Negative impacts of coffee management system

Generally, human exploitation of the forest has the potential to influence the patterns of wild coffee distribution. In the absence of natural regeneration, the existing shade trees will eventually mature, reach post-reproductive stage and die (Senbeta and Denich 2006), exposing the coffee plants to altered environmental conditions (Bote and Struik 2011). If the conversion of forest coffee into semi-forest coffee system continues, most of the coffee forests will be lost, leading to the loss of forest biodiversity.

The coffee management activity involves complete removal of the competing undergrowth, including the seedlings and saplings of the canopy trees on annual basis, in an effort to increase coffee productivity. This is in agreement with (Senbeta and Denich 2006; Schmitt *et al*. 2009) who expressed that the negative consequence of these practices is not only on the forest species composition and structure, but also on the long term survival of coffee shrubs and productivity.

CHAPTER THREE

3. METHODOLOGY

3.1 Description of the study area

The study was conducted in Anfillo District of Kellem Wollega Zone, Oromia Region. Anfillo is bordered on the southwest by the Gambela Region, on the north by Jimma Horo and Gidami district, on the northeast by Hawa Walel, and on the east by Sayo districts. The major town in Anfillo is Mugi (Fig. 1).

The three largest ethnic groups reported in Anfillo were the Oromo (89.66%), the Amhara (4.6%), and the Mao people (4.46%). Oromiffa was spoken as a first language by 95.41%, 2.92% Amharic, and 0.64% speak Mao, one of the northern group of Omotic languages; the remaining 1.03% spoke other languages.

The majority of the inhabitants were Protestants, with 63.74% reporting that as their religion, while 26.52% observed Orthodox Christianity, and 8.84% observed Islam. In the zone, about 99% of the coffee is produced by small scale farmers, which include forest coffee, semi-forest coffee, semi-plantation coffee and garden coffee which accounts for 15%, 40%, 20% & 25% respectively. The district consists of diverse indigenous groups and settlers who come from other parts of Ethiopia.

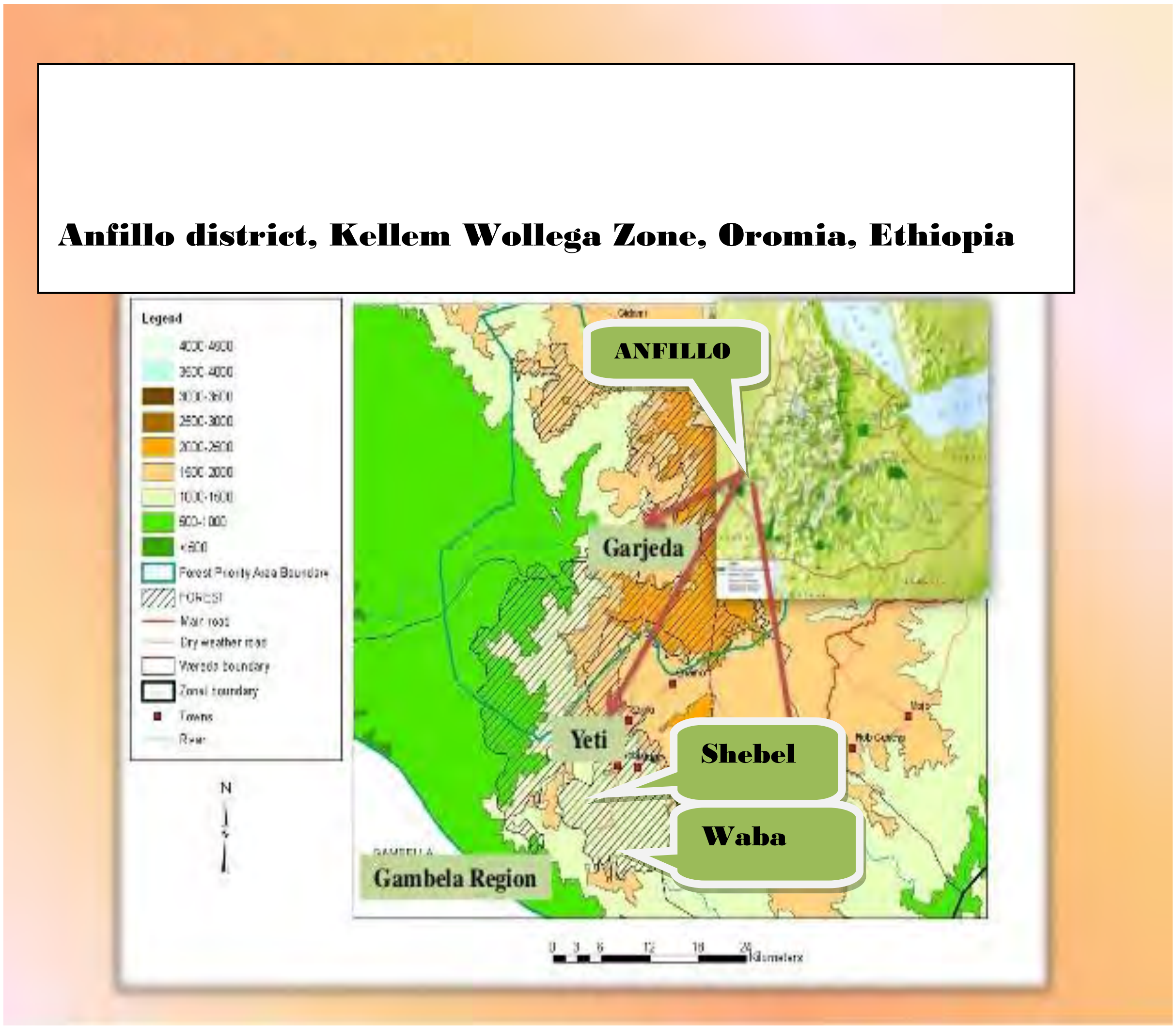

Fig. 1 Map of Ethiopia showing the location of the study area

Of the 10 districts in Kellem Wollega Zone, Anfillo is known as predominantly coffee growing district and is situated about 42 km to the south west of Dambi Dollo town. It is located at $8^0$30"E and an elevation range from 500 to 2200m above sea level. The mean minimum and maximum temperature of the area is 12^0C and 27^0C respectively. The average annual rain fall is 1200-2320mm. The district is generally divided in to three agro-climatic zones from which 28% is high land, 8% is mid altitude and 64% is low land (source: Anfillo district agricultural and rural development office). Coffee is the major cash crop of the district and the site is considered as one of the major coffee cultivating areas, with various annual crops like maize, wheat, sorghum, etc, and livestock production. Multipurpose trees such as *Albizia gummifera, Cordia africana, Acacia abyssinica, Croton macrostachyus, Millettia ferrugenia, Vernonia amygdalina* and others found in coffee plantation system to provide shade.

3.2 Method of data gathering

Field trips were conducted five times in the semi-forest coffee; and six times in the semi-plantation to perform the data collection. In both of these coffee production systems, a total of twelve most commonly used coffee shade trees were recorded. Qualitative and quantitative data were collected using appropriate ethnobotanical methods. Semi-structured and structured interviews, questionnaire, participatory observation, guided field walk were the major data collecting tools used to gather the ethnobotanical data. Semi-structured interview was conducted with eight key informants using 'interview guide' or 'paper-based interview' and often contains open-ended questions.

Informants involved in this study were selected among the coffee farmers in the district, agricultural and rural development agents, agricultural experts from Jimma agricultural Research Centre, and other knowledgeable elders of the Anfillo District dwellers. The questions included in the interview and questionnaires were based on the questions of the study, filled by the respondents and there were both open and closed ended questions in the questionnaire. The collected information included 1) demographic and basic farm data, 2) coffee shade trees and overall uses, 3) coffee shade tree management; through semi-structured interview schedules and using questionnaires to satisfy pre-determined objectives.

In addition to the primary data, secondary data from Agricultural and rural development office of Anfillo district were gathered to make a thorough comparison on shade tree trend analysis and socio-economic data.

3.3 Population of the study and Sampling technique

General informant selection was performed by using simple random sampling technique while purposive sampling technique was used to select the key informants. A total of 65 informants (55 male and 10 female) between ages of 25 and 70 were involved in this research of which eight were selected as key informants. The key informants were selected on the basis of long experience and knowledge of growing coffee under key shade tree species.

3.4 Method of data analysis

Descriptive statistics and ethnobotanical data analyses tools were employed to analyze the data. Preference ranking for eight coffee shade trees was analyzed by entering the responses of key informants in data matrix; as well as paired comparison of twelve coffee shade tree species was conducted to determine the relative importance of these trees in coffee plantation. Generally, direct matrix ranking, paired comparison, preference ranking, and percentage were used to analyze the data and finally the findings were discussed with relevant literature and conclusions were made.

CHAPTER FOUR

4. RESULTS

4.1 Factors affecting plant knowledge distribution

Sixty five informants were considered in this study, of which the majority (34, 52 %) of the respondents' age lies above 50 years. The results further indicated the smallest proportions of the respondents 5 (8%) were within a range of 25-35 years of age (Fig. 2a). People above 50 years of age cited more species than others. Surprisingly, no much difference in use reports was observed between the different gender groups.

Most of the interviewed farmers' holdings in the coffee farms range from 0.5 to 5 hectares. The main income sources for the household heads included coffee (70%), non-coffee crops mainly cereal crops (5%); and coffee and non-coffee including honey production (25%) (Fig. 2b). Therefore, almost all farmers grow coffee as the major income source in the area.

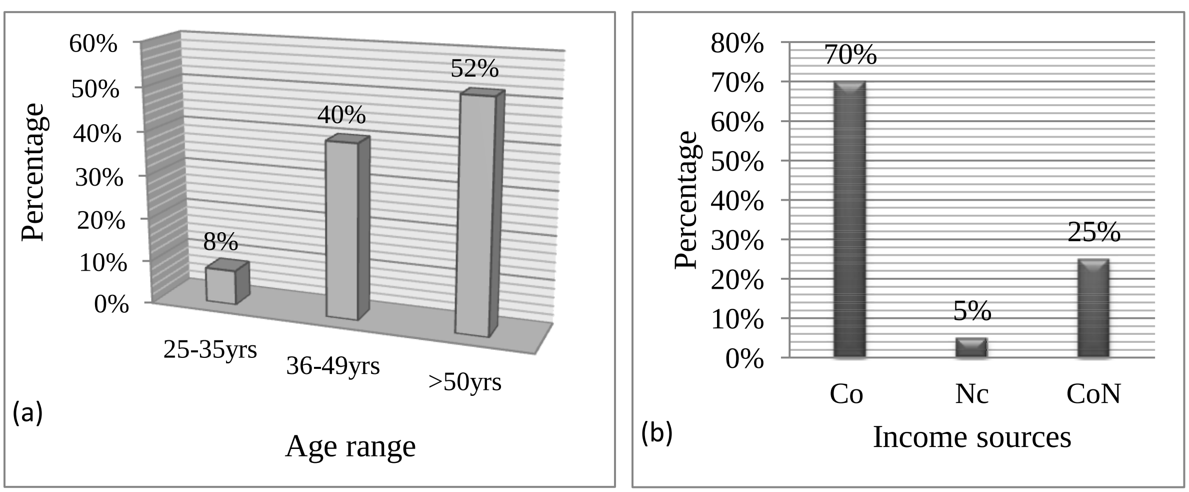

Fig. 2 a) Age of the respondents; b) Sources of income of the house hold (Co=Coffee; Nc=Non-coffee; CoN=Coffee & non-coffee)

Concerning level of education of the respondents, 2 of them were illiterate, 40 (62%) elementary and the rest 23 (35%) were secondary and above. Access to important information on coffee growing and management, 90% of the respondents were obtained from coffee farmers, 8% of the respondents were obtained from agricultural and rural development offices and the remaining 2% of respondents were obtained from research center. The interviewed farmers had long experience in growing coffee bushes under shade tree species. Their overall impression of shade was quite positive and they considered shade as a prerequisite for coffee production systems.

Socio-economic factors such as age, occupation, and proximity to the resources were found to affect the knowledge distribution among the informants. Of these socio-economic factors, age was found to be important than gender, occupation and place of residence/proximity to the resources.

4.2 Farmers preference of shade trees

Farmers classified shade trees as suitable for integration with coffee or unsuitable based on their leaf size, foliage density, crown shape, and root system attributes (Table1). Faster growth rate, deciduousness, faster litter decomposition rate, possession of thin and small leaves were among the characteristics that are taken into consideration when planting coffee shade trees. This was reported by most of the farmers involved in this study (38, 58%). Almost all the interviewed informants preferred deciduous shade trees (57, 88%) compared to evergreen ones (5, 8%).

All the informants preferred trees with spreading crowns as favorable shade trees, rather than those with a narrow crown as it provides better shade for coffee plants than a narrow crown. Leaf size was also considered an important characteristic by the majority of the farmers interviewed which preferred trees with smaller leaves (38, 58%) to the larger ones. Some farmers (16, 25%) noted that succulent leaves decompose faster than less succulent ones even if they are bigger in size. Others, (11, 17%), however, had observed that some leaves (either the smaller or larger leaves) are liked by termites and these decompose faster.

Almost all interviewed farmers (62, 95%) responded that trees that have intermediate height are preferred for coffee shade. Concerning the root depth and root spread of the coffee shade tree, all the informants preferred deep rooted trees with few roots in the upper soil layers.

Table 1 Shade tree preference of farmers for their coffee production system

Coffee shade tree characters	Character states	Number of respondents	Percentage
Deciduousness	Deciduous	57	88
	ever green	5	8
	no effect	3	5
Tree height	Large	3	5
	Small	0	0
	Medium	62	95
Growth rate	Fast	63	97
	Slow	2	3
Leaf size	Small	38	58
	Big	16	25
	no effect	11	17
Crown type	Open	65	100
	Closed	0	0
Root depth	Deeper	65	100
	Shallower	0	0

4.3 Relationship between amount of coffee shade trees, canopy closure and coffee yield

In the correlation analyses, canopy closure has shown positive correlation with tree density and average tree height (Fig. 3a). Informants in the study area also reported the importance of moderate shade conditions which is also considered favorable for good coffee growth since photosynthetic rates of coffee are generally at a maximum at intermediate (50%-60%) shade levels (Fig. 3b).

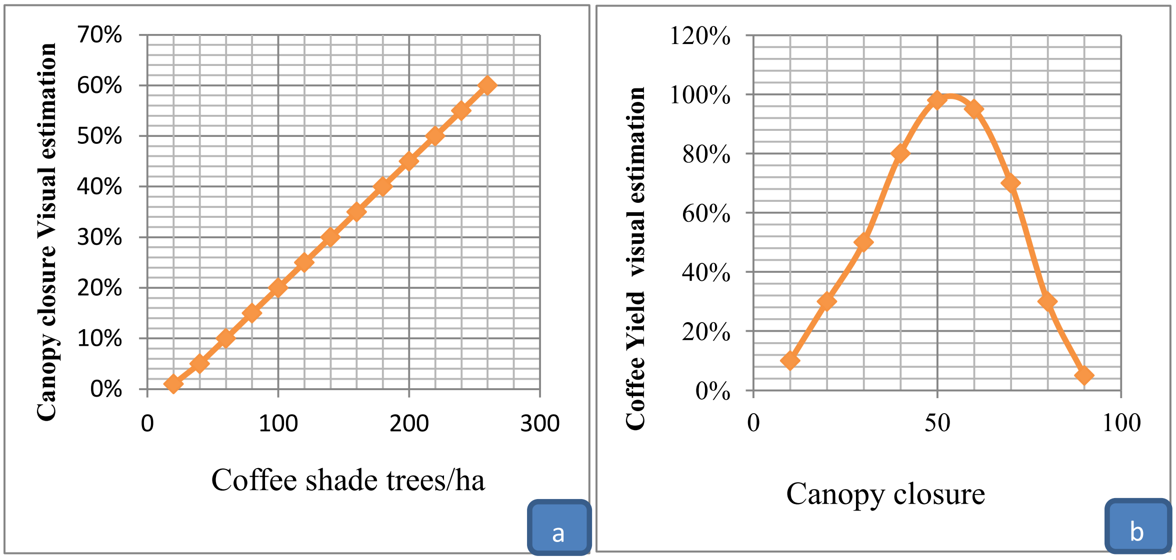

Fig. 3 a) Relationship between canopy closure and amount of shade trees b) Impact of canopy closure on coffee yield

Farmers' decision in lopping and retention of canopy trees is based on their knowledge of the tree species attributes such as height, crown architecture, leaf size and deciduousness, leaf decomposition rate, impact on soil fertility, effect on coffee productivity (Table 2).

Based on the above criteria, *Albizia gummifera*, *Acacia abyssinica*, *Millettia ferruginea*, *Cordia africana, Pouteria adolfi-friederici*, *Croton macrostachyus, Grevillea robusta* and *Erythrina brucei* as permanent shade trees*;* and, *Sesbania sesban*, *Ricinus communis*, *Greviella robusta*, *Vernonia auriculifera* and *Vernonia amygdalina* as temporary shade trees were considered as preferred coffee shade trees by farmers.

Permanent shade tree species are more prevalent in semi-forest coffee of the study area and sparsely distributed in semi-plantation coffee. These trees should be cut down and removed whenever the permanent shade trees have fully grown to provide appropriate shade.

According to the interviewed informants, temporary coffee shade trees are considered having growth rate faster than the permanent coffee shade trees .

Table 2 Characteristics of twelve shade trees commonly used in coffee plantation system

Scientific name	Crown	Leaf size	Height	Litter decom.	Deciduo Usness
1.Permanent shade trees					
Acacia abyssinica	Wide	Small	Tall	Fast	Yes
Albizia gummifera	Wide	Small	Tall	Fast	Yes
Cordia africana	Wide	Large	Medium	Fast	Yes
Croton macrostachyus	Wide	Large	Medium	Fast	Yes
Erythrina brucei	Wide	Large	Medium	Fast	Yes
Grevillea robusta	Inter	Small	Medium	Fast	No
Milletia ferruginea	Wide	Small	Medium	Fast	Yes
Puteria adolfi-friederici	Medium	Small	Tall	Fast	Yes
2. Temporary shade trees					
Ricinus communis	Wide	Medium	Medium	Medium	Yes
Sesbania sesban	Inter	Small	Medium	Fast	Yes
Vernonia amygdalina	Wide	Medium	Medium	Fast	Yes
Vernonia auriculifera	Wide	Medium	Medium	Medium	Yes

Problems related to the shade trees in coffee plantation system

Concerning the negative effect of shade trees on coffee cultivation (Table 3), the respondents strongly agree and gave the highest value to the resource competition, undesirable growth of single stemmed coffee trees and reduction of the quality and quantity of the crop. The other major effect of the shade trees that the key informants and other interviewed informants reported were creation of favorable micro environment for the occurrence of some coffee disease and damage to coffee shrubs by falling trees. All the interviewed informants strongly stressed the necessity of shading coffee bushes at all developmental stages and at seedlings in particular, especially during dry and sunny seasons (December to April) and at bean filling stage (Table 3). The respondents gave little value to the effect of shade trees on the flower production of coffee shrubs.

Table 3 Response of the key informants about the problems related to coffee shade trees (5=strongly agree; 1= agree; 0=disagree; R=Respondents)

	R1	R2	R3	R4	R5	R6	R7	R8	Total	Rank
1. Problems related to the shade trees in coffee plantation system										
Resource competition	5	5	5	5	5	5	5	5	40	1st
Occurrence of some coffee diseases and insect pests	3	5	4	4	5	3	5	4	33	4th
Reduce the quality and quantity of the crop	5	5	5	5	5	5	5	5	40	1st
Falling trees can damage the understory crop	3	4	3	4	3	2	4	3	26	5th
Undesirable growth of single stemmed coffee trees under shade	5	5	5	5	5	5	5	5	40	1st
2. Shade requirement stage										
Seedling stage	5	5	5	5	5	5	5	5	40	1st
Flowering stage	2	2	3	2	2	2	3	2	18	3rd
Fruiting stage	5	4	5	4	4	4	5	4	35	2nd

4.4 Identification of coffee shade trees species based on their uses and nativity

Most indigenous trees species and some exotic trees can be used as coffee shade trees as they are less competitive with crops. Of the total 12 coffee shade trees species (Table 4), 11 (92%) are indigenous; and only 1(8%), *Grevillea robusta* is exotic.

Table 4 Identification of coffee shade trees based on their growth form (habit), uses and nativity

Scientific Name	Family	Growth form	Nativity
Albizia gummifera (J.F.Gmel.) C.A.Sm	Fabaceae	Tree	Indigenous
Milletia ferruginea (Hochst.) Bak.	Fabaceae	Tree	"
Acacia abyssinica Hochst.ex Benth.	Fabaceae	Tree	"
Erythrina brucei Schweinf.	Fabaceae	Tree	"
Pouteria adolfi-friederici (Engl.) Baehni	Sapotaceae	Tree	"
Croton macrostachyus *D*el.	Euphorbiaceae	Tree	"
Cordia africana Lam.	Boraginaceae	Tree	"
Vernonia amygdalina Del.	Asteraceae	Shrub	"
Vernonia auriculifera Hiern.	Asteraceae	Shrub	"
Ricinus communis L.	Euphorbiaceae	Shrub	"
Grevillea robusta R.Br.	Proteaceae	Tree	Exotic
Sesbania sesban (L.) Merr.	Fabaceae	Shrub	Indigenous

4.5 Comparison of Coffee Shade Trees

The highest value was assigned by key informants to *Albizia gummifera* as the most multipurpose and the most preferred shade tree species in coffee plantation system in the study area (Table 5). *Milletia ferrugenia, Erythrina brucei and Pouteria adolfi-friederici ranked 2nd, 3rd and 4th respectively.* The least ranked species (*Croton macrostachyus* and *Vernonia auriculifera*) are the least threatened and the dominantly distributed species in the study area. However, some of the species with the highest rank (eg. *Pouteria adolfi-friederici) is* being threatened for the purpose of house construction and timber production.

Table 5 Paired comparison of twelve shade tree species by eight key informants in reference to coffee production

Coffee shade tree species	Total number of pairs of one species with 11 others species by 8 informants (1x11x8)	Frequency of each species	Rank
Acacia abyssinica	88	39	6th
Albizia gummifera	"	88	1st
Cordia africana	"	27	8th
Croton macrostachyus	"	20	9th
Erythrina brucei	"	58	3rd
Grevillea robusta	"	43	5th
Mellitia ferruginea	"	84	2nd
Pouteria adolfi frederici	"	48	4th
Ricinis communus	"	35	7th
Sesbania sesban	"	43	5th
Vernonia amygdalina	"	43	5th
Vernonia auriculifera	"	0	10th

4.6 Tree species commonly used in semi-forest coffee system of the study area

Semi-forest coffee system is a type of coffee production system where farmers slash weeds, lianas and competing shrubs; and contains less amount of weeds and so requires less management system. Preference ranking by the eight key informants of the study area for eight shade tree used in forest coffee (Table 6) shown that *Albizia gummifera* with score summed up 39 (ranked 1st) and hence is the most effective coffee shade tree. The second, third, fourth and fifth most preferred shade trees in coffee plantation system are *Milletia ferrugenia, Erythrina brucei, Pouteria adolfi-friederici*, and *Vernonia amygdalina* respectively while, the least preferred coffee shade tree species compared to the other five species are *Acacia abyssinica, Cordia africana,* and *Croton macrostachyus* according to informants.

Table 6 Preference ranking by the eight key informants of the study area for eight shade tree used in semi-forest coffee system of the study area (R=Respondents)

	Key informants (Coded R1 to R8) with the ranks they gave									
Scientific name	R1	R2	R3	R4	R5	R6	R7	R8	Total	Rank
Milletia ferrugenia	5	4	5	5	4	4	5	5	37	2nd
Erythrina brucie	5	5	5	4	4	5	4	4	36	3rd
Acacia abyssinica	4	4	4	5	3	5	4	4	28	6th
Pouteria adolfi	4	4	5	4	4	5	4	4	35	4th
Albizia gummifera	5	5	5	5	5	4	5	5	39	1st
Vernonia amygdalna	5	4	4	4	5	4	5	5	32	5th
Cordia africana	3	3	4	3	3	3	3	4	26	7th
Croton macrostachyus	2	3	3	2	3	3	3	4	23	8th

A total of eight common coffee shade tree species were identified and documented by the researcher and key informants in the Anfillo district semi-forest coffee system, which belongs to five families (Fig 4) and (Table 7). Fabaceae (nitrogen fixing legume coffee shade trees) are the most dominant and highest diversity with 4 species which include *Albizia gummifera* (ambabesa), *Milletia ferrugenia* (sotalo), *Acacia abyssinica* (lafto), and *Erythrina brucei* (walensu). The other four families involved in the semi-forest coffee of the study area were Asteraceae, Euphorbiaceae, Boraginaceae and Sapoteaceae which include the species *Croton macrostachyus* (bakanisa), *Cordia africana* (wadesa), *Vernonia amygdalina* (ebicha), and *Pouteria adolfi-friederici* (kararo) respectively.

Fig. 4 Semi-forest coffee

From field trip observation, the most frequent coffee shade trees in the semi-forest coffee of the study area were *Acacia abyssinica, Croton macrostachyus* and *Albizia gummifera.* In this area, even though the farmers cited *Pouteria adolfi-friederici* as suitable shade trees, this preference was not visible and it represents less than 3% of shade tree abundance in the coffee farm (Table 7).The distribution of coffee shade tree species was analyzed using relative frequency (RF) which is the appearance frequency of a particular species divided by all species and multiplied by 100%.

Table 7 Frequency of shade trees on five plots surveyed in semi-forest coffee system

Families	Lists of species obtained	Local Name	Total Plot Studied	Frequency	RF
1. Fabaceae	*Milletia ferrugenia*	Sotalo	5	4	
	Erythrina brucie	Walensu	5	3	55
	Acacia abyssinica	Lafto	5	5	
	Albiza gummifera	Ambabesa	5	5	
2. Asteraceae	*Vernonia amygdalina*	Ebicha	5	3	10
3. Euphorbiaceae	*Croton macrostachyus*	Bakanisa	5	5	16
4. Boraginaceae	*Cordia africana*	Wadesa	5	4	13
5. Sapoteaceae	*Pouteria adolfi-frederici*	Kararo	5	2	3

4.7 Coffee shade tree diversity in semi-plantation coffee

Semi-plantation coffee is characterized by having temporary shade tree species with some permanent trees. Unlike semi-forest coffee, semi-plantation coffee contains more weeds and requires more management system.

In semi-plantation coffee of the study area, a total of eight most commonly used coffee shade tree species (four families) were identified. (Fig. 5) and (Table 8). This include Fabaceae with the species containing *Sesbania sesban, Albizia gummifera* and *Acacia abyssinica*; Asteraceae containing plant species such as *Vernonia amygdalina* and *Vernonia auriculifera;* Euphorbiaceae containing the species *Croton macrostachyus* and *Ricinus communis*; and Proteaceae containing *Grevillea robusta*. However, *Croton macrostachyus* and *Vernonia amygdalina* are the most frequently found coffee shade trees in semi-plantation coffee system. Like in the forest coffee, the family Fabaceae is the most diverse group in the semi-plantation coffee**.**

Table 8 Frequency of coffee shade trees on six plots surveyed in semi-plantation coffee system of Anfillo district (RF=relative frequency)

Species Name	**Family Name**	**Local name (Oromic)**	**Total plots surveyed**	**Frequency**	**RF**	**Rank**
Croton macrostachyus	Euphorbiaceae	Bakanisa	6	6	22	1st
Grevillea robusta	Proteaceae	Gravila	6	2	7	5th
Vernonia amygdalina	Asteraceae	Ebicha	6	5	19	2nd
Vernonia auriculifera	Asteraceae	Reji	6	4	15	3rd
Ricinus communis	Euphorbiace	Kobo	6	3	11	4th
Sesbania sesban	Fabaceae	Sasbania	6	1	4	7th
Acacia abyssinica	Fabaceae	Lafto	6	3	11	4th
Albizia gummifera	Fabaceae	Ambabesa	6	3	11	4th

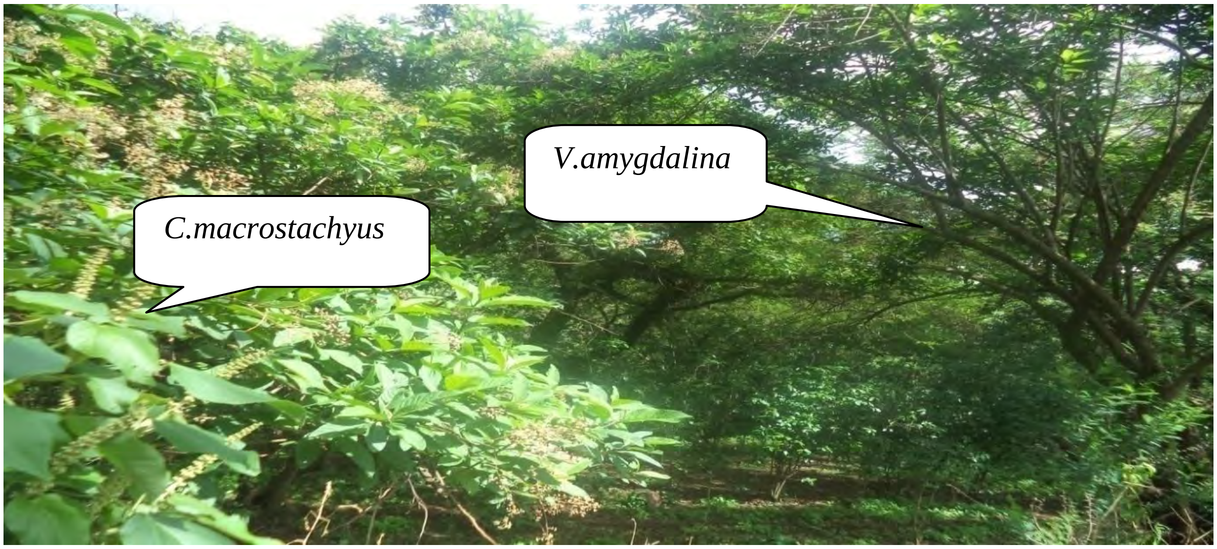

Fig. 5 Semi-plantation coffee

The interviewed informants reported that some species of plants such as *Vernonia amygdalina* and *Vernonia auriculifera, Croton macrostachyus*, *Ricinus communis* and *Grevillea robusta* as the most preferred coffee shade trees for proper growth of the seedling of coffee plants during the conversion of agricultural land to coffee cultivation (for the establishment of semi-plantation coffee system) (Fig. 6a &b).

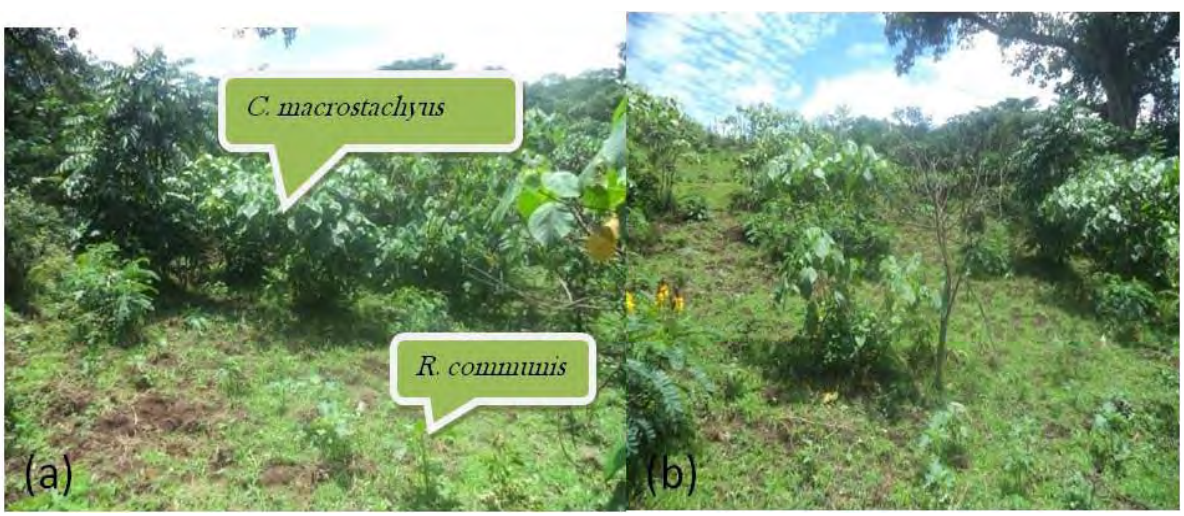

Fig. 6 a & b- Shade trees used during the conversion of agricultural land to coffee cultivation

In addition to coffee and crop production, honey production is one of the most sources of income of the community of the Anfillo district (Fig. 7). Most coffee shade trees such as *Vernonia amygdalina* and *Vernonia auriculifera* are highly preferred for their flowers by the honey bees; and some other trees such as *Albizia gummifera, Milletia ferrugenia, Cordia africana,* and *Croton macrostachyus*were retained for their height and shape for putting traditional beehives.

Fig. 7 Multi-purpose coffee shade tree species in semi- forest coffee

4.8 Investigation of the roles of coffee shade trees

Eight selected key informants were asked to assign value to each species for a particular service. These values were summed up and divided by eight to get the average (Table 9). Accordingly, the highest value, 42 (1st rank) was assigned to *Albizia gummifera.* It is found to be highly used by local community for multiple purposes. This is followed by *Milletia ferrugenia, Erythrina brucei* and *Pouteria adolfi-friederici* with the value of 41, 38 and 38 respectively. Four of them (*Albizia gummifera, Milletia ferrugenia, Erythrina brucei* and *Pouteria adolfi-friederici*) were more ranked by the informants for almost all use categories.

Both *Pouteria adolfi-friederici* and *Cordia africana* were ranked more for provision of timber, beehive support and as a source of food for some animals. *Croton macrostachyus* was preferred more as a shade for the growth of the seedlings of coffee plants; and as a traditional medicine. Both *Vernonia amygdalina* and *Vernonia auriculifera* were ranked more for honey production, traditional medicine and for shading of the seedlings of coffee plants.

Table 9 Direct matrix ranking by eight key informants to compare the use values of each coffee shade trees (5 = the best, 4 = very good, 3 = good, 2 = less used, 1 = the least, 0 = not used).

Use categories	Coffee shade tree species													
	A. gummifera	*M. ferruginea*	*A .abyssinica*	*E. brucei*	*P. adolfi-friederici*	*C. macrostachyus*	*C. africana*	*V .amygdalina*	*V .auriculifera*	*R .communis*	*G. robusta*	*S. seban*	Total	Rank
Micro- regulation	5	5	3	5	4	2	2	4	3	3	4	4	44	3rd
Beehive support	5	5	2	5	4	4	4	0	0	0	0	0	29	7th
Bee forage	4	3	4	3	3	5	4	5	5	2	3	3	44	3rd
Coffee bean yield, size	5	5	3	4	4	3	3	4	3	3	4	4	45	2nd
Soil fertility	5	5	5	5	4	4	4	4	4	3	4	5	52	1st
Biodiversity conservation	5	5	4	4	5	5	5	2	2	2	3	2	44	3rd
Timber	3	3	2	3	5	4	5	1	0	0	5	0	31	6th
Wood charcoal	4	4	5	4	5	4	4	4	3	1	4	3	45	2nd
Fodder	4	5	0	3	3	4	4	4	4	3	3	3	41	4th
Medicine	2	1	1	2	1	4	4	5	2	4	3	3	32	5th
Total	42	41	29	38	38	39	39	33	26	21	33	27		
Rank	1	2	6	4	4	3	3	5	8	9	5	7		

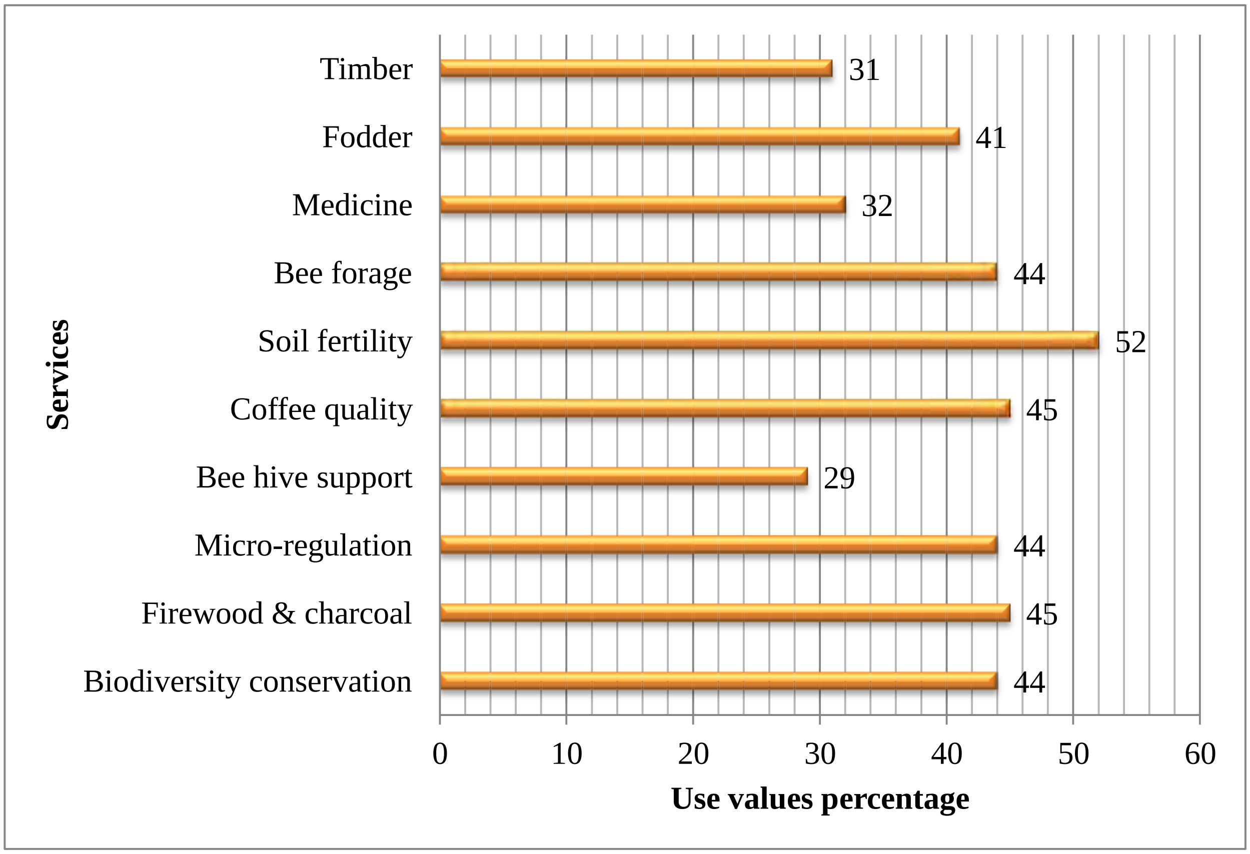

Fig. 8 The service priorities of coffee shade trees

Effect of coffee shade trees on coffee bean size and yield

The respondents reported that the highest and most stable coffee yield performances were obtained under *Albizia gummifera* and *Milletia ferrugenia* than other coffee shade trees and the open sun (Fig. 9).This could be attributed to the contributions of such these trees to enrich soil fertility status and provide moderate light intensity through their small leaves. They also reported that coffee yields are affected with the interactions with the shade trees, particularly the size of coffee beans is bigger under agro-forestry (shaded condition) than under direct sun light.

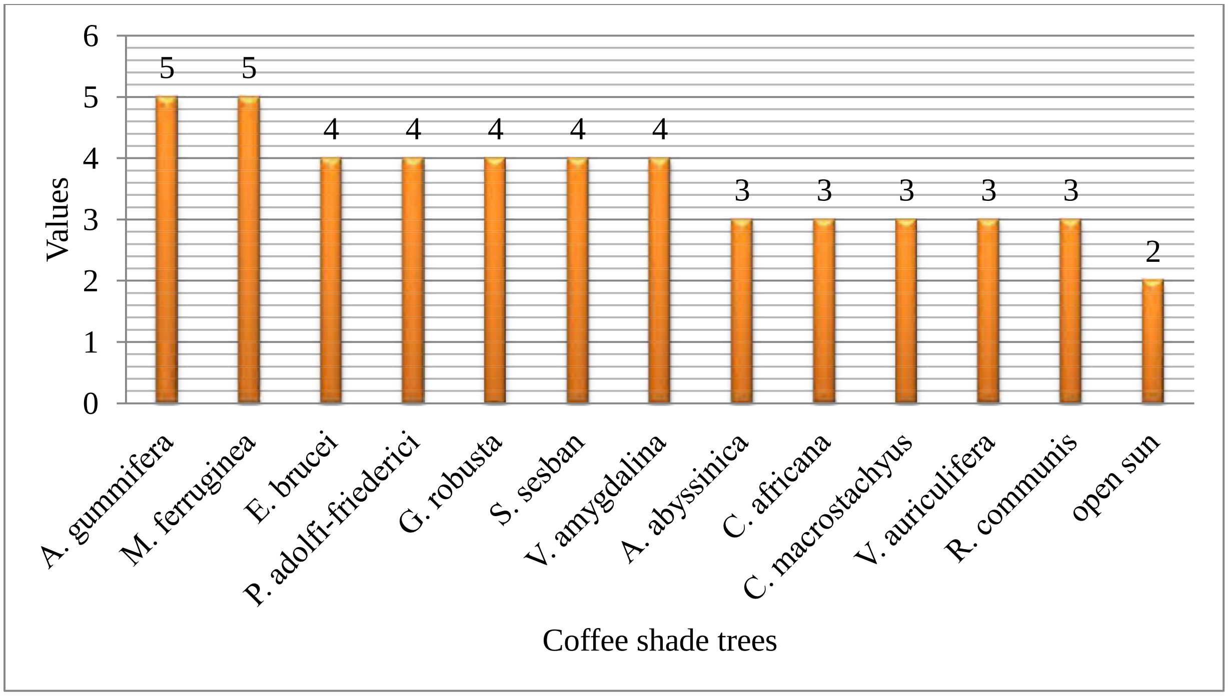

Fig. 9 The direct matrix value given to each coffee shade tree species on the bases of their effect on coffee bean size and yield (5 = the best, 4 = very good, 3 = good, 2 = less used, 1 = the least, 0 = not used; 5 is the maximum value).

Coffee shade trees, bee abundance and coffee production

The interaction between bee abundance and number of flowers had a positive impact on the number of coffee berries harvested. Thus coffee production increased with increasing bee abundance, and this effect was amplified by an increase in the initial number of flowers (Fig. 10).The higher species richness (including pollinators) was largely a function of the higher number of individual trees present in the shade coffee systems. Shade tree diversity and density were positively associated with pollinator abundance and diversity.

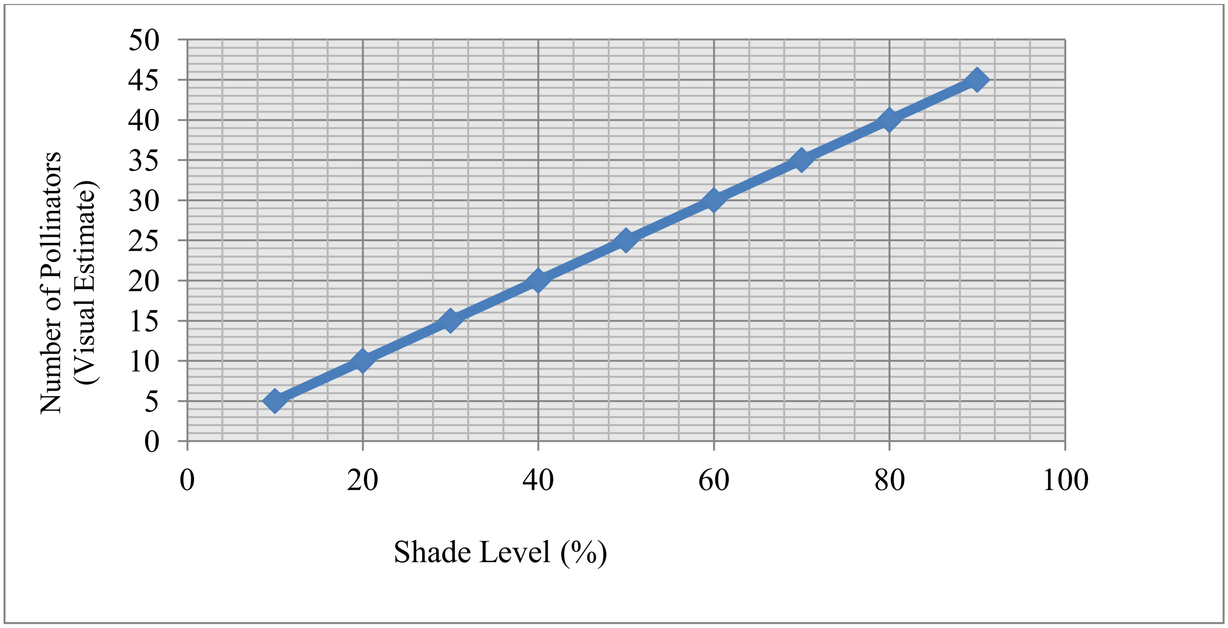

Fig. 10 The impacts of shade trees on the number of pollinators

Effect of shade trees on the density of coffee plants

From the result obtained from field observation, coffee shrub was observed to be denser in shaded zone (Fig. 11). Coffee shrub density was significantly higher under *Albizia gummifera* and *Acacia abyssinica*. The majority of the respondents of study sites also mentioned that coffee stems with more number of branches, increased lifespan, increased number of coffee stem in the sample, coffee bean with better taste, stronger coffee stems, improved photosynthesis and increased leaf area index, as some of the salient features of shaded coffee systems.

Fig. 11 Effect of shade trees on the density of coffee plants

Impacts of growing coffee without shade trees

All the key informants and the majority of the interviewed farmers assigned the highest value about the effect of sun grown coffee to decreased soil quality, decreased life span of coffee shrubs, increased temperature and wind, demanding more management, increased temperature and wind problem and decreased biodiversity; followed by yield reduction, increased in weed problem, increased evapotranspiration, prematurity of coffee beans, increased in soil erosion and decreased air and water quality (Table 10). However, growing coffee without shade has little effect on the flowering of coffee shrubs, according to the informants.

Table-10 Response obtained from the eight key informants about the problems of growing coffee without shade (5=strongly agree, 1=agree, 0=disagree)

Problems related to sun grown coffee	**Key informants (R1-R8) with the ranks they gave**									
	R1	R2	R3	R4	R5	R6	R7	R8	Total	Rank
Yield reduction	5	5	5	5	5	4	5	4	38	7th
Increased evapotranspiration	4	3	5	4	5	4	5	5	35	9th
Decreased soil quality	5	5	5	5	5	5	5	5	40	1st
Increased in weed problem	4	5	4	5	4	4	5	5	36	8th
Decreased lifespan	5	5	5	5	5	5	5	5	40	1st
Increased T^o & wind	5	5	5	5	5	5	5	5	40	1st
Increased soil erosion	4	4	5	4	3	5	4	5	34	10th
Decreased biodiversity	5	5	5	5	5	5	5	5	40	1st
Prematurity of coffee beans	4	5	3	5	5	5	4	4	35	9th
Demand more management	5	5	5	5	5	5	5	5	40	1st
Fluctuation of T^o &humidity	5	5	5	5	5	5	5	5	40	1st
Decreased air/water quality	4	4	5	4	3	4	3	4	31	11th
Decreased coffee flowers	3	2	3	3	2	2	3	4	22	12th

4.9 Tree species that are not preferred for coffee production

Shade trees such as *Syzygium guineese, Ficus vasta, Ficus sur* and *Eucalyptus globulus* compete with coffee plants for water and nutrients (Fig 12a, b, c & d). The interviewees did not favor highly emergent shade trees such as *Eucalyptus globules* and others particularly those with few branches, because the shading effect is being reduced and coffee bushes could be exposed to strong sun during extended dry season. They believe that non-deciduous trees with deep shade such as *Syzygium guineense* compete for water with coffee during the dry period.

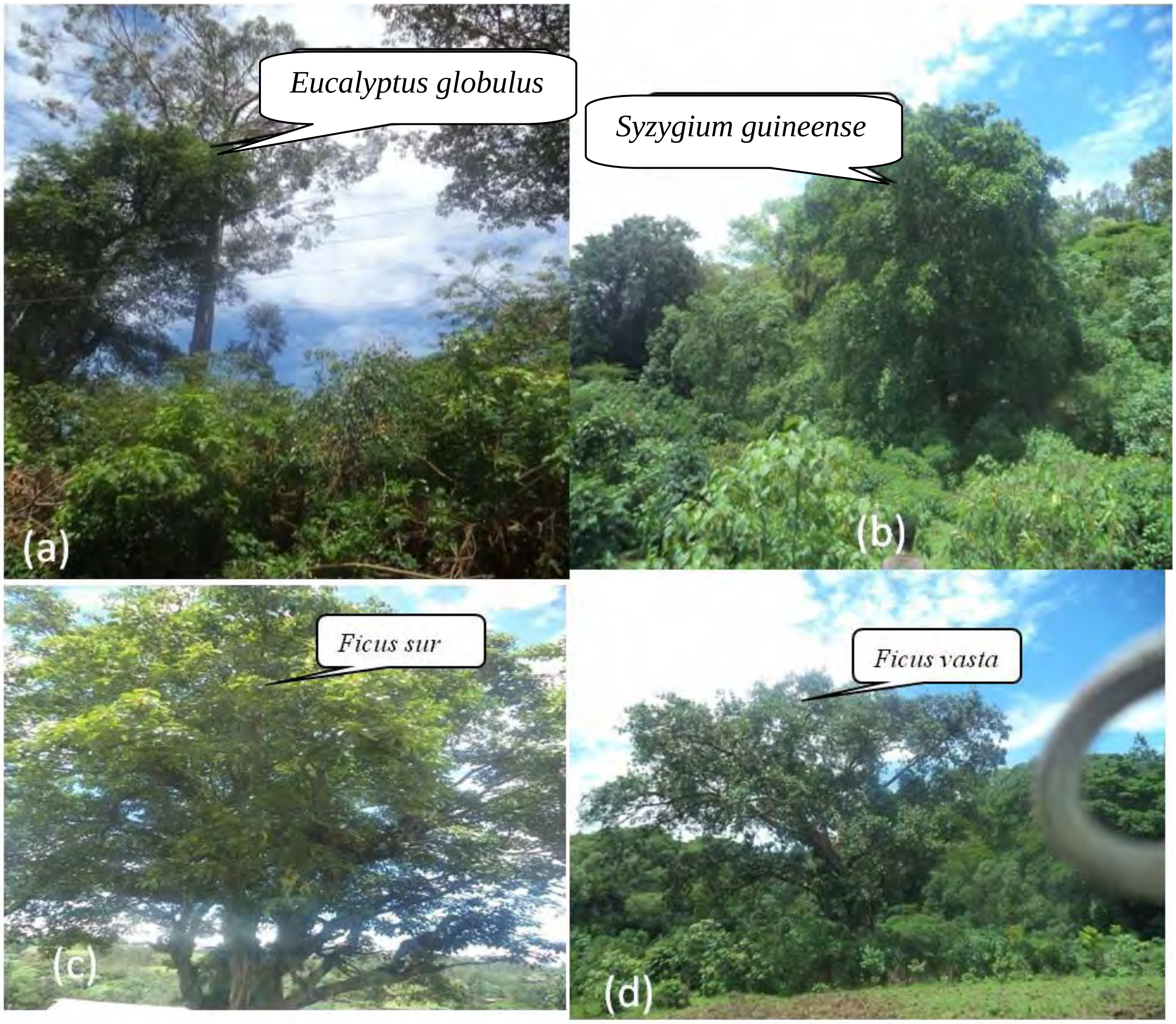

Fig. 12 Tree species that are not preferred for coffee production a) *Eucalyptus globules;* b) *Syzygium guineense*; c) *Ficus sur*; d) *Ficus vasta*

4.10 Coffee and shade tree management

The majority of the species mentioned by farmers were established through natural regeneration in more diverse coffee shade tree areas; and by replanting of the desired coffee shade trees in less shaded area (Table 11). Concerning shade management, the methods reported by some of the informants include weeding of under growth, intercropping, debarking, pruning and cutting of the side branches.

Table 11 Shade tree management practice in semi-plantation and semi-forest coffee

Management type	Semi-plantation coffee	Semi-forest coffee
Weeding of under growth	more common	less common
Intercropping	more common	more common
Debarking	less common	more common
Cutting side branches	less common	more common
Pruning	less common	more common
Replanting	more common	less common
Natural regeneration	less common	more common

Most of the interviewed informants responded that when a diseased trees or heavy shades were found, they often de-barked these trees to promote moderate shade in their coffee plantation (Fig. 13 a & b).

Fig. 13 a & b- Debarking of coffee shade trees

Weeding- occurs more than three times for young seedlings of coffee plants and in areas of sparse shade. But for the forest coffee, where there were dense and diverse populations of shade trees, management system occurred one or two times in a year. The growth of temporary shade trees should be controlled by slashing the side branches, to avoid any eventual disturbance to the young coffee. Dead or dry weeds can be used as mulch. Mulching will reduce the amount of weeds. Growing a cover crop such as tree legumes (living mulch) under the coffee trees can give many of these benefits. Weeds compete for both nutrients and water, so it is essential to keep the area under the canopy of the trees, weed-free. Weeding/slashing will provide substantial volume of organic matter which will improve the physical condition of coffee soil (Fig 14).

Fig. 14 Weeding of unwanted plants in coffee cultivation system

Pruning-pruning of shade trees within agro-forestry systems is performed to limit light and root competition between tree and crop. Pruning of trees is important practice as both a management practice and means of obtaining fuel-wood for rural communities. It helps to achieve the desired plant shape, and contribute to sustainable higher yields, while contributing to disease and pest control (Fig 15a).

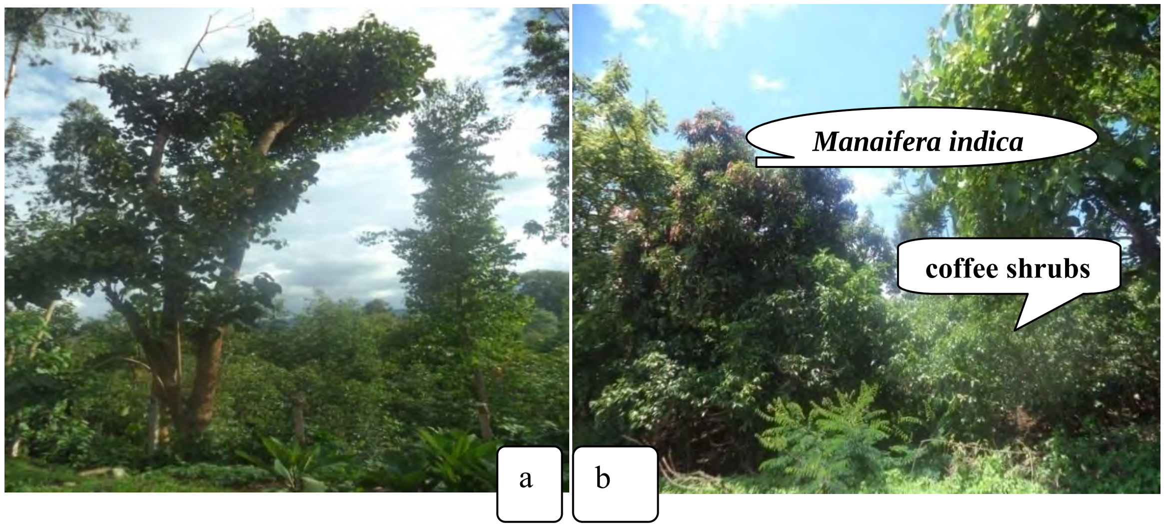

Fig. 15 (a) Pruning and (b) Coffee intercropping practice

Intercropping- coffee is grown with fruit trees and annual crops such as spices in most the coffee farms (Fig 15b). This is done through intercropping of coffee with *Musa paradisica*, *Persea americana*, *Mangifera indica*, *Citrus aurantifolia*, *Afromomum korrorimum* and *Zingiber officinale*. These systems of cultivation are also common around homestead areas and the purpose is multidirectional, i.e., shade and fruit provision as well as soil erosion control.

4.11 Threats to coffee shade trees

The result obtained from direct matrix/priority ranking of the factors threatening coffee shade trees by the key informants indicate that intensive management practice was identified as the most distructive factor of forest plants followed by illegal logging, construction, using chemical substances (fertilizers, herbicides, and pesticides), agricultural expansion, overgrazing, drought, and using them for charcoal and firewood (Table 12).

Table 12 Results of the preference ranking of factors threatening to coffee shade trees(5=strongly agree, 1=agree, 0=disagree)

	Key informants (coded K1 to K8) with the rank they gave									
Major factors	R1	R2	R3	R4	R5	R6	R7	R8	total	Rank
Illegal logging	4	3	5	5	4	4	4	3	32	2nd
Agricultural expansion	4	2	4	4	2	3	3	3	25	5rd
Overgrazing	2	4	2	2	3	2	3	4	22	6th
Construction	4	3	4	4	3	4	4	3	29	3rd
Intensive management	5	5	4	5	5	5	4	4	37	1st
Charcoal & firewood	0	0	2	1	1	0	1	1	6	7th
Chemical fertilizer & herbicides	3	4	3	4	3	3	4	3	27	4th

CHAPTER FIVE

5. DISCUSSION, CONCLUSION AND RECOMMENDATION

5.1 DISCUSSION

5.1.1 Farmers preference of coffee shade trees

The effects of shade trees on biophysical conditions and their interactions with coffee productivity were well understood by farmers. They classified shade trees as suitable for integration with coffee or unsuitable based on their leaf size, foliage density, crown shape, and root system attributes. Similarly (Schmitt *et al*. 2009) indicated that there is a long local tradition of managing coffee forests for coffee production by thinning the canopy through removal of some tree species.

Knowledge about and the great contribution of coffee shade trees to increase soil fertility which in turn was generalized as suitability for coffee growth was quite uniform among the informants. The majority of the interviewed informants preferred deciduous shade trees compared to evergreen ones. Some of them responded that evergreen trees are needed in dry area and during dry season, the time that coincides with dropping of leaves by deciduous trees.

All the informants preferred trees with light and spreading crowns as favorable shade trees, rather than those with a narrow and dense crown as it provides better shade for coffee plants than a narrow crown. Crown density of coffee shade trees linked with how easily the sun rays go through; and trees which had cool shade were considered having high crown density than the others. However, a dense shade canopy will provide better soil protection than an open canopy during high intensity rainfall.

The majority of the farmers preferred moderate shade conditions which is also considered favorable for good coffee growth since photosynthetic rates of coffee are generally at a maximum at intermediate shade levels. Crown density of coffee shade trees linked with how easily the sun rays go through; and trees which had cool shade were considered having high crown density than the others. However, a dense shade canopy will provide better soil protection than an open canopy during high intensity rainfall. Most interviewed informants preferred smaller leaves to the larger one. Their justifications were: light can easily filter through them as compared to larger leaves; small leaves do not harm coffee flowers and fruits when they are shedding as they do not accumulate on flowers and branches; and also high rate of litter decomposition.

When plant residues are returned to the soil, various organic compounds undergo decomposition. Swift *et al*., (1979) included other factors like climate and soil microorganisms as being most important in regulating leaf decomposition which the farmer did not seem to have this considered possibly because climate has been relatively uniform that farmers were not able to recognize its impact. The leaf fall timing was least understood by the farmers as most of them considered leaf fall as a continuously event. The growth rate of trees were the major attribute that most farmers pointed out they consider in tree selection and also emphasized that before they plant a particular tree. Most farmers preferred trees that have intermediate height 10-15m in their coffee production system. The major reasons cited for this preference were provision of good shading to coffee shrubs better than too large trees with higher crowns and ease of management for pruning.

Most of the interviewees did not favor highly emergent (too tall) shade trees particularly those with few branches, because the shading effect is being reduced and coffee bushes could be exposed to strong sun during extended dry season. The other unfavorable feature of too tall shade trees mentioned was damage caused to coffee plants when a branch or twigs break from shade trees by monkeys and other arboreal animals as well as high speed wind especially during coffee flowering and fruiting stages (Beer, 1987) strongly stressed the damage caused to coffee plants by branch/stem breakage. Farmers had more knowledge on the crown spread, growth rate and crown density. This probably was due to the daily observations they noted while on their farms. Schroth (1995) noted that reducing below-ground competition may be achieved by selecting trees with less competitive root architecture, i.e. deep rooted trees with few roots in the upper soil layers are preferred.

Most of those who ranked trees based on this attribute were considering resistance to strong winds. However, some noted that the rooting depth of the trees can be determined from the height of the trees. They thus deduced that those that did not fall have deeper roots. The farmers argued that strong winds were the common measure for this attribute because they were able to observe that the tree species which fall frequently had less deep roots and are not considered as coffee shade trees. Tree roots contribute to the maintenance and regeneration of soil fertility, but they are also important in competition with crops.

Agro-forestry trees should also be deep-rooted and take up a maximum of water and nutrients from subsoil horizons beneath the main rooting zone of the crops. An ideal tree from a nutrient-cycling perspective should possess a deep root system with limited lateral extension in the topsoil, thus recycling nutrients from the subsoil and forming a safety net against nutrient leaching below the crop rooting zone without interfering much with the crop root systems in the topsoil.

5.1.2 The Relationship between shade trees and coffee productivity

The major effect of the shade trees that the interviewed informants reported were resource competition with coffee, reduction of the quality and quantity of the crop, creation of favorable micro environment for the occurrence of some coffee disease and damage to coffee shrubs by falling trees. Similarly, (Beer *et al*., 1998) indicated that the principal disadvantage of the use of trees in agroforestry systems is competition with the associated crop.

Coffee plants needs to be shaded in its all developmental stage and at seedlings in particular, especially during dry and sunny seasons and at bean filling stage. In line with this, (Cannell,1974) indicated that water shortage, particularly during the rapid fruit expansion stage (a critical period), often reduces the growth of the berries, as the ovules do not reach their potential full size under limiting water. Climate change will affect the crop physiology.

Coffee Shade Tree Spacing- All the informants indicated that there is need to determine the appropriate density of shade trees to maximize the productivity of coffee and forest biodiversity in coffee system (Cannell, 1985), indicated that high-planting density systems may increase pest and pathogen attack. Farmers need to be guided on how to plant trees in the right spacing in order to harness maximum benefits. According to the informants shade tree are grown some time before coffee seedlings are planted in the field; one year before the coffee planting for permanent shade trees; and three to four months before coffee planting for temporary shade trees. The productivity of coffee trees can be improved by planting at its optimum population density in strip between the afore-mentioned prominent shade trees. Mean canopy diameter of most of the shade trees ranged between 16 m x 16 m to 20 m x 20 m. The coffee cultivars were planted at 2m x 2 m, while the shade trees should be planted in the spacing of 22m x 22m for *Acacia abyssinica*; 20m x 20m for *Albizia gummifera*; and 5m x 5m for *Sesbania sesban* (Source-Anfilo district Agricultural Office).

5.1.3 Temporary and Permanent Coffee Shade Trees

Permanent shade tree species are more prevalent in semi- forest coffee of the study area and sparsely distributed in semi-plantation coffee. Temporary shade trees are normally required in hot environment and in low land areas, to protect the young coffee plant from the high temperature and strong wind. These trees should be cut down and removed whenever the permanent shade trees have fully grown to provide appropriate shading. The permanent shade trees used in coffee plantation system of the study area includes *Albizia gummifera*, *Milletia ferruginea, Pouteria adolfi-friederici, Grevillea robusta* and *Erythrina brucei* and the like. Coffee shrubs growing under the shade of these trees are considered by farmers as having higher productivity and superior cup quality than coffee plants grown under open sun. (Tolera *et al*., 2008) indicated that fast-growing exotic agroforestry tree species such as *Grevillea robusta*, and *Eucalyptus globulus* used as coffee shade, wind breaks, fuel wood and timber.

However, the interviewed informants did not preferred *Eucalyptus globulus* in the coffee production system. Temporary coffee shade trees such as *Vernonia amygdalina*, *Sesabania sesban*, *Ricinus communis*, and *Vernonia uriculifera* are considered having growth rate faster than the permanent coffee shade trees. In this investigation, farmers gave special emphasis to those shade trees which they mainly retained on their fields/ farmlands for their favorable characteristics and other uses.

5.1.4 Classification of coffee shade trees based on their growth form, uses and nativity

Coffee production systems represent a gradient from the most traditional and structurally diverse systems (forest coffee) to the least diverse system (plantation). Similarly, (Lin *et al*., 2008), categorization of coffee agroecosystems is based on their shade and input management. Greater species richness in forest coffee than in semi-plantation coffee was observed in the study area. Crown cover and dominant tree height were also lower in the semi-plantation coffee than in the forest coffee. Most exotic trees are considered unsuitable for agro-forestry as they are too competitive or damage the soil. Exotic plants such as Grevillea when grows large and other tree species such as eucalyptus species are considered the worst in terms of damaging soils by farmers. As Grevillea grows larger, farmers experience negative effects. Food crops growing close to the trees dry out because of competition for water and nutrients in the soil, which farmers attribute to increased leaf fall and slow leaf decomposition. However, the key informants indicated that Grevillea planted in the coffee farms as shade and windbreaks. Grevillea leaves are used as mulching material under coffee bushes. It is also important source for timber production.

5.1.5 Comparison of Coffee Shade Trees

Farmers' perspectives were mostly comparable to the documented scientific facts with some noticeable differences concerning the type of shade tree species used in coffee plantation. According to the interviewed informants, the most multipurpose and the most preferred shade tree species in coffee production system includes *Albizia gummifera*, *Millettia ferrugenia, Erythrina brucei, Pouteria adolfi-friederici, Vernonia amygdalina, and Sesbania sesban.*

Some of the least ranked species *Croton macrostachyus and Acacia abyssinica* were the less threatened and the dominantly distributed species in the study area. However, some of the species with the highest rank (*Pouteria adolfi-friedrici) is* highly threatened in Anfillo district. Despite the knowledge of attributes known to be negatively affecting coffee production, farmers' decision to plant or retain trees in coffee plot was influenced by the perception of utility. This is notably the case for timber trees like *Cordia africana* which appeared most commonly across the coffee farm, suggesting their contribution to timber provision and income generation was important and justified their presence in coffee plots despite their negative effect on coffee production. (Beer *et al.*, 1998) explained that the effect of shade trees on coffee production has been debated for a long time and the general belief is that the advantages outweigh the felt negative impacts. This study identified which trees species were ranked more consistently than others by farmers and factors for this may be due to different tree growth rate in different areas, as well as knowledge levels of the farmers.

The consistence in the ranking by the farmers could confirm that they actually had a common understanding. The superior/ the most preferred coffee shade trees such as *Albizia gummifera*, *Milletia ferruginea*, *Erythrina brucei* and *Pouteria adolfi-friedrici* and inferior/ the least preferred shade trees such as *Croton macrostachyus and Vernonia auriculifera* for some attribute (coffee quality, soil fertility, nitrogen fixation, climate regulation and others) was ranked consistently by the interviewed informants but for some other trees such as *Acacia abyssinica* and *Cordia africana* were inconsistent.

5.1.6 Coffee shade tree diversity in semi-forest coffee production system

Semi-forest coffee retains a high degree of canopy cover next to the natural forest coffee system. Similarly, (Kitessa Hundera *et al.* 2013) showed that coffee production systems are recognized as semi-forest or semi-plantation coffee depending on the forest management intensity and plant diversity. Most interviewed farmers cited *Albizia gummifera, Milletia ferruginia, Erythrina brucei, Poutria adolfi-friederici* and others as the best coffee shade tree species in the forest coffee. The family Fabaceae was the most dominant and highest diversity with the species containing *Albizia gummifera, Milletia ferrugenia, Acacia abyssinica,* and *Erythrina brucei.* Some species of the family Asteraceae, Euphorbiaceae, Boraginaceae and Sapoteaceae which include the species *Croton macrostachyus, Cordia africana, Vernonia amygdalinal,* and *Pouteria adolphi-friederici* respectively, were also found in the semi- forest coffee of the study area. The least preferred coffee shade tree species compared to the other five species are *Acacia abyssinica, Cordia africana,* and *Croton macrostachyus* according to informants. *Pouteria adolfi-friederici* is one of the most known woody plants for quality timber extraction next to *Cordia africana* and it is highly used for construction and house hold equipment as observed in the area. Thus, *Pouteria adolfi-friederici* is highly threatened species in the study area, because of the daily demand of it for the purpose of timber, construction, and so on.

But species such as *Croton macrostachyus* and *Cordia africana* although not preferred shade trees, were common in the coffee farms as shade trees and were retained in the coffee plantation. Despite their big leaves, farmers believe that they have a fast decomposition rate, and contribute to increased soil fertility. In addition, ecosystem services associated with semi-forest coffee include timber and non-timber forest products (Senbeta *et al*. 2013), regulation of soil moisture and nutrient content and soil fertility (Grossman *et al*.2006), biodiversity conservation and carbon storage.

5.1.7 Coffee shade tree diversity in semi-plantation coffee production system

Semi-plantation coffee system is an area where coffee is cultivated after land clearing with systematic soil preparation and seedling planting and managed in order to maximize the volume of production and productivity but unlike plantation coffee system it does not require the use of excessive fertilizer. In the semi-plantation coffee systems, the management is so intense than the semi-forest coffee and includes systematic planting of coffee seedlings to fill open spaces between coffee plants. Similarly (Reyes-Garcia *et al*. 2007) showed that conducting forest and farm activities is associated with greater ethnobotanical skills and with greater theoretical ethnobotanical knowledge. There were eight most common coffee shade tree species recorded in semi- plantation coffee of the study area, and these species are classified in to four families. This include Fabaceae with the species containing *Sesbania sesban, Albizia gummifera* and *Acacia abyssinica*; Asteraceae containing the species *Vernonia amygdalina* and *Vernonia auriculifera;* Euphorbiaceae containing the species C*roton macrostachyus* and *Ricinus communis*; and Proteaceae containing *Grevillea robusta*.

The family Fabaceae is the most diverse group in both the semi-plantation coffee and semi-forest system (personal observation)**.** Most of these trees were temporary shades and are also used in places where farmers convert farmlands to coffee plantations. These temporary shade trees were also known for the provision of improving soil fertility and animal food. Temporary shading has also been adopted, as to protect young coffee plants against frosts and extreme temperature; and to increase ground cover and maximize the efficiency rate of nutrient and water utilization during the juvenile phase of the coffee crop.

Some permanent coffee shade trees such as *Albizia gummifera, Cordia africana* and *Acacia abyssinica* were also observed in the semi-plantation coffee of the study area (personal observation). Farmers preferred these species in their coffee plantation due to their wide crowns and soil fertility improvement. However, the informants reported that the necessary amount of light could not deliver to the coffee shrubs through the dense canopy of *Cordia africana* and *Acacia abyssinica*. *Croton macrostachyus* is fairly fast growing on good sites but grow slowly on drier sites.

In addition to shade provision, this tree is an important soil improver (leaf fall provide mulch), soil erosion control, fodder, firewood, and traditional medicine (juice from fresh leaves is applied on wounds to hasten clotting) and also provides a useful timber. Recent studies by Sendeku *et al.* (2015) indicated that the methanol and ethanol extracts from leaves of *Croton macrostachyus* showed antibacterial activity. It is a broad-leaved and deciduous tree with a spreading crown. It is often planted to provide shade in coffee plantations, where it also stabilizes and enriches the soil and provides protection.

The interviewed informants reported that the seeds of *Ricinus communis* are primarily used as a high quality lubricant. According to the all informants *Ricinus communis* is used as a coffee shade tree when planting coffee seedlings on bare land (during the conversion of farm land in to coffee production), live fences, fodder, bee forage, and anti-pest properties.

5.1.8 Investigation of the roles of coffee shade trees

When considering all use categories combined, shade tree with the greatest number of citations were *Albizia gummifera, Milletia ferrugenia, Acacia abyssinica* and *Pouteria adolfi-friederici.* They were most highly cited for shade, wood for household energy, timber, soil erosion control as they have extensive root system, improving coffee bean attributes and also serve as beehive support. Tree species with the least number of citation were the temporary shade trees which include *Sesbania sesban, Grevillea robusta, Ricinus communis* and *Vernonia uriculifera* which are cited for shade, soil fertility improvement and some of them used as fodder.

The top-ranked species such as *Pouteria adolfi-friederici* and *Cordia africana* are being threatened, as the daily demand of the local society is continuous with lesser rate of replantation. Many of the most commonly mentioned species are valued more for their additional uses than for their shade-providing qualities. Farmers did not have consistent knowledge about the medicinal value of most of these coffee shade trees reported.

With the exception of *Cordia africana, Acacia abyssinica* and *Croton macrostachyus* which are considered unsuitable in coffee farm, all other coffee shade trees species mentioned were also consistently ranked as having the highest value in temperature regulation, coffee quality and others. According to the informants, besides controlling the amount of solar radiation reaching the coffee shrubs, the highest services priorities that the coffee shade trees have on the environment are maintenance or improvement of soil fertility, conservation of biodiversity, improving the quality of coffee and an important reduction in the amount of fertilizers and pesticides used in comparison with un-shaded plantations.

5.1.9 Effect of coffee shade trees on coffee bean size and yield

According to the informants the highest and most stable coffee yield performances were obtained under *Albizia gummifera* and *Milletia ferrugenia.* The two coffee shade tree species are well known in soil fertility improvement and in provision of moderate light through their small leaves. Similarly, (DaMatta, 2004) explained that exposing coffee plants continuously to extreme temperatures higher than 30°C can cause a reduction in the coffee production due to depressed growth and occurrence of abnormalities such as yellowing of leaves.

The interviewed informants also reported that size of coffee beans is bigger under agro-forestry (shaded condition) than under direct sun light. Similarly, (Muschler, 2001) indicated that shade may positively affect bean size and composition as well as beverage quality (lesser bitterness and astringency) by delaying and synchronizing berry flesh ripening. Poor beverage quality is obtained if beans have not reached its full development. Coffee grown under the shade of the preferred trees tend to flower and bear more berries each year whereas under unshaded plantation conditions, the crop tends to alternate between years according to the interviewed informants.

5.1.10 Biodiversity Conservation and coffee shade trees

According to the interviewed informants, coffee shade trees reduce the growth of weeds and also increase local biodiversity by providing food or shelter for many other species, such as birds and insects. Compared to empty pastures, wildlife thrives on shade-grown coffee farms. Even dead trees and shrubs in the shade cover were considered as useful because they provide habitat for birds and other macro and micro fauna. Shade trees help promote the activity of beneficial soil organisms, such as nitrogen fixers, and material decomposers. They also said that as shade increased, the diversity of ground-foraging ants in coffee plantations increased, at least partly as a result of changes in microclimate.

Shade trees create more habitats for birds and soil insects, increasing the species and trophic diversity in the ecosystem. Birds and bats predate on arthropods in shaded coffee plantations. For example, a research made in Mexico have found that, 94-97% fewer bird species in sun grown coffee than in shade grown coffee farms (Kent *et al.*, 2006). The humus layer is also enhanced in shaded systems, resulting in greater diversity and abundance of the detritivorous fauna.

Macro-fauna, were frequently observed by farmers and are related to farmers with fertile soils. Species richness of ants, birds, and trees was highest in forests and declined in other coffee-management systems, especially in sun coffee. This is in line with (Perfecto *et al.*, 1996),who explained that shaded coffee plantations compared quite favorably to natural forest as refuges for migratory birds and also have high potential as refugees for the conservation of biodiversity. Tree richness was an important predictor of both bird and ant richness.

The interaction between bee abundance and number of flowers had a positive impact on the number of coffee berries harvested. Thus coffee production increased with increasing bee abundance, and this effect was amplified by an increase in the initial number of flowers. In addition, honeybees are the most important pollinators of agricultural crops including coffee plants. According to (Roubik, 2002), Coffee is self-fertilizing, but fertilization by bees increases the yield substantially. Crop productivity is improved by ecosystem services, including pollination.

Pollination service occurs through the provision of potential nesting sites and the management of alternative floral resources. The higher species richness (including pollinators) was largely a function of the higher number of individual trees present in the shade coffee systems. This loss of vegetation leads to a reduced bee population and honey production as well. Shade-grown coffee farms support the ecosystems needed to sustain a diverse range of pollinators, from bees to bats and increases crop pollination. The production of some crops increased after honeybees pollinated flowers. Honey bees are essential parts of the agricultural system.

5.1.11 Effect of shade trees on the number and density of coffee plants

Coffee shrub was observed to be denser in shaded zone. Field trip observation and the interviewed informants indicated that coffee shrub density was significantly higher under *Albizia gummifera* and *Acacia abyssinica*. Although coffee shrubs plantation has been performed in similar design the difference in density may be caused from the relative suitable soil plant relationship in the shaded system. Additionally, shade makes the soil physical property to be maintained and enhanced the coffee plant to be viable and saved. Similarly, (Beer, 1987) indicated that by regulating light transmission to coffee plants which regulates coffee yields shade trees can also extend the life of the coffee plantation. These characteristics of coffee would cause more annual harvests under diverse shaded systems as compared to unpredictable yields of sun grown systems. The density of coffee shade tree also varies between 150-300 trees/ha and the coffee shrubs density varies between 200-400trees/ha. However, lower density of coffee shrubs was also found in the study site where coffee is intercropped with several other crops and fruit trees such as *Mangifera indica* and *Persea americana*. There was a great difference in coffee tree flowering knowledge by farmers for fruiting.

Most of the interviewed informants indicated that light is very important for the proper flowering of coffee shrubs. This finding contras with, the work of (Lin, 2007) who found that coffee grown under shade had more flowers per bush and flowers per node than coffee grown in full sun. However, high temperature during blossoming, especially if associated with a prolonged dry season, may cause abortion of flowers.

5.1.12 Other Benefits of Coffee Shade Trees

The majority of the interviewed farmers signed out other desirable benefits derived from shaded systems. Some of the mentioned advantages such as firewood, timber value, construction and honey/ bee production. Although both farmers and lists published in the literature generally agree on what are considered favorable attributes for an ideal shade tree, many of the tree species found in the farmers' fields such as *Croton macrostachyus, Acacia abyssinica* and *Cordia africana* are far from this ideal.

Cordia africana is grown in coffee plantation because of additional economic benefits that they provide to the farmers' households. The majority of farmers in the study area also viewed *Cordia africana* as unsuitable shade tree, and others considered it as suitable for coffee. Several farmers mentioned the possibility of damage to the coffee plants during felling. However, Somarriba (1992), showed that the damage caused to coffee plants should not be a limitation to planting timber trees. Reduced densities (scattered throughout the system and along the edges) are considered better for coffee production, they said. According to the informants, *Cordia africana* was considered superior for fruit and timber attributes. *Acacia abyssinica* was ranked consistently by respondents above the trees for charcoal and firewood provision. But both *Cordia africana* and *Acacia abyssinica* were inferior/ not preferred for coffee production by farmers.

5.1.13 Effects of Sun-grown Coffee

The major problems related to sun grown coffee include exhaustion of soil fertility due to lack of fertilizers or shade tree leaves, decreased life span of coffee shrubs, increased temperature and wind problem, demanding more management, decreased biodiversity including honey bee population, yield reduction, increased in weed and pest problem, increased evapo-transpiration, prematurity of coffee beans and increased in soil erosion.

In sun coffee plantations, fluctuations of both temperature and humidity become more extreme. Similarly, (DaMatta, 2004) indicated that exposing coffee plants continuously to extreme temperatures higher than 30 $^{\circ}$C can cause a reduction in the coffee production due to depressed growth and occurrence of abnormalities such as yellowing of leaves. Coffee shrubs grown under full sun are susceptible to fungal diseases. (Nataraj and Subramanian, 1975) indicated that damage caused by a fungus disease which can completely defoliate coffee plants, is greater in unshaded plantations, possibly due to the higher susceptibility of water stressed or nutrient-deficient plants. The problem with sun coffee is that it requires much higher levels of external inputs. The conditions under which sun coffee is grown encourages coffee leaf rust, which has resulted in a large increase in fungicide use. Although full sun coffee varieties have the potential to produce more coffee beans per plant, they require high levels of synthetic fertilizers and pesticides to do so.

5.1.14 Tree species that are not considered beneficial as coffee shade trees

There are canopy tree species which are not preferred by the farmers as shade tree because of associated impacts on the productivity and survival of the coffee shrubs. (Yacob *et al*., 1996) showed that excessive or inadequate shading by overhead shade trees and low coffee population density under coffee plantation are the major constraints which accounts for such low production and productivity of the crop in the country.

Farmers believe that trees with deep shade such as *Syzygium guineense* compete for water during the dry period. Similarly, (Beer *et al*., 1998) indicated that excessive shading/ light interception by overhead shade trees would decrease growth and productivity of the crop as the plant spend much of its photosynthetic product for maintenance, which under normal conditions would have been utilized for the formation of plant parts and as substrate for respiration.

The interviewed informants also indicated that the leaves of *Syzygium guineense* do not decompose fast and do not improve soil fertility. Therefore, coffee plants under these shade trees grow in height without producing much branches which in turn affect the quantity and quality of coffee beans. Shade trees such as *Ficus vasta*, *Syzygivm guineese, Ficus sur,* and *Eucalyptus globules* compete with coffee plants for water *and* nutrients.

5.1.15 Coffee and shade tree management

In the semi-forest coffee systems, the intensity of management is low as compared to the semi-plantation coffee system and consequently this system has high canopy cover, enabling it to support high species richness. In order to improve productivity in the semi-forest coffee system, farmers regularly remove understory trees, shrubs and lianas. Farmers manage the shade tree canopy so as to optimize coffee production while maximizing the use of the different tree species. Similarly, (Beer *et al*., 1998) indicated that the effects of shade trees on coffee yield are most likely also dependent on site specific conditions and management practices.

In semi-forest coffee, farmers were not regularly plant trees, but tend to manage what is already there, and what grows from natural regeneration. Management options are available to improve the attractiveness of coffee systems, while simultaneously maintaining coffee output at consistent and productive levels. Dead or dry weeds can be used as mulch. Mulching will reduce the amount of weeds. Similarly, (Silva *et al*., 1990) indicated that the proper selection and management of permanent shade species can reduce labor input and weeding costs considerably.

Weeding occurs more than three times for young seedlings of coffee plants and in areas of sparse shade. But for the semi-forest coffee and where there were dense and diverse populations of shade trees in Anfillo district, management system occurred one or two times in a year. The growth of temporary shade trees should be controlled by slashing the side branches, to avoid any eventual disturbance to the young coffee. Growing a cover crop such as tree legumes (living mulch) under the coffee trees can give many of these benefits. Legumes have a special ability to fix nitrogen from the air in the soil though specialized bacteria that live on their roots, thus indirectly increasing the nitrogen content of the soil. Shade tree itself and due to the fallen leaves from the shade trees acting as a natural mulch. Mulching involves covering the soil with a layer of dry vegetation or leaves of coffee shade trees and coffee pruning. Mulching can have many benefits, including: reducing the loss of soil moisture; prevention of soil erosion, which is particularly important where coffee is grown on steep slopes; increasing soil nutrient levels; improving the structure of the soil; and suppression of weeds.

The majority of the species mentioned by farmers were established through natural regeneration in forest coffee (more diverse areas); and by replanting of the desired trees in semi-plantation (less shaded area). Shade tree management by farmers includes weeding of under growth, intercropping, debarking, pruning and cutting of the side branches. Weeds should be controlled as they compete with the coffee trees for moisture and nutrients. (Vernon, 1967a) indicated that shade can shift species composition towards less aggressive weeds. Coffee trees are shallow-rooted, which means that most feeder roots are near the surface.

Pruning-most shade trees are pruned aiming to leave a 40 to 50 percent shade cover. Prune easiness was considered in terms of the height of the tree, trees that grow very tall were considered to be difficult to prune, some farmers also noted that trees that have hard wood are more difficult to prune than those with relatively soft wood. Pruning is an essential part of coffee production, and basically it involves thinning of branches and removal of old or dead stems. Pruning serves many purposes: it prevents the tree from growing too tall to make the desired shape in the coffee plantation, maximizes the size of new wood for the next time. For example by cutting away less productive wood (in case of *Cordia africana* and some others), farmers encourage the growth of new, vigorous stems and branches. Pruning also helps prevent some pest and disease problems. This is done by opening up the canopy so that light can penetrate to the centre of the tree, and air circulates more freely, certain pests and disease problems are reduced or prevented. More importantly, heavy disturbance may limit the performance of wild coffee, while intermediate disturbance may enhance the abundance of wild coffee populations.

Intercropping of fruit trees and spices in coffee plantation-farmers intercropped bananas and other fruit trees as shade in coffee plantation which provided additional income and food security. Farmers used to plant *Musa paradisica*, *Persea americana* and others on sloppy areas to reduce soil erosion. However, (Robinson, 1961) showed that bananas (*Musa spp.*), compete strongly with coffee. Furthermore, during harvest or because of windfall, banana stems may damage underlying crops and newly established permanent shade trees.

When farmers manage one of the crops, the other crops also benefited. Inter-planting with some other crops helps reduce soil temperature, smothers weed growth and supplies the soil with organic matter when crop residues are turned back into the soil.

5.1.16 Threats to coffee shade trees

According to priority ranking, intensive management was identified as the most distractive factor of forest plants. The coffee management activities in the semi-forest coffee and semi-plantation coffee of the study area involve complete removal of the competing undergrowth, including the seedlings and saplings of the canopy trees on annual basis, in an effort to increase coffee productivity. However, intensive management suppresses tree regeneration and reduces tree density, leading to the disappearance of some forest species. (Senbeta and Denich 2006; Schmitt *et al*. 2009) indicated that the negative consequence of intensive management practice is not only on the forest species composition and structure, but also on the long term survival of coffee shrubs and productivity.

Moreover, the indigenous shade trees such as *Pouteria adolfi-friederici, Cordia africana* and some exotic species such as *Grevillea robusta* are being threatened because of biotic stresses in the study area, as the daily demand of the local society is continuous with lesser rate of re-plantation. Diversity losses are very likely to lower ecosystem resilience and disrupt ecosystem services related to coffee yield, such as pollination.

5.2 Conclusion

Farmers have an excellent knowledge of the potential and constraints of coffee shade trees. They could state most of the facts in the way they are presented in the scientific literature. However, some of the respondents were deficient on some basic concepts. Local knowledge not only provides information on the use of species, but can also contribute valuable information on how to maintain and conserve the genetic materials, species and ecosystems. The pressure of an increasing global demand and a changing climate is threatening the sustainable production of coffee.

Shade coffee agro-ecosystems have a high potential for strengthening ecological processes. In general, the survey identified a set of shade trees species considered to be the most important to local communities which include *Albizia gummifera, Milletia ferruginea, Pouteria adolifi-friederici, Erythrina brucei, Vernonia amygdalina, Sesabania sesban, Ricinus communis,* and *Grevillea robusta.* Another interesting result was that although many of the most common species used by farmers in coffee plantations were not considered beneficial to coffee production, they were nevertheless maintained in the system for values other than shade. The highest and stable coffee yield performances were obtained under *Albizia gummifera* and *Milletia ferruginea*.

Shade grown coffee plants also produce larger and heavier beans with better cup taste than coffee plants grown in the open sun. Tree cover is used to moderate temperature, humidity, and sunlight. Therefore, planting shade trees can be an adaptation strategy to climate change. Denser shading resulted in lower yields and under full sun, fruit quality decreased. Age was seen to be an important factor, with older people being better than the younger in the acquisition and consolidation of local knowledge of plants. Shade-grown coffee plantations increase biodiversity by providing a welcoming habitat for a host of birds, bats, reptiles, insects, and native flora. The way to conserve coffee forests and coffee genetic diversity is a strategy which strikes the balance between use and conservation. That means, sustainable management of the coffee forests can only be achieved if there is a balance between conservation and use the forest for coffee production can be achieved.

The dependence on few selected shade trees has a huge impact on forest biodiversity and consequently on ecosystem services generated from the forests. Therefore, training on uses of different coffee shade trees, their management practices, legume plants and their association with beneficial soil microorganisms, involvement of microorganisms in organic matter transformation, and overall other interactions of coffee with shade trees should be provide to farmers to enrich their local knowledge**.**

5.3 Recommendation

Effective conservation and sustainable use of the forests with coffee populations therefore need the involvement of many stakeholders including local communities. Sustainable use of the forest fragments in the region will have greater ecosystem service values than short-term logging and overharvesting. The decline in coffee production has been attributed to decline in soil fertility, it is therefore important for the community having coffee production with no or sparse shade to increase tree diversity for provision of tree products as well as improve soil fertility and coffee quality which is linked to tree shade. Farmers should better consider trees with best compatibility with coffee shrubs such as *Albizia gummifera* and *Milletia ferruginea* to harvest more coffee yield. There is a need to determine the appropriate density of shade trees to maximize the productivity of coffee and forest biodiversity.

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APPENDICES

Questionnaire for respondents on the ethnobotany of shade trees in coffee plantation system in Anfillo District, Kelem Wollega Zone, Oromia region, Western Ethiopia.

Personal information:

Age: 25-35yrs[ ] 36-50 yrs[ ] above 50yrs[ ]

Sex: male [ ] female [ ]

Level of education: Illiterate[ ] 1-8[ ] secondary and above [ ]
Sources of income: Coffee[ ] non-coffee/ other crops[ ] coffee and non-coffee[ ]

Give short answer for the following questions.

1. Which tree species are more preferred as coffee shade?
2. What are the criteria used for selecting a tree species as shade tree?
3. Do the coffee bean size and yield differ because of the type of shade tree you use?
   a) no b) yes c) have no idea
4. If your answer for the above question is yes, which species is preferred?
5. Is coffee yield affected by the density of shade trees?
   a) yes b) no
6. Is there a practice of planting other important crops in the coffee farm?
   a) yes b) no
7. If yes which crops?
8. How do farmers manage shade trees in coffee farm?
9. How often do you practice weeding of unwanted plants in your coffee farm?
10. Apart from shade provision, what are the roles of coffee shade trees?

Table 1 Characteristics of shade tree preference by farmers for their coffee production

Coffee shade tree characters	Characters
Deciduousness	Deciduous [ ] ever green[ ] no effect[ ]
Tree height	Large [ ] Small [ ] Medium[ ]
Growth rate	Fast [ ] Slow[ ]
Leaf size	Small[ ] Big [ ] no effect[ ]
Crown type	Wide[ ] Closed[ ]
Root depth	Deeper[ ] Shallower[ ]

Table 3 Response of the key informants about the problems related to coffee shade trees (5=strongly agree; 1= agree; 0=disagree; R=Respondents)

	R1	R2	R3	R4	R5	R6	R7	R8
1. Problems related to coffee shade trees								
Resource competition								
Occurrence of some coffee diseases and insect pests								
Reduce the yield of coffee								
Falling trees can damage the understory crop								
Single stemmed coffee trees								
2. Shade requirement stage of coffee								
Seedling stage								
Flowering stage								
Fruiting stage								

Table 5 Paired comparison of twelve shade tree species by eight key informants in reference to coffee production

A	*A. abyssinica*	B	*M. ferrugenia*	C	*G. robusta*	D	*P. adolfi-friederici*
E	*V. amygdalina*	F	*A. gummifera*	G	*E. brucei*	H	*R. communis*
I	*C. macrostachys*	J	*S. sesban*	K	*C. africana*	L	*V. auriculifera*

	A	B	C	D	E	F	G	H	I	J	K	L		
A														
B														
C														
D														
E														
F														
G														
H														
I														
J														
K														
L														

Table 9 Direct matrix ranking by eight key informants to compare the use values of each coffee shade trees (5 = the best, 4 = very good, 3 = good, 2 = less used, 1 = the least, 0 = not used)

Use categories	*A.gumifera*	*M.ferruginea*	*A.abyssynica*	*E.brucei*	*P.adolfi fre.*	*C.macrostachyus*	*C.africana*	*V.amygdalina*	*V.auriculifera*	*R.communis*	*G.robusta*	*S.sesban*
Micro-regulation												
Beehive support												
Bee forage												
Coffee bean yield												
Soil fertility												
Biodiversity conservation												
Timber												
Wood charcoal												
Fodder												
Medicine												

Table 10 Response obtained from the eight key informants about the problems of growing coffee without shade (5=strongly agree, 1=agree, 0=disagree)

Problems related to sun grown coffee	Key informants with the ranks they gave							
	R1	R2	R3	R4	R5	R6	R7	R8
Yield reduction								
Increased evapotranspiration								
Decreased soil quality								
Increased in weed problem								
Decreased lifespan								
Increased T^o & wind								
Increased soil erosion								
Decreased biodiversity								
Prematurity of coffee beans								
Demand more management								
Fluctuation of T^o &humidity								
Decreased air/water quality								
Decreased coffee flowers								

Table 12 Results of the preference ranking of factors threatening to coffee shade (5=strongly agree, 1=agree, 0=disagree)

	Key informants with the rank they gave							
Major factors	R1	R2	R3	R4	R5	R6	R7	R8
Illegal logging								
Agricultural expansion								
Overgrazing								
Construction								
Intensive management								
Charcoal & firewood								
Chemical fertilizer & herbicides								