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SOCIOCULTURAL DETERMINANTS OF COFFEE PRODUCTION SYSTEMS AND ECOSYSTEM SERVICES IN SOUTHWESTERN ETHIOPIA

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ABSTRACTS

It is difficult to separate coffee cultivation from the social and cultural life of the Ethiopian people, as the two are deeply interconnected in multiple ways. Improvements in coffee production should not be evaluated solely in terms of yield or economic returns; rather, they depend strongly on sociocultural determinants embedded within coffee production systems. Accordingly, this study examines the socio-economic characteristics of coffee-producing households, the dominant coffee production systems (CPS), and their implications for sustainability. Data were collected from 148 coffee-producing households (60 % men and 40 % women) using a semi-structured questionnaire administered through Kobo Toolbox. Statistical analyses were conducted using SPSS software. Land allocation to coffee cultivation differed significantly among households ($p < 0.05$), with an average of 0.70 ha allocated to coffee out of a total mean farm size of 2.05 ha, reflecting the predominance of smallholder production systems. The study areas more domain by semi-forest (54 %), followed by garden (36 %) production system. Forest coffee shared only 1 % that under risk of extinction, but plantation is not practiced. Around 97.4 % farmers uses trees for shade purpose, while obtaining its ecosystem service. About 68 % of households grew coffee inter-cropped, which made food security and land use more efficient. Inter-cropping practices differed significantly among CPS ($p < 0.05$) and were ranked as garden > semi-plantation > semi-forest coffee. Forest coffee systems were unsuitable for inter-cropping but exhibited greater shade-tree diversity, distribution, and evenness. Dominant shade tree species included *Albizia, Erythrina, Milletia,* and *Acacia*. The socio-economic characteristics of coffee producers in southwestern Ethiopia are shaped by production environment, cultural heritage, and technological access. The sustainability of future coffee production systems depends on improved land management, adoption of appropriate technologies, and better market integration. Limited access to improved technologies remains a major constraint to coffee productivity and long-term sustainability among smallholder farmers.

Keywords: Smallholder farmers; Agroforestry; Sustainability; Shade coffee; Technology adoption; Southwestern Ethiopia; Land-use systems

INTRODUCTION

Arabica coffee originates from the tropical belt of the African continent, specifically the rainforest highland montane region of southwestern Ethiopia. It has traditionally been harvested from the country's natural forests; however, the majority of these forests are diminishing due to agricultural land expansion and efforts to enhance productivity (Gole *et al*., 2008). Nearly all Ethiopian coffee is cultivated under a shaded canopy, either in its natural state or modified by human intervention. Arabica coffees adapted relatively narrow microclimate zones of 18 - 23℃ mean temperature, 1300 - 2200 m of altitude and 1500 - 2000 mm of annual sum of rain fall (Moat *et al*., 2017: Etana & Merga, 2021).

Ethiopia remains the leading producer of Arabica coffee in Africa and is the only country that consumes approximately half of its annual production (250,000 metric tons) out total production over 501,000 metric tons in 2023/24 (USAID, 2024). The coffee sector is the country's primary source of export revenue, accounting for approximately 30-35 % of total exports and 60-65 % of agricultural exports, while contributing 5-10 % to the nation's Gross Domestic Product (GDP) (Gizaw *et al*., 2022). Moreover, nearly a quarter of the population (30 million people) depends directly or indirectly on the coffee value chain (Martins *et al.,* 2015; Toensmeier *et al*., 2020; Dogiso, 2022). Unlike in other countries, the relationship between Ethiopian farmers and coffee production is deeply intertwined, with farmers actively shaping the production system and vice versa.

Coffee production systems (CPS) refer to the methods and designations of coffee cultivation, which evolve both temporally and spatially over time. These systems influenced by agronomic practices and the objectives of producers. Key agronomic factors that determine the type of CPS include shade management, shade tree species, forest cover, the level of agricultural technology application, and the intended purpose of production. Previously, CPS were classified into four categories, but recent advancements have expanded them to five distinct types: forest systems (5-10 %), semi-forest systems (30-35 %), garden systems (30-40 %), plantation systems (5-10 %), and semi-plantation systems approximately 10 % (Labouisse *et al*., 2008; Gole *et al*., 2013; Hundera *et al*., 2013).

Understanding the farming systems and perceptions of coffee producers is crucial in shaping both conventional and modern agricultural management practices (Meylan *et al.,* 2017). Factors such as family size, production area, applied technologies, and production systems play a significant role in sustainable agricultural technology development and extension services. These insights provide valuable guidance for policymakers and technology developers in designing location specific strategies. Moreover, the level of management practices within CPS is largely influenced by farmers' characteristics, as coffee cultivation demands intensive care and meticulous attention (Hundera *et al*., 2013).

In Ethiopia, beyond its economic values, coffee is represent cultural, connect social at community level, attitude based produced crop, management application, and long-term stewardship for biodiversity conservation (Duressa, 2018). Hence, still more than 90 % of its farm managed by inherited cultural practice, which serves as connector for social interaction, oral information transmission, and even conflict resolution. Such sociocultural characteristics of coffee produces enhance forest and biodiversity conservation in coffee ecosystem than over short-term benefits only. Ingenuously coffee system classified field management and major market by male, while ceremony, cleaning, and processing more covered with female that indicated gender role is specified. Further, majority of coffee farmers believes as landscape of coffee forests contribute in natural balance or burden from ancestral to protect and transmit to generation. Thus, coffee production systems contribute substantial role in ecosystem conservation and socio-cultural of coffee producers determinant (Duressa, 2018; Bulitta & Duguma, 2021).

There several sociocultural characteristics influence coffee production, but some of them are; multi-cultural coffee ceremony, production types, rule and regulation in coffee systems, religious roles, and other aesthetic values embedded in society. Further, the other social determinant such as gender role (male field management, female processing and cleaning), land shortage factor (less land holder more in practicing intensive or garden), and producers general assumption determine sustainability of coffee and its role in ecosystem balance. These characteristics shape production decisions, labor organization, quality management, and sustainability outcomes. Recognizing and integrating sociocultural dimensions into coffee development interventions is therefore essential for enhancing productivity while preserving Ethiopia's unique coffee heritage.

Although Coffee Production Systems (CPS) offer multi - advantages in ecosystem services, huge gaps CPS role in demographic stability, environments, social, cultural, and economy of producers revealed. These can be fully assessed and complete through sociocultural characterization of producers that makes easy to access extension services. In particular, the sociocultural characteristics of coffee producers, their diversity in CPS, and its implications for their livelihoods are not well-documented in southwestern Ethiopia. Understanding and characterizing farmers is essential for formulating effective policies and develop suitable technologies to address coffee production constraints, which currently limited productivity to just 0.7 tons per hectare, which is very small as compare to other coffee producers countries. Limitation of well organized extension services compatible with production system of the societies may rose as root cause of existed yield gap. Additionally, such efforts contribute to broader sustainability goals. Therefore, this study aims to assess the socio-cultural characteristics of coffee producers, in relation to their production systems and examine its role in their livelihoods contribute to sustainability.

MATERIALS AND METHODS

The Study Area

This study was conducted in montane Southwestern parts of Ethiopia where coffee is originated, being produced under shade with diverse production systems. The selected study zones: Jimma, Gedeo, Waliata, and Shekka which major in coffee production, and known for their diverse weather parameters; temperatures, rainfall, humidity, and altitudes (Table 1). The preferred study zones, districts, and villages were major and have potential in coffee production and selected purposefully.

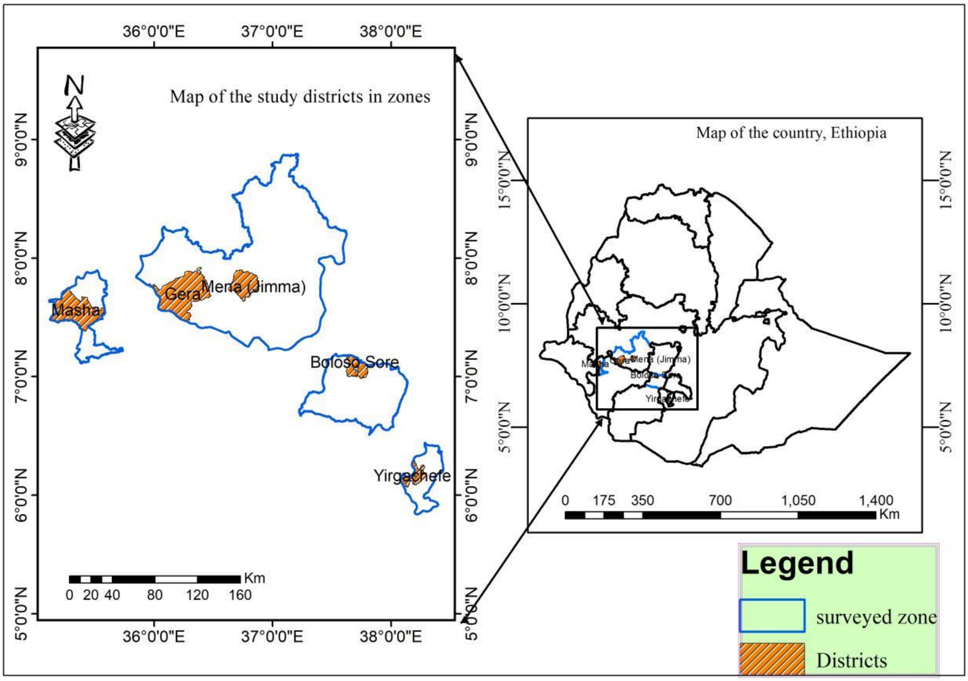
Table 1: Regions, zones, districts and village of the study

Regions	Zones	Woradas	Villages		Respondents
Oromia	Jimma	Mana	Gube bosoka	Hundaa toli	30
		Gera	Achibo	Gechi	30
C.Ethiopia	Wolaita	Bolososore	Dubo	Wermuma	30
SNNP	Gedio	Yirgachaffe	Horo betela	Wogida	28
South west	Shekka	Masha	Kewo	Keja	30

SNNP: southern nation, and nationality People

Jimma is found in Oromia region to the southwestern direction on the distance of 354 km from Addis Ababa with Geo-spatial location between 35º 0’0” N-to-37º 0’ 0” N and 7º 0’ 0” E to 8 º 0’ 0” Elongitude and latitude, respectively. The samples were taken from Jimma zone; Mana and Gera districts. Manna is found on 18 km distance from Jimma town with diverse agro-ecologies and altitudes of 1200 m - 2200 m a.s.l., while Gera is found on 98 km far from Jimma town to south direction with entirely highland characters, deep forest and altitudes of 1500 m to 2800 m a.s.l.

Fig. 1: Map of study area



Sheka is far 450 km from Addis Ababa to the geographical direction of southwest with location of 34.5º 0’0” N-to-36º 0’ 0” N and 6º 0’ 0” E to 7 º 0’ 0” E latitude and longitude, respectively. Masha district is one of the selected from Sheka zone which is located at center of the zone. The areas known with high rainfall of annual 1600-1800 mm with average temperature mean of 18-21℃, and two to three times annual rainfall system covered seven to nine months. Thus, Masha is highland and known by various agroforestry, focused on enset, and other fruits crops. An Agro-climate characteristic of the Masha is at-most highland and midland of various altitudes expected 800 - 2600 m.a.s.l.

The selected district from Gedeo zone called Yirgachaffe which is one of the most known coffee producer and brand found in southern nation and nationality region on the distance of 327 km from Addis Ababa. Yirgachaffe is suitable weather condition for coffee situated with altitude between 1800 - 2300 m.a.s.l and exceptional bimodal rainfall (Worku *et al*., 2019). The sum average of annual precipitation varied from 1000 -1600 mm with 16 - 20°Cmean temperature (Moat *et al*., 2017).

Bolososore is one of the major in coffee production of Waliata zone in central Ethiopia region declared recently, located 317 km southwest of Addis Ababa, the country’s capital city. Bolososore has suitable condition for coffee production with altitude of 1500 –

2300 m.a.s.l, with mean temperature of range between 11- 26℃ and mean annual sum of rainfall 1200 mm (Tegeng *et al*., 2024).

The listed regions, zones, and districts were selected purposefully based on coffee production potential, and availability of production system (Table 1). The survey study was conducted in selected region, zones, districts and villages from number of respondents enumerated depend on statistical system. Accordingly, total of five districts and ten villages were purposefully selected based on the objectives and potential of coffee production and representatives of the area.

Survey study design

A total of ten villages were purposefully selected, with two villages chosen from each district. The selection process was initiated by first identifying villages with high coffee production potential within each district through purposive sampling. During the study design and selection process, relevant information was obtained from Village Administrations (VA) and Development Agents (DA).

The number of representative respondent households (HHs) per village was determined using power analysis. The pwr package in R (Champely *et al*., 2016) was employed to perform the analysis, considering a significance level of 5 %, a power of 0.8, and an effect size of h = 0.5. The analysis was conducted using R software, utilizing the "pwr" package.

The number of respondents (sample size) for each district was determined using a power analysis approach. Power analysis is a standard statistical method used to estimate the optimal sample size required for a study. It is based on the relationship among four key parameters: significance level (α), statistical power (1−β), effect size, and sample size. By specifying any three of these parameters, the fourth can be calculated.

In this study, the significance level (α) was set at 0.05. Statistical power, defined as the probability of correctly rejecting a false null hypothesis, was set at 0.80, which corresponds to accepting a 20 % probability of committing a Type II error. The third parameter, effect size, represents the magnitude of the effect being measured. Following Cohen’s guidelines, effect sizes are classified as small (h = 0.2), medium (h = 0.5), and large (h = 0.8). In this study, a large effect size was assumed to ensure adequate sensitivity. The sample size was calculated using R software with the pwr package. The analysis indicated a minimum of 12 households per village. To enhance representatives and account for potential non-response, the sample size was increased to 15 households per village, resulting in a total of 30 households per district included in the study.

Simple random sampling was applied to select households. Based on the power analysis results, 30 households per district were selected, with 15 coffee-producing households chosen from each village. In total, 150 household respondents participated in semi-structured interviews, which were conducted using the KoBo Toolbox data collection software (www.kobotoolbox.org). Both qualitative and quantitative data were collected.

Data analyzing methods

The semi-structured questionnaire data were systematically managed using Excel software after being downloaded from the KoboTool software. Qualitative data were then summarized using descriptive statistics and analyzed through inferential methods, including chi-square tests. Quantitative data were analyzed using both descriptive and inferential statistical techniques. SPSS software were utilized for data analysis. Finally, the results were interpreted and discussed in relation to the study objectives.

RESULTS AND DISCUSSION

Socioeconomic characteristics of respondents

The socioeconomic backgrounds of the respondents summarized in Table 2. The ages of respondents were categorized into four (18-30, 31-45, 46 - 60, and >60) groups based on their physiological growths stages. Approximately 49.3 % belonged to the 31- 45 age category, while only 4.1 % was grouped in above 60 years old. The majority of respondent's age indicated they were mature enough to provide reliable information. Ogunjinmi *et al*. (2022) reported findings consistent with this study regarding the socioeconomic characteristics of participants, specifically age, gender and its importance to get representative data.

Similarly, about 60 % of the participants were male, while the remaining ~40 % were female; and male (97 %) and all female respondents (100 %) were married. Wongnaa et al. (2021) reported 61.65 % of the coffee farmers were males, while 38.35 % were females and 86 % were married which slightly similar with this result. Similar to this study, Ken *et al*. (2020) reported that 88.8 % respondents during agroforestry inventory survey were married, while only 0.5 % was single.

The education levels of respondents were categorized into four groups, as shown in Table 2. The largest proportion (28.4 %, or 42 out of 148 respondents) had attained education beyond grade 9, whereas small percentages (5.4 %) were illiterate. Overall, these findings suggest that the respondents possessed a considerable potential to adopt new information and technologies. This is consistent with the findings of Kivimaki *et al*. (2020), who highlighted that socioeconomic characteristics significantly influence adoption behavior and practices within communities.

Table 2: Gender and marital status of the respondents

		Frequen	Percentage	Sex		Freq	Percentage
Age	18- 30	27	18.2	Male		89	60.14
	31-45	73	49.3	Female		59	39.86
	46-60	41	27.7	Marital status			
	> 60	7	4.7	Married	Male	87	97.75
	>9 grade	42	28.4		Female	59	100
	1-4 grade	27	18.2	Single	Male	2	2.25
	5-8 grade	71	48.0		Female	0	0.00
	Illiterates	8	5.4	Total		148	

Ages and education levels of respondents results described in Table 3. The mean age of the respondents was 41.70 years old, aligning with the data indicating that the majority were in the middle-aged or mature stage of life. This demographic is particularly valuable for providing deeply rooted insights into trends of coffee in agricultural practices, climate changes over time, and their comparison with current issues. Respondents ages contributed substantial role into get important information and its reliability (Mossie *et al*., 2020).

Similarly, the mean educational level of respondents was 6.56 grades, suggesting an adequate level of education for providing meaningful responses, identifying similar issues of coffee production system, and comprehended the questionnaire effectively. The mean household size was between 6 and 7 members per household. Larger family sizes were noted to contribute to greater labor force availability, which supports agricultural activities and reduces labor costs. This finding alike with Mossie *et al*. (2020) reported that 5 - 6 per household members which is larger than the mean 4.3 report of CSA (2014) of the country. The mean of total land allocated for agricultural per household were 2.05 hectares; however, only 0.7 hectare of land for coffee farm per household, and reflects the designation of small-scale producers. Over 95 % of smallholder coffee farmers in Ethiopia produce less than hectare in size (Wubie *et al.,* 2015).

Table 3: Means of Age, education level, household size, total land, and coffee land

Variable	Mean	Minimum	Maximum
Age	41.70	22	75
Mean of education level	6.56	0	14
Household size	6.53	18	18
Total owned land (Ha)	2.05	0	10
Farm land allotted for coffee (Ha)	0.71	0.063	3.50
Ages of coffee	18.73	1	70

Livelihood sources, and topography of their lands

Table 4 was presented participants' main occupations, sources of family income, and the slopes of their farmland. Almost all of respondents (98 %) identified agriculture as their primary occupation, with approximately 84.5 % of family income derived from on-farm agricultural activities. A smaller proportion of respondents (13.5 % or 20 individuals) reported earning income from both on-farm and off-farm activities. Ken *et al*. (2020) reported similar finding during survey study that majority of respondents based on agriculture, while some of them added abroad activities. Thus, all respondents are well knowledgeable about agricultural practices that enhanced the reliability of the information provided. Furthermore, most respondents' farmland was categorized as having gentle slopes land (61.5 %), while only 3.4 % was classified as steeply sloped.

Table 4: The main occupation of farmers, family income, and farm slopes

Main occupation			Sources of family income			Slopes of the land		
Sources	Fre	Perc	Sources	Freq	Perc	Category	Freq	Perc
Agriculture	145	98.0	Both	20	13.5	Gentle	91	61.5
Non agriculture	1	0.68	Off farm	3	2.0	Gentle and steep	52	35.1
Wage labour	2	1.35	On farm	125	84.5	Steep	5	3.4
Total	148	100.0	Total	148	100	Total	148	100.0

Freq: Frequency, Per: percentage

Farming systems and types of crop grown in the study areas

Farmers in the study areas engaged in various farming systems as illustrated in Fig. 2. Majorities of crops grown were perennial, cereals, legumes, root, oil, and spices, respectively. Significantly different ($p = 0.034$) observed in proportion of respondents (Yes/No) in farming systems. Coffee based production systems accommodate wide ranges of crops from annuals to perennials, including specific spice crops that require partial to dense forest cover and exhibit climbing growth habits. Keerthika *et al*. (2024) reported multistory of coffee agroforestry accommodate diversity of crop species that generates changes in various morphological, phonological, physiological, and over all ecosystem characteristics.

According to this study, farmer coffee production systems characterized into: coffee-based Enset, Enset-based coffee, coffee-based cereal, cereal-based-coffee, coffee-livestock-Enset, coffee-timber and or non-tree products-livestock-cereal, and multistory coffee systems with different vertical strata. These coffee farming systems are currently practiced in the country and significantly influence farmers' preferences, coffee production practices, technology adoption, and the long-term sustainability of coffee production.

Fig. 2: Types of farming practices in the study area, x2 = 6.75, p values: 0.034 (n = 148, SW Ethiopia)

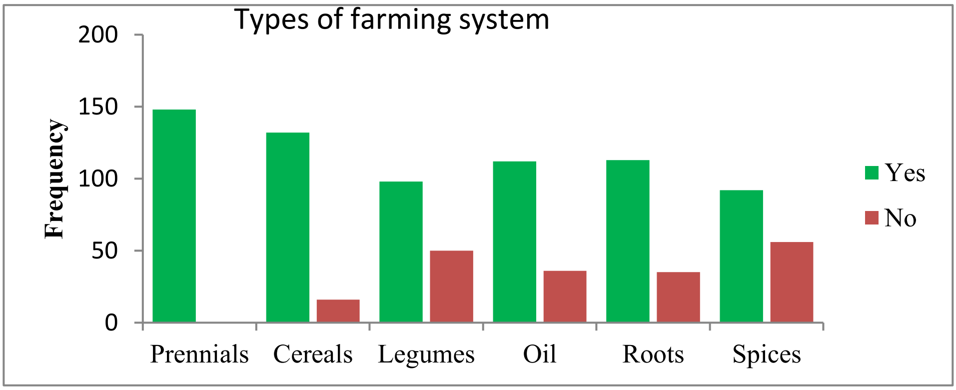
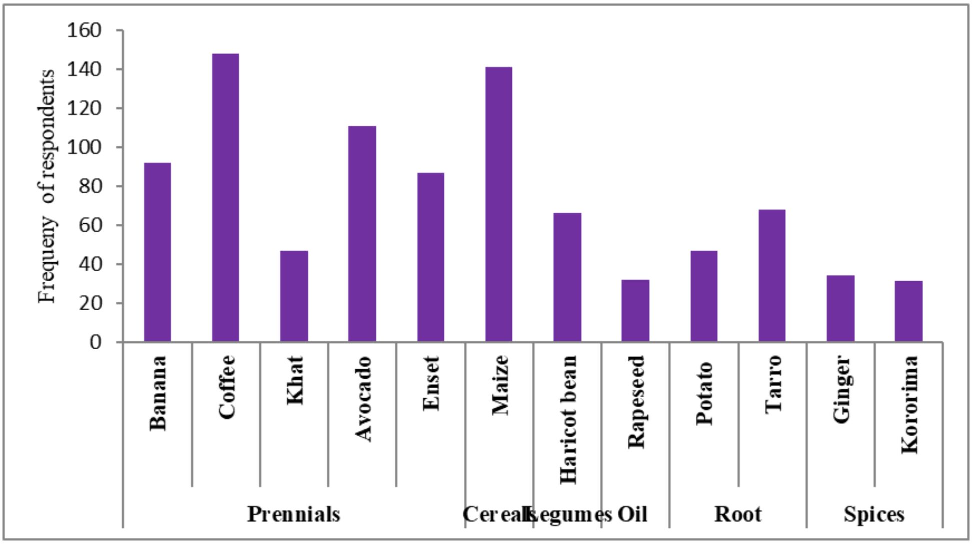


Fig. 3 exhibited types of crop grown in coffee based farming systems, but coffee is major and mandatory. Some of coffee based intercropping crop species identified during the study were: taro (*Colocasia esculenta* L. Schott), korarima (*Aframomum corrorimaBraun*), enset (*Ensete ventricosum*) and black pepper notable crops. In addition to Enset perennial fruits such as avocado, banana, Ginger, and Turmeric were revealed as supporting crops in coffee production system that use to achieve sustainability of income and food security. Terfassa (2021) coffee based intercropping of fruits, spices, and root crop species practiced with multi-strata that efficienctly use spatial and temporal of limited farm lands in southern Ethiopia. But, such practiced most often practiced as culture, farmers adopt from each other rather than as new agricultural coffee based agroforestry technology. Further, its advantage over sole crop is less investigated and huge gap of formal coffee based agro forestry practices.

Fig. 3: Types of crop grown in farming system (n = 148, Ethiopia)



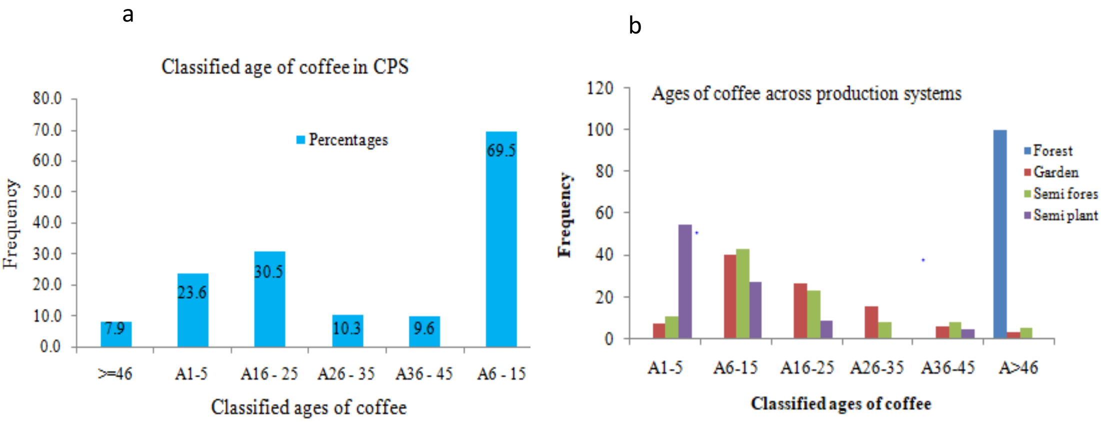
Similarly, coffee based enset inter-cropping is widely practiced in study areas. Enset serves as staple crops that substantial role in food security. For instance, farmer's in Gedeo such as Yirgachaffe, and Waliatta zone of Boloso Sore districts commonly practice than other regions and districts of major coffee growing areas in the country. Because of highest population per square kilometer, though land scarcity is existed and maintain through intensive farming such as intercropping of companion crops. Coffee based agroforestry of Enset, banana, taro and korarima often practiced in southwestern Ethiopia and more influenced by land scarcity of farmers (Tegegne, 2017).

Thus, farmers inter cropped perennial fruits and spices following traditional planting system. However, huge gap of intensive technology such as coffee with Enset/Banana intercropping existed across the study area. In addition, gap of the few released technologies also revealed across the study areas due to limitation of extension services specific to coffee technology popularization. For instance either false Enset highly important for shade semi-permanent shade or true Enset and Banana served as staple food security fruits in addition to serving shade purposes for the coffee production. But, it's practiced only in suitable coffee production system rather than in all coffee field in Ethiopia may be in contrast of other African countries.

Relationship of ages with coffee production systems

Coffee age categorized based on stage of production cycle, 1-5; pre potential yield, 6-15; potential yield and assumed still young by farmers, 16-25 period where coffee start to constant in production and decline at farmer level, 26-35 age coffee yield is almost decline but affected by managements, soil fertility status and slope of the land. But it often needs renewing appropriate for coffee trees. 36-45 are almost outdated, and need urgent decision either uprooting or stumping. But, above 46 age coffee tree is more difficult define with its production and productivity including quality. Most of such coffee trees found in forest, provide lowest yield, within three to four years (Fig. 4 a and b). The age of coffee plants influences type of coffee production systems, technologies, and production potential.

Fig. 4: Classification of Coffee Ages Based on Production Potential (n = 148)



Aged or oldest (>46) coffee plants typically associated with forested (forest and semi-forest) systems, whereas younger plants, particularly those less than five years old, are often part of semi-plantation systems, which recently expanding in the country (Fig. 4b). The coffee trees generally allowed to become old and large in both the semi-forest and forest coffee (Hylander *et al*., 2024), and expected to hold largest shade trees with largest diameter with diverse species (Valencia *et al*., 2016).

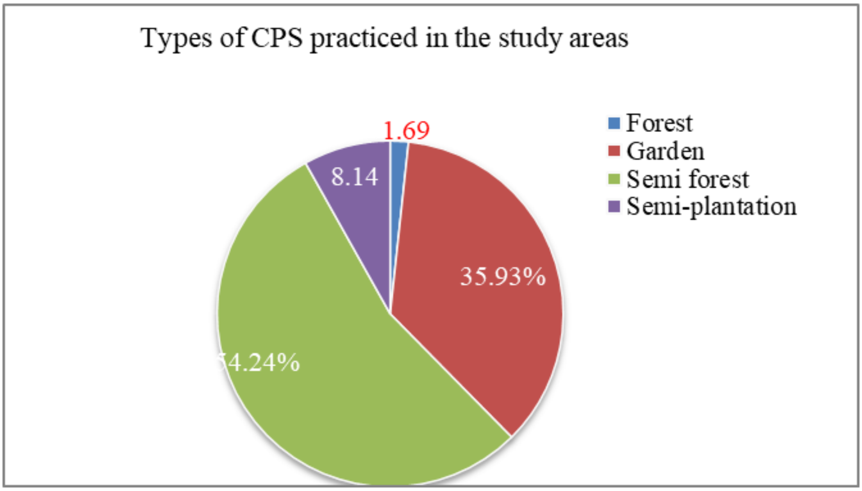
Multi-advantageous trees, herbaceous and other plant species presented in coffee based forests. However, most semi-forest coffee systems transitioning into garden systems due to factors such as production improvement, new technologies, and influence of emerging agricultural extensions. Natural forest cover in southwestern Ethiopia is deteriorating due to the growing tendency of cereal cropping, resettlement, and commercial agriculture (Kassa *et al*., 2017). Several studies reported biodiversity deterioration, soil quality decline, and less preference of conservation agricultural methods. Replanting practices were observed often in semi-forest systems, which have impacts on the aging of coffee plantation.

Consequently, with the exception of forest coffee systems, garden, plantation, and semi-plantation systems expanding from year to year. The expectation rate of biodiversity is directly proportional to ages of coffee; means as age increase, more inside to all above soil ecosystem condition expected. However, productivity is inversely correlated with ages and forest coffee. In this study, the mean age of coffee plants was 18.73 years, its above primary productive cycle. Indirect evidence reported by Lelamo (2021) suggests that undisturbed soil and the presence of shade trees enhance soil biodiversity, including both fauna and flora, thereby contributing significantly to ecological balance, while removing and deforestation against.

Types of coffee production system (CPS)

Four types of coffee production systems were reported in this study, excluding plantation systems (Fig. 5). The majority of respondents practiced and managed semi-forest coffee production systems (160 ~ 54 %), followed by garden coffee (106 ~ 36 %) production systems. However, forest coffee had the lowest frequency (5) of occurrence. This indicates that a significant portion of forest coffee is being converted into other systems, putting it at risk of extinction. Haylander *et al*. (2024) reported that ecology and evolution of coffee within its native range influence biodiversity conservation, from genes to social-ecological systems.

Fig. 5: Distribution of coffee production system intensities in the study area (n = 148)



Inter-cropping and shade practices in coffee production systems.

Statistical variation existed ($p < 0.05$) between an association of inter-cropping and shade practices in coffee production systems (Table 5). More than half (56.8 %) of the respondents reported practiced inter-cropping on their coffee farm and statistically highly significant differences ($p < 0.01$) observed among the coffee production system. The reason behind is that suitability and intensity of CPS for inter-cropping different; garden > semi-plantation > semi-forest, but forest coffee is not suitable for inter-cropping. Further, majority of inter-cropped crops provides shade services for coffees. Tadesse *et al*. (2014) reported 96 % of households use inter-cropping and shade species in coffee based agroforestry.

While, around 97.4 % respondent planted shade trees in their coffee farms with highly significant differences ($p < 0.01$) observed among coffee production systems due different intensity of shade in order of Forest > Semi forest > Semi plantation> garden production system. These results assured coffee production being under shade system of either trees, inter-cropping or their combination at small scale level. Depends on species and population, shade and inter-cropping provides multi-advantage beyond shading and food security but ecosystem services. In addition to shading and food security services, improve soil fertility, soil healthiness, herbal medication, fire wood, timber and non-timber, mulching, soil and water conservation. This is exceptional advantages of farmers obtaining from coffee based agroforestry and unique characteristics often only from Ethiopia being natural without supplements of any fertilizers or other chemicals.

Table 5: Farmers' responses on inter-cropping and shade tree planting in coffee farms

Responses	Inter-cropping		Planting shade	
	Frequency	Percentage	Frequency	Percentage
No	138	42.6	14	2.6
Yes	152	56.8	282	97.4
X^2	184.32		254.21	
	0.001		0.00	

Shade and crop species integrated into coffee fields detailed in Table 6. Shade species such as Albizia species (486), Croton (*Croton macrostachyus* Hochst. ex Delile) (207), *Cordia africana* (175), Erythrina species (129), Milletia (*Millettia ferruginea* Hochst Baker) (116), and Acacia species (100) were frequently reported in the study area. Kitessa (2016) reported that species of Albizia, Acacia, and Millettia were considered as preferred coffee shade trees by farmers due to canopy sculpture, feathery type, easy to light transmission, litter decomposition and nitrogen fixing potential.

Table 6: Major shade trees and inter-cropping crops in the study area

Shade species	Freq	%tage	Crops	Fre	%tage	Crops	Freq	%tage
Acacia species	100	67.57	Enset	71	47.93	Cowpea	2	1.35
Albizia species	486	328.37	Har.bean	61	41.22	Yam	2	1.35
Cordia africana	175	118.24	Avocado	26	17.57	Soybean	2	1.35
Croton species	207	138.93	Banana	20	13.51	Sugarcane	2	1.35
Erythrina species	129	87.16	Taro	19	12.84	Red pepper	2	1.35
Ficus species	30	20.27	Maize	11	7.43	Filed pea	1	0.67
Gravellia	26	17.57	Ginger	6	4.05	Turmeric	1	0.67
Leucaena	11	7.432	Chat	5	3.38	Sweetpotato	1	0.67
Milletia species	116	78.38	Korarima	5	3.38	Beetroot	1	0.67
Sesbania susban	22	14.86	Mango	4	2.71	Alfalfa	1	0.67
Others	16	10.81	Potato	4	2.71	Others	7	4.73

Freq= Frequency, %tage= percentage, species: indicated trees with different species

Similarly Enset (*Ensete ventricosum* Welw.Cheesman) (47.93 %), Haricot bean (*Phaseolus vulgaris*) (41.22 %), Avocado (*Persia americana*) (17.57%), Banana (*Musa sapeintum* L.) (13.51 %), and Taron (*Colocasia esculenta* L. Schott) (12.84 %) were major listed intercropped in coffee identified during the study (Table 6). Cover crops such as haricot beans being predominantly cultivated during the first three years before canopy close the lands. In contrast, perennial crops such as Enset, Avocado, Banana, Ginger (*Zingiber officinale* Roscoe), and Korarima (*Aframomum corrorima* Braun) were continuously cultivated within the coffee fields throughout their lifespan. The garden coffee production system incorporated inter-cropping with various fruit crops, including avocado, banana, oranges, as well as other annual cereals, legumes, spices, and root crops (Blomme *et al*., 2023; Mng'omba *et al*., 2024). Overall advantages of intercropping are to improve land equivalent ratio through food security, cash income, medicinal values, spices, soil improvement, and temporary shading.

Farmers' shade tree preferences and reasons

Farmers' preferred shade tree species and the reasons for their preferences were summarized in Table 7. The majority of respondents indicated a preference for shade trees with specific characteristics, including small feathery leaves, evergreen foliage, umbrella-shaped canopies, deep root systems, decomposing leaves, dissimilarity with coffee fruits, zero impact on coffee quality (odorless), and the ability to improve soil fertility. Preferred shade trees include *Albizia species* (83.1 %), *Erythrina species* (58 %), *Milletia* (57 %), *Acacia* (39 %), among others. Lelamo (2021) reported preffered shade trees such as *Cordia africana*, *Millettia ferruginea*, *Erythrina brucei*, and *Olea capensis* are the predominant indigenous multipurpose tree species utilized in agroforestry systems in southern Ethiopia.

Table 7: Farmers' preferred shade tree species and reasons

Shade species	Frequency	%tage	Reason	Frequency	%tage
Albizia	123.00	83.12	Defoliation characters	51.0	34.46
Acacia	58.00	39.18	Less competition	51.0	34.46
Erthrina	87.00	58.72	Litter fallen	48.0	32.43
Milletia	57.00	38.51	Shade quality	139.0	93.92
Gravillea	24.00	16.22	Soil fertility	115.0	77.71
Leucaena	8.00	4.23	Timber	65.0	43.92
Sesbania	7.00	4.11	Fodder for animals	63.0	42.57
Croton species	8.00	4.23	Shade	53.0	35.81
Ficus species	7.00	4.11	Others	27	18.24
Casterbean	4.00	2.13			
Cordia africana	55	36.82			

%tage: percentage

The primary reasons for these preferences was shade quality with 93.32 % (139) respondents reported with features of canopy, leave size, soil fertility, small fruit, light transmission, and less resource competition. A similar finding reported by Hundera (2016) indicated that 97 % of respondents regarded leaf size as an important feature in their preference for shade trees. Feathery type and small leaves plays substantial role in light transmission and regulate coffee yield by optimizing photosynthesis and reduce dark reaction.

The second reason of preference of respondents was soil fertility improvements (77.71 %) that reported due to different factors combination such as reduce erosion, litter and leaf decomposition, and atmospheric nitrogen fixing potential. Therefore, farmers believed that these native species' presence was essential for providing ecosystem services like conserving soil and water (Amare *et al*., 2019; Lelamo, 2021).

The third reason of choice was timber (43.92 %) purposes that support farmers for construction purposes as well as sources of income. In Ethiopia, tree species such as *Cordia africana* scattered in farming fields, mostly for their wood products that support to build home, doors, windows, and furniture (Mamo & Asfaw, 2017; Lamesso & Bekele, 2020).

The fourth reason was fodder (42.57 %) that uses as animals feeds. Some of shade trees used as animals feed that huge contribution in farmer's life sustainability. The fifth reason was defoliation character (34.46 %) such as less defoliation, disability to serve as shade during dry season and may defoliate either early onset or off set of rainfall that at a time where sunlight causes impacts on coffee physiological growths even though it has little advantages like characterized under shade quality.

The last reason was less competition with coffee (34.46 %), followed by importance of litter fallen (32.43 %) that used to improve soil fertility. The selected shade tree species and reasons for their preferences reflected an importance of species diversity in supporting semi-plantation and garden coffee production systems in addition to forest component system.

While full management practices are often applied in these systems, shade remains a mandatory component of coffee production in the country. Ayalew *et al*. (2022) identified 17 shade tree preference criteria, but most important were leaf shape; feathery type (66.1 % preference), less competition (57.6 %), enhance bean quality (49.2 %) and crown shape of shade trees. Misgana *et al.* (2024) reported that coffee shade trees with lengthy heights, broad umbrella shapes, improve soil fertility, zero competition, and evergreen leaves throughout the growing season preferred by farmersthough scale of preferences were varied.

Thus, respondents preferred shade trees with sequencing of *Albizia shemperiana*, *Albizia gummifera*, *Albizia grandbractetta*, *Erthrina species*, *Acacia abyssinica*, *Millettia ferrugineaand Cordia africana*. Ayalew *et al*. (2022) reported parallel findings that *Albizia* spp. (96.6 % of farmers), *Acacia abyssinica* (76.3 %), *Millettia ferruginea* (66.1 %), *Cordia africana* (30.5 %), and *Sesbania sesban* (18.65 %) were the top five shade tree species.

Shade trees effects in Coffee Production Systems

The impacts of shade trees on coffee production systems (CPS), including both advantages and disadvantages were summarized in Table 8. The respondents listed out the benefits of shade trees for coffee cultivation and the surrounding environment, were: increased income and improved land use efficiency (LUE) (71.62 %), enhanced regulation of the microclimate during the day (-) and night (+), including temperature stabilization (64.86 %), improved soil (52.70 %), control of sun light transmission (45.27%), and increased coffee yield or production (41.89 %).

Additionally, shade trees were noted to delay the early aging of coffee plants (32.43 %) and support long-term/period of productivity an aspect that has become increasingly critical due to the challenges posed by climate change. Respondents emphasized that separating coffee plants from shade trees creates significant ecological imbalances, which negatively affect coffee production, human well-being, and the broader ecosystem services. Consequently, respondents identified several positive effects of shade trees on coffee and its ecological niche. Sauvadet *et al.* (2019) reported that coffee production under shaded systems is more sustainable than intensive conventional systems cultivate in full-sun plantations. The integration of leguminous tree species is vital for improving soil fertility and supports organic production systems, offering an intriguing alternative with productivity levels comparable to medium-intensity conventional systems (Meylan *et al*., 2017).

Conversely, respondents highlighted very few of negative impacts of shade trees (Table 8), including competition with coffee crops for resources (23 %), hosts for pests and wild animals (16.89 %), reduced coffee yields due to excessive shading (11.49 %), and management costs (9.46 %). Additionally, shade trees can cause mechanical damage to under-story crops. Sebuliba *et al.* (2021) observed that resource competition and damage from falling tree branches pose significant challenges to the utilization of shade trees in coffee production systems. Similarly, Ayalew *et al*. (2022) reported that shade trees provide habitats for wild animals, insect pests, and diseases.

Overall, the respondents concluded that the negative impacts of shade trees minimized through planting and tree managements systems. Align with this supposition, Meylan *et al*. (2017) concluded that well-managed shade systems provision of beneficial services by shade trees and the lack of a significant negative impact on overall coffee yield were not unexpected.

Table 8: Merits and demerits of shade tree in coffee farms

Advantages of shades tree	%tage	Disadvantages of shade tree	%tage
Income and LUE	71.62	Host for pest and wild animals	16.89
Improve and regulate microclimate	64.86	Compete with coffee	15.54
Regulate light transmission	45.27	Yield reduction due to heavy shades	11.49
Improve of soil fertility	52.7	It needs Intensive management	9.46
Home of wild animals	45.27	Vector for pests	8.11
Regulate coffee production	41.89	Favor disease occurrences	5.41
Control early aging of coffee	32.43		
Control biotic and aboitic stress	21.62		
Reduce management cost and weeding frequency	13.51		
Used as windbreak	12.16		

%tage: percentage

Status of Agronomic and soil conservation practices

The majority of respondents were familiar with coffee agronomic technologies (Fig. 6). All respondents were practiced weeding (Yes = 148), predominantly using hand weeding methods. They did not prefer herbicide use due to inter-cropping practices and the risk of organic contamination. Similarly, most respondents reported practicing thinning (Yes = 121), spacing (Yes = 115) and digging (Yes = 88), respectively. However, relatively other agronomic practices, such as fertilizer application (No = 80), coppicing (No = 93), and pruning (No = 83) were seldom implemented. The result indicated that adopted agronomic technologies were favorable for biodiversity conservation than the technologies less adopted.

Here the reason behind farmers still less in fertilizer application might be to due fertility is protected through forests; reduce erosion, decompose of litter and weeds, conserve moisture and reduce desiccation of inert materials that improve natural reaction under coffee agroforestry system.

For instance, hand weeding reduces chances of total destruction of herbicides and selection and survival opportunity for various biotic important species. In contrary, fertilizer application still not well practices that may have negative effects in coffee productivity and low level of intensive farming mechanisms. Its slightly similar findings with Castillo et al. (2024) reported that gap of coffee farmers skills revealed in application of SMART technology intervention for coffee farming (69.70 %), proper pruning and rejuvenation of old coffee trees (63.84 %), harvesting and processing of produced coffee (63.10 %), and seedling production and planting (59.04 %). Similarly, Tadesse *et al.* (2020) reported that many farmers in southern Ethiopia (Wolayta (17.5 %), Gamo Goffa (62.5 %), and Gedeo (26.7 %) less adopted in improved agronomic practices (composting, spacing, seedling preparation, improved varieties, and pruning) in coffee growers. This might be happening despite of the country's available improved technologies, farmers unable to use them due to a lack of extension and awareness. Overall, adoption rate is still request integrated extension services aid to disseminate production technologies in the communities.

Fig. 6: Agronomic technologies practiced in coffee field by farmers (n=148)

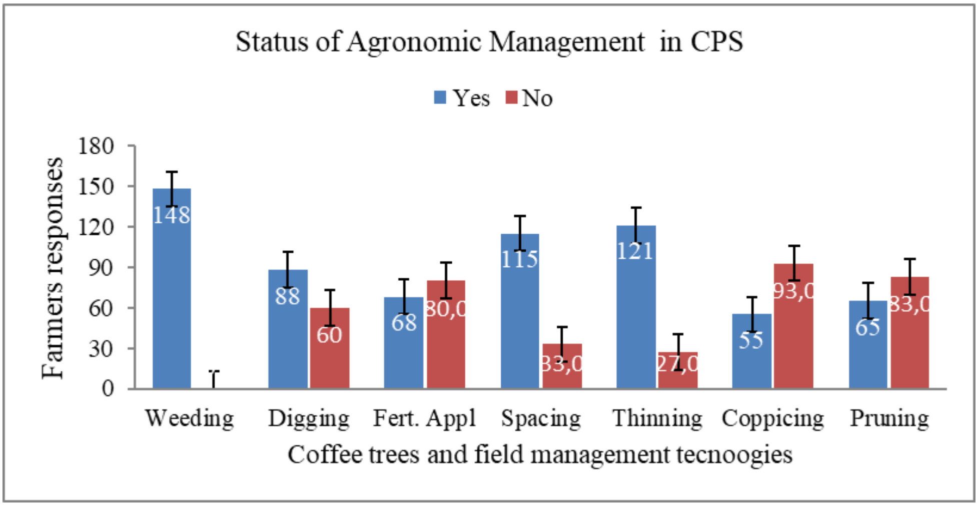
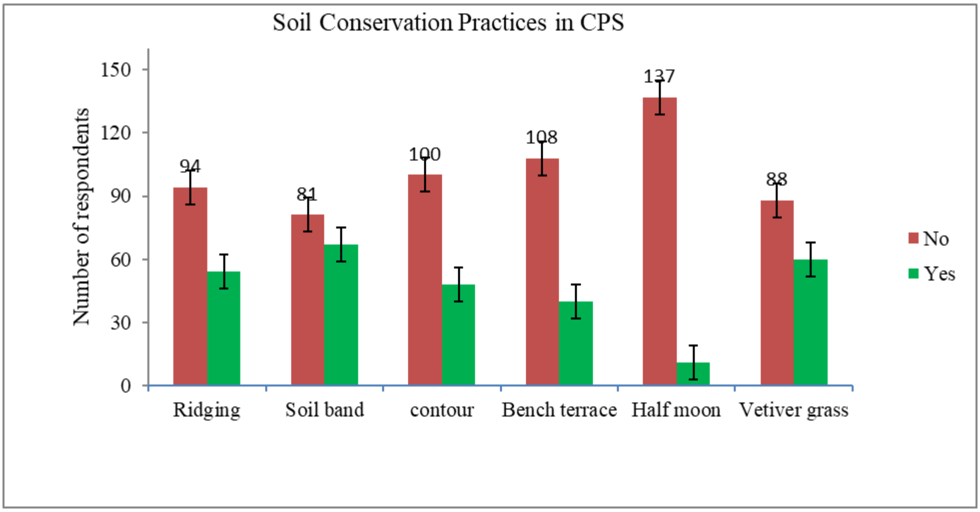


Fig. 7 depicted the farmers' responses regarding their use of soil and water conservation (SWC) technologies. Majorities of farmers not used SWC that responded “No” for (ridging (No= 94 %), soil band (No= 81 %), contour (No = 100), half-moon (No = 137), and vetiver grass (No = 88) practices, likely due to a lack of familiarity with these methods. According to the Fikirie (2021) study's findings about 45 % built soil band in annual crops field; while expect to be lower in perennial crops field. Soil and water conservation practices in CPS were varied and more found in garden coffee production system, but very rare in forest components coffee production. Almost of improved SWC technologies left on shelf. Tadesse *et al*. (2020) reported that SWC technology adoption rate is very far less than agronomic practices at coffee producers farmer level, specially those producing under forest and forest components, while its very important with topography of coffee fields. Soil and water conservation needs special attention or intervention to improve its application in coffee field.

Fig. 7: Soil and water conservation practiced in coffee field (n = 148)



Role of CPS Economic and climate change mitigation

Coffee production system highly involved in cultural and social engagement (yes =123), economic improvements (yes = 125), and environmental conservation (yes =147) (Table 9). Respondents confirmed that CPS regulated temperature and frost effects (yes = 145), improve infiltration rates and reduced water loss (yes = 145), maintain relative humidity, and act as windbreaks (yes =145) (Table 9). Societies utilized coffee-based agroforestry systems for various cultural purposes, including holidays celebrations, places of worship, conflict resolution under tree canopies (e.g., the Gada System and Jaarsummaa), and medicinal herbs for treating wounds, diseases, and illnesses in children, women during childbirth, and animals.

Additionally, these societies have established cultural rules and regulations for tree cutting and management to ensure sustainability for current and future generations. Moreover, communities maintain a deep rooted, often unwritten connection to their coffee-based agroforestry systems, which holds significant importance within their culture. The ecosystem services derived from these systems, particularly cultural /services in CPS, are invaluable, and cannot easily be quantified or expressed in monetary terms. Align with study of Duguma *et al*. (2019) reported CPS provides cultural values such as spiritual (culturally respected tree: e.g: Odaa tree = Sycamore Tree; ficus species), aesthetic, educational, and recreational services. An economist Polanyi (1994) explained the role of agroforestry in social by direct narration "man's economy, as a rule, is submerged in his social relationships. He does not act so as to safeguard his individual interest in the possession of material goods; he acts so as to safeguard his social standing, his social claims, and his social assets. He values material goods only in so far as they serve this end." Smallholder coffee growers in the tropics can use agroforestry techniques to benefit themselves and their own needs while also inadvertently benefiting the rest of humanity, including distant consumer groups (Wienhold & Goulao, 2023; Hylande *et al*., 2024).

Temperature and rainfall are the most critical weather parameters, both influenced by human activities on the Earths' surface. The ability of shade trees to provide cooling effects, mitigate frost, windbreaks, and reduced soil erosion known locally and scientifically. For instance, shade trees abilities to regulate day and night temperatures approximately 0.5°C compared to open fields (Etana & Merga, 2020). Coffee is highly sensitive to frost, which can be managed effectively through the use of shade trees, as they help elevate nighttime temperatures. Duguma *et al*. (2019) reported that coffee produced as agroforestry plays substantial role in soil moisture conservation, shade for human being and other organisms.

Table 9: Responses of CPS in societies and climate change mitigation

Parameters		Responses	
		Yes	No
Social roles	**Cultural**	120	28
	Social	123	25
	Economics	145	3
	Environments	147	1
Climate change mitigation roles	**Regulate Temperatures and frost effect**	145	3
	Reduce water loss	145	3
	Increase Relative humidity	145	3
	Wind break purposes	145	3

Benefits of CPS in Sociocultural and its rates

Majority of respondents replied CPS bestowed sociocultural benefit except traditional worship which under extinction due to modern organized worship system (Table 10). Traditional medicine (yes = 126), togetherness (yes = 89), fruit trees (yes = 141), and construction materials (yes = 139) were basic sociocultural benefited from agroforestry and diversity in CPS with various levels. Though most of sociocultural benefits of coffee systems not well understand, it could help in promoting improved management of forest coffee and its diversification (Bulitta & Duguma, 2021).

In issues of togetherness, CPS plays substantial role as country as well as study region. Coffee sector is known as the "school of socialization," provides a chance for networking. On this occasion, elders teach the children the rituals and beliefs of the community, as well as the norms and values of the society, including stories, proverbs, and communal beliefs. Southern Ethiopian population growth ethnic numbers, local migration highly depends on financial advantages and job opportunity embedded in coffee produced areas. Duressa (2018) reported that CPS listed among the primary reasons for the unity of different ethnic groups in southwestern Ethiopia during its production and marketing processes.

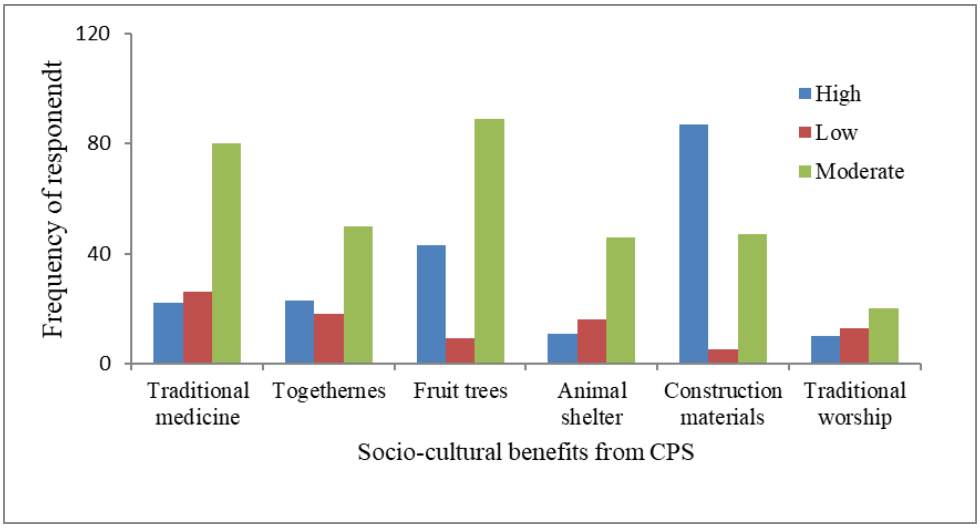
The author further elaborates that factors such as population growth, lack of employment opportunities, poverty, famine, and land scarcity have led a substantial number of Ethiopians migrated to major coffee-producing regions. This migration, in turn, fostered community cohesion and contributed to the expansion of coffee plantations (Duressa, 2018). Coffee system served in practical and symbolic purposes, such as a food and beverage, a commodity crop, a religious object, a communication tool, and a cultural and inherited item (Bulitta & Duguma, 2021). The relationship between sociocultural and CPS narrated as heritages in the community, expected to transfer from generation to generation (Huang *et al.*, 2020; Jin *et al.,* 2020).

Table 10: Sociocultural benefits of coffee production system

Response	Traditional medicine	Togetherness	Fruit trees	Animal shelter	Construction materials	Traditional worship
No	22	59	7	75	9	106
Yes	126	89	141	73	139	42

Further, respondents rated sociocultural benefited as described in Fig. 8. Majorities of sociocultural benefits of CPS rated as moderated as compare to others sociocultural sources. Specific results showed that construction materials which all respondents rated as highly important in sociocultural of the societies. Its fact that CPS serving as major and reliable sources of timber, non-timber trees and held multi-values in from lower fence to higher construction stages.

Fig. 8: Rate of Sociocultural Benefit for the society



SUMMARY AND CONCLUSION

Coffee production in Ethiopia makes a substantial contribution to the national economy, and its production systems are strongly shaped by sociocultural practices that also determine the provision of ecosystem services. This study demonstrated that coffee production systems and their associated ecosystem services are significantly influenced by the sociocultural characteristics of producers. Social attributes can enhance coffee production through conservation-oriented practices, whereas exclusive reliance on traditional systems without technological integration can negatively affect productivity.

Coffee production in the study areas is deeply embedded in local culture, demographics, land-use patterns, social interactions, and ecosystem service provision. The results indicate that land allocated to coffee by smallholder farmers averages less than one hectare and has declined compared to previous reports. Forest coffee systems have diminished to approximately 1 %, highlighting the urgent need for targeted conservation measures to preserve on-farm genetic resources. The majority of farmers (97 %) cultivate coffee under shade trees, with significant differences ($p < 0.05$) observed among coffee production systems (CPS). More than 68 % of respondents practice inter-cropping, primarily to enhance shade management and improve land equivalent ratio (LER).The reason behind is that suitability and intensity of CPS for intercropping different; garden > semi-plantation > semi-forest, but forest coffee is not suitable for intercropping.

Technology adoption was observed among approximately half of the respondents, although fertilizer use remains very limited. This low fertilizer application is largely attributed to the widespread use of shade trees and intercropping systems, which enhance soil fertility through biological nitrogen fixation, litter input, and organic matter decomposition. Cultural practices strongly influence CPS distribution across the study areas: Yirgacheffe and Boloso Sore are dominated by garden coffee systems, whereas Manna, Gera, and Masha are characterized by semi-forest coffee systems.

Overall, producers' sociocultural characteristics determine the type of CPS adopted and influence productivity, food security, and ecosystem service provision. These systems play a critical role in environmental sustainability, biodiversity conservation, and long-term resilience. Therefore, understanding sociocultural dynamics is essential for designing effective policies, extension strategies, and interventions aimed at improving sustainability, productivity, and livelihoods in coffee-growing communities. The study also revealed gaps in the dissemination and adoption of released coffee technologies, primarily due to limitations in extension services tailored to coffee-specific technology promotion.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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