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Contribution of Arabica Coffee Production Systems into Ecosystem Services in Southwestern Ethiopia

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Abstract
Arabica coffee, in addition to ascertain international market, it provides significant ecosystem services (ES) through its production systems (CPS). These systems serve as repositories of precious societal livelihood and its genetic resources which remain a backbone of Ethiopian people. However, there is a gap in understanding the role of CPS and their multistory structures in delivering ES, which that endorse to develop sustainable production systems. The objective of this study was to assess farmers' perceptions in role of CPS in ES into sustain producers' livelihoods across five districts (Manna, Gera, Masha, YirgaChafe, and Bolososare) in southwestern Ethiopia. Data were collected through surveys used KoboToolbox platform with a semi-structured questionnaire. The collected data were analyzed using SPSS and Stata software. The study participants consisted of 60% men and 40% women, all of whom were coffee producers. Among the five types of CPS, the semi-forest system was the most prevalent (54%), followed by the garden system (36%). In contrast, only 1% of respondent farmers (~5 individuals) practiced forest coffee production, which is a concerning finding, while none of the participants engaged in plantation-based coffee farming. Nearly all respondents acknowledged that CPS plays a crucial role in maintaining environmental balance (>97%), economic sustainability (>96%), and land productivity (95.95%). Additionally, 77.7% of respondents reported achieving food security, particularly through garden coffee production. Forest-based CPS was reported to be more effective in climate change buffering and biodiversity preservation. Overall, CPS plays an critical role in the area sustaining producers' livelihoods, with its diverse contributions intertwined with daily life. These contributions are complex and difficult to isolate into individual functions. Farmers emphasized that CPS contributes to all ES, underscoring the need for in-depth research into its various roles to develop more sophisticated and sustainable production systems that align with global sustainability goals.

Keywords
Arabicca coffee, Coffee production, Ecosystem services, Production system

INTRODUCTION

Coffee species originates around tropical belt of the African continent. Arabica coffee (*Coffea arabica L.*) is originated specific to the rainforest highland montane region of southwestern Ethiopia. It is being conventionally collected from the country's natural forests (Gole et al., 2008, Davis et al., 2019). Coffee is deeply intertwined with the historical, cultural, and economic fabric of Ethiopia, sustaining millions of farmers, merchants, and traders at various levels (Perfecto et al., 2005). The production of coffee is inextricably linked to the ecological, cultural, and economic dynamics of the nation (Labouisse et al., 2008).

Ethiopia ranks first in coffee production in Africa and fifth globally. It is unique in being the only country that consumes approximately half of its annual coffee production (Temam et al., 2024). Previous estimation was indicated that over 22 million hectares of land in Ethiopia suitable for coffee production; however, only 856,529.03 hectares (approximately 4%) under cultivation (Gole et al., 2013; CSA, 2022).

The coffee sector plays a significant role in both foreign and local income generation, either independently or in combination with other agricultural products (Dogiso, 2022; Gurmessa et al., 2022). It contributes in approximately 65% of the foreign exchange earnings from agricultural exports, and accounts for 5-10% of the country's Gross Domestic Product (GDP) (Gizaw et al., 2022). Roughly, around 30 million people or a quarter of the country's population, being relied on the coffee industry, ranging from producers to exporters (Martins et al., 2015; Toensmeier et al., 2020; Gizaw et al., 2022).

Beyond its role as a major source of foreign income in the country's macro-economy, coffee cultivation, particularly in agroforestry systems, plays a multifaceted role in environmental dynamics and ecosystem services (Beyene et al., 2020; Niguse et al., 2022; Zewdie et al., 2022). Several studies reported that smallholder coffee producers relied on coffee ecosystem services for their livelihoods (Worku et al., 2015; Dos Santos, 2021; Valencia et al., 2022). Coffee farming systems contributing to resilience, sustainability, and overall productivity (Haines-Young and Potschin, 2018; Zewdie et al., 2022). Thus, CPS are essential for both environmental stewardship and as a significant economic force.

Intensive coffee management practices, such as selective and uniforming shade, thinning, fertilizer application, and reduced tree species diversity have been widely adopted (Tadesse et al., 2014). However, these practices have led to a loss of species richness, deterioration in coffee quality, decline in soil fauna and flora, and disruption of the natural balance within coffee ecosystems (Hundera et al., 2013; Tassew et al., 2021). Consequently, ecosystem services in CPS, particularly in coffee-based agroforestry systems have been significantly degraded, with limited focus on restoration activities. This has had profound impacts on environmental balance. For instance, the adoption of intensive agricultural practices, such as open-field CPS, has contributed to the degradation of biotic and abiotic resources.

Understanding farmers' perceptions of CPS and their role in ecosystem services is critical for guiding conventional and modern agricultural management practices (Meylan et al., 2017). Hence, CPS contribute to all categories of ecosystem services, including provisioning, regulatory, supporting, and cultural services (Worku et al., 2019; Budiastuti et al., 2021). The impact of each CPS on ecosystem services varies depending on the management practices implemented within the system.

Although CPS provides multiple benefits, research investigating its role beyond yield, particularly from the perspective of farmers, remains limited. Consequently, there is a lack of understanding regarding producers' perceptions of the role of CPS in environmental, social, and biodiversity aspects. Farmers' perceptions are crucial for formulating policies and recommending technologies to address degradation and shifts in production practices that undermine restoration and conservation efforts, contrary to the ecosystem services expected from coffee agroforestry.

To develop effective policies and appropriate technologies, it is essential to assess farmers' understanding and indigenous knowledge of the role of CPS in ecosystem services. Information gathered from producers can serve as tangible evidence to guide the development of restoration strategies, policies, and technologies that support the relationship between producers, CPS, and ecosystem services. Therefore, the objectives of this study were to assess farmers' responses to CPS and evaluate its contribution to ecosystem services, environmental balance, and the sustainability of their livelihoods.

MATERIALS AND METHODS

The Study Area

The Southwestern montane highland rainforest is part of the world's southern biosphere reserves. This area is renowned for its Arabica coffee, cultivated under various production systems, with being coffee genotype collecting from the forests of Yayo, Bonga, and surrounding areas. Farmers in the study areas being actively participated in coffee production, with landholdings of varying sizes. Small-scale farmers handled around 95%, typically cultivating less than an hectare of land. The selected study areas characterized by diverse climatic parameters, including temperature, rainfall, humidity, and altitude. These names of areas are: Jimma zone in the Oromia region, the Gedeo zone in the Southern Nations, Nationalities, and Peoples' Region (SNNPR), the Waliata zone in the Central Ethiopia Region, and the Sheka zone in the Southwestern region of Ethiopia.

The Jimma zone, located in the southwestern part of the Oromia region, is the largest zone in the study area, situated approximately 354 km from Addis Ababa. Its geographic coordinates range from 35º 0'0" N to 37º 0' 0" N latitude, and 7º 0' 0" E to 8º 0' 0" E longitude. Two districts, Manna and Gera, were selected from the zone. Manna is located 18 km from Jimma town, and features diverse agro-ecological zones with altitudes ranging from 1200 to 2200 meters above sea level (m.a.s.l.). Gera, situated 98 km south of Jimma town, is characterized by highland terrain, dense forests, and altitudes ranging from 1500 to 2800 m.a.s.l.

The Sheka zone is located approximately 450 km southwest of Addis Ababa, with geographic coordinates ranging from 34.5º 0'0" N to 36º 0' 0" N latitude and 6º 0' 0" E to 7º 0' 0" E longitude. Masha district, one of the selected district in the Sheka zone, is located at the center of the zone. This area is known for its high annual rainfall, ranging from 1600 to 1800 mm, and an average temperature of 18-21℃. The region experiences two to three rainfall periods annually, spanning seven to nine months. Masha is predominantly highland and is recognized for its agroforestry systems, which focus on enset (false banana) and other fruit crops. The agro-climatic characteristics of Masha range from midland to highland, with altitudes varying between 800 and 2600 m.a.s.l.

Yirgacheffe, a selected district in the Gedeo zone, is one of the most renowned coffee-producing areas in the Southern Nations, Nationalities, and Peoples' Region (SNNPR). Located 327 km from Addis Ababa, it is known for its favorable climatic conditions for coffee cultivation, with altitudes ranging from 1800-2300 m.a.s.l. and a distinctive bimodal rainfall pattern (Worku et al., 2019). The annual precipitation in this area ranges from 1000 - 1600 mm, with a mean temperature of 16-20 ℃ (Moat et al., 2017).

Bolososore, a major coffee-producing district in the Waliata zone of the Central Ethiopia Region, is located 317 km southwest of Addis Ababa. This district has recently gained recognition for its coffee production. It features suitable conditions for coffee cultivation, with altitudes ranging from 1500-2300 m.a.s.l., a mean temperature range of 11-26℃, and an average annual rainfall of 1200 mm (Tegeng et al., 2024).

The regions, zones, and districts were selected purposely based on their coffee production potential and the availability of diverse production systems (Table 1). The survey study was conducted in selected regions, zones, districts, and villages, with the number of respondents determined based on statistical sampling methods. A total of five districts and ten villages were purposely selected, considering their coffee production potential, representative, and alignment with the study objectives.

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
Central 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

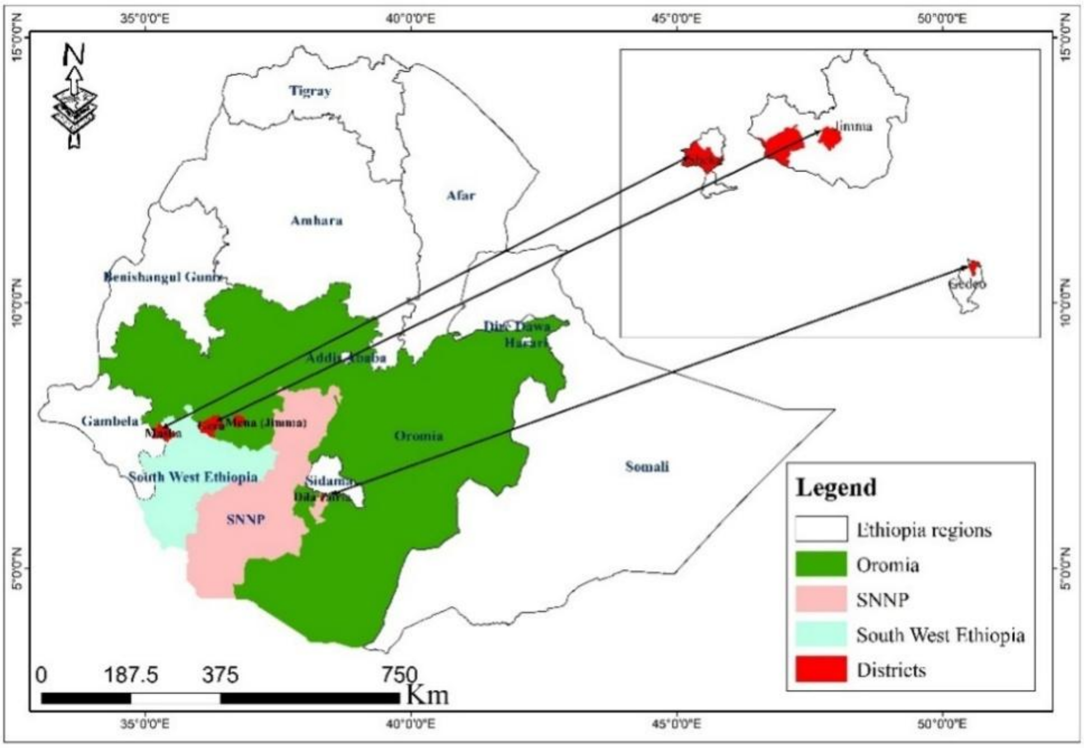


Fig. 1 Map of study area

Survey Study Design

Two villages were selected from each district, resulting in a total of ten villages randomly selected after identifying potential coffee-producing villages in each district through purposive sampling. During the design and randomization process, 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 analysis was conducted using the "pwr" package in R software (Champely et al., 2016), with a significance level of 5%, a power of 0.8, and an effect size (h) of 0.5.

The power analysis was performed using the "pwr" package in R software. Simple random sampling was employed for household selection. Based on the results, 30 households per district were selected, with 15 coffee-producing households per village, resulting in a total of 150 household respondents. Data collection was carried out using the www.kobotool.com software. Both qualitative and quantitative data were collected using a semi-structured questionnaire. Ultimately, 148 fully completed responses were downloaded and analyzed in accordance with the research questions proposed in the study.

Data Analysing Methods

The collected semi-structured questionnaire data were systematically managed using Excel after being downloaded from the Kobotool software. Qualitative data were summarized using descriptive statistics and analyzed inferential using the chi-square test. Quantitative data were analyzed using both descriptive and inferential statistics. SPSS and Stata were used for data analysis. The analyzed results were then used to address the objectives of the study as outlined in the research proposal.

RESULTS AND DISCUSSION

Socioeconomic Characteristics of Respondents

The socioeconomic status of the respondents was primarily based on agriculture, including the cultivation of crops (perennial, annual, root), and other agricultural activities (Table 2). The primary livelihood of all respondents relied on coffee production, though they also participated in the production of other crops such as annual, root, spices, and livestock. Approximately 98% of the respondents were primarily engaged in agriculture, with 84.5% deriving their income exclusively from on-farm production.

The respondents were involved in the production of various crops, including cereals (132 respondents), root crops (113 respondents), oil crops (112 respondents), legumes (98 respondents), and spices (92 respondents), in addition to coffee. Each respondents produces various number of crops, though in small plot sizes of lands. The majority of smallholder farmers in southwestern Ethiopia commonly cultivate cereals (e.g., maize, teff, and sorghum), root crops (e.g., enset and sweet potatoes), oil crops (e.g., nug and sesame), legumes, and spices alongside perennial crops like coffee (Abebe et al., 2013; Tsegaye et al., 2017; Tesfaye et al., 2018). Furthermore, Wolka et al. (2023) reported that farmers in the Jimma zone participate in the production of maize, teff, potatoes, onions, sesame, soybeans, haricot beans, cardamom, and ginger as part of a dual-purpose farming system aimed at ensuring food security.

Table 2 Respondents main occupation, sources and crops produced

Main occupation			Sources of family income			Crops	Yes	No
Sources	Freq	Percent	Sources	Freq	Percent	Prennials	148	0
Agric	145	98.0	Both	20	13.5	Cereals	132	16
Non-agric	1	0.68	Off farm	3	2.0	Legumes	98	50
Wage	2	1.35	On farm	125	84.5	Oil	112	36
Total	**148**	**100.0**	**Total**	**148**	**100**	Roots	113	35
						Spices	92	56

Freq: frequency, ***Percent***: percentage

Major Crops in the Study Area

The types of crops produced in the study area were described in Figure 2. Coffee is the primary perennial crop, cultivated by all respondents (148/148). Other crops, such as avocado (111), banana (92), enset (87), and khat (47), are also widely cultivated in the area. Among cereal crops, maize is produced by the majority of respondents (141) on varying scales of land area, primarily to sustain food security. Legume crops, such as haricot bean (66), are often inter-cropped with coffee during the early planting stages, particularly in the first two years, especially in garden and semi-plantation production systems. Rapeseed (32) is cultivated either alongside coffee during its early stages or independently by producers.

Root crops compatible with the coffee production system include taro (68) and potato (47). However, taro is underutilized and often referred to as an "orphan" crop, as it is not preferred by all families and is frequently associated with long-term use by poorer households. Consequently, popularization efforts are underway to provide extension services to communities, aiming to increase taro production within the coffee system to enhance food security.

Spices are also commonly produced, but challenges arise due to wild animals and their heavy feeding habits, which negatively impact the coffee system. Specifically, the relationships between karorima, ginger, and turmeric in coffee production have been frequently reported. Karorima thrives in deep shade with very moist soil, particularly in forest coffee systems. It is endemic to Ethiopia and is predominantly produced in coffee agroforestry systems with minimal management.

Recent challenges with ginger production include the Ralstonia disease, which affects the xylem and phloem of ginger rhizomes devastating and affected its relation with coffee. Additionally, ginger's deep feeding characteristics pose challenges in coffee systems, requiring substantial amounts of organic and inorganic fertilizers. Similarly, turmeric has invasive traits that can negatively affect coffee if not properly managed. The agroforestry system is commonly practiced in the study area, with coffee as the primary crop, often inter-cropped with other species such as maize, beans, khat, ginger, banana, avocado, karorima, and others (Teketay et al., 2010; Tadesse et al., 2014; Tegegn et al., 2017).

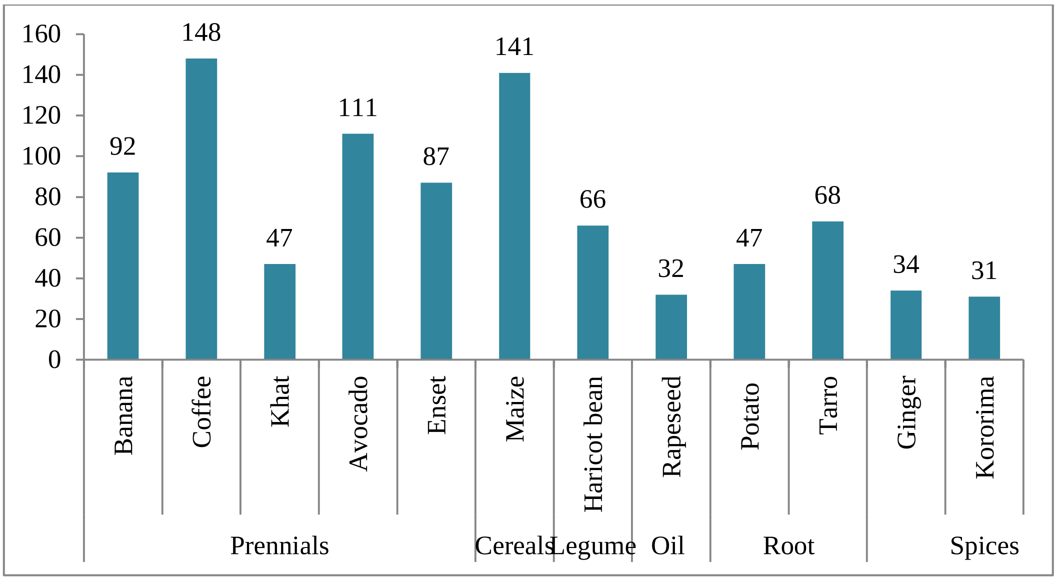


Fig. 2 Supplemental crops produced in the study area

Suitability Potential of CPS for Inter-Cropping and Crop Diversity

The suitability of CPS (Coffee Production Systems) for inter-cropping is sequentially presented in Table 3. Respondents indicated that the potential of CPS for inter-cropping was ranked from most suitable to least suitable as follows: Garden Coffee (54), Semi-Forest Coffee (24), Semi-Plantation Coffee (6), and Forest Coffee (0). This ranking was based on the intentional integration of crops within these systems. However, there is a limited occurrence of naturally growing edible spices, medicinal plants, and trees in forest coffee systems. Additionally, forest coffee systems often include wild honey-producing plants and species with medicinal value, which are not considered man-made inter-cropping practices. Despite this, such natural inter-cropping provides significant ecological and societal benefits alongside coffee production.

Several studies in Ethiopia on coffee-based agroforestry have highlighted that garden coffee systems are highly suitable for inter-cropping and contribute substantially to food security (Worku et al., 2015; Jemal et al., 2021; Fahad et al., 2022). The results of this study demonstrate that garden coffee systems exhibit significant inter-cropping potential, with the scale and intensity of inter-cropping influenced by factors such as the age of coffee plants, the presence of wild animals, the skill level of producers, and the adoption of local technologies. In contrast, semi-forest coffee systems offer limited opportunities for inter-cropping.

The study also revealed that certain spice crops, such as ginger, turmeric, Korarima, taro, and enset, are intentionally integrated into semi-forest coffee systems due to their lower susceptibility to damage by wild animals. Additionally, fruit crops (e.g., orange, mango, and avocado) and root crops (e.g., sweet potato) are occasionally inter-cropped in semi-plantation systems, where wild animals have minimal impact on the inter-cropped species. Semi-plantation coffee systems show potential for future inter-cropping, while plantation and forest coffee systems were reported to be unsuitable for edible crop diversification. The highest biodiversity is observed in successional agroforestry systems and multi-strata home gardens (Montagnini, 2020). Home garden coffee-based agroforestry systems play a critical role in supporting smallholder livelihoods and are rich in purposeful genetic resources.

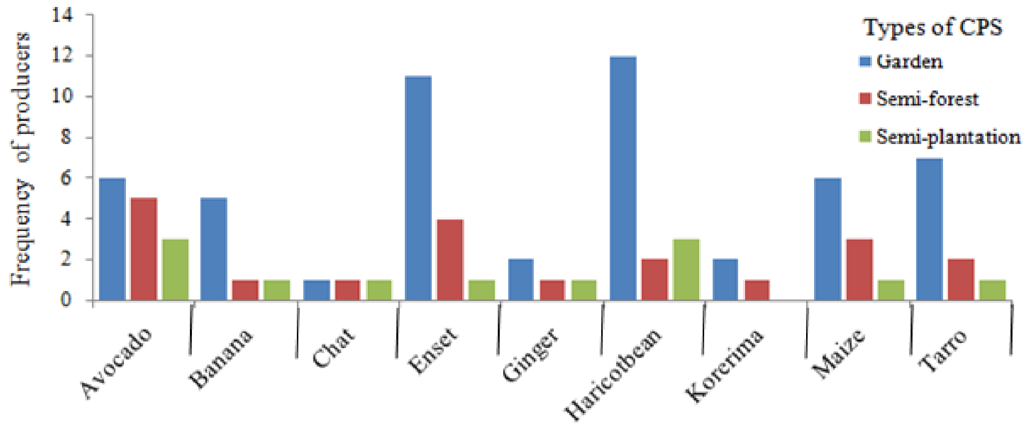
Table 3 Farmer Responses on the Suitability of CPS Types for Inter-cropping

Types of CPS	Responses of farmers in Inter cropping in CPS		Total
	No	Yes	
Forest	0	0	1
Garden	10	54	64
Semi forest	48	24	72
Semi plantation	5	6	11
X^2		0.000	

Respondents identified various crops used for intercropping, as illustrated in Figure 3. The species of crops intercropped in the study areas included common bean, enset, banana, avocado, taro, and maize, across three cropping systems (CPS): garden, semi-forest, and semi-plantation, each with distinct scales. Farmers intercropped these crops intentionally for specific purposes. For example, leguminous species such as common bean, soybean, and faba bean were planted in coffee fields during the first two years to improve soil fertility, reduce competition, achieve early maturity, ensure food security, and manage weeds.

Other pseudo-stem edible crops, such as banana and enset, were found to be important for providing shade, acting as windbreaks, and managing open spaces between coffee trees. In Ethiopia, enset is a staple food security crop and plays a significant role in supporting small-scale food security, benefiting coffee production in the past, present, and future. For instance, approximately 20–30 million people in southwestern Ethiopia rely directly on enset for their food security, either as a sole crop or intercropped with coffee (Abebe, 2013; Ayalew, 2018; Senbeta et al., 2022). A formal coffee-enset intercropping ratio of 3:1 provided a relative efficiency ratio (RER) of 1.63 and a 63% yield advantage compared to sole cropping (Ajema and Nuguse, 2021).

Coffee-banana intercropping is widely practiced in East Africa, including Rwanda, Uganda, and Kenya, and is increasingly being adopted in Ethiopia. For example, coffee-banana intercropping reduced irradiance by up to 60% while maintaining the same net primary production as other fields (Burgess et al., 2022). A coffee-banana intercropping ratio of 3:1 (3 coffee plants to 1 banana plant) resulted in a land equivalent ratio (LER) of 1.78 and a net benefit of 55% over sole coffee production (Tehulie and Nigatie, 2023). This approach demonstrates an efficient use of resources within the soil-plant-atmosphere continuum, optimizing soil, trees, sunlight (radiation), and water resources.



Beehive Holders in the Study Areas

The majority of respondents in southwestern Ethiopia utilized both modern and traditional beehives, which are closely associated with the coffee production system (Fig. 4). Respondents from Masha, Gera, and Yirgacheffe were more involved in both traditional and modern beehive production alongside coffee cultivation. Coffee production is often compatible with honey production, and this compatibility has been reported multiple times. Beehives were reported in all districts; however, Boloso Sore district had the lowest number, with only traditional hives reported. In contrast, Masha, Gera, and Yirgacheffe districts practiced both traditional and modern beekeeping, albeit with fewer modern hives. The integration of beekeeping and coffee production is intentionally practiced due to the significant role of beehives in supporting pollination. Bareke and Addi (2019) reported that beekeeping is a common practice in the southwestern regions, where coffee farming is predominant, and is often integrated to enhance productivity and diversify income. The integration of either traditional or modern beehives into the coffee production system has been shown to contribute to increased coffee production (Amssalu and Adgaba, 2014).

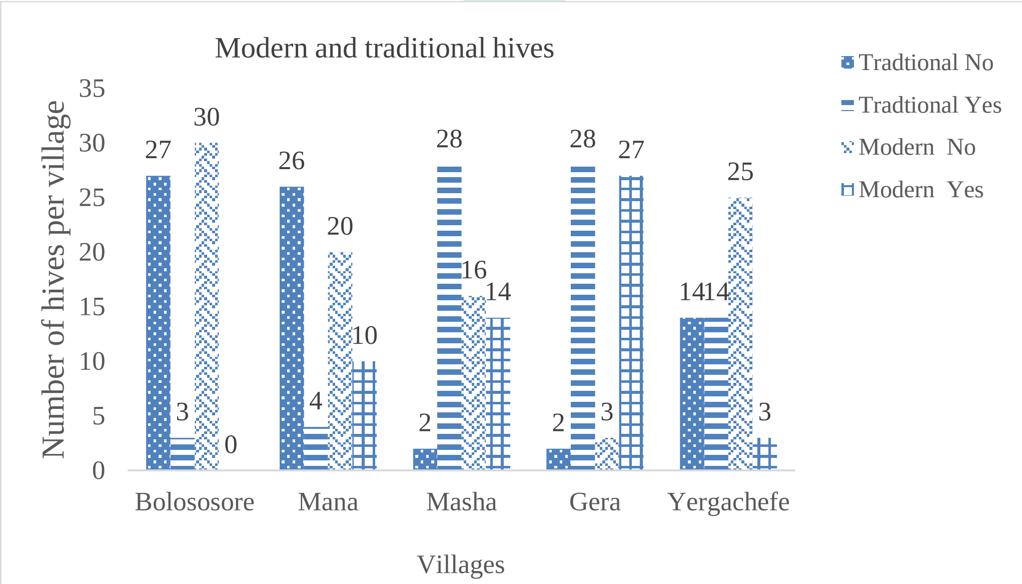


Fig. 4 Beehive holders across districts of the study area

Major Shade Trees in the Study Area

The impacts of shade trees on coffee production systems (CPS), including both advantages and disadvantages, are summarized in Table 4. Respondents identified several benefits of shade trees for coffee cultivation and the surrounding environment. These benefits include increased income and improved land use efficiency (LUE) which reported by 71.62% of respondents, enhanced microclimate regulation by reducing temperature during the day (-) and improve over night (+) and temperature stabilization (64.86%), improved soil quality (52.70%), control of sunlight 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 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 and ecosystem services. Consequently, respondents identified several positive effects of shade trees on coffee and its ecological niche. Schnabel et al. (2019) reported that coffee production under shaded systems is more sustainable than intensive conventional systems cultivated in full-sun plantations. The integration of leguminous tree species is vital for improving soil fertility and supporting organic production systems, offering a promising alternative with productivity levels comparable to medium-intensity conventional systems (Meylan et al., 2017).

Conversely, respondents highlighted a few negative impacts of shade trees (Table 4), including competition with coffee crops for resources reported by 23% of respondents, serving as hosts for pests and wild animals (16.89%), reduced coffee yields due to excessive shading (11.49%), and increased 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. Ayalew et al. (2022) reported similar findings, noting that shade trees provide habitats for wild animals, insect pests, and diseases. Overall, respondents concluded that the negative impacts of shade trees can be minimized through proper planting and tree management systems. Aligning with this perspective, Meylan et al. (2017) concluded that well-managed shade systems provide beneficial services, and the lack of significant negative impacts on overall coffee yield was not unexpected.

Issues of coffee production and shade is simultaneous, seems not separate in Ethiopia. During raised shade issues automatically missed its as under-story is coffee and vise versa. Even elders still informally thought that coffee produced from open field expressed low in quality, short life span, and appear like out of coffee norms. Thus this study underline that shade is critical in coffee production, though its disadvantage can be controlled either by management or integrated system.

Table 4 Merits and Demerits of Shade Trees in Coffee Farms

Advantages of shades tree	**%age**	**Disadvantages of shade tree**	**%age**
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 abiotic stress	21.62		
Reduce management cost and weeding frequency	13.51		
Used as windbreak	12.16		

%age: percentage

Types of CPS Used for Food Security and Their Reasons

The potential significance of CPS in ensuring food security is illustrated in Table 5. The findings revealed highly significant association ($p < 0.01$) between the type of CPS and inter-cropping practices. Among the various types of CPS, 77.7% of respondents confirmed garden system is most significant contributor to food security due to its suitability for inter-cropping with both crops and fruit species. Producers preferred the integration system practiced with various crops in the garden system because of its potential to provide multiple sources of daily food. This was identified as a key advantage of the garden coffee system, which complements the primary crop, coffee. The income generated per unit area of garden coffee was found to be more advantageous than that of sole coffee plots, whether during the early stages of planting with annual crops or throughout the cultivation period with fruit crops. For instance, enset inter-cropping provided economic benefits of 9-11% compared to sole coffee crop plots, as studied at the Jimma Research Center (Netsere et al., 2015).

Although other CPS offer opportunities for inter-cropping, challenges such as wild animal interference (e.g., apes and monkeys) and theft often hinder their success. In contrast, garden coffee, typically located near homes, is easier to manage during extra hours (e.g., early morning, evening, or after completing planned tasks such as village meetings or religious gatherings) with or without prior planning. While respondents ranked the semi-forest coffee production system as second to garden coffee in terms of contributing to food security, they also reported significant challenges posed by wild animals. These challenges primarily affected annual crops, including root crops like taro and enset, as well as certain fruit and spice crops.

Coffee researchers in Ethiopia have developed suitable inter-cropping technologies that integrate coffee with other crops such as banana, enset, korarima, and avocado, which are well-adapted to the southwestern regions of the country. Jamal et al. (2021) emphasized that coffee-based agroforestry systems contribute to food security by enhancing food availability, utilization, stability, sovereignty, and access. Furthermore, coffee inter-cropped with suitable crops demonstrated highest land equivalent ratios (LER) and marginal returns. For example, coffee inter-cropped with banana showed 911% marginal rate of return and an LER above 2.3 (van Asten et al., 2011). Thus, the ecosystem services provided by CPS through inter-cropping have expanded significantly, offering solutions to current challenges such as food insecurity, climate change, and income enhancement.

Table 5 Types of CPS and Their Contributions to Food Security Achievements

	Reasons			
	High yield and inter cropping	**Inter cropping**	**Manageable**	**Manageable and Inter cropped**
Garden	1.00	115 (77.7%)	1.00	1.00
SFC	0.00	31 (21%)	0.00	0.00
X^2	0.00**	.00**		

SFC = semi forest coffee

Roles in Soil and Water Conservation (SWC) and its Reasons

Table 6 presents farmers' responses regarding the types of conservation practices and CPS deemed effective for soil and water conservation, along with their associated reasons. Statistical analysis revealed a significant ($p < 0.05$) association between farmers' preferences for specific soil and water conservation practices and their reasoning. The findings suggest that SWC is more strongly linked to maintaining ecological balance, in contrast to practices observed in many developing countries, where population pressure drives farmland expansion at the expense of natural resources. Moat et al. (2017) reported an inverse correlation between rural population growth and the conservation of natural forests, while noting a strong positive correlation with deforestation.

Forest Coffee (FC) and Semi-Forest Coffee (SFC) systems were found to significantly contribute to soil and water conservation for various reasons. Shade trees, whether deliberately planted or naturally occurring within coffee fields, were identified as key factors improving soil and water conservation, as illustrated in Figure 6. Consequently, minimal or zero manipulation during the management of FC and SFC systems was identified as beneficial for conservation. The lowest intensity of management in these systems was positively correlated with soil and water conservation in the fields. However, an inverse relationship was observed between SWC and intensive management practices. Boroux et al. (2016) reported that nutrient recycling and ecosystem services were significantly affected by the intensive use of industrial fertilizers, pesticides, and reduced shade tree diversity. Thus, in descending order of their contribution to soil conservation, garden, semi-plantation, and plantation coffee systems were found to be less effective than forest-based systems, though still superior to annual crop systems.

Evidence from Fahad et al. (2022) indicated that coffee-based agroforestry systems reduced soil erosion and surface runoff more effectively than monoculture coffee production systems. Additionally, agroforestry within CPS has been shown to serve as an effective physical soil conservation measure, preventing soil loss and promoting decomposition processes that enhance soil physico-chemical properties (Bulitta & Duguma, 2021; Jemal et al., 2021; Fahad et al., 2022; Castillo et al., 2024). Another study reported that agroforestry systems exhibited a 50% lower soil erosion rate compared to monoculture systems (Fahad et al., 2022). Moreover, these systems demonstrated a 25 - 40% advantage over other SWC practices, such as minimum tillage, no-tillage methods, and the use of cover crops.

Table 6 Types of CPS and Reasons Selected for Soil and Water Conservation

	Reasons			
Types of CPS	**No manipulation and disturbances**	**Shade tree and less management**	**Shade trees**	**Total**
FC and SFC	4.00	143	1	148
Pearson X^2	0.00**			

Contribution of CPS to Soil Fertility

The components of CPS used to improve soil fertility are illustrated in Figure 6. The majority of respondents recognized the importance of CPS in enhancing soil fertility. Out of 148 respondents, 146 identified litter fall, 112 acknowledged nitrogen fixation, 141 noted crop residues, 141 highlighted improved soil organic matter, 117 mentioned farmyard manure, and 84 recognized coffee byproducts as key components of CPS that contribute to soil fertility improvement.

Soil conservation is closely linked to food security, population dynamics, and awareness levels. In developing countries, farmland is highly vulnerable to erosion due to intensive farming practices, knowledge gaps, and overpopulation. Consequently, CPS provides an effective alternative for sustainable soil management, delivering essential ecosystem services to humans and other organisms, in addition to its economic benefits. Muleta et al. (2011) reported similar findings, with approximately 86% of respondents indicated that coffee plants benefit from shade trees through enhanced nutrient absorption and improved soil moisture (79.1%), primarily attributed to shade tree foliage. Additionally, 69.1% of farmers expressed a strong preference for shaded coffee plants over unshaded ones.

Most respondents described the coffee production system as a form of savings, akin to a bank, and expressed hope that coffee fields would benefit future generations. Today, CPS serves as a source of income, ensures food security, and fulfills various secondary purposes while preserving invaluable soil resources for future generations. Unlike other tree fields, such as Eucalyptus globulus, which deplete soil moisture and make it difficult to restore soil health, coffee fields offer multifaceted benefits. Coffee fields represent hope for future generations, and multi-advantage shade trees are integral to their success. Therefore, the propagation of suitable shade trees, whether fruit-bearing or otherwise, is essential in coffee-growing areas.

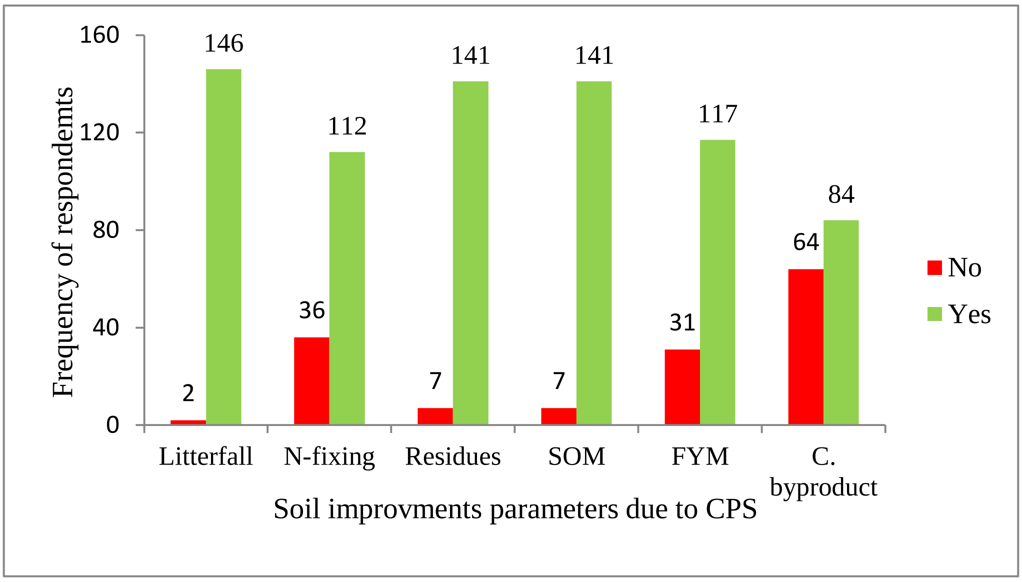


Fig. 6 Soil improvement parameters in CPS (n = 148)

Suitability of CPS in Biodiversity Conservation

Biodiversity conservation is another advantage of CPS at various scales, as presented in Table 7. Respondents ranked CPS based on their effectiveness in conserving ecosystem diversity, from highest to lowest, with statistically significant associations ($p < 0.01$). Based on the expected biodiversity richness of each production system, 132 out of 148 respondents ranked CPS in the following order: forest coffee (FC) > semi-forest coffee (SF) > shade-planted coffee (SPC) > garden coffee (GC) > plantation coffee (PC). According to the respondents, forest coffee (FC), which experiences minimal human activities and management intervention, was considered the richest in biodiversity. In contrast, plantation coffee (PC), characterized by intensive management and modern production systems, was ranked as having the lowest biodiversity.

The primary objective of forest coffee is to conserve the genetic diversity of coffee and forest ecosystems, including their ecological niches. In contrast, the main goal of plantation coffee is to increase production and productivity, even though it partially adopts agroforestry practices. There is an inverse relationship between biodiversity conservation expectations and the intensity of management. The species diversity and composition of a coffee production system are influenced by the level of management (Worku et al., 2015). Increased intensification across a production system gradient has been shown to result in higher species dominance and lower diversity. Species evenness and dominance in CPS are strongly associated with intensive management, while species diversity and richness are linked to less intensive management systems, such as those observed in forest coffee (FC) and semi-forest coffee (SFC).

These findings align with studies conducted in other regions, including Indonesia, Mexico, and Tanzania (Kessler et al., 2005; Duguma and Hager, 2010; Worku et al., 2015). For example, Boreux et al. (2016) confirmed that ecosystem diversity decreases with the intensity of management in agroforestry coffee systems. This further supports the observed inverse relationship between biodiversity and management intensity.

Table 7 Types of CPS suitable for Maintenance of Biodiversity

Types of CPS	Reasons Based on intensity of management	Total
FC>SF>SPC>GC>PC	132	148
FC>GC>SC>SPC>PC	11	11
FC>SFC>PC>SPC>GC	5	5
X^2	0.00**	

FC =forest coffee, ***SF*** = semi forest coffee, ***SPC*** = semi plantation coffee, ***GC*** = garden coffee, ***PC*** = plantation coffee

Roles of Coffee Production Systems in Gender Dynamics

The respondents' perspectives on the effects of Coffee Production Systems (CPS) on gender dynamics were categorized as either positive or negative, as detailed in Table 8. Consistent with other parameters, CPS was found to play a significant and positive role in the daily lives of women, men, and youth. The specific benefits for each group are outlined in Table 8. In addition to formal and quantifiable advantages, producers emphasized the substantial role of the coffee industry in providing specific job opportunities. For instance, low-income and marginalized women are often engaged in tasks such as cleaning broken, dirty, and inert materials from green coffee during processing (both dry and wet methods), as well as harvesting. In contrast, activities such as field management, harvesting, and grading are more frequently practiced by men and youth than by women. According to Sari et al. (2020), CPS enables individuals of both sexes to identify and prioritize the types of activities they prefer, thereby making these activities more profitable.

Table 8 Roles of CPS in gender dynamics and specific benefits

Responses (%)	Women	Men	%age	Youth	%age
No (%)	20.27	No (%)	29.73	No (%)	45.95
Yes (%)	79.73	Yes (%)	70.27	Yes (%)	54.05

%age= percentages

Gender-Specific Benefits from CPS

Gender groups (women, men, and youth) derived distinct benefits from Coffee Production Systems (CPS) at varying scales (Table 9). Respondents reported that women benefited from CPS through additional income (91.89%), home consumption (37.84%), job opportunities (16.89%), firewood (84.19%), construction materials (9.14%), medicinal resources (0.68%), reduced dependency on coffee yield (4.73%), and fodder (0.68%). These benefits were in addition to the primary yield from coffee production.

Similarly, men obtained advantages from CPS, including home consumption (13.51%), job opportunities (8.11%), firewood (3.38%), diversified food sources (1.35%), reduced burden on coffee production (8.11%), construction materials (23.18%), additional income (35.81%), charcoal (2.70%), recreational opportunities (2.03%), and beekeeping (1.35%), alongside coffee yield. Youth also received specific benefits from CPS, such as income sources (51.54%), firewood (27.43%), diversification opportunities (71.35%), fumigation sources for beehives (50.68%), construction materials (11.49%), job opportunities (3.38%), reduced anxiety (0.68%), recreational purposes (52.70%), and educational support (52.03%).

The garden coffee production system is predominantly managed by women, who often utilize it for daily consumption, thereby contributing to household food security, albeit with limited recognition from their husbands. In contrast, men (husbands) typically assume responsibility for formal payments and construction activities, accessing resources such as wood, timber, honey, fodder, and medicinal products from garden, semi-forest, and forest coffee systems.

Youth, on the other hand, derive additional income from CPS components, either through direct sales or employment opportunities within coffee fields. This income supports educational expenses and other personal needs. Overall, the components of CPS provide significant benefits to women, men, and youth, extending beyond coffee yield alone.

Table 9 Gender-Specific Benefits from Coffee Production Systems

Women special benefits		Men special benefits		Youth special benefits	
Reason	%age	Reason	%age	Reason	%age
Additional income	91.89	Home consumption	13.51	Sources of Income	51.54
Home consumption (food security)	37.84	Job opportunity	8.11	Fire woods	27.43
Job opportunities	16.89	Firewood	3.38	Income Diversification	71.35
Fire wood	84.19	Diversify foods	1.35	Fumigation sources hives	50.68
Economic benefit	8.78	Reduces burden on coffee	8.11	Construction material	11.49
Construction materials	9.14	Construction materials	23.18	Job opportunity	3.38
Recreation places	4.73	Additional income	35.81	Reduces anxiety	0.68
Reduced coffee dependent costs	4.73	charcoal	2.70	For recreational	52.70
Medicinal values	0.68	Recreation	2.03	Quality opportunity	0.68
Fodder	0.68	Beekeeping	1.35	For study coverage	52.03

SUMMARY AND CONCLUSION

Coffee production occupies major forested areas in the southwestern region of Ethiopia, providing significant ecosystem services. The majority of these forests are preserved due to the additional benefits embedded within the agroforestry systems associated with coffee production. This is evident as coffee serves as the backbone of Ethiopia's economy. Approximately 95% of coffee is produced by small-scale farmers, supporting more than a quarter of the country's population and contributing entirely to the national foreign currency earnings. Durign this study of CPS role in ecosystem services, five distinct types of coffee production systems are identified: forest coffee (FC), semi-forest coffee (SFC), semi-plantation coffee (SPC), garden coffee (GC), and plantation coffee (PC), each tailored to meet specific needs. Importantly, each production system plays a significant role in delivering ecosystem services alongside its economic contributions.

This study evaluates farmers' perceptions of the role of coffee production systems (CPS) in providing ecosystem services, which are critical for maintaining sustainability, supporting production, and guiding future sustainable coffee production technology developments. The survey results indicate that farmers are well aware of the additional benefits provided by CPS. These benefits include provisioning services such as coffee yields, inter-cropping crops, honey, timber, and other woody resources, as well as regulating services like soil and water conservation, climate change mitigation, environmental balance, biodiversity conservation, gender roles, and aesthetic values.

In conclusion, CPS plays a substantial role in supporting food security, not only through coffee production but also by enhancing ecosystem services. It demonstrates significant contributions to environmental preservation, biodiversity conservation, and overall sustainability.

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