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Research Article

Enhancing environmental sustainability and income diversification through agroforestry practices in the Dollo Watershed, Kamba Zuria District, Southern Ethiopia

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Abstract

This study evaluated the contributions of agroforestry to community welfare and environmental health in targeted regions. Data were collected from 231 farm households across five villages using close-ended and open-ended questionnaires, complemented by focus group discussions with community leaders male and female heads of households, and farmers with various experience levels. A relative scoring method was employed to rank preferred woody species, with results indicating that 90% of participating farmers integrated agroforestry with monocropping, while only 9% practiced non-agroforestry agricultural activities. Among the 32 most preferred tree species identified for agroforestry, 79% were native and 21% were exotic. The findings revealed that 91% of respondents viewed agroforestry as their primary source of income while the 9% relied on non-agroforestry agricultural activities. Furthermore, 51% of households believed that agroforestry enhances biodiversity compared to monoculture, and 66.67% recognized increased crop output as its main advantage. However, as data collection was confined to a specific timeframe, seasonal variations in agroforestry systems and income generation were not fully captured. This underscores the necessity for innovative extension services and proactive engagement from governmental and non- governmental organizations to enhance the role of agroforestry in improving rural livelihoods and the environment.

Keyword: Carbon sequestration; Community; Environmental sustainably; Income; Soil improvement

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1. Introduction

Ethiopia's economy is based on agriculture, which provides employment opportunities for 85% of the population, accounts for approximately 90% of exports, supplies over 90% of the raw materials for agro-industries, and generates 33.88% of the country's GDP (Zenebe et al., 2011). However, ensuring food security for the Ethiopians is becoming a big challenge, as a result of the rapid population growth, rapid urbanization, negative consequences of climate change, increasing demand for agriculture and forest products and civil conflict (Yigezu, 2021). At a rate of 2.5 percent

per year, Ethiopia's population is expected to reach 171.8 million by 2050 (Bekele and Lakew, 2014). The demand for livestock and agricultural products will rise as a result (Hemathilake and Gunathilake, 2022). Adopting agroforestry techniques is crucial to reducing them. Many current and upcoming environmental issues may be resolved with the help of agroforestry, a traditional land use system (Pantera et al., 2021). The intentional integration of a woody component with an agricultural output in the lower story is part of the sustainable land management practice known as agroforestry (Damianidis et al., 2021).

In recent years, agroforestry has gained recognition as a crucial practice for promoting environmental sustainability and enhancing community livelihoods, particularly in regions such as Ethiopia. Empirical evidence confirms that agroforestry adoption supports to the farming income by generating an assured income for the local community (Rosati et al., 2020; Tesfay, 2024). Study carried out by Mulugeta and Mabrate (2017) Gedeo's indigenous agroforestry practices provided 40% of Ethiopia’s premium grade coffee. Current studies of Bussa and Feleke, (2020) result revealed that increased income source and food security values of agroforestry practices for farmers had positive impression on their living standard.

The addition to the understanding of how agroforestry methods will become a conduit for sustainable agricultural land management, environmental benefit, and as such, help link science to practice, is what makes this special issue novel. According to Mosquera-Losada et al. (2020), agroforestry is a way to meet the European and global biodiversity targets while addressing the world's biodiversity problems. An extremely promising technique for Mediterranean regions with traditional olive agroforestry systems is the work of Mantzanas et al. (2021), which advances our understanding of intercropping perennial trees with species of cereal crops. According to Bateni et al. (2021), agroforestry has the potential to restore and improve soil health while reversing the effects of climate change in a variety of ways. One of the most important resources for the wellbeing of natural and agro-ecosystems is undoubtedly healthy soil, which allows them to continue producing food and providing ecosystem services.

Agroforestry promotes eco-intensification based on a more effective use of the land resources while offering a variety of provisioning, regulating, cultural, and supporting ecosystem services and environmental advantages. The impact of agroforestry on the environment in general and on climate change, carbon sequestration, and forest fires in particular, however, has not received much attention in recent years. Several articles that discuss the various environmental advantages that agroforestry offers are included in this special edition. This special issue's addition to our understanding of how

agroforestry methods will become a means of managing agricultural land sustainably and the multifaceted benefits that agroforestry offers to the environment and people in the study region is what makes it distinctive. Although agroforestry's potential advantages are becoming more widely acknowledged, there isn't much thorough research that focuses on the Dollo Watershed and its particular environmental and socioeconomic circumstances.

2. Materials and Methods

2.1. Study setting

The Dollo watershed in Southern Ethiopia's Kamba Zuria area served as the study's site. The watershed under study is located between 39° 37" E and 9° 41" N. 607 kilometers southwest of Addis Ababa, the capital. The watershed is a portion of Ethiopia's Gamo highlands, which are part of the Omo basin. The elevation and topography of the watershed vary greatly, ranging from 1647 to 2180 meters above sea level. The region experiences 19.7 °C of annual average temperature and 1470 mm of yearly average precipitation. The farming system is reliant on rainfall.

2.2. Sample size determination and sampling technique

A household sample size was determined (Eq. 1) based on Yamane developed method (Yemane, 1967).

$$n = \frac{N}{1+N(e^2)} = 547/6.47 = \mathbf{231} \quad (1)$$

Where, N is total household, n is number of sample size and ‘e’ is precision level for this case 5%. Systematic random sampling was used for selecting the participants from the total households as the total list of households was available.

2.3. Data collections

Data were collected from January 2022 to April 2023. Primary data for the study were collected using close-ended and open-ended questionnaire. The watershed had a total population of 547 household farmers of which 231 were selected systematically from household. Household socio- economic characteristics, farmers’ species preferences, and agroforestry contribution to income diversification and environmental benefit were collected through questionnaire, focus group discussion and key informant interviews.

2.3.1. Key informant interviews

Key informant interviews were conducted to get their opinions on how agroforestry contributes to household income diversification. Key informants include agriculture development

agents, elders, young farmers, model farmers, and the head of the kebele government. Forty key informants were chosen for interviews from five villages.

2.3.2. Focus group discussions

Members of the kebele administration were chosen at random to participate in two focus groups. Gender group separation gave both men and women an equal chance to express and verify their views on how agroforestry contributes to household income diversification. Every interviewee was made aware of the goals, topics, and rationale behind the study. Their involvement was entirely voluntary. Discussions and communication between researchers and respondents were made easier by the participation of local agricultural development agents and kebele managers. The duration of each focus group session was one hour.

2.3.3. Questionnaire

The data were collected using a standard close-ended and open-ended questionnaire administered through face-to-face interviews. This questionnaire was filled for the same rural respondents who adopted agroforestry activities.

2.4. Data analysis

The data collected from the survey were first checked for completeness. The quantitative data was analyzed through descriptive statistical analysis such as frequency, mean and percentage. The qualitative data were summarized by using narrative analyses. Simple majority/Relative score was used to calculate species preference in the study area.

3. Results and Discussion

3.1. Socio-economic characteristics of the household

During household surveys, data on age, family size, land holding size, and educational status were collected. The mean age of the respondents was between 25 and 35 years. Most respondents were males (84.5%), and the majority of the respondents (77.38%) were married. Most of the respondents (62%) had undergone formal education, with the majority (23.81%) having completed primary education, few (21.43%) had attended secondary education. Majority of the respondents (66.67%) had land size between 0 and 0.5 hector (Table 1).

3.2. Agroforestry practice

According to the survey on agroforestry practices, the majority (95.2%) of the population engaged in home gardens, followed by parkland (64.3%), woodlots (60.7%), and grazing systems (36.9%), respectively (Figure 1).These findings are consistent with Berihanu et al. (2020), who found that in northern Ethiopia, parkland agroforestry (90%) was practiced alongside woodlots

(7%), home gardens (3%), and other land uses. The majority of the crops integrated with multipurpose trees, included *Zea mays* (maize) and *Eragrostis teff* (teff). Key informants explained that home garden agroforestry practices are the most dominant in the study area since they are simple to manage. Similarly, key informants raised that parkland agroforestry is next highly adopted practice because of providing extra yield and services to human and animals.

Table 1. Socio-demographic characteristics of the households

Households data	Variables	Frequency	Percentage
Sex	Male	195	84.5
	Female	36	15.5
Family size	4	44	19.04
	5	50	21.43
	6	41	17.85
	7	36	15.47
	8	22	9.52
	9	25	10.71
	10	14	5.95
Age	Below 25	52	22.62
	Between 25-35	83	35.73
	Between 35-45	55	23.8
	Above 45	41	17.85
Marital status	Single	25	11.92
	Married	179	77.38
	Divorce	11	4.76
	Widowed	17	7.14
Land holding size (hector)	Below 0.5	154	66.67
	Between 0.5-0.1	52	22.62
	Between 1-1.5	17	7.14
	Above 1.5	8	3.57
Educational status	Not read and write	88	38.09
	Read and write	39	16.67
	1-8th grade	55	23.81
	8-12th grade	50	21.43

3.3. Species preference among farmers

A total of 32 different tree species were identified as suitable candidates for agroforestry, with 21% categorized as exotic species and 79% classified as native species. From highest to lowest, these were the top 10 that a significant percentage of farmers preferred: *Persea americana* (93%), *Coffee arabica* (87%), *Cordia africana* (83%), *Croton macrostachyus* (73%), *Combretum molle* (57%), *Casuarina equisetifolia* (45%), *Olea africana* (43%), *Terminalia brownii* (39%), *Eucalyptus globulus* (38%) and *Eucalyptus grandis* (38%) from highest to lowest (Figure 2). This study is consistent with studies of Alao and Shuaibu, (2013) and Adewusi, (2006),

which showed that fruit trees both native and exotic are the most preferred. This suggests that food is considered the most important resource, and the fire wood species are also the second critical resources for human existence.

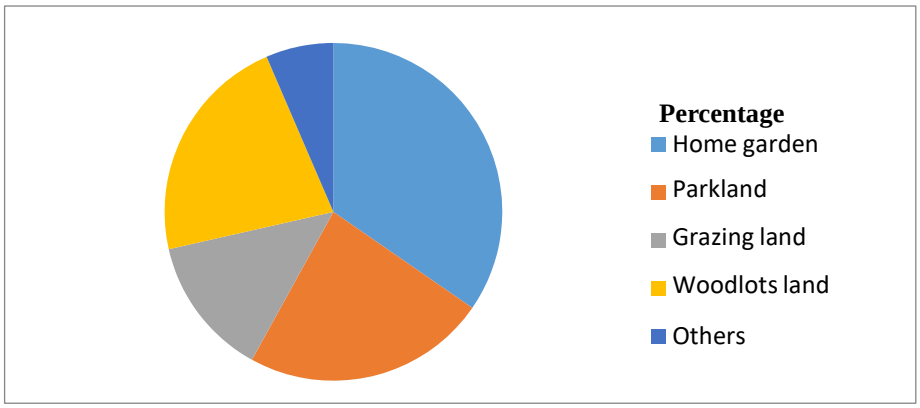

Figure 1. The dominant agroforestry practices in the study area

The results of the study also align with those of Nkurikiye et al. (2024), who discovered that farmers preferred growing trees that increase maize yields through agroforestry. Calliandra calothyrsus, Gliricidia sepium, and Senna spectabilis are being researched for their capacity to preserve natural resources, protect the environment, and yield excellent fuel wood in addition to their contribution to agricultural production (Kuyah et al., 2020). These findings also aligned with those of Tazebew and Asfaw (2018), who discovered that, in the context of coffee-focused agroforestry methods, farmers' decisions to plant native multipurpose trees on their properties influence the species' ecological and economic value.

A relative score was used to determine the preference rating for woody species. Among the species they plant and maintain, respondents were asked to rank the top nine woody species from most preferred to list preferred. The following woody-species were preferred in order of significance: *Persea americana* (93%), *Coffee arabica* (87%), *Cordia africana* (83%), *Croton macrostachyus* (73%), *Combretum molle* (57%). Their preference was were ordered based the species ability to serve multiple purposes, such as providing food, generating income, providing firewood, being used as building materials, serving to shed from sunlight, providing fodder, and enhancing soil fertility (Table 2). Woody plants, both native and alien, are valuable assets on farms because of their significance to farmers' daily life. In the study area, *Cordia africana* and *Terminalia brownii* were the first and second species to integrate with crops. For example, species of trees that benefit agricultural crops, such as *Cordia africana* and *Terminalia brownii*, are planted widely throughout agriculture fields, but species of trees that compete with crops are planted individually to lessen their impact. Farmers set a variety of requirements for integrating trees on farmlands, such as the trees'

ability to decompose quickly, their compatibility with crops, their multipurpose use value, their ability to promote soil fertility, and their low branch volume. In the Lemo district of Southern Ethiopia, similar results were observed in crop livestock tree mixed systems (Kuria et al., 2014).

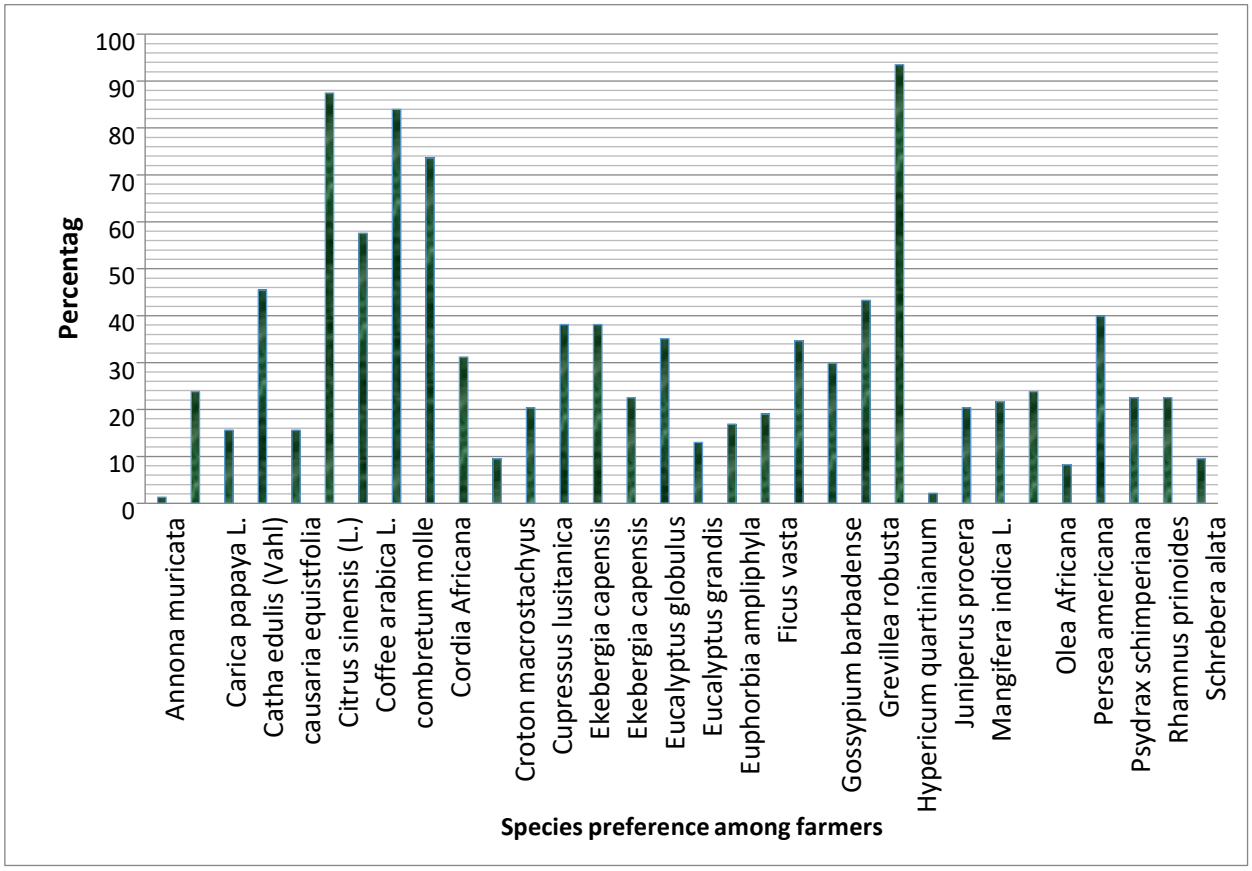

Figure 2. Species preference among farmers in the study area

The tree species found on grazing forms of agroforestry are incredibly large and dispersed, according to information from key informants. Based on information from key informants, field observations, and household interviews, the common tree species found in grazing land are Terminalia schimperiana, Cordia Africana, Terminalia brownii, Ficus vasta, Croton macrostachyus, and Terminalia laxiflora. According to data acquired from interviews with households, the types of trees recognized in agroforestry woodlots are large and densely populated. According to field observation and home interviews, the common tree species in woodlot agroforestry types are Cupressus lusitanica, Eucalyptus grandis, Eucalyptus globulus, Combretum molle, Terminalia brownii, and Croton macrostachyus. Agroforestry tree species that are found in woodlots are also listed.

Table 2. Respondents' species preference ranking according to their benefit in the study area

Species Scientific name	Respondents					Relative score					Total score	Rank	Reason of preference
	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th			
Persea americana	143	55	30	25	-	88.5	13.1	3.9	2.7	-	108.2	1st	2, 1 and 5
Coffee arabica	55	55	25	74	14	13.1	13.1	2.7	23.7	0.85	53.65	2nd	2,5 and 7
Cordia Africana	-	83	22	14	-	-	29.8	2.1	0.85	-	32.75	3rd	2, 3 and 4
Croton macrostachyus	-	8	17	25	80	-	0.28	1.25	2.71	27.71	31.95	4th	2, 3, 4 and 7
combretum molle	11	-	83	14	3	0.52	-	29.8	0.85	0.04	31.21	5th	2, 4, 5 and 7
causaria equistfolia	-	8	28	22	28	-	0.28	3.39	2.09	3.39	9.15	6th	3, 4, 6 and 7
Olea Africana	22	14	11	11	-	2.1	0.85	0.52	0.52	-	3.99	7th	7, 2 and 1
terminalia brownie	-	-	-	22	3	-	-	-	2.09	0.04	2.13	8th	5 and 7
Eucalyptus globulus	-	-	6	8	-	-	-	0.16	0.28	-	0.44	9th	3 and 4
Total	231	223	222	215	128								

Footnote: relative score was calculated by multiplying the number of respondents in each ranks by its proportion (e.g. 143*143/231=88.52). Reason of preference, 1= food, 2=income generation, 3= fire wood, 4= construction materials, 5= shade benefit, 6= animal fodder 7= soil fertility improvement

(n=231)

The results of FGD, key informant interviews, and household surveys indicate that farmers' choices for particular species rely on the significance of those species within each type of agroforestry practice and how those components interact with one another. This conclusion is consistent with that of López-Sampson and Andrade (2024), who found that farmers placed a high value on animal temperature regulation and that providing environmental services can make agroforestry species more appealing. Furthermore, the findings of Hailu *et al*. (2024) investigation showed that farmers' choices for woody species differed across the nation and that they planted various woody species according to their respective advantages.

3.5. Role of agroforestry to livelihoods diversification

The farmers in the study area generate household income from both agroforestry and monoculture farms. Out of the farmers surveyed, 90% practice both agroforestry and monocropping. Meanwhile, 9% of the farmers engage in non-agroforestry farming activities, and the remaining 1% is involved in non-agricultural pursuits. Additionally, 91% of households reported that their primary source of income comes from agroforestry operations, while 9% indicated that their main source of income stems from non-agroforestry farming activities. These

indicate that the agroforestry significantly increases farm income compared to non-agroforestry farm activities.

Table 3. Preferred tree species for different types of agroforestry in the Dollo watershed

Species scientific name	Home garden	Parkland	Grazing land	Woodlots	Percentage
Annona muricata	2	-	-	-	0.21645
Carica papaya	70	-	-	-	30.303
Catha edulis	12	-	-	-	5.19481
Casuarina equisetifolia	-	50	-	-	21.645
Citrus sinensis	13	-	-	-	5.62771
Coffee Arabica	110	-	-	-	47.619
Combretum molle	-	-	11	21	6.92641
Cordia Africana	0	0	36	23	6.38528
Croton macrostachyus	20	41	43	46	16.2338
Cupressus lusitanica	-	-	-	16	6.92641
Ekebergia capensis	-	12	-	-	5.19481
Eucalyptus globulus	-	-	-	34	14.7186
Eucalyptus grandis	-	-	-	31	13.4199
Euphorbia ampliphyla	-	-	-	19	8.22511
Ficus vasta	-	-	70	-	30.303
Gossypium barbadense	8	-	-	-	3.4632
Grevillea robusta	30	-	-	-	12.987
Hypericum quartinianum	-	-	-	14	6.06061
Juniperus procera	20	-	-	13	7.14286
Mangifera indica	60	23	-	-	17.9654
Olea Africana	-	32	7	-	8.44156
Persea Americana	120	98	-	-	47.1861
Psydrax schimperiana	-	-	-	18	7.79221
Rhamnus prinoides	60	-	-	-	25.974
Schrebera alata	-	-	9	-	3.8961
Syzygium guineense	-	-	-	19	8.22511
Tamaranus indicus	-	8	-	-	3.4632
Terminalia brownie	10	102	30	43	20.0216
Terminalia laxiflora	-	-	17	-	7.35931
Terminalia schimperiana	-	-	12	-	5.19481
Vernonia amygdalina	-	9	-	15	5.19481

Agroforestry can diversify Farmers' income in a number of ways. These include fruits, coffee, fodder crops, fire wood and dairy products. More than 93% of respondents use fruits from home garden agroforestry, such as banana, *Carica papaya, Persea americana*, and *Mangifera indica;90% use crops from parkland, such as Zea mays (Maize), Eragrostis teff (teff),*

haricot bean, and groundnuts; and 88% use woodlots, parkland, and home garden agroforestry for fuel and other wood products for construction. 83 % of the respondents declared that their primary source of income comes from coffee plantations, which are a significant cash crop in the region. 67% of all respondets employed home gardens, parklands, and agroforestry to produce fodder for animals (Figure 3). Fruit was the most popular product harvested from agroforestry trees, demonstrating how dependent farmers were on these items for their primary source of revenue. This outcome was consistent with findings from related studies which looked into the roles of agroforestry in increasing farmers' income (Mabel *et al*., 2017; Tharlakson, 2012; Quinon *et al*., 2010). This outcome was consistent with reports from other academics (Kalaba, 2010; Maroyi, 2009) that said that agroforestry's various productions have enabled people to build sustainable lives.

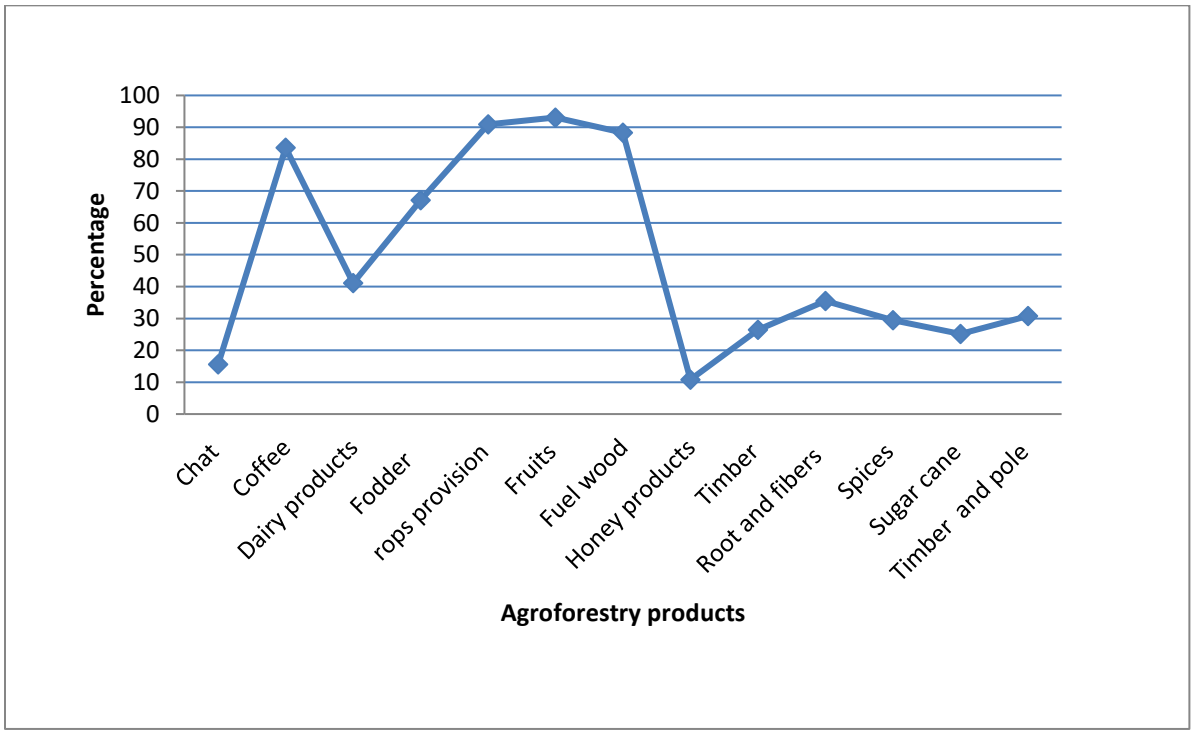

Figure 3. List of products to livelihoods diversification from agroforestry practices

3.6. Role of agroforestry to environmental sustainability

Based on the results of the poll, farmers concur that agroforestry contributes to environmental sustainability by making more nutrients available to the soil, which helps to preserve and restore soil fertility. Out of all the households surveyed, 51% thought that agroforestry offered superior woody biodiversity than mono cropping farming, while 66.67% thought that the main advantage of agroforestry techniques was an increase in crop yield. Out of all the respondents, 46% claimed that agroforestry could improve soil nutrient availability

and decrease soil erosion, while 36% claimed that it could provide shade for cattle and control the microclimate (Figure 4). Additionally, by increasing soil organic matter through leaf litter, agroforestry practices improve soil fertility. Traditional land use practices like agroforestry could help find a solution of environmental problems in agriculture (Pantera *et al*., 2021).

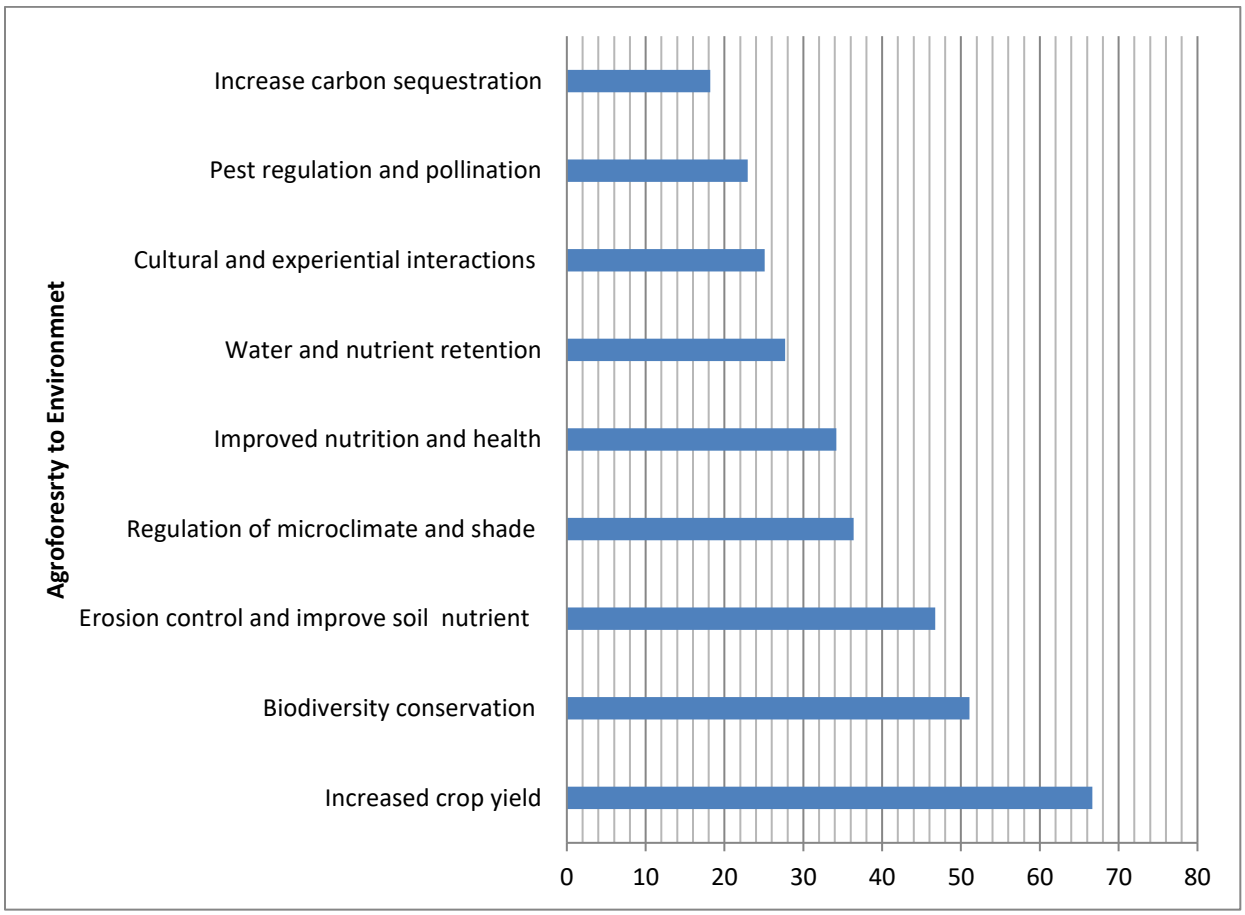

Figure 4. Contribution of agroforestry practices to environmental sustainability

One acknowledged effect of agroforestry practices was increased crop yield. This results from enhanced soil characteristics, microclimate, and nutrient levels (Fahad et al., 2022). The current findings in lined with (Akinnifesi *et al*., 2006; Castle, 2021), who found that agroforestry techniques can raise crop yields in many regions of the world. Agroforestry in the Umbria area of Italy improved soil health and counteracted the negative impacts of soil erosion in a variety of ways (Bateni *et al*., 2021; Pantera *et al*., 2021). This result is consistent with that of Ndalama *et al*. (2015), who found that the primary ecosystem services received from agroforestry were soil improvement, water and nutrient retention and conservation, and biodiversity conservation. Increased agroforestry adoption, according to Khanal (2011), lessens

the strain on forests and protected conservation areas. Furthermore, the present findings are consistent with the reviews conducted by Rolo *et al.* (2021) and Rosati *et al.* (2021), which suggested that implementing agroforestry techniques might enhance the sustainability of organic farming and augment soil fertility. Additionally, Tsegaye's (2023) study result shows that agroforestry practices provide protective services such soil improvement, climate regulation, biological conservation, and recreational value in addition to their productive role.

4. Conclusions

The study demonstrates that agroforestry significantly enhances the livelihoods and environmental sustainability of farmers. Practices such as home gardens, parklands, woodlots, and grazing systems are common, with a preference for multipurpose tree species like *Persea americana*, *Coffee arabica*, and *Cordia africana*. Agroforestry contributes to household income through products like fruits, coffee, and firewood, and improves soil quality, crop yields, and reduces soil erosion, aligning with previous research on its benefits for economic stability, biodiversity, and environmental resilience. To maximize agroforestry benefits, further research on species selection, management practices, and innovations is encouraged. Knowledge sharing platforms should be established to disseminate best practices. Integrating agroforestry into national and local agricultural policies can promote food security and income generation, especially in rural areas, through technical support, subsidies, and incentives. Agroforestry is vital for sustainable land management, enhancing soil fertility, and reducing soil erosion. It supports biodiversity conservation by promoting native, multipurpose species, contributing to ecosystem resilience. By providing diverse income sources, agroforestry reduces dependency on single crops and enhances resilience to market fluctuations and climate change, mitigating its impacts through improved soil health and carbon sequestration. Policymakers should consider agroforestry in climate adaptation and mitigation strategies, particularly in vulnerable regions.

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Conflict of Interest

The authors declare no conflict of interest.

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