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Role of Agroforestry in Biodiversity Conservation and Response to Climate Change

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***Abstract:** Agriculture is the primary driving force leading to biodiversity loss and environmental change. However, Agroforestry combines land use practices and is one of the proposed systems to merge biodiversity conservation, food production, and the delivery of ecosystem services. Therefore, agroforestry practices have received huge attention globally by delivering ecosystem services like biodiversity conservation and carbon sequestration. Understanding the role of agroforestry in carbon storage and biodiversity conservation is crucial for achieving an optimum balance and identifying existing gaps, such as which system performs better in different situations. The objective of this review is to synthesise various articles on the role of agroforestry in biodiversity conservation and climate response. To achieve this, multiple articles related to biodiversity conservation and climate response in agroforestry practices in Ethiopia were systematically searched in Google Scholar and synthesised. Consequently, based on this review, maintaining agroforestry is also vital for conserving faunal diversity in addition to flora. This area serves as a refuge for threatened, endemic, and native plant species retained from deforestation. Again, agroforestry is noted as having full potential in adapting to and mitigating the adverse effects of climate change. Therefore, further research should consider the sustainability of biodiversity conservation in agroforestry by facilitating agroforestry-based carbon payments, maximising the diversification of various agroforestry components, and developing a management strategy.*

***Keywords.** Agroforestry, Biodiversity, Carbon Storage, Species Diversity, Climate Change.*

Nomenclature:
AF: Agroforestry
Agc: Above-Ground Carbon
Bgc: Below-Ground Carbon
E: Evenness
E1/D:Simson Diversity Index
H':Shannon Diversity
L: Least Concern
Soc: Soil Organic Carbon
V: Vulnerable

I. INTRODUCTION

The loss of biodiversity and climate change are endangering around 40% of the world's population [1]. Agricultural expansion is among the primary driving forces leading to biodiversity loss and environmental change [2].

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This is due to the increasing demand for food, driven by rapid population growth and enhanced production through agricultural intensification and scale management [3]. However, this has raised food insecurity because of greenhouse gas emissions, soil degradation, water pollution, and biodiversity loss [4]. The consequence of ecosystem service degradation due to land use change and climate-related risk is a significant challenge for sustainable development and human well-being [5]. To alleviate such adverse impact, practising an agroforestry system becomes an effective means of reducing greenhouse gases in the atmosphere [6]. Agroforestry is proposed as a sustainable land management system option, as it offers both ecological and socio-economic benefits simultaneously [7]. Considering this, agroforestry practices have recently gained significant attention, as the loss of biodiversity and ecosystem services has become an increasingly pressing issue. Thus, agroforestry is a nature-based approach that delivers ecosystem services such as biodiversity conservation, carbon sequestration, improved soil quality, and preservation of air and water quality [8]. Another study also supports this statement, indicating that it's often a promising decision for biodiversity conservation and mitigation of ecosystem degradation [9]. Additionally, for a developing country relying on rain-fed agriculture, adopting agroforestry as the primary strategy can reverse global challenges, mainly climate change, food security, and land degradation [10].

Regarding Ethiopia, several studies have highlighted the importance of AF practices for enhancing carbon sequestration, improving soil fertility, and conserving biodiversity [11]. Even though AF systems play a significant role, they still lack adaptability, sustainability, and integration with indigenous knowledge. To achieve balance, we need to understand how agroforestry affects carbon storage and biodiversity conservation. This study aims to review existing research on carbon stock and woody species diversity, providing valuable insights for incorporating national strategies and policies on biodiversity conservation and climate change mitigation.

II. MATERIAL AND METHODS

A. Search Methods and Screening Criteria Literature

This review systematically conducted the latest literature from 2016 to 2025 based on systematic searching the published articles related to "contribution of agroforestry for carbon stock" OR" contribution of agroforestry for Biodiversity "in different parts of Ethiopia from Southern, Northern, Eastern, and South-western, North-western, mid-rift valley, and central highlands were included by using Google scholars and web of science.

III. REVIEW RESULTS AND DISCUSSION

A. Role of Agroforestry in Biodiversity Conservation

An agroforestry system can enhance the sustainability of biodiversity than treeless land. Farmers are planting trees, and conserving the existing trees on farmland can boost tree and woody species diversity [12]. Regarding the numerous studies conducted in different parts of Ethiopia, these confirm this statement (Table I). In a study by [13], the estimated Shannon diversity for home gardens was 2.17, significantly higher than 1.71 and 1.66 estimated for cropland and grazing land, respectively. Similarly, a recent study by [14] found that the highest Shannon diversity was in Home Garden 2.13, compared to 1.64 in the exclosure. Again the estimated Simpson and evenness to be 0.86 and 0.83 in home garden agroforestry was high, when comparing the estimated value of Simpson and evenness was 0.76 and 0.80 in exclosure. which is significantly lower compared to home garden. Also other study by [15], reported, the estimated Shannon diversity of 2.43 in the home garden was higher than the estimated Shannon diversity of crop land, grazing land, and wood lot. Other studies conducted in woodlot agroforestry practices have noted high species diversity [16]. Moreover, more species diversity and evenness were reported from the home garden at 3.27 and 0.87, respectively [17]. In line with this [18], they also report high diversity, evenness, and Simpson's index from the home gardens. The implication of higher diversity estimated in AF compared to crop land suggests that AF practice can create on-farm in situ sites important for conserving locally threatened plant species and multipurpose tree species.

Table I: Contribution of Agroforestry Practice to Woody Species Diversity

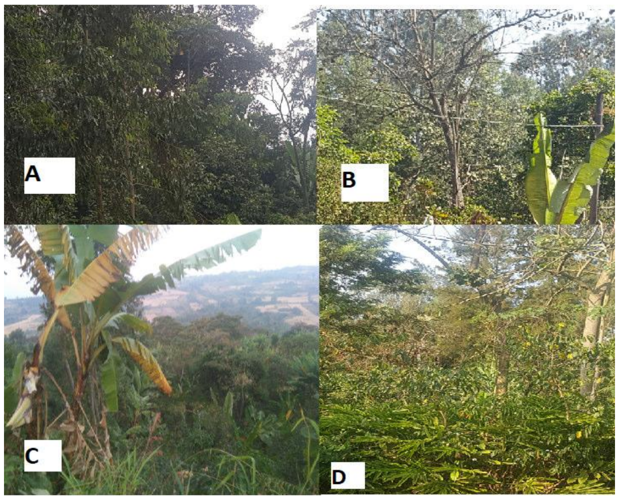
Agroforestry Practice	H'	E	E1/D	No of Plants	Source
Crop land	1.71 (0.18)		0.74(0.4)	3.55(0.4)	[13]
home garden	2.17 (0.18)		0.60(0.4)	4.35(0.4)	
forest	2.49 (0.19)		0.54(0.3)	4.90(0.3)	
grazing land	1.66(0.18)				
Homegarden	2.13(0.16)	0.83(0.08)	0.86(0.03)		[14]
Exclosure	1.64(0.23	0.80(0.11)	0.76(0.07)		
Homegarden	2.79	0.89			[15]
Grazingland	2.62	0.81			
cropland	2.16	0.94			
woodlot	0.30	0.21			
Home garden	3.27	0.87	0.053	4(3)	[17]
Home garden	1.31 (0.46)	0.79(0.16)	0.64(0.7)	6 (2.60)	[18]
Coffee based	1.22	0.78	0.65	4.95	[19]
Wood lot	0.20	0.21		1.53	[16]
Agroforestry	0.94	0.69	0.49	3.76	[20]

More agroforestry practices play a significant role in saving endangered plant species, endemic and native species, as described in (appendix 1 and 2). *Erythrina brucei, Millettia ferruginea, Pygeum africanum, Rhus glutinosa, Solanecio gigas*, and *V. Dainellii* are some endangered plant species recorded from farmland.

As described in the following (Fig. 1), most of the indigenous and endemic plant species were conserved on farmland agroforestry for different purposes. Regarding [2], noted *Acacia abyssinica, Albizia gummifera, Millettia ferruginia, Croton macrostachyus,* and *Sesbania sesban* for shading purposes. Similarly, *Millettia ferruginea*, *Vernonia amygdaline*, and *Croton macrostachyus* were dominant species recorded from Southern Ethiopia [19]. *Again, Cordia africana and Millettia ferruginea* are native and endangered species that farmers retain to enhance their soil fertility. *As well as Acacia nilotica*, *Tamarindus indica*, and *Ziziphus* spp., retained in farmland for fuel wood, farm tools, food, and medicine [22].

Regarding the number of native species compared to exotic species, among the 52 recorded plant species from AF systems, 33 (63.5%) were native [23]. Most studies conducted on different practices of AF in Ethiopia have also reported plant species listed under the IUCN Red List, which need priority for conservation. For instance, *Milletia ferruginea and Erythrina brucei were reported within several studies on agroforestry systems (*Appendix*).*

This implies that the AF system plays a significant role in the sustainable conservation of plant diversity, which is necessary to maintain ecosystem services and safeguard native and threatened species. A study conducted in home garden AF systems of central, Ethiopia by [24] confirms the contribution of AF systems in conserving plant species diversity.



[Fig 1.: Woody Species Diversity in Home Garden Agroforestry, Like *Cordia African* (A, B, C &D), *Aframomum Corrorima* (D), *Enset Ventricosum* (A&B), *Musa Paradisiaca* (C). [25]].

Regarding fauna conservation, the contribution of agroforestry to creating habitats for wild animals is clearly acknowledged. For instance, most of the wild animals were present in agroforestry compared to conventional agriculture. A review study by [25] revealed that agroforestry systems have great potential for both flora and fauna species. Plant species conserved on farms could provide multiple benefits to animals, such as nesting sites, safe places against predators, a source of food, and support for pollinator species [26]. The studies align with this report, as agroforestry in tropical areas serves as a reserve for insect species [27]. This

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indicates that maintaining agroforestry is vital for conserving both faunal diversity and flora.

Even though today several challenges could decrease the number of indigenous tree species in farmland, such as the lack of adequate research and extension services, the expansion of exotic trees, land and tree tenure insecurity, increased strategy towards market-oriented mono-cropping, and small land size of individual and invasive alien species [28], these factors are being addressed. The absence of a multidisciplinary system at the policy level poses a significant challenge to the use of indigenous tree agroforestry species. In Africa, many studies highlighted the lack of adequate information regarding indigenous trees, their characteristics, and functions [29].

B. Role of Agroforestry in Adaptation to Climate Change

AFPs offer numerous opportunities for economic and environmental support, helping farmers reverse the adverse impacts of climate change through the joint actions of adaptation and mitigation [30].

Regarding the contribution of AF in adaptation, many studies have confirmed that non-practising AF farmers have a higher livelihood vulnerability index than adopted farmers [31]. On the contrary, practising an agroforestry system helps to raise farm profit by enhancing resilience to current climate shocks and diversifying livelihoods [32]. These studies align with the research conducted by [33], who reported that agroforestry can increase local household food security by 25% and curb soil erosion. Again, it is noted for its ability to protect against the damaging effects of wind and water flow [32].

Not only this, agroforestry also contributes to offering various goods and ecosystem services crucial for responding to climate risk. For instance, [34] reports *Cordia africana* as a valuable fodder tree species during fodder shortages and as a source of income during rain shortages by producing timber. This evidence underscores how agroforestry helps farmers adapt and build resilience to the adverse effects of climate change [35]. In addition, *Acacia abyssinica, Albizia gummifera, Millettia ferruginia, Croton macrostachyus,* and *Sesbania sesban* are essential tree species for shading [21].

Moreover, some species are conserved on farmland for the direct benefit of food. *Citrus medica and Annona senegalensis* are reported among the most fruit tree species used for food [36] (Fig. 2). In Ethiopia, farmers used agroforestry as a source of honey production, for household tools, and the handles [34], as illustrated in (Fig. 2).

[Fig.2: Acacia Spp. (Left) Albizia Schimperiana (Right) is Used in Agroforestry for Hanging Traditional Bee Hives. [25]]

C. Role of Agroforestry Practices in Climate Change Mitigation

In line with mitigating climate change, combining crops and trees on agricultural land helps as a primary source of carbon sinks. Widely, the role of agroforestry in climate change mitigation is summarized in the following (Table II).

Additionally, the benefit of agroforestry in improving soil is acknowledged. Planting trees in agricultural land can enhance soil fertility, limit soil erosion, and improve water infiltration [37]. As a result, agroforestry can reduce water infiltration, thereby mitigate the risk of drought and address food insecurity by increasing yields by up to 30% in agroforestry-based systems compared to monocropping [38].

Agroforestry practices enhance SOC stocks by 25% compared to monocropping systems [39]. Several studies conducted in different parts of the world report the role of agroforestry systems in climate change adaptation. For instance, a study by [40] conducted in Tigray highlights that practising stone bands with multiple purposes can protect against soil erosion and enhance carbon stock. As a result, the estimated carbon storage indicated that agroforestry can sequester 772.02 Mg CO_2e per hectare reported from southern Ethiopia [41]. In line with this, several studies have been conducted on the contribution of different agroforestry practices in carbon storage [19]. For instance, [16] revealed that agroforestry practices greatly contributed to the storage of above and below-ground carbon stock, as well as soil carbon stock, in the home garden. The results of various research conducted on the biomass carbon of traditional agroforestry systems in Ethiopia indicate that it falls within the range of international reports (Table III).

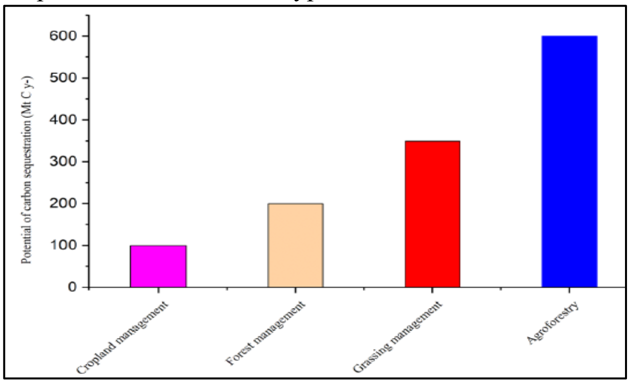
[42], reported the estimated total biomass carbon stock and soil carbon stock at 20.69 and 249.69, respectively. Similarly, recent studies confirm the potential of agroforestry in carbon stock compared with other land use types in Ethiopia. For instance, the estimated (171.17 Mg ha^{-1}) total carbon in home garden AF is larger than the estimated total carbon 78.06 and 92.5 Mg ha^{-1}, for crop land and exclosure, respectively [14]. According to [19], who studied home gardens in different parts of Ethiopia, home garden agroforestry demonstrates a high capacity to store above and below-ground carbon stock, as well as in the soil, compared to adjacent agricultural land with fewer trees (Table III).

Another study on parkland agroforestry found that it can store 8.3 and 51.3 tons ha-1 in total biomass and soil, respectively [43], consistent with a similar study reported by [44]. This also supported the study conducted by [45]. In line with this recent meta-analytic synthesis by [46], the noted average carbon storage potential in Agroforestry systems is reported as 3.5–9.8 Mg CO_2 ha^{-1} $year^{-1}$. Again [47], Ethiopia's semi-forest coffee agroforestry holds 75% of the carbon stored in natural forests. The above empirical data imply that agroforestry practices play a significant role in carbon storage, comparable to forests, and are greater than monocropping.

Table III: Different Studies Show Carbon Potential in Agroforestry in Ethiopia

Studied Site	Land Use System	AGC and BGC	SOC, Mgh^{-1}	Reference
Gedeo	Home garden AF	67.1	181	[48]
East Hararge	Coffee agroforestry	20.69	249.69	[42]
Southern Ethiopia	Home garden	70.1	137.1	[19]
Minjar Shenkora	Parkland	8.3	51.3	[43]
Northern Ethiopia	Home garden	7.8	108.8	[16]
	Parkland	7.8	71.7	
	Wood lot	31.1	96.9	
Northern Ethiopia	Parkland	10.9	20.1	[44]
Southern Ethiopia	Home garden	76	155	[49]
southwestern Ethiopia	Home garden	45.2	131.1	[50]

Regarding this, the overall estimate for all the land described in (Fig. 3) indicates that AF can store more carbon compared to other land use types.



[Fig.3: Carbon Stock of Diverse Across Land Use Adapted from [51]]

IV. CONCLUSION

Based on this review, Agroforestry as a combined land use system can offer significant benefits for the conservation of both flora and fauna and mitigate CO_2. The trees planted or retained in agroforestry systems play an essential role in managing faunal diversity and regulating climate change. It also served as a refuge for several native and endangered woody species, as well as wild animals like birds, ants, and soil invertebrates. Besides, provides a suitable place for mammals. Regarding climate change, agroforestry plays a significant role in adaptation and CO_2 mitigation by sequestering through live biomass and soil, and by reducing emissions resulting from deforestation and soil erosion. Besides, it serves as a source of food, forage, and fuel wood, increases income, and improves crop productivity by enhancing soil fertility, maintaining soil moisture, protecting against pests, increasing resistance to diseases, and protecting against wind damage to combat unwanted climatic change impacts.

According to experts, agroforestry has full potential in maximising species diversity of flora and fauna. It is also more substantial in carbon storage than mono-cropping. Therefore, further research should consider the sustainability of biodiversity conservation in agroforestry by facilitating agroforestry-based carbon payment and maximising the diversification of various agroforestry components and management strategies. The role of agroforestry in preserving faunal and soil biodiversity should be enhanced through further research, as should the roles of urban agroforestry in biodiversity preservation and climate change regulation.

APPENDIX 1

No	Scientific Name	Local Name	Conservation Status
1	Erythrina brucei Schweinf	waleensuu	L
2	Millettia ferruginea	Birbira	L
3	Prunus africanum	Tikur inchet	L
4	Rhus glutinosa	*	V
5	Solanecio gigas	*	V
6	V. dainellii	*	L

APPENDIX 2

AF Types	Total No of Species	Counted % of Native Species	Source
Coffee AF	63	73	[52]
Traditional AF	55	85	[53]
Traditional AF	77	33	[53]
Farmland	77	70	[28]
Home garden, Parkland, woodlot	33	67	[43]

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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