Обзор / Review

https://doi.org/10.18619/2072-9146-2025-6-225-232

Kasu Hailu Biru*

Ethiopian Forestry Development Hawassa center, Plantation Research program
Addis Ababa, Ethiopia

Correspondence: kasuhailu128@gmail.com

Funding. This review did not receive any specific grant from funding agencies in the public, commercial or not for profit sector.

Author's Contribution: Kasu Hailu Biru: conceptualization, formal analysis, visualization, writing – review & editing.

Conflict of interest. I declare that there is no conflict of interest.

For citation: Biru K.H. Agroforestry contribution to livelihood and Carbon sequestration in Ethiopia. *Vegetable crops of Russia.* 2025;(6):225-232. https://doi.org/10.18619/2072-9146-2025-6-225-232

Received: 21.04.2025
Accepted for publication: 25.08.2025
Published: 18.12.2025

Agroforestry contribution to livelihood and Carbon sequestration in Ethiopia

ABSTRACT

Agroforestry is a powerful practice for sustainable and regenerative intensification because it promotes multifunctional landscapes that deliver ecological functions that contribute to livelihoods, land productivity, biodiversity conservation, and other ecosystem services. The main idea of this paper is to review Agroforestry contribution to livelihood and carbon sequestration in Ethiopia. Home gardens, farms, woodlots, and coffee farms are the most prevalent forms of agroforestry methods; yet, farmer perceptions and their distribution differed. Amazingly, because agroforestry produces a variety of services from a small unit of land, each technique adds many advantages. The main benefit was diversification of production, which is the optimal approach, especially for smallholder farmers whose livelihoods depend on agricultural systems. In comparison to monocropping, agroforestry is much more acceptable and recommended. As a result, it offers both environmental and socioeconomic benefits, such as reduced soil erosion, increased soil moisture and fertility, coffee shade, and maintenance of the microclimate balance, as well as tree products and income. These and other advantages help rural communities diversify their sources of income and provide protection. Much of the aboveground carbon is held in homegardens (28.2 ± 6.0 Mg C ha^{-1}), perennial tree crop systems (23.7±10.0 Mg C ha^{-1}) and trees on boundaries (26.7±14.1 Mg C ha^{-1}). In general, it's a useful tool for adjusting to and reducing climate change. As a consequence, farmers considered it as essential to maximize the productive potential of their land and enhancing the standard of living for smallholders. Therefore, in order to help farmers improve their standard of living and adapt to the unpredictable nature of climate change, the government should support agroforestry practices.

KEYWORDS:

Agroforestry systems, Carbon sequestration, Socio-economic, Environmental and Livelihood

Касу Хайлу Биру*

Эфиопский центр развития лесного хозяйства в Хавассе, Программа исследований плантаций
Аддис-Абеба, Эфиопия

Автор для переписки: kasuhailu128@gmail.com

Финансирование. Данный обзор не получил никакого конкретного гранта от финансирующих организаций государственного, коммерческого или некоммерческого сектора.

Вклад автора: Биру К.Х.: концептуализация, формальный анализ, создание рукописи и её редактирование.

Конфликт интересов. Автор заявляют об отсутствии конфликта интересов.

Для цитирования: Biru K.H. Agroforestry contribution to livelihood and Carbon sequestration in Ethiopia. *Vegetable crops of Russia.* 2025;(6):225-232. https://doi.org/10.18619/2072-9146-2025-6-225-232

Поступила в редакцию: 21.04.2025
Принята к печати: 25.08.2025
Опубликована: 18.12.2025

Вклад агролесоводства в обеспечение средств к существованию и поглощение углерода в Эфиопии

РЕЗЮМЕ

Agroforestry is a powerful practice for sustainable and regenerative intensification because it promotes multifunctional landscapes that deliver ecological functions that contribute to livelihoods, land productivity, biodiversity conservation, and other ecosystem services. The main idea of this paper is to review Agroforestry contribution to livelihood and carbon sequestration in Ethiopia. Home gardens, farms, woodlots, and coffee farms are the most prevalent forms of agroforestry methods; yet, farmer perceptions and their distribution differed. Amazingly, because agroforestry produces a variety of services from a small unit of land, each technique adds many advantages. The main benefit was diversification of production, which is the optimal approach, especially for smallholder farmers whose livelihoods depend on agricultural systems. In comparison to monocropping, agroforestry is much more acceptable and recommended. As a result, it offers both environmental and socioeconomic benefits, such as reduced soil erosion, increased soil moisture and fertility, coffee shade, and maintenance of the microclimate balance, as well as tree products and income. These and other advantages help rural communities diversify their sources of income and provide protection. Much of the aboveground carbon is held in homegardens (28.2 ± 6.0 Mg C ha^{-1}), perennial tree crop systems (23.7±10.0 Mg C ha^{-1}) and trees on boundaries (26.7±14.1 Mg C ha^{-1}). In general, it's a useful tool for adjusting to and reducing climate change. As a consequence, farmers considered it as essential to maximize the productive potential of their land and enhancing the standard of living for smallholders. Therefore, in order to help farmers improve their standard of living and adapt to the unpredictable nature of climate change, the government should support agroforestry practices.

KEYWORDS:

Agroforestry systems, Carbon sequestration, Socio-economic, Environmental and Livelihood

Introduction

It is commonly acknowledged that agroforestry is a land use plan that helps with both adaptation and mitigation of climate change while offering smallholder farmers answers to their problems [1]. Agroforestry helps local populations that are experiencing climatic shocks by producing goods (such as food, fuel, firewood, and medications) and generating revenue for them. Additionally, agroforestry is recognized to support livelihoods by protecting people, places, and property from the effects of climate change, such as floods, and by enhancing crop and animal output by their impact on soil water and light availability [2]. By slowing down water flow, providing windbreaks, and anchoring the soil with their roots, trees stop soil erosion [3,4]. The establishment of a favorable microclimate [5], increased soil fertility [3], control of water [6], and control of agricultural pests [7] are the reasons behind the benefits of agroforestry on crop and livestock production. By fixing nitrogen, increasing the richness and abundance of the microbial population, and boosting soil organic carbon, agroforestry can also make soils more resilient to drought [3]. In order to optimize the benefits of agroforestry, trees' negative impacts on crops namely, shade and competition for water are often handled.

Agroforestry might potentially be used to mitigate climate change by sequestering carbon in soil and plant biomass. Globally, agroforestry systems store an average of about 21.4 Mg C ha^{-1} in biomass [8]. In the tropics, agroforestry systems store an average of 9, 21 and 50 Mg C ha^{-1} in semiarid, sub-humid, humid areas, respectively [9]. For agroforestry systems in Africa, a cautious estimate of 1.0 to 18 Mg C ha^{-1} in aboveground biomass has been proposed [10]. These approximations are imprecise and only serve to highlight the possibilities of agroforestry. Because some of them are drawn from researches that were based on generalizations or false assumptions, their scientific worth has been called into doubt [10]. We need to improve our understanding of the amount and distribution of biomass carbon in agroforestry systems by conducting a quantitative synthesis of the information from primary investigations. Agroforestry's potential as a carbon sequestration technology is highly anticipated. First, even if the total quantities of climate financing are small, subsistence farmers are the primary practitioners of agroforestry and may profit from it. Second, agroforestry has been recognized by several nations as a means of accomplishing both the Nationally Determined Contributions (NDCs) to the Paris Agreement [11,12] and their restoration objectives [13]. However, agroforestry is not taken into consideration by national measuring, reporting, and verification (MRV) systems, in part due to the difficulty of quantifying carbon emissions. Although there has been considerable improvement in estimating biomass carbon in agricultural landscapes, methodological issues are to blame for the literature's varying estimates [10]. To fully utilize the promise of agroforestry as a climate change mitigation method, this constraint must be overcome. The overarching goal of this review is to provide available evidence and knowledge gaps regarding the contribution of Agroforestry to livelihood and carbon sequestration in Ethiopia.

Major Agroforestry practice in Ethiopia

There is an abundant type of agroforestry practice in Ethiopia. Such as pasture land, farm land and home garden in Northwestern Ethiopia as cited by Ketsela Hailemicael [14]. Also, coffee shade tree, scattered trees on farmland, home garden, woodlots, farm boundary and grazing lands are types of traditional agroforestry practices in southern Ethiopia [15,16]. The enlargement of tree-based agroforestry land use practice under different landforms is the alternative method of increasing the efficiency of land because planting or maintaining of tree or shrub on farmland, roadsides, pasture land, and farm boundary use to minimize a shortage of wood products and improve the production ability of land simultaneously [17].

Both coffee-enset-based and parkland agroforestry practices are commonly known as an economical eye-catching. However, coffee-enset-based agroforestry practice is the best economical presentation than parkland agroforestry practices and accepted as the best strategy for improving the livelihood of smallholder farmers in Yirgachefe district of Gedeo Zone, Ethiopia [18]. Woodlot of *Eucalyptus* is also the most agroforestry practice in Ethiopia, because it playing a vital role in improving the livelihood of the farmer [19-21].

Home Garden Agroforestry System

Homegardens referred to a land use near the homestead where a mix of annual and perennial crops are grown with multipurpose trees, and sometimes in association with domestic animals. The plant component includes trees, shrubs, herbs, climbers and food crops that form three to four canopy layers. A prominent type of homegarden in Ethiopia is the ‘enset-coffee’ home garden typified by a combination of enset (Enset ventricosum) and coffee (*Coffea arabica*) [22,23]. Ethiopia also has unique "enset-based" and "coffee-based" home gardens.

Homegardens are characterized by high species diversity with multipurpose trees or fruit tree species as the dominant woody component. In Ethiopia, homegardens are dominated by coffee, enset, khat (*Catha edulis*), avocado, banana (*Musa* spp.) and vegetables [24-26]. These may be left unfenced or encircled by a Living fence made of species of trees with multiple uses [27]. Because home gardens include a variety of plant species and phases of development, the advantages of livelihood in them range. At their initial stages, homegardens provide more vegetables, spices and traditional medicines [28-30] When a home garden is established, it yields fruits and other tree products as well as revenue. Shade tolerant spices such as wild cardamom (*Aframomum angustifolium*), small cardamom (E*lettaria cardamomum*) and wild pepper (*Piper capense*) were frequently reported in homegardens In Ethiopia [31]. While *Grevillea robusta* and *Erythrina brucei* sustain the spices and vines, trees like *Millettia ferruginea* and *Albidia gumminifera* offer shade [31].

Farmland Agroforestry System

This is a kind of agroforestry land use system centered on trees, in which a tree is always growing alongside a grain crop, such sorghum, maize, or teff. Another name for it is a farming method in parklands [18]. This method is planting single Syzygium guineense trees in large areas or dispersed over farms, without interfering with the growth of other crops. These kinds of tree species that are widely distributed throughout agriculture may be supported by planting new trees or by protecting and carefully maintaining trees that have naturally regenerated. There is no set strategy for planting trees on fields; in Ethiopia's central highlands, *Acacia albida*, *Croton macrostachyus*, and *Ficus species* are the most commonly planted tree species [19]. In addition, the most common tree species found on farmland in the Jabithenan district of Northwestern Ethiopia are *Croton macrostachyus, Ficus sure, Albizia gummifera, Cordia africana, Acacia abyssinica, Rosa abyssinica,* and Erythrina abyssinica [27]. *Eucalyptus spp*. and *Grevillea robusta,* on the other hand, are grown as live fences, boundaries, and small-scale woodlots. In Ethiopia's central highlands, around half (42%) of farmers would like to grow dispersible trees on their property [19]. Common approaches involve intercropping maize with *Cordia africana* in western Ethiopia and *Acacia albida* in the Hararge Highlands and Debrezeit region [32]. The integration of tree species with annual crops is now seen to be one of the most effective strategies to increase a single land's production capacity by diversifying the crop and achieving greater yields. The farmer is deliberately keeping or growing diverse tree species on their acreage because of their multifunctional advantages. Among its advantages include reducing soil erosion, increasing soil's ability to retain water, and boosting soil fertility by fixing nitrogen [33]. Additionally, farms with trees, especially those with *Croton macrostachyus* Del. and *Cordia africana* Lam., have better soil nutrients because they store more leaves in the soil, which decomposes in Badessa, Eastern Ethiopia, and reduces nutrient loss [34]. Additionally, Southeast Langano, Ethiopia's trees on farms offer socioeconomic advantages such fuel wood, fodder, and medical benefits [35].

Table 1. The most commonly studied Agroforestry practices in Ethiopia and their contribution to livelihood benefit.

Agroforestry systems/practices	Description and example	Livelihood benefit	References
Homegardens	A land use near the homestead where annual and perennial crops are cultivated with trees, and sometimes in association with livestock. Homegardens are characterized by a high diversity of plants, multi-story structure, and primarily function to produce food for household consumption. Specific types of homegardens described are enset, enset-coffee and coffee homegardens.	Food, firewood, medicinal use, fodder, shade, income, construction material, household items and timber	[24-27,31,44]
Perennial tree-crop systems	A system containing plantation (cash) crops such as coffee, tea, cacao.	Food, fodder, firewood, timber, income, poles, medicinal use, construction material	[45,46]
	Coconut, cashew, khat, cardamom and multipurpose trees or shade tolerant herbaceous crops as the main components. Plantation crops can generate value added goods for the international market		[47]
Woodlots	An area on the farm set aside entirely for trees. Single or mixed species stands of trees can be planted on cropland or degraded land for wood production, or to rehabilitate the land. Woodlots can be intercropped, e.g. with vegetables in the first two years early; the trees then grow alone and are harvest around the fifth year; food crops are replanted in the case of rotational woodlots	Wood, firewood, fodder, income, timber, construction material	[48]
Scattered trees on farm	A practice where scattered trees grow on cropland, often from naturally dispersed seeds that germinate and are protected during farm operations, or from seedlings planted by the farmer. The spatial arrangement of trees may be random or linear	Income, firewood, fodder, charcoal, gum arabic, resin, wood	[49]
Silvopastures systems	Integration of trees with livestock. The animals freely roam and graze under natural stands of trees or scattered trees in croplands, or may be stall-fed with forage from fodder trees and shrubs grown on the farm. The trees provide high-quality forage that supplement available feeds	Fodder, shade, firewood, timber, food	[50-52]
Parkland Agroforestry systems	A traditional land use system where scattered multipurpose trees are retained on cultivated land or land that was recently fallowed. Parklands constitute extensive tree-crop intercropping, where crops are grown beneath the crowns of trees such as Faidherbia albida, Ficus vasta	Food, fodder, firewood, income, shade, timber, charcoal, construction material, farm implements / tools	[30,53,54]
Boundary planting	The practice of growing trees on farm boundary. Trees can be planted in rows, initially at a close spacing (e.g. 1 m) and later thinned to 2 or 4 m spacing; trees may also be retained as scattered trees along boundaries. The trees mark farm boundaries or enterprises, and can be pruned or pollarded for various products	Fodder, food, firewood, income, shade, timber, charcoal, wood, poles, bee forage	[55-59]
Fruit tree-based agroforestry	The intentional simultaneous cultivation of annual or perennial crops with fruit producing trees on the same area of land. Fruit tree-based agroforestry may occur as orchards or low intensity homegardens based on apple (*Malus domestica*), mango (*Mangifera indica*), avocado (*Persea americana*); or fruit trees intercropped with staples	Income, food	[47]
Trees on soil conservation structure	Trees planted on soil-conservation structures to control runoff, reduce soil loss, stabilize the structure and maximise utilization of the land use. Examples include tree strips or grass strips with trees; trees planted on bench terraces, progressive terraces	Food, fodder, firewood, green manure, staking material	[58,60]

Coffee Farm Agroforestry System

A coffee farm is a kind of agroforestry land use where different tree species are planted alongside coffee to provide shade [15]. Ethiopian farmers are accustomed to growing coffee under various shade plants. The best trees for coffee shade in southwest Ethiopia include *Albizia schimperiana, Albizia gummifera, Millettia ferruginea, Cordia africana,* and Erythrina abyssinica. Apart from providing shade, they also sell a variety of tree products, such as building materials, firewood, and lumber, and they also work to improve soil fertility and lessen soil erosion [36,37]. Furthermore, in Southwestern Ethiopia, *Acacia abyssinica* is the best tree species for providing shade for coffee [38]. This was quite similar to the coffee plantation in Jimma town [39]. The majority of scholars concurred that shade is essential for coffee production, but they disagreed over which tree species was their preference. In the Manasibu District of Ethiopia, where agroforestry was used for the cultivation of coffee, *Croton macrostachyus* is acknowledged as the most beneficial shade tree among other tree species [40].

Woodlot Agroforestry

A woodlot is an area of forest land used for building and other uses, such as the production of firewood [21]. They also verified that many farmers were separately planting tree as the greatest substitutes for conventional land use techniques on a small-scale woodlot. Because, it provides firewood, construction materials, and income, which reversely help smallholder farmers to meet their family's needs in Eza district of Ethiopia [41].

In Ethiopia, particularly in rural areas, woodlot tree-based agroforestry land use is cultivated by smallholder farmer [20,21]. The primary goals of introducing *eucalyptus* into Ethiopia were to decrease natural forest degradation and increase the availability of tree products. But, currently this perception is gradually changed to more benefits market-oriented [42]. The greatest way to help smallholder farmers in the Arsi Zone of Oromia improve their standard of living is to plant *eucalyptus* woodlots, which provide both revenue and wood products for domestic use [43]. Furthermore, in the central highlands of Oromia, Ethiopia, the revenue from *Eucalyptus* woodlots contributes comparatively more income (e.g., 50%) than that from cattle and grain crops [20]. Due to this fact reason, the farmers are allocated their land for *Eucalyptus* cultivation. In the woodlot agroforestry practice surrounding Jimma town, the most trained tree species are *Cupressus lusitanica* and *Eucalyptus camaldulensis* [39].

Socio-economic Benefits

The majority of the rural population depends on rain-fed agriculture, which leaves an agroforestry footprint. Fruit, firewood, honey, spices, lumber, poles, and charcoal are examples of both non-timber forest products (NTFP) and timber forest products (TFP) that are used to compute income derived from tree products [61,62] Farmers' lifestyles are greatly improved by the additional revenue, even though the amount varies depending on the location, especially during some risks occurred related to crop production due to climate changes [63]. Furthermore, the farmer obtains 47% income from NTFPs in Kaffa Zone (62), 800 to 1500 ETB in Wolaita Zone [64] and 1683 ETB an annual average income from home garden agroforestry in southwest Ethiopia's Jimma Zone [63]. However, the amount of income derived from tree product is influenced by various factors. Experiences with planting trees, the age of the farmer, the wealth status of the family, the size of the land, and the degree of education are all factors that have been found to favorably influence household income [65,66].

Numerous literary works demonstrate the advantages of trees or shrubs for traditional medicine in diverse regions of Ethiopia [67,68]. For example, *Euphorbia candelabrum* for ringworm, *Millettia ferruginea* for fungal infection, *Vernonia amygdalina* for diarrhea and stomach discomfort, *Croton macrostachyus* for malaria, diarrhea, epilepsy, ringworm, and skin rush. As a result, over 52 species of medicinal plants were discovered in the Boosat region in central-eastern Ethiopia [69], while 39 species of medicinal plants that are used to cure a variety of illnesses were distinguished in the Jimma zone in southwest Ethiopia [68]. Agroforestry land use practices centered around trees offer shade. In Southwestern Ethiopia, people congregate under a shade tree for religious purposes, such as playing, and social matters [70].

Environmental Benefit

Improved soil fertility, decreased soil and water erosion, increased soil moisture retention, and enhanced environmental health may all be achieved with an environmentally friendly agroforestry system [71]. Agroforestry can mitigate climate change through various techniques For instance, it is significantly reducing the adverse effects of climate change on agricultural productivity [72]. Because combining trees with annual crops can boost yield and diversify products [72,73]. Additionally, it helps to slow down environmental deterioration and offers smallholder farmers several advantages [74]. This outcome will improve rural farmers' ability to adapt to climate change. Agroforestry land use practices based on trees are effective in achieving food security, particularly in subsistence agricultural farming systems where the farmer receives income to buy cereal crops for domestic use [63]. Agroforestry practice contributes incredible service in watershed management. For example, the indigenous expertise of the local people on agroforestry management (fertilizer application, pruning, regulated burning, thinning, pollarding, protection against animal and human damage, etc.) in the Wolaita Zone of the Gununo Watershed, grass mulch, crop residue, watering and coppicing) was accepted as the option in reducing land degradation through modifying micro- climate and reducing soil erosion, improving soil fertility and increasing soil moisture, which in turn raises agricultural production [75]. Besides, it has huge advantages in rehabilitating the degraded land in highlands of Ethiopia [76]. The most effective substitute method for addressing environmental issues is agroforestry. Degradation of environmental health quality is put the world under serious challenges especially in developing countries. This environmental deterioration is more accurately described as land degradation, which is brought on by increased population expansion, deforestation, overexploitation, overgrazing, and soil erosion.

Carbon sequestration in Agroforestry systems in Ethiopia

In agroforestry systems, carbon is sequestered in both aboveground biomass such as stem, branch, and foliage and belowground biomass such as soil and roots. In particular, agroforestry systems' substantial aboveground biomass and deep tree root systems have drawn more attention for mitigating and adapting to climate change [77].

Table 2. Estimates of above- and below ground biomass carbon (Mg C ha− 1) and soil organic carbon (0–60 cm depth, Mg C ha− 1) in major agroforestry practices in Ethiopia.

Agroforestry practice	Aboveground carbon	Belowground carbon	Soil organic carbon	References
Boundary planting	26.7 ± 14.1		112.7	[58,59]
Fodder bank	9.2 ± 4.2		14.5 ± 1.4	[31,50]
Homegarden agroforestry	28.2 ± 6.0	9.6 ± 2.8	115.7 ± 15.1	[22,23,25,26,59,78]
Parkland systems	4.9 ± 2.5	1.9 ± 0.8	41.6 ± 11.3	[59,80-82]
Perennial tree crop systems	23.7 ± 10.0	8.2 ± 4.8	110.9 ± 30.3	[25,83]
Scattered trees on farm	8.2 ± 1.4	2.9 ± 1.0	52.5 ± 23.4	[84-86]
Silvopasture	2.1 ± 0.01		73.0 ± 35.6	[79,80]
Woodlot	25.0 ± 5.6	4.559	58.6 ± 8.5	[23,59]

*The values are mean ± standard error. **

Further, between 30 and 300 mg C ha^{-1} may be stored in agroforestry soils up to 1-m depth [87]. Aboveground biomass estimated by CO2FIX model for enset-tree (73.2 mg ha^{-1}), enset coffee (105.7 mg ha^{-1}) and tree-coffee system (116.2 mg ha^{-1}), translating to biomass carbon of 96.6, 139.5, 153.4 mg ha^{-1}, respectively [22] was excluded from the computation of mean carbon storage since it was greater than estimates published in the area. Comparable system estimates for enset (34.9 mg ha^{-1}), enset-coffee (59.2 mg ha^{-1}), and fruit-coffee (58.3 mg ha^{-1}) yield half that amount [88]. Although it was not measured, small-scale *eucalyptus*-based woodlots in Ethiopia would have increased aboveground carbon [23,48,57]. Aboveground carbon in fodder banks with *S.micratha*, *S.rostrata*, *S.quadrata* and *S.seban* stored 5.4 mg C ha^{-1} in the same carbon pool in Ethiopia [50].

Increases in biomass C returned to the soil, improvements in soil organic matter (SOM) stabilization, and/or reductions in the rate of biomass decomposition and SOM destabilization are the main ways to attain higher SOC pools in agroforestry systems [89,90]. Agroforestry systems are more effective than monocultures in harnessing the resources on the site for biomass development, and the greater growth might lead to higher soil C inputs. Certain approaches in agroforestry may also have the effect of increasing direct carbon inputs into the soil. These include: (a) composting woody species prunings back into the soil as mulch and letting copious amounts of tree litter break down naturally; (b) letting cattle graze on the land and add manure; (c) letting woody species grow and contribute surface and subsurface litter during crop fallow phases; (d) incorporating trees and their litter input into animal production systems; (e) allowing shade-tolerant species to grow beneath trees and contribute litter to the soil; and (f) reaping the benefits of the soil carbon inputs from agricultural crops planted in the early phases of forestry plantations.

Even in intricate agroforestry systems where yearly crops and tree products are continuously harvested, soil organic carbon is predicted to be steady. Complex agroforestry systems are distinguished by the creation of copious amounts of litter and prunings, which enhance the organic matter content of the soil. In these environments, the buildup of SOC is further facilitated by organic debris resulting from root breakdown. For example, the rate of annual loss of SOC was three times higher in areas converted (from forest) to khat monoculture than to agroforestry systems with both khat and coffee [78]. The soil organic carbon (SOC) in agroforestry plots aged 32–54 years was 117.3 mg C ha^{-1}, which was lower than the 94.1 mg C ha^{-1} in a khat monoculture aged 15–27 years and the 171.8 mg C ha^{-1} in the forest (78). Compared to khat monocropping, agroforestry has more carbon in its trash and roots [78].

Conclusion

Although Ethiopia's agroforestry system is the oldest traditional practice, it is now recognized as the country's current land use system. The reviewed literature showed that agroforestry systems are multifunctional and supports livelihoods by increasing farmer's capacity to acquire food, firewood, fodder and income, and provides other products are used by communities facing climate-related threats. The primary uses of trees and tree products are for revenue and subsistence; smaller uses include insurance and asset building for rural communities. Agroforestry systems also store substantial amounts of carbon in plant biomass and in the soil. Homegardens are the most multifunctional agroforestry practice with the highest number of livelihood benefits and largest amount of carbon stocks in aboveground biomass and in the soil.

As a co-benefit, agroforestry can generate income from sequestering carbon. The fact that there aren't many studies on the carbon benefits of agroforestry raises the possibility that issues like carbon rights, land tenure, tree tenure rights, and the possible effects of climate change on the expanding niches of tree species should be addressed in order to fully realize the benefits of carbon sequestration. Additionally, laws and institutional structures governing the region's participation in the carbon market must be developed.

• References / Литература

1. van Noordwijk M., Catacutan D.C., Duguma L.A., Pham T.T., Leimona B., Dewi S., et al. Agroforestry matches the evolving climate change mitigation and adaptation agenda in Asia and Africa. Agroforestry for Sustainable Intensification of Agriculture in Asia and Africa: Springer; 2023. p. 21-52.

2. Muthuri C., Ong C., Black C., Mati B.M., Ngumi V., van Noordwijk M. Modelling the effects of leafing phenology on growth and water use by selected agroforestry tree species in semi-arid Kenya. *Land Use and Water Resources Research.* 2004;4(1732-2016-140280).

3. Muchane M.N., Sileshi G.W., Gripenberg S., Jonsson M., Pumariño L., Barrios E.. Agroforestry boosts soil health in the humid and sub-humid tropics: A meta-analysis. *Agr. Ecosyst. Environ.* 2020;295:106899.

4. Quandt A., Neufeldt H., Gorman K. Climate change adaptation through agroforestry: Opportunities and gaps. *Curr. Opin. Environ. Sustain.* 2023;60:101244. https://doi.org/10.1016/j.cosust.2022.101244

5. Bayala J., Sanou J., Teklehaimanot Z., Kalinganire A., Ouédraogo S. Parklands for buffering climate risk and sustaining agricultural production in the Sahel of West Africa. *Curr. Opin. Environ. Sustain.* 2014;6:28-34. https://doi.org/10.1016/j.cosust.2013.10.004

6. Kuyah S., Whitney C.W., Jonsson M., Sileshi G.W., Öborn I., Muthuri C.W., et al. Agroforestry delivers a win-win solution for ecosystem services in sub-Saharan Africa. A meta-analysis. *Agron. Sustain. Dev.* 2019;39:1-18. https://doi.org/10.1007/s13593-019-0589-8

7. Pumariño L., Sileshi G.W., Gripenberg S., Kaartinen R., Barrios E., Muchane M.N., et al. Effects of agroforestry on pest, disease and weed control: A meta-analysis. *Basic Appl. Ecol.* 2015;16(7):573-582.

8. Zomer R.J., Neufeldt H., Xu J., Ahrends A., Bossio D., Trabucco A., et al. Global Tree Cover and Biomass Carbon on Agricultural Land: The contribution of agroforestry to global and national carbon budgets. *Sci. Rep.* 2016;6(1):29987. https://doi.org/10.1038/srep29987

9. Montagnini F., Nair P.R., editors. Carbon sequestration: an underexploited environmental benefit of agroforestry systems. New Vistas in Agroforestry: A Compendium for 1st World Congress of Agroforestry, 2004; 2004: Springer.

10. Nair P.R., Nair V.D. 'Solid–fluid–gas': the state of knowledge on carbon-sequestration potential of agroforestry systems in Africa. *Curr. Opin. Environ. Sustain.* 2014;6:22-27. https://doi.org/10.1016/j.cosust.2013.07.014

11. Rosenstock T.S., Wilkes A., Jallo C., Namoi N., Bulusu M., Suber M., et al. Making trees count: Measurement and reporting of agroforestry in UNFCCC national communications of non-Annex I countries. *Agr. Ecosyst. Environ.* 2019;284:106569. https://doi.org/10.1016/j.agee.2019.106569

12. Duguma L.A., Minang P.A., Watson C., Nath A.J., Muthee K.W., van Noordwijk M., et al. Agroforestry as a key intervention to achieve nationally determined contribution (NDC) targets. Agroforestry for Sustainable Intensification of Agriculture in Asia and Africa: Springer; 2023. p. 641-664.

13. Mansourian S., Berrahmouni N. Review of forest and landscape restoration in Africa 2021: Food & Agriculture Org.; 2021.

14. Ketsela Hailemicael B. The contribution of *Eucalyptus* woodlots to the livelihoods of small scale farmers in tropical and subtropical countries with special reference to the Ethiopian highlands. 2012.

15. Abebe T. Diversity in homegarden agroforestry systems of Southern Ethiopia: Wageningen University and Research; 2005.

16. Asfaw Z., Ågren G.I. Farmers' local knowledge and topsoil properties of agroforestry practices in Sidama, Southern Ethiopia. *Agroforestry Systems.* 2007;71:35-48. https://doi.org/10.1007/s10457-007-9087-0

17. Duguma, Hager H. Woody plants diversity and possession, and their future prospects in small-scale tree and shrub growing in agricultural landscapes in central highlands of Ethiopia. *Small-scale Forestry.* 2010;9:153-174. https://doi.org/10.1007/s11842-009-9108-0

18. Ayele Y., Ewnetu Z., Asfaw Z. Economic evaluation of coffee-enset-based agroforestry practice in Yirgachefe Woreda, Ethiopia: Comparative analysis with parkland agroforestry practice. *Journal of Economics and Sustainable Development.* 2014;5(27):72-82.

19. Duguma, Hager H. Forest products scarcity perception and response by tree planting in the rural landscapes: farmers' views in central highlands of Ethiopia. *Ekológia (Bratislava).* 2009;28(2):1581-69.

20. Kebebew Z. Profitability and household income contribution of growing *Eucalyptus* globulus (Labill.) to smallholder farmers: the case of the Central Highlands of Oromia, Ethiopia. 2002.

21. Duguma L.A., Hager H. Forest products scarcity perception and response by tree planting in the rural landscapes: farmers' views in central highlands of Ethiopia. *Ekológia (Bratislava).* 2009;28(2):158-169.

22. Negash M., Kanninen M. Modeling biomass and soil carbon sequestration of indigenous agroforestry systems using CO2FIX approach. *Agr. Ecosyst. Environ.* 2015;203:147-155. https://doi.org/10.1016/J.AGEE.2015.02.004

23. Lulu M., Lemma B., Melese A. Soil organic carbon and nutrients in smallholding land uses in southern Ethiopia. *J. Plant Nutr. Soil Sci.* 2020;183(1):69-79. https://doi.org/10.1002/jpln.201900243?urlappend=%3Futm_source%3Dresearchgate.net%26utm_medium%3Darticle

24. Sahle M., Saito O., Fürst C., Yeshitela K. Quantification and mapping of the supply of and demand for carbon storage and sequestration service in woody biomass and soil to mitigate climate change in the socio-ecological environment. *Science of the total environment.* 2018;624:342-354. https://doi.org/10.1016/j.scitotenv.2017.12.033

25. Betemariyam M., Negash M., Worku A. Comparative analysis of carbon stocks in home garden and adjacent coffee based agroforestry systems in Ethiopia. *Small-Scale Forestry.* 2020;19:319-334. https://doi.org/10.1007/s11842-020-09439-4

26. Birhane E., Ahmed S., Hailemariam M., Negash M., Rannestad M.M., Norgrove L. Carbon stock and woody species diversity in homegarden agroforestry along an elevation gradient in southern Ethiopia. *Agrofor. Syst.* 2020;94:1099-1110.

27. Linger E. Agro-ecosystem and socio-economic role of homegarden agroforestry in Jabithenan District, North-Western Ethiopia: implication for climate change adaptation. *SpringerPlus.* 2014;3(1):1-9. https://doi.org/10.1186/2193-1801-3-154

28. Mekonen T., Giday M., Kelbessa E. Ethnobotanical study of homegarden plants in Sebeta-Awas District of the Oromia Region of Ethiopia to assess use, species diversity and management prac-

tices. *J. Ethnobiol. Ethnomed.* 2015;11:1-13.
https://doi.org/10.1186/s13002-015-0049-8

29. Sahle M., Saito O., Demissew S. Characterization and mapping of enset-based home-garden agroforestry for sustainable landscape management of the Gurage socioecological landscape in Ethiopia. *Env. Sci. Poll. Res.* 2022;29(17):24894-910.
https://doi.org/10.1007/s11356-021-17605-0
30. Tadesse E., Abdulkedir A., Khamzina A., Son Y., Noulèkoun F. Contrasting species diversity and values in home gardens and traditional parkland agroforestry systems in Ethiopian sub-humid lowlands. *Forests.* 2019;10(3):266. https://doi.org/10.3390/f10030266
31. Furo G., Manaye A., Negasa A. Identification of spice shade and support tree species, south western Ethiopia. *Agrofor. Syst.* 2020;94(1):95-102. https://doi.org/10.1007/s10457-019-00372-w
32. Hoekstra D., Torquebiau E., Bishaw B. Agroforestry: potentials and research needs for the Ethiopian highlands: ICRAF; 1990.
33. Yadessa A., Itanna F., Olsson M. Contribution of indigenous trees to soil properties: the case of scattered Cordia africana lam. Trees in croplands of western Oromia. *Ethiop. J. Nat. Resour.* 2001;3(2):245-70.
34. Gindaba J., Rozanov A., Negash L. Trees on farms and their contribution to soil fertility parameters in Badessa, eastern Ethiopia. *Biol.Fertil. Soils.* 2005;42:66-71.
35. Biruk A. Woody species composition and socio-economic roles of traditional agroforestry practices across different agro-ecological zones in South Eastern Langano, Oromiya: M. Sc. Thesis, Hawassa University, Wondo Genet, Ethiopia; 2006.
36. Nigussie A., Taye E., Bukero G. Survey on potentials and constraints of shade tree species for arabica coffee production in South Ethiopia. *Int. J. Recent Res. Life Sci.* 2014;1(1):1-11.
37. Hundera K., Honnay O., Aerts R., Muys B. The potential of small exclosures in assisting regeneration of coffee shade trees in South-Western Ethiopian coffee forests. *Afr. J. Ecol.* 2015;53(4):389-397. https://doi.org/10.1111/aje.12203
38. Muleta .D, Assefa F., Nemomissa S., Granhall U. Socioeconomic benefits of shade trees in coffee production systems in Bonga and Yayuhurumu districts, southwestern Ethiopia: farmers' perceptions. *Ethiop. J. Educ. Sci.* 2011;7(1):39-55.
39. Endale B. Environmental Contribution of Agroforestry Systems to Smallholder Farmers around Jimma town, southwestern Ethiopia, unpublished MSc: Thesis; 2017.
40. Ebisa L. Effect of dominant shade trees on coffee production in Manasibu District, West Oromia, Ethiopia. *Science, Technology and Arts Research Journal.* 2014;3(3):18-22.
https://doi.org/10.4314/STAR.V3I3.3
41. Zerga B. Ecological impacts of *Eucalyptus* plantation in eza wereda, Ethiopia. *Int Inv J Agric Soil Sci.* 2015;3(4):47-51.
42. Pohjonen V., Pukkala T. *Eucalyptus* globulus in Ethiopian forestry. For. *Ecol. Manag* 1990;36(1):19-31.
43. Mekonnen Z. Community opinion, marketing and current debates on *eucalyptus* in Huruta District, Arsi Zone of Oromia Region, Ethiopia. *Eucalyptus* Species Management, History, Status and Trends in Ethiopia. 2010:15-7.
44. Reyes T., Luukkanen O., Quiroz R. Small cardamom—precious for people, harmful for mountain forests. *MRD.* 2006;26(2):131-137.
45. Teketay D, Tegineh A. Traditional tree crop based agroforestry in coffee producing areas of Harerge, Eastern Ethiopia. *Agrofor. Syst.* 1991;16:257-267.
46. Biazin B., Haileslassie A., Zewdie T., Mekasha Y., Gebremedhin B., Fekadu A., et al. Smallholders' avocado production systems and tree productivity in the southern highlands of Ethiopia. *Agrofor. Syst.* 2018;92:127-137. https://doi.org/10.1007/s10457-016-0020-2
47. Admasu T.G., Jenberu A.A. TheImpacts of Apple-based Agroforestry Practices on the Livelihoods of Smallholder Farmers in Southern Ethiopia. *Trees, Forests and People. 2022;7:100205.*
https://doi.org/10.1016/j.tfp.2022.100205
48. Gebreegziabher Z., van Kooten G.C. Does community and household tree planting imply increased use of wood for fuel? Evidence from Ethiopia. *Forest Policy and Economics.* 2013;34:30-40. https://doi.org/10.1016/j.forpol.2013.03.003
49. Mekonnen M., Worku T., Yitaferu B., Cerda A., Keesstra S. Economics of agroforestry land use system, Upper Blue Nile Basin, northwest Ethiopia. *Agrofor. Syst.* 2021:1-13.
50. Mengistu S., Keftasa D., Yami A. Productivity of four Sesbania species on two soil types in Ethiopia. *Agrofor. Syst.* 2002;54:235-244.
51. Balehegn M., Eik L.O., Tesfay Y. Silvopastoral system based on Ficus thonningii: an adaptation to climate change in northern Ethiopia. *Afr. J. Range Forage Sci.* 2015;32(3):183-191.
https://doi.org/10.2989/10220119.2014.942368
52. Yaebiyo G., Birhane E., Tadesse T., Kiros S., Hadgu K.M. Evaluating woody species composition and regeneration in controlled and free grazing systems for scaling up agroforestry in the highlands of northern Ethiopia. *Agrofor. Syst.* 2021;95(6):1229-1244.
53. Birhane E., Teklay R., Gebrehiwet K., Solomon N., Tadesse T. Maintaining Acacia polyacantha trees in farmlands enhances soil fertility and income of farmers in North Western Tigray, Northern Ethiopia. *Agrofor. Syst.* 2019;93:2135-2149.
54. Tadele M., Birhane E., Kidu G., G-Wahid H., Rannestad M.M. Contribution of parkland agroforestry in meeting fuel wood demand in the dry lands of Tigray, Ethiopia. *J. Sustain. For.* 2020;39(8):841-53. https://doi.org/10.1080/10549811.2020.1738946
55. Kassa A.W., Nigussie Z.A. Management and Woody Species Diversity in Boundary Agroforestry of Banja District, Northwestern Ethiopia. *Small-scale Forestry.* 2022;21(3):393-415.
https://doi.org/10.1007/s11842-022-09503-1
56. Kidanu S., Mamo T., Stroosnijder L. Biomass production of *Eucalyptus* boundary plantations and their effect on crop productivity on Ethiopian highland Vertisols. *Agrofor. Syst.* 2005;63:281-90.
57. Duguma. Financial analysis of agroforestry land uses and its implications for smallholder farmers livelihood improvement in Ethiopia. *Agrofor. Syst.* 2013;87:217-231.
58. Nigatu A., Wondie M., Alemu A., Gebeyehu D., Workagegnehu H. Productivity of highland bamboo (Yushania alpina) across different plantation niches in West Amhara, Ethiopia. *For. Sci. Technol.* 2020;16(3):116-122.
https://doi.org/10.1080/21580103.2020.1791260
59. Manaye A., Tesfamariam B., Tesfaye M., Worku A., Gufi Y. Tree diversity and carbon stocks in agroforestry systems in northern Ethiopia. *Carbon Balance Manag.* 2021;16(1):14.
https://doi.org/10.1186/s13021-021-00174-7
60. Abdelkdair A., Schultz R.C. Water harvesting in a 'runoff-catchment'agroforestry system in the dry lands of Ethiopia. *Agrofor. Syst.* 2005;63:291-298.

61. Kebebew Z., Garedew W., Debela A. Understanding homegarden in household food security strategy: case study around Jimma, Southwestern Ethiopia. *Res. J. Appl. Sci.* 2011;6(1):38-43.
62. Melaku E., Ewnetu Z., Teketay D. Non-timber forest products and household incomes in Bonga forest area, southwestern Ethiopia. *J. For. Res.* 2014;25:215-223. https://doi.org/10.1007/s11676-014-0447-0
63. Kebebew Z, Urgessa K. Agroforestry perspective in land use pattern and farmers coping strategy: experience from southwestern Ethiopia. *World J. Agric. Sci.* 2011;7(1):73-77.
64. Agize M., Chama E., Shonga A. Income Generating Activities of Women on Home Garden Farming in Damot Gale District (Woreda) of Wolaita Zone, Southern Ethiopia. International Journal of African and Asian Studies. P. 2016;23.
65. Jama B., Zeila A. Agroforestry in the drylands of Eastern Africa. A call for action World Agro-forestry Center. 2005.
66. Gebreegziabher Z., Mekonnen A., Kassie M., Köhlin G. Household tree planting in Tigrai, northern Ethiopia: Tree species, purposes, and determinants. 2010.
67. Mesfin F., Demissew S., Teklehaymanot T. An ethnobotanical study of medicinal plants in Wonago Woreda, SNNPR, Ethiopia. *J. Ethnobiol. Ethnomed.* 2009;5(1):1-18.
68. Abera B. Medicinal plants used in traditional medicine by Oromo people, Ghimbi District, Southwest Ethiopia. *J. Ethnobiol. Ethnomed.* 2014;10:1-15. https://doi.org/10.1186/1746-4269-10-40
69. Hunde D, Asfaw Z., Kelbessa E. Use of traditional medicinal plants by people of 'Boosat'sub district, Central Eastern Ethiopia. Ethiop. *J. Health Sci.* 2006;16(2).
70. Negash M. Trees management and livelihoods in Gedeo's agroforests, Ethiopia. Forests, *Trees and Livelihoods.* 2007;17(2):157-68.
71. El Tahir B.A., Vishwanath A. Estimation of economic value of agroforestry systems at the local scale in Eastern Sudan. *Journal of Geoscience and Environment Protection.* 2015;3(09):38. https://doi.org/10.4236/gep.2015.39005
72. Mbow C., Van Noordwijk M., Luedeling E., Neufeldt H., Minang P.A., Kowero G. Agroforestry solutions to address food security and climate change challenges in Africa. *Curr. Opin. Environ. Sustain.* 2014;6:61-67. https://doi.org/10.1016/j.cosust.2013.10.014
73. Bishaw B., Neufeldt H., Mowo J., Abdelkadir A., Muriuki J., Dalle G., et al. Farmers' strategies for adapting to and mitigating climate variability and change through agroforestry in Ethiopia and Kenya. 2013.
74. Muleta D., Assefa F., Nemomissa S., Granhall U. Composition of coffee shade tree species and density of indigenous arbuscular mycorrhizal fungi (AMF) spores in Bonga natural coffee forest, southwestern Ethiopia. *For. Ecol. Manag.* 2007;241(1-3):145-54.
75. Madalcho A., Tefera M. Management of traditional agroforestry practices in Gununo Watershed in Wolaita Zone, Ethiopia. *For. Res.* 2016;5(1):1-6. https://doi.org/10.4172/2168-9776.1000163
76. Bishaw B., Abdelkadir A. Agroforestry and community forestry for rehabilitation of degraded watersheds on the Ethiopian highlands. 2003.
77. Nair P. Carbon sequestration studies in agroforestry systems: a reality-check. *Agrofor. Syst.* 2012;86:243-53. https://doi.org/10.1007/s10457-011-9434-z
78. Negash M., Kaseva J., Kahiluoto H. Perennial monocropping of khat decreased soil carbon and nitrogen relative to multistrata agroforestry and natural forest in southeastern Ethiopia. *Reg. Environ. Change.* 2022;22(2):38. https://doi.org/10.1007/s10113-022-01905-3
79. Gelaw A.M., Singh B., Lal R. Soil organic carbon and total nitrogen stocks under different land uses in a semi-arid watershed in Tigray, Northern Ethiopia. *Agr. Ecosyst. Environ.* 2014;188:256-63.
80. Gurmessa B., Demessie A., Lemma B. Dynamics of soil carbon stock, total nitrogen, and associated soil properties since the conversion of Acacia woodland to managed pastureland, parkland agroforestry, and treeless cropland in the Jido Komolcha District, southern Ethiopia. *J. Sustain. For.* 2016;35(5):324-37. https://doi.org/10.1080/10549811.2016.1175950
81. Chiemela S.N., Noulèkoun F., Chiemela C.J., Zenebe A., Abadi N., Birhane E. Conversion of degraded agricultural landscapes to a smallholder agroforestry system and carbon sequestration in drylands. *Int. J. Clim. Chang. Strateg. Manag.* 2018;10(3):472-87. https://doi.org/10.1108/IJCCSM-08-2015-0116
82. Dilla A.M., Smethurst P.J., Barry K., Parsons D. Preliminary estimate of carbon sequestration potential of Faidherbia albida (Delile) A. Chev in an agroforestry parkland in the Central Rift Valley of Ethiopia. *Forests, Trees and Livelihoods.* 2019;28(2):79-89.
83. Toru T., Kibret K. Carbon stock under major land use/land cover types of Hades sub-watershed, eastern Ethiopia. *Carbon Balance Manag.* 2019;14:1-14. https://doi.org/10.1186/s13021-019-0122-z
84. Gebrewahid Y., Gebre-Egziabhier T.-B., Teka K., Birhane E. Carbon stock potential of scattered trees on farmland along an altitudinal gradient in Tigray, Northern Ethiopia. *Ecol. Proc.* 2018;7:1-8. https://doi.org/10.1186/s13717-018-0152-6
85. Gebremeskel D., Birhane E., Rannestad M.M., Gebre S., Tesfay G. Biomass and soil carbon stocks of Rhamnus prinoides based agroforestry practice with varied density in the drylands of Northern Ethiopia. *Agrofor. Syst.* 2021;95(7):1275-93.
86. Hagos H, Tesfay G, Brhane E, Abrha H, Bezabh T, Tesfay B, et al. Comparison of carbon stock potential of farmland trees in the midlands of Hawzen, Northern Ethiopia. Sust. *Environ.* 2021;7(1):1973696. https://doi.org/10.1080/27658511.2021.1973696
87. Nair P.R., Nair V.D., Kumar B.M., Showalter J.M. Carbon sequestration in agroforestry systems. *Adv. Agron.* 2010;108:237-307. https://doi.org/10.1016/S0065-2113(10)08005-3
88. Negash M., Starr M. Biomass and soil carbon stocks of indigenous agroforestry systems on the south-eastern Rift Valley escarpment, Ethiopia. *Plant Soil.* 2015;393:95-107. https://doi.org/10.1007/s11104-015-2469-6
89. Lai R. Soil carbon sequestration in natural and managed tropical forest ecosystems. *J. Sustain. For.* 2004;21(1):1-30.
90. Sollins P, Swanston C, Kramer M. Stabilization and destabilization of soil organic matter—a new focus. *Biogeochemistry.* 2007;85:1-7.

About the Author:
Kasu Hailu Biru – Researcher, https://orcid.org/0000-0002-2549-8736, Corresponding Author, kasuhailu128@gmail.com

Об авторе:
Касу Хайлу Биру – исследователь, https://orcid.org/0000-0002-2549-8736, автор для переписки, kasuhailu128@gmail.com