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Agroforestry for Carbon Sequestration and Climate Change Mitigation: A Comprehensive Review of Ecological, Socioeconomic and Policy Perspectives

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ABSTRACT

The technique of associating trees and shrubs to agricultural systems and cropping systems, known as 'agroforestry' is set out as the potential solution to the two major challenges of global warming and climate change. Because of the challenges occurring in the modern world connected with climate change, deforestation, and increased agricultural activities, agroforestry provides a viable solution that helps to satisfy the people's need in food without any negative impact on the environment. Here, an attempt has been made to identify the carbon sequestration potential of different agroforestry systems in different parts of the world and the carbon stocks in above and below ground biomass. This way, agroforestry may bring benefits such as the enhancement of the soil and biodiversity, as well as the mitigation of the emissions of greenhouse gases. Social and economic impact, along with the disadvantages that arrest the practice of agroforestry are also disclosed in the review, they include tenure insecurity, financial constraints, and technical know-how. This way, this article synthesizes the current knowledge about how agroforestry can help to regulate global carbon and improve Climate Change resilience with the insights into policy and practical measures that can support the enhanced and broader use of the framework. Secondly, the importance of agroforestry in enhancing livelihoods of rural communities, sustainable land management, and climate smart agriculture painting on the whole.

Keywords: *Agroforestry; Carbon Sequestration; Climate Change Mitigation; Ecosystem Services; Nature-Based Solutions.*

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INTRODUCTION

1.1 Background

The increasing rates of climate change have become the important drivers of the demand for appropriate tools helping to assess different ways of mitigation within the environmental, economic, and social aspects (Hellweg et al., 2023). Carbon sequestration; the process of capturing and storing atmospheric carbon dioxide (CO2) has therefore emerged as a critical factor in managing climate change (Don et al., 2024). Although afforestation and reforestation have been for long recognized for their carbon sequestration opportunities (Sakti et al., 2024), agroforestry is unique and embraces functional diversification because it involved the establishment of trees in agricultural settings, which combines food production with environmental management (Nair et al., 2022f). The techniques of agroforestry are diverse ranging from silvopastoralism, alley cropping, forest gardening, home plotted farming and among others, and their effectiveness in carbon sequestration differ (Birla et al., 2024). These systems not only stock carbon in biomass and soil but also increase biological abundance, and health of soil, and offer benefits to the rural people. Coherently, agroforestry therefore is also more than Climate Change mitigation strategy as it has so many other advantages (Jama Ali et al., 2022). The Continuation of the Significance of Agroforestry in Combating Climate Change Scientists and policymakers have recently paid much attention to the potential of Agroforestry in Climate Change Mitigation (Abebaw et al., 2025). Agroforestry interacts farm systems with the trees and can tremendously enhance carbon storage in agricultural landscapes, reduce greenhouse gas emissions, and increase resilience to climate variability (Dmuchowski et al., 2024). In the agroforestry systems there is a variation in species and thus the production system is more stable and robust than the monoculture production leading to high flexibility of the system to climate change (Scordia et al., 2023). This adaptability is peculiar since there is an enhancing trend in the occurrence and severity of adverse weather conditions which hampers agricultural output and food availability.

1.2 Importance of Agroforestry for Climate Change Mitigation

It can be noted that, in addition to carbon stocks, agroforestry affords other ecosystem services in the fight against climate change (Cardinael et al., 2025). For example, trees in agroforestry systems help in enhancing the water infiltration, reducing the surface runoff therefore help in protect [sic] the watersheds (Barbault et al., 2024), hence play a vital role in managing water resources under the changing climate systems. Trees also provide shades and windbreak which help in moderation of temperature and reduce the impact of hot weather due to frost (Ickowitz et al., 2022). These microclimates can also enhance the general growing requirements for the plants and thus associated crop production reliability and resilience to the effect of climate change induced stresses on the current cropping systems (Biswas et al., 2023). Other environmental benefits include improvement of soil fertility as well as structure through soil conservation through the creation of sustainable and productive years for agricultural systems (Gerke, 2022). Growths in agroforestry systems which include trees assist in recycling of nutrients which are returned to the soil through decomposition of the leaves, dropping of the twigs or excretion of root suckers which add to the organic matter, water holding capacity and nutrient holding capacity of the soil (Chappa et al., 2024). It also improves the healthier crop growth and also minimize the use of chemical fertilizers and thus encourage the sustainable agriculture.

1.3 Objectives of the Review

This review seeks to sum up the existing literature on the ability of the numerous agroforestry systems to sequester carbon depending on the climatic zone of the world. This comprehensively analyses the existing literature on aboveground and below ground carbon stocks (Sandra et al., 2025), assesses the economic and social impacts of agroforestry and articulates the prospects and constraints to the global propagation of agroforestry. Therefore, this review aims to provide an overview and update of the sources and importance of agroforestry in order to let policymakers, practitioners, and researchers know how important it is in climate change mitigation (Psistaki et al., 2024). However, this review goes a step further to establish how systems of agroforestry act in combination, for instance, in carbon sequestration, or how increases in carbon content improve the following benefits of agroforestry including protection of biological diversities, soil conservation, and water conservation (Abiye, 2022). Such co-benefits are crucial in developing sustainable agricultural systems that can sustain the inherent volatility with regard to climate change (Muhie & Research, 2022). In addition, the review also analyses the potential of agroforestry to positively impact other SDFs such as food security, poverty eradication and sustainable land use (Montagnini & Metzel, 2024). The review also identifies various agroforestry practices apparently adopted in the different ecological and cultural regions such as silvopastoral systems in Latin America, and home gardens in Asia while in Africa the systems include alley cropping (Nair et al., 2022c). Thus, while comparing the efficiency of the analyzed practices within different regions, the review indicates the factors, which affect these practices success, including species choice, climatic conditions, and measures taken on land. This cross-sectional analysis is useful to understand how agroforestry needs to be shaped according to regional contexts and obstacles.

2. Agroforestry and Carbon Sequestration

2.1 Carbon Sequestration Potential of Agroforestry Systems

Existing agroforestry systems are extremely diverse, which may be defined as the management of trees and crops, and occasionally livestock, together. Such systems can immobilize carbon in organic pool that includes live (e.g. boles, branches, and leaves) and dead (e.g. root and soil organic matter) biomass (Nair et al., 2022f; & Rolo, 2022). The capacity of sequestering carbon within the AF systems bears relation to the practice- level type of agroforestry practice, species mixture, age of trees and the climatic conditions (Anjali et al., 2024). There are diverse and complex relationships that define how and to what extent such AGS can sequester carbon which must be managed for the contexts and objectives (Birla et al., 2024). Species density of the trees planted, another important aspect of the type of agroforestry practice, is directly related with carbon stock and CO2 fixation capacity of the agroforestry ecosystem (Mathis et al., 2024). The techniques include silvopasture, alley cropping, riparian buffer, and forest farming whereby all of them have different advantages and ability to store carbon (Sarun & Environment, 2026). In particular, silvopasture systems—those where trees and/or shrubs are combined with access for grazing livestock – can store significant amounts of carbon, above and below ground (Baker et al., 2025), whilst at the same time enhancing pasture quality and productivity of livestock. Riparian buffers are specifically known to sequester carbon through planting trees and shrubs along water ways and also filters the water runoff and decreases soil erosion as compared to the other methods of LULC changes (Graziano et al., 2022).

2.2 Above-Ground Carbon Sequestration

Trees in agroforestry systems improve the enrichment of Carbon in the biomass and therefore a valuable tool in climate change solution (Kehinde et al., 2024). For instance, silvopasture, where trees and pastures are combined and livestock graze under these tree Planting trees together with your livestock for instance in silvopasture can lead to sequestration of carbon in trees trunks, branches and roots (De-Sousa et al., 2023). Trees offer shade for pastures also enhance the quality of the pastures as a result livestock are not stressed by heat hence high yields (Contosta et al., 2022). This means that through adoption of the silvopasture systems we end up with multiple both fixed and flowing stocks, enhanced ecosystem and flora and fauna, reduced soil and water runoff besides being carbon poles with both above and below ground storage (Poudel et al., 2024). Apart from carbon stocks, trees on silvopastoral systems can also enhance the soil nutrient through factors such as erosion control, accumulation, and water control (Jafari et al., 2022). The trees within these systems have root systems that control land erosion, control soil runoff and encourage water infiltration into the ground useful for the tree and the pasture located beneath (Vinodhini et al., 2023). Because of the effectiveness of silvopasture in enriching the soil and sequestering carbon, this particular practice of agroforestry is very favorable in a range of zones, especially where there are signs of land degradation (Marques et al., 2022). The ability to plant trees in silvopasture systems maybe the key for a more diversified and sustainable agricultural production (Poudel et al., 2024). The trees themselves can be an economic resource through provision of timber, fruits or nuts among others; this is on top of the actual products from the trees being income generating for the farmers (McConnachie et al., 2025). This diversification decreases the probability of a specific type of agricultural production being a failure and increases the stability of agriculture practices. Further, trees also provide shelter to animals and can enhance the species genetic stock and thus enhance the ecological status of the surrounding environment (Isaac et al., 2024).

2.3 Below-Ground Carbon Sequestration

The total carbon stock of trees and the carbon inputs in their roots and related organic debris are input structures of below ground stock (Handavu et al., 2021). In the case of agroforestry systems, SOC is usually higher than in conventional systems of agriculture and farming thus improving the well-being of the soils within the affected regions (Shi et al., 2018). This approach of growing trees in agroforestry systems also allows soil to have deep and extensive root systems such that it can anchor soil, prevent soil erosion and allows organic matter deposits to be made in deeper layers of the soil since such layers provide longer retention of this factor (Cardinael et al., 2020). It results in sequestration of carbon from the atmosphere and also improves water and nutrient retention capacity of the soils which in turn contribute to development of improved and efficient agricultural systems (Gayathri et al., 2021).

Another reason is that the continuous import of organic material by tree through foliar litter, root secretion and breakdown of plant matter in various agroforestry systems supports complex microbial base (Beule et al., 2022). Accomplishing these functions, it is an important component of the soil's microbial community involved in the decomposition of organic matter, stabilization of soil organic carbon, and nutrient cycling (Sridhar & Bagyaraj, 2017). Diversity in agroforestry boosts the production of organic man lock to soils hence improving the crop productivity rather than using chemical fertilizers (Nair et al., 2022a). Because of the rise in the amount of SOC in agroforestry systems, it was ascertained that well-structured soil aggregates reduce soil compaction (Mayer et al., 2022). This with the result of improving the ability of the root to penetrate the deeper layers of the soil for water and nutrients (Carranca et al., 2022). That is, agroforestry systems more resistant to drought and other climate related stress and this make them a better environment to grow crops even in troubled soils (Satish et al., 2024). The style of planting of agroforestry systems also brings long-term income in the accumulation of soil carbon (Isaac et al., 2024). Because of this modern and constant addition of organic matter into the soil, the decomposition forms what is known as humus which is a stable form of organic carbon that may even take decades or centuries to disappear (Dollinger & Jose, 2018). They stress the important of sequestration of carbon in the long-term, while noting that this process assists in counteracting emissions of carbon from other sources (Lal et al., 2018). Some of the major differences can be described as follows:

3. Carbon Sequestration Across Different Climatic Regions

In terms of carbon stock, the differences of carbon sequestration of different regions of agroforestry systems depend on climate conditions, soil and vegetation types (Nandal et al., 2023). Such practices as Agroforestry common in tropical climates can provide high rate of carbon sequestration because of the high tree growth rate and high biomass accumulation (Mahmud et al., 2020). The various factors like rainfall and temperature in Central Part countries are favorable hence increasing growth of trees and subsequently increasing carbon stock in the above ground live biomass and SOC (Watts et al., 2022). This makes the tropical agroforestry systems to be very effective in the capture and sequestration of carbon hence playing very vital role in the fight against climate change (Rolo, 2022). Still, temperate and arid lands are equally viable options for agroforestry, as long as one triggers proper measures suited for the ecosystem of the region in question (Satish et al., 2024). Agroforestry practices on shelterbelts, riparian buffers and alley cropping could in temperate areas store carbon although at a lower rate compared to that of the tropical areas (Abebaw et al., 2025).

3.1 Influence of Climatic Conditions

Due to these climatic conditions whereby the climate is colder and there are seasonal changes in regions therefore limiting tree growth; yet the capacity to store carbon for long-term storage is still significant (Pancholi et al., 2023). They help in stabilization of soil, water conservation and also in increasing the biological diversity, thus the value of temperate agroforestry systems for the ecological rehabilitation and sustainable land use (Birla et al., 2024). In regions experiencing water stress, and land degradation, of which many are arid and semi-arid, there is always a lot that can be achieved as far as carbon sequestration is concerned through agroforestry (Krishnamurthy et al., 2019). Agroforestry systems in these areas could therefore improve soil water availability, water conservation through efficient practices like mulching, contour planting (La et al., 2023), and rain water harvesting, as well as improving on soil structure through improving the organic matter content of the soil by planting trees whose species are adapted to dry areas (Dollinger & Jose, 2018). While the carbon sequestration rates may not be as profound as those in faster-growing regions (Anjali et al., 2024), the ecological outcomes – combating desertification, or reclaiming degraded landscapes are vast. These practices also help enhance the land’s ability to stand the stiff climatic conditions currently obtaining in the arid regions due to climate change like droughts, and heat waves (Gold & Garrett, 2021).

3.2 Tropical Regions

Plantations included in arboriculture and fruticulture techniques differ from agroforestry systems within the tropics of Africa, Asia and Latin America have indicated high potential for carbon assimilation (Fagan et al., 2022). Such a climate fosters fast growth of trees and a high accumulation of biomasses, hence the big sink of carbon in both the tree bole and below the soil surface (Yang et al., 2026). This feature can explain a higher co-efficient of carbon sequestration in short terms since the trees within the same tropical agroforestry systems can absorb huge quantities of the atmospheric C02 (Mey & Gore, 2021). The agroforestry of tropical trees further increases the carbon stock since different trees species are more effective than mere bushes (Vinodhini et al., 2023). A large number of high-growth and high-biomass species found in the tropic are excellent carbon stockers besides offering other co-benefits (Alaejos et al., 2023). For instance, *Gliricidia sepium* and *Leucaena leucocephala* are used for fixing nitrogen; they will help in replenishing the soil nutrients hence eliminating the use of chemical fertilizers (Sileshi et al., 2020). They also benefit the stability and yield of agroforestry systems since they help to determine soil structure, nutrient cycling and water holding capacity of the soil (Edwards et al., 2024).

The inclusion of a wide range of tree species in tropical agroforestry systems enhances species conservation a way of enhancing system balance in ecology (Nair et al., 2022d). The diversity of species that can be supported in such systems not only provides for increased naturalistic conditions that require less supplementation, but general ecosystem structures, including pest control and pollination, are more efficiently at work in those complex systems (De-Sousa et al., 2023). This also has significant services of conserving physical space for wildlife and supporting species threatened with extinction and ensuring sustainable connectivity of spatially broken habitats (Singh, M., Kumar, A., & Sharma, M. 2021). It is also worthy to note that tropical agroforestry systems are also involved with water conservation and management (Zhu et al., 2020). Absorption of water through the large root systems enhances the stabilization of the top layers of the soil enhances the reduction of soil erosion and at the same time promotes water recharge especially in the areas where water may be scarce (Kumar et al., 2020). The cover of the trees minimizes the rate of evaporation of water from the ground and underlying crops hence allowing the soil to maintain moist conditions and eventually diminish the need to water it (Vinodhini et al., 2023). This type of water conservation is particularly crucial in the tropical areas where there exists a clear distinction of the rainy and the dry seasons, so that farming is possible throughout the year (van Noordwijk, 2019).

3.3 Temperate Regions

The average temperature is reasonably high, usual practices of agroforestry like shelterbelts, riparian strips, and alley cropping have potential for carbon storage although it is at a relatively slower pace as is the case with the tropical systems (Rolo et al., 2023). These practices favorably influence other factors such as stockpile of organic carbon in the soil and preserving the soil from erosion which is fundamental in extending carbon storage (Don et al., 2024). Trees in the farming systems in temperate areas are intermingled with crops and pastures to give a layered ecosystem that provides a buffer to various stresses in the climate (Dobhal et al., 2024). Some measures, for instance, include shelterbelts which refer to planted lines of trees or shrubs around the fields to minimize crop destruction by wind borne particles as well as to decrease wind speed throughout the area (Jafari et al., 2022). Apart from checking soil erosion by providing wind breaks, shelterbelts also conserve moisture and check evapotranspiration thus helping in improving the micro climate and better conditions of growth for crops (Muhie & Research, 2022). This comes in the way that roots of the trees have also enhanced aeration of soil, besides checking on encroachment and soil erosion apart from accumulation of organic matter in the soil (Barbault et al., 2024). It helps in the improvement of the soil fertility, facilitating nutrient cycling by its support for the microbes and aiding in water retention and making the land suitable for production and not easily arid (Tschora et al., 2020).

Riparian buffers involve planting trees and shrubs along water channels and are helpful in temperate agroforests as a technique to filter the runoff, to prevent nutrients wash off and further, to reduce sedimentation in water bodies (Buchanan et al., 2020). Such buffers act as means to prevent water pollution since most of the pollutants are trapped before they find their way to the streams and rivers (Mathieu et al., 2024). Riparian zones are involved in carbon storage in view of the fact that the vegetation stores above ground biomass while the roots of trees also store carbon (Schultz et al., 2019). Besides, riparian buffers offer homes to wildlife, which increases the species' variety and consequently the overall health of the ecosystem (Salceda et al., 2023). There is also the role of the trees which are used to check the erosion of river banks as well as check the adverse effects of flooding which has become rampant due to change in climate (Yang et al., 2026). Alley cropping, the third form of agroforestry practiced in temperate regions includes cropping between trees or shrubs (Garrett et al., 2021). By so doing, this system optimizes on the use of land whiles at the same time benefiting from the crops as well as the trees. The trees grow in alley cropping systems protect the crops from strong, damaging winds and prevent the incidence of wind erosion of soil (Koch et al., 2025). They also control carbon through stock in their biomass and the encouragement of soil-carbon stock through litter buildup (Zárate-Salazar et al., 2026). More so, the fallen leaves which cover the ground return nutrients to the ground hence reducing on the use of fertilizers and improving on the fertility of the soil in due course (Embarek et al., 2026).

3.4 Arid and Semi-Arid Regions

Although rates of sequestration may be lower in these ecosystems the potential of these areas to make a contribution when considering the context of global carbon capture are vital (Huebner et al., 2021), such as in preventing land degradation, improving water holding capacity of the soil and increasing its carbon content (Sierra et al., 2021). Desert afforestation is relevant to agroforestry as the species to be planted are drought-resistant since they are predisposed for water losses in these areas and they are able to stand long periods without rain (Dong et al., 2025). Thus, it appreciable that, depending on the chosen tree species, the agroforestry in arid and semi-arid areas can combine such practices as water harvesting, mulching and cover crops to increase the level of water in the soil and reduce the evaporation (Yang et al., 2026). They also assist in shaping the micro environment to suit the trees and crops because of water scarce situation (Teshnehdel et al., 2020). Through enhancing the water holding capacity of the soil, agroforestry would give the agricultural systems the power to endure droughts as well as other climatic shocks (Satish et al., 2024). In other aspects, conservation of soil is perhaps another area that agroforestry in arid and semi-arid areas can enhance in order to enhance moisture retention in the soils (Krishnamurthy et al., 2019). Trees also have a way of checking erosion because they hold the soils firmly with their root systems, and they counteract erosive influences such as wind and water bounded territories as are these areas (Kehinde et al., 2024). This stabilized soil prevents washing away of the topsoil which provides nutrients and elements that enhance productivity of a piece of of land (McConnachie et al., 2025). Over the years the layer of fallen leaves, decomposing roots and similar items improve the structure and fertility of the soil to the extent that the capability of supporting life ventures from plants improves (Embarek et al., 2026).

Such systems can also be as windbreaks thus reducing the effect of strong winds which results in crops wilting or being damaged physically by the winds (Mume & Workalemahu, 2021). In addition to shielding crops from the wind, these structures lower the amount of wind borne soil particles such as dust and sand that have a negative impact on soil quality or the health of human and animals (Awazi, 2022). Such systems also provide the means of creating sheltered environments, which help to sustain quite stable microclimates, which are all-important for tree growth and crop production in arid and semi-arid lands (Bhol et al., 2026). Planting trees in arid and semi-arid regions for instance through practices such as agro forestry can increase on the diversity of agricultural systems (Zhang et al., 2025). The accommodation of trees and shrubs in the region allows for the habitation of birds, insects and other forms of wildlife, thus enhancing the ecological factor in the region (Camarero et al., 2021). This has a beneficial impact on the agricultural pest, pollination and the quality of the soil and therefore increases the sustainability of the agricultural system (Kingazi et al., 2024).

Apart from carbon sequestration, agroforestry has many other socio-economic and environmental returns which make it a strategic component of sustainable land management (Mukhlis et al., 2022). These include; improved overall biological diversity, better soil stocks, higher rates of crop yields, and multiple streams of revenues in the farmer’s economies (V. Singh et al., 2021). Agroforestry is a practice that involves growing trees and shrubs together with crops, and it also helps in climate resilience provide the farming communities with measures to deal with the effects of climate which include unstable weather patterns, dry spells and floods (Rolo, 2022). Other socio economic advantages of agroforestry are that it breaks the over reliance on one source of income (Pédelahore et al., 2023). Farmers have the ability to get an added income stream by growing trees for timber, fruits and nuts, resins and medicinal plants among other products (Sollen-Norrlin et al., 2020). This diversification also has the benefits of avoiding the concentration of the farmers' investments in a single crop, which in turn makes them have low risk exposure and are not affected by fluctuations in the farming market or failure in yields (Cialdella et al., 2023). Also, it can give other products linked to the forest like honey, mushrooms, and fodder that boosts food security and income of the households in the rural areas (Teel & Buck, 2023).

The incorporation of trees in farming systems also counts towards enhancing the conditions of the soils, which are important if farming is to be made productive in the long run (Vinodhini et al., 2023). Due to root systems the trees in agroforestry practices help to prevent soil erosion and also retain for valuable top soil and fertility of the land (Dollinger & Jose, 2018). The organic production provided by the trees the litter and the fallen organic matter also contribute to the improvement of organic content of the soil in addition to the fertilizer and moisture retention (Embarek et al., 2026). This enhanced soil structure yields better crops, less application of chemicals, and better yields per acre of land (Marques et al., 2022). It therefore improves on the provision of living spaces for both plant and animal species as compared to the case of normal crop farming (Awazi, 2022). The varieties of plants in the agroforestry practices sustain a diverse flora and fauna which can increase pest find and control, pollination services and disease resistance (Sharma et al., 2026). This biodiversity also assist in discouraging the loss of crop diversity which is essential in giving the farming systems the capabilities of withstanding harsh environments (Udawatta et al., 2019).

4.1 Biodiversity Enhancement

Agroforestry systems are better in supporting higher levels of species complexity as compared to species complexity that is supported by monoculture systems of farming (Zemp et al., 2019). Hence, these biodiversity's make contributions towards ecosystem socio-security, bio-security through pest control (VijayKumar et al., 2024), pollination and physical security through enhancing the health of productive agricultural systems (Staton et al., 2019). The plant species under the agroforestry systems form a more complex food chain thus requiring a more stable environment than that of the single stand crops (Demie et al., 2024) so that the surviving ground and aerial organisms such as insect, birds, mammals and microorganisms within and around them (Marsden et al., 2020). This increased production increases the balance of resources in the ecosystem which makes pests and disease which are common in monoculture systems less of a problem (Govindasamy et al., 2024). Observation cast studies suggest that the presence of ground beetles, ants and birds that are components of the agroforestry ecosystems can effectively arrest pests thereby alleviating the relentless use of chemical control (Martin-Chave et al., 2019). In addition, plant species that differ from one another can confuse pest life cycles, thus reducing the pest infestations' probabilities (Singh, M., Kumar, A., & Sharma, M. J. A. R. 2021).

4.2 Soil Health Improvement

Trees in agricultural settings contribute to better physical status of the field, suppress potentially erosive influences and promote nutrient cycling (Nair et al., 2022e). Vertical growth of trees through putting up a network of roots that interlock with the different layers of soil make agroforestry to reduce soil erosion through firm anchorage of the various layers of soil (Saleh et al., 2022). It is more helpful in; regions that have inclined plane as a major landform feature such as hillside where soil erosion is usually rampant (Somarriba et al., 2023). Trees also help in acting as screens against wind and water borne erosions that would otherwise compromise the tops oil productivity of the ground (Nath et al., 2022). Appropriate tree species planting, for instance leguminous trees, helps in replenishing of soil nutrients in that they provide nitrogen in the soil naturally (Saleh et al., 2022). Plants of these trees have a mutualism with nitrogen fixing bacteria which plays a big role in changing the nitrogen in the atmosphere into a soluble form (Nair et al., 2022b). It also has the advantage of making the soil more nitrogenus which is a fundamental nutrient in the growth of plants (Karki et al., 2026). This process makes the farmers to use small levels of chemical fertilizers hence cutting down on the expenses by the farmers and at the same time the decreased use of chemical fertilizers minimize water pollution and greenhouse emissions (Nungula et al., 2024). In agroforestry system, the tree organic inputs including the fallen leaves, decomposing branches, roots and root exudations are known to exert positive influence on SOC (Cardinael et al., 2018). This organic matter enhances the capacity of the soil to have better structure as it has been seen to increase the porosity and water intake of the soil so that, in dry seasons, water retention is enhanced (Gusli et al., 2020). This also leads to the enhancement of the SOC, benefits the population of base and active soil microorganisms that play crucial roles in the cycling of nutrients and stimulating growth of the soil organisms (Vaupel et al., 2023). This biological activity also improves nutrient uptake by crops hence promote growth and productivity of crops (Sollen-Norrlin et al., 2020).

4.3 Economic Opportunities

Additional livelihoods are generated through sale of timber and fruits, nuts and other tree products in case of agroforestry (Nair et al., 2022a). The differentiated income ensures that farmers are not entirely depended on the price of their produce and or crops and also that they are protected from fractures that may result from unfavorable climate conditions (McConnachie et al., 2025). This approach to land and crop management also helps farmers to achieve better yields and better organization of farm land by intercropping the land together with tree planting(Yang et al., 2026). The existence of trees contributes to the increased restorative capacity of the environment, meaning that varieties are more productive and less prone to disease, which helps to increase farmers' revenues (Pantera et al., 2018). For instance, trees reduce pollination services, control pests, and improve the fertility of soils leading to enhanced agricultural productivity (Blanco et al., 2020). The environmental benefits which result from organic farming have their equivalent in the economic advantages whereby farmers can be in a position to produce more and better yields of crops (Staton et al., 2022).

5. Challenges and Future Opportunities

Agroforestry investment like tree planting and production has long term returns, and can act as a source of income to farmers (Applegate et al., 2022). It grows with time, meaning that when grown to the right age, it can be cut down and be of more value income wise (Abebaw et al., 2025). This kind of steady and long-term income becomes a sort of 'savings' or 'investment' which one can cash in by the times when one may need extra money to cover his expenses and therefore makes an individual economically more secure (Do et al., 2020). It will be revealed that integrated agroforestry uses can help introduce interested farmers to new business opportunities, especially in specialized and/or high-value products (Gold & Garrett, 2021). Eco-Products; fruits and nuts; medicinal plants; and timber that has been obtained from well-managed forests may be sold at the higher prices in markets where consumers and buyers are willing to pay premium price for goods produced in environmentally sound socially responsible manner (Govindasamy et al., 2024). The access to these markets can enhance farmers' incomes and promote the use of proper strategies in farming that is environmentally friendly (Mahmud et al., 2020). It can also help in providing employment both for planting as well as for the management, harvesting as well as processing of tree crops, thus uplifting the standard of living of a community (Marsden et al., 2020). These jobs can help to boost Economic activities within the regions as well as reduce poverty index among people living in rural areas of the respective countries since most of them lack many employment opportunities (Keprate et al., 2024). As the result agroforestry can promote the development of local enterprise and entrepreneurship and contribute to the creation of stronger communities (Torquebiau, 2024). That is, the opportunity to increase the number of foods that are produced in the farms through practice of Agroforestry would help boost food security and nutrition (Jung et al., 2025). Fruits and nut trees combined with edible shrubs make it possible to reap a number of other nutritious foods apart from the conventional crops (Pantera et al., 2021). This diversity enhance the improved relativity of diet quality for the farming families and makes it possible for them to have foods at every times of the year eliminating odd shaped foods (Birla et al., 2024).

5.1 Major Challenges

However, as has been indicated above, the practice of agroforestry has been faced with the following challenges (Kala, 2025). Some of them include: tenure rights, lack of proper technical knowhow, and market and financial constraints (Montagnini & Sovereignty, 2024). Disproportionately in the developing countries, lack of legal access to land or a risk of being evicted may prevent farmers from investing in long-term agroforestry (Sollen-Norrlin et al., 2020). Due to lack of ownership or usage rights farmers will not be encouraged to plant trees or practices in agroforestry systems that need long term commitment (Rolo et al., 2020). Another cause is the lack of technical content knowledge and the necessary experience in carrying out studies (Gold & Garrett, 2021). Some of the farmers especially those from rural or less endowed area may not even know about agroforestry or the measures that may be needed for its practice (Jung et al., 2025). This lack of understanding may result in practices that are below par thus denying agroforestry this opportunity of supporting carbon stocks, increasing biodiversity, as well as supporting incomes (Nandal et al., 2023). Also, due to lack of adequate training, the farmers are likely to have challenges in choice of tree species, tree-crop interrelationships and the overall management of the agroforestry system (Kala, 2025). Inability to access markets and financial capital also conspires against the practice of agroforestry (Nair et al., 2022a). One of the major challenges that are encountered by the smallholder farmers include the lack of appropriate markets where they can market their agroforestry commodities like timber, fruits and or nuts at reasonable and fair prices (Jhariya et al., 2019). However, due to the fact that they have not developed value chains and markets for most of these products, their profits may reduce as compared to the agricultural returns and due to this, agroforestry is not more attractive for the farmers who depend on the ready cash income (Tranchina, Reubens, et al., 2024). Furthermore, the start-up costs of planting agroforestry such as tree seedling and implements and fertilizers can be very expensive for most farmers (Kehinde et al., 2024). If credit or any financial help cannot be obtained cheap and early these initial cost may not be affordable especially for the small holders in the developing world (Hastings et al., 2021).

5.2 Policy Support and Incentives

The governments can also support any form of agroforestry by implementing policy supports that include on tax credits, subsidies, and payments for ecosystems services (Mosquera-Losada et al., 2023). All these incentives can make farmers embrace agroforestry and seek to uphold tree production for many years (Rolo et al., 2023). Through the adoption of this policy, governments can encourage the tweaking of National Agricultural and National Environmental Policies in order to ensure provision of an environment that supports the development of agroforestry systems across the different regions (Santiago-Freijanes et al., 2021). To this end, governments should make it possible for credit and microfinance resources to be available to those farmers who want to practice agroforestry (Raj et al., 2019). This can be made possible by setting up of agroforestry funds of the organization or engaging financial institutions to provide low interest or subsidized credit facilities or grants (Santiago-Freijanes et al., 2018). These financial instruments may ease the costs that are often incurred when establishing the vegetation cover, soil conservation and tree planting venture to make it affordable to farmers who consider themselves financially deficient (VijayKumar et al., 2024). Governments can also actively participate in the promotion of agroforestry practice in as much as they can undertake research and extension services (Applegate et al., 2022). It's crucial for governments to invest in research and development – this way, it would be possible not only to learn more about the benefits of agroforestry and related practices but also to figure out which species of trees are best for planting, how it is best to plant them, and how to manage the related processes sustainably (Krčmářová et al., 2021). This knowledge can then be transferred to extension service delivery in the form of farmer empowerment, the technical support and education that is required in employing and sustaining agroforestry configurations (Hemmelgarn & Gold, 2021). Extension services seek to provide information to farmers regarding agroforestry practices and improve their efficiency in the determination of adoption levels of various agroforestry practices (Oduniyi et al., 2019).

Governments can promote markets for agroforestry products by put in place certification programs, defining standards for sustainable agroforestry and putting in place markets for the products of smallholder farmers (Swadhi, 2025). Through the intervention of the policy makers, the governments can ensure that the communities involved in agroforestry are given favorable markets for the products as a way of increasing profitability of this noble practice (Santiago-Freijanes et al., 2021). Marketing and awareness creation can also be used in the creation of awareness among the consumers on the importance of the agroforestry products which would in turn increase demand in the products and hence more market for the products (Rolo et al., 2023).

5.3 Capacity Building and Knowledge Sharing

Capacity building is the twinning of institutions so that they help each other to develop their capacity; knowledge sharing is another key area in which the EU has invested (Lalrochunga et al., 2024). Educational requirements in agroforestry projects include technical skills in nature and are indispensable to the process (van Noordwijk, 2019). Extension activities that raise the awareness of farmers and render them capable of serving as trainers in agroforestry can help to improve agroforestry practice and extend them (Sollen-Norrlin et al., 2020). These program should be localize with specific reference to broad climatic conditions of the regions, the type of soils and socio-economic status of farmers to give them practical information for copying (Mendelson et al., 2021). With regard to formal training, peer-to-peer learning and knowledge exchange platforms are very useful in sharing of best practices and new ideas and development in the area of agroforestry (Hemmelgarn et al., 2019). There are mature farmers who have practiced and developed agroforestry systems and these can be contacted to explain their techniques and possible consultations for existing issues (Hemmelgarn & Gold, 2021). Such a bottom-up approach can help to strengthen social capital and create a feeling of ownership of the practice among farmers leading to more people embracing the practice of agroforestry (Birla et al., 2024).

Other stakeholders which include; the agricultural extension services, universities and NGOs can help in the capacity building if they are involved, by offering support as well as technical expertise to the farmers (Barlagne et al., 2023). Such institutions can help in the regular provision of information in terms of research findings, new arts and technologies on agroforestry to farmers (Dumont et al., 2019). It also encourages the co-production of knowledge by farmers and researchers where farmers' practices get authenticated through scientific knowledge and research so as to create technologies for agroforestry systems that are productive and sustainable (Blanco et al., 2020). Capacity building programs should also ensure that farmers in particular have the skills and information they require to acquire funds, to manage these and to plan for sustainable finite benefits of Agroforestry (Swadhi, 2025). Information on the market potential of agroforestry products, their value addition and cost and returns analysis would assist the farmers in making informed decisions and invest in agroforestry with confidence (Sollen-Norrlin et al., 2020). This the reason why digital tools and technologies can also be employed to expand the capacity building interventions' impact (Tranchina, Burgess, et al., 2024). Mobile applications and Social Media platforms can then be used for sharing of training documentation and training success stories, facilitate farmer to farmer learning and interact with experts (Pippi et al., 2025). Some of these can facilitate access to information especially to farmers in the rural or other hard to reach areas and promote real time solutions to problems and decision making on the farm (Stewart et al., 2022).

5.4 Market Development

Market promotion lead to divers sources of income such as timber, fruits, carbon credits hence encourage farmers to continue practicing agroforestry (Do et al., 2025). Some of the evaluations include the following: Through establishment of these markets, farmers will access diversified source of income thus eliminating the various risks associated with single-borne markets due to natural produce weights and climate changes (Pandit et al., 2019). Programs that create value chains and open opportunities for selling products in fair trade markets may also strengthen economic profitability of agroforestry, with the farmers being fairly compensated for their products to encourage them to practice sustainable farming (Cai et al., 2021). In addition, the formation of cooperatives and farmer associations may help smallholder farmers to increase their negotiation capacity, market opportunities and make collective investment on processing and storage (Bijalwan et al., 2019). These developments can help to decrease post-harvesting losses and, thus, raise the worth of products, which are produced by agroforestry systems (Dollinger & Jose, 2018).

This paper has shown that linking agroforestry with carbon markets may help farmers to get paid for having adopted practices that store carbon while they mitigate the impacts of climate change at the same time, making agroforestry both an effective climate change tool and an economic opportunity. The linking of agroforestry with carbon markets may lead to increased funding from public and private sources and more integration of agroforestry systems (Awazi et al., 2025). Moreover, carbon credits may be sold together with other ecosystem service, for instance, in the form of integrated packages that include the production of biotic and abiotic services like biodiversity conservation and watershed protection for farmers as marketable ventures (Raj et al., 2025). National and global bodies have a crucial role to play in helping these markets to emerge through providing the right legal and policy environment, sharing of expertise and best practice and guaranteeing trust and integrity in the trading of carbon credits (Waldén et al., 2020). Through the offer of certifications and standards for agroforestry products that are produced sustainably, governments can support farmers in finding access to high-value markets that are concerned about environmental responsibility and ethical production (Minoli et al., 2023).

CONCLUSION

Speaking of climate change mitigation, people meet numerous opportunities in increasing carbon stock through agroforestry. By incorporating trees into farmers' fields, agroforestry systems can thus considerably address concerns of carbon, species, 'soil-sequestration,' and revenue. Besides sequestering carbon in above and below ground biomass these systems also establish more complex and stable ecosystems that are less vulnerable to climate change and associated variations in climate. This way agroforestry also helps in water conservation, less soil erosion and in a way enhances nutrient cycling of the soil, and therefore, can be very sustainable for the land. It important to note that green carbon has more economic values other than mitigating climate change. Farmers can obtain extra revenues from timber, fruits, nuts and a lot of other tree products hence mitigating on risks associated with single-crop farming, market risks and increased climate volatility. In addition, food security can be accomplished by obtaining a more diverse output in terms of the products that people consume, and by increasing yields through better stewardship of the local environment.

Despite the current limitations in diffusing agroforestry programmers across the globe, policy intervention, capacity enhancement and market promotion strategies can enhance the functional capacity of agroforestry in mitigating climate change. They can particularly involve themselves through spreading awareness about agroforestry by enacting supportive polices, subsidies, and incentives. Education and the sharing of information and good practices are critical in technical constraints removal and the adaptation of AFS to suit local conditions through technology incubation through research and development. Education and training are other important activities which should be invested in since it will equip the farmers who are the main handlers of the policy with the necessary skills in handling the agroforestry activities. These can involve the local people and the use of their knowledge in a way that would make the practice of agroforestry suitable to the cultures of the people and sustainable.

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