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The Role of Agroforestry in Ecosystem Service and Climate Change Regulation: A Review

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ABSTRACT: Agroforestry systems are believed to provide several ecosystem services; however, until recently evidence in the agroforestry literature supporting these perceived benefits has been lacking. This paper aimed to provide empirical information on the role of agroforestry in ecosystem maintenance and climate change adaptation and mitigation provided by agroforestry. Agroforestry has played a greater role in the maintenance of the ecosystem and mitigation of CO2 than monocropping and open cereal-based agriculture but less than natural forest. The three components of agroforestry are important for biodiversity conservation, CO2 sequestration, and climate change adaptation. CO2 sequestration through above and ground biomass, offsetting CO2 emission from deforestation and microclimate modification are major climate change mitigation effects. Provision of numerous ecosystem services such as food, fodder, and fuel wood, income source, and enhancing soil productivity help the community to sustain changing climate effects. Hence, considerable attention needs to be given to agroforestry to contribute considerable benefit to the maintenance of the ecosystem, and climate change mitigation and adaptation next to a forest.

Keywords: Biodiversity conservation, Carbon sequestration, Air and Water clean, Soil enrichment, and Socio-Economic benefits.

REVIEW PAPER

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1. INTRODUCTION

Through the application of agroforestry, crop production can be maintained while providing an alternate solution to ecological problems [1; 2]. According to the spatial arrangement or temporal order, this system integrates tree culture, crop cultivation, and/or animal production on the same land management [3]. Through sustainable land management (including reforestation) and effective resource management, agroforestry can help conserve natural ecosystems. Additionally, agroforestry has the potential to mitigate climate change because it involves several activities that have been shown to increase carbon absorption and hence lower GHG emissions [2; 4]. Furthermore, the system can support biodiversity by incorporating several plant/crop species that could serve as homes for a variety of wildlife [5; 6]. Numerous studies have emphasized the socioeconomic advantages of agroforestry for rural populations in addition to its beneficial effects on the environment [7]. Implementing a broad agroecosystem with livestock, trees (for wood and fruit), and other crops could increase the community's economic resilience [8]. Through a variety of food sources, the system may also increase household food security [9; 10]. As a result, agroforestry may potentially help with current socio-economic problems.

Ripple et al. [11] noted that climate change is currently occurring and that immediate action is needed to keep the global temperature increase to 1.5 degrees [12]. Risks associated with climate change, such as severe droughts, flooding, and diseases, can have a significant negative influence on agricultural systems, leading to soil erosion, crop failure, biodiversity loss, decreased soil moisture, insect damage, and financial losses. Farmers are already finding it challenging to plan planting and harvesting due to more extreme events and more frequent drier and wetter weather [13], endangering current production systems and the availability of food. To reduce carbon emissions and meet the goals outlined in the Paris Agreement, agriculture, forests, and trees are essential. Farmers can adjust to the effects of climate change by replanting the proper tree species in the right location.

Although the potential contribution of agroforestry systems to the maintenance of the ecosystem is still in argument and it remains largely unexplored [14]. Furthermore, there is a lack of empirical data on the relationships between agroforestry and household livelihood resilience, particularly concerning mitigating climate change [15; 16]. These are all brought on by a lack of comprehensive empirical data. Therefore, the purpose of this paper is to provide empirical data on the specific contribution that agroforestry makes to ecosystem management as well as to solutions to climate change.

2. Agroforestry for Socio-economic Benefits

The inclusion of woody plants within the system distinguishes agroforestry from other land-use systems. By diversifying the products produced, this type of tree-based farming can increase economic resilience from an economic viewpoint [1]. The use of multipurpose trees, in particular, may increase the profitability of agroforestry since they can fulfill a variety of needs, including providing alternate sources of revenue, fodder, or food (such as wild edible fruits) during hard times among rural people [17]. In addition, some trees with the higher economic worth may be able to create cash for the community in addition to that from yearly crops. According to research on teak-agroforestry (Tectona grandis) systems in Indonesia, for instance, although having a lower recycling time (because of the plant's delayed growth phase), these systems can produce up to 12 percent of the total household income [18]. Additionally, a study on the agroforestry of damar (Agathis dammara) in Pesisir, West Sumatra, revealed that the production of damar contributed up to 50% of the household's overall revenue [19]. Furthermore, the adoption of coffee agroforestry in Wey-Besay Watershed, Lampung, contributed to more than 50% of household income as opposed to just 12% from the conventional agriculture system (non-agroforestry system) [20].

Another way to increase the benefit-to-cost ratio is through agroforestry. Some techniques involve growing woody plants that require little input (chemical fertilizers, insecticides, etc.), which can reduce production costs and increase farmer revenue [21; 8]. The farmers' understanding of the procedure, particularly regarding how to choose the best plants or trees for their system, maybe a major factor in how this outcome turns out. Some trees benefit from being grown alongside crops that are complementary to them. Contrarily, the incorrect choice of tree or crop components can result in nutrient competition [22], which consequently reduces yield and, as a result, the farmers' profit. In rural areas, the implementation of agroforestry may create new employment opportunities for off-farm tasks (Table 1) ([23]. Women may also benefit from more job opportunities since they can participate directly in production activities, which can increase gender equality in rural areas [10]. Additionally, the retention of jobs in rural areas may stop the rural exodus and so help the rural economy [24].

Agroforestry has the potential to increase food security for the locals living near the forests in addition to producing income. Ickowitz et al. [25]'s analysis of spatial data revealed that children in Indonesia between the ages of one and five were consuming micronutrients at a higher rate than previously thought. They discovered a link between agroforestry and rising national consumption of legumes. Their research also revealed a link between agroforestry and a rise in the consumption of vitamin A-rich fruits and leafy vegetables at the regional level. Following the introduction of agroforestry, low-income farmers who had participated in agroforestry training also showed increased food output and diversity, indicating greater food availability [26]. Other studies, including those conducted in numerous countries in Sub-Saharan Africa, South Asia, and Latin America [2; 10; 27], have provided evidence of a beneficial relationship between the adoption of agroforestry and food security among households.

Table 1: Employment generation potential of agroforestry in India and rates of return from investment in the agroforestry system

Agroforestry System	Area (million/ha)	Additional employment (Persons/ha/year)	Total employment (million/days)	The ratio of the rate of investment (%/year)
Silviculture	1.8	30	53.3	126
Agrisilviculture (irrigated)	2.3	40	91.3	150
Agrisilviculture (rainfed)	1.3	30	38.0	157
Agrihorticulture (irrigated)	1.5	50	76.1	129
Agrihorticulture (rainfed)	0.5	40	20.3	131
Silvopasture	5.6	30	167.4	89
Tree borne oilseeds	12.4	40	497.1	38
Total	25.4	-	943.4	117

Source: Murthy et al., [28].

3. Agroforestry for Ecosystem Services

Agroforestry poses several ecological-based practices that can potentially improve the ecosystem service for the rural community. These practices include improving soil fertility, reducing erosion, improving water quality, promoting biodiversity, improving aesthetics, and sequestering carbon [29]. It is widely acknowledged that the services and benefits supplied by agroforestry methods occur at many geographical and temporal ranges. The following section addresses some of the most important environmental benefits of agroforestry.

1. Biodiversity Conservation

Ecosystems and species critical to human survival and the health of our planet are disappearing at an alarming rate. As a result, the necessity for quick action to develop effective biodiversity conservation measures is gaining prominence around the world. Scientists and politicians are becoming more conscious of the importance of agroforestry in preserving biological variety in both tropical and temperate regions of the world. Several authors have investigated the methods through which agroforestry systems contribute to biodiversity [30; 31; 32]. In general, agroforestry plays five key functions in biodiversity conservation:

- Provides habitat for species that can tolerate a certain level of disturbance;
- Helps preserve germplasm of sensitive species;
- Helps reduce the rates of conversion of natural habitats by providing a more productive, sustainable alternative to traditional agricultural systems that may involve clearing natural habitats;
- Provides connectivity by creating corridors between habitat remnants which may support the integrity of these remnants and the conservation of area-sensitive floral and faunal species; and
- Helps conserve biological diversity by providing other ecosystem services such as erosion control and water recharge, thereby preventing the degradation and loss of surrounding habitat.

2. Agroforestry for Soil Enrichment

The function of agroforestry in increasing and sustaining long-term soil productivity and sustainability is well established. In tropical agroforestry systems, the inclusion of nitrogen-fixing trees and crops is rather widespread [33]. Non-N-fixing trees can also improve soil's physical, chemical, and biological qualities in agroforestry systems by supplying a considerable amount of above and belowground organic matter and releasing and recycling nutrients. A substantial body of literature has detailed the effects of agroforestry on soils in the tropics, including both original research and synthesis papers [34].

Agroforestry systems have also been shown to be capable of reclaiming polluted land as well as reducing soil salinization and acidity [28]. Eco restoration and soil resource sustainability via AF is also one of the most viable strategies for managing land and soil resources. Agroforestry is thought to increase soil organic carbon (SOC) through litter fall [35; 28] and rhizospheric effects increase land productivity [36], control soil erosion [34], conserve moisture in the soil, and diversify farm income [37].

3. Agroforestry for Improved Air and Water Quality

Windbreaks and shelterbelts, for example, are promoted as having several advantages. These advantages include effectively protecting buildings and roadways from drifting snow, cost savings in livestock production by reducing wind chills, crop protection, wildlife habitat, removing atmospheric carbon dioxide and producing oxygen, reducing wind velocity and thus limiting wind erosion and particulate matter in the air, noise pollution reduction, and odor mitigation from concentrated livestock operations, among others. In recent years, there has been a lot of interest in employing shelterbelts as a viable solution to dealing with livestock odor [38]. Aerosols carry the majority of odor-causing chemicals and substances (particulates). By eliminating dust, gas, and microbiological elements, vegetative buffers can filter particles from airstreams. In their comprehensive review of the subject, they focus on swine odor. According to these authors, efficiently control odor in a socioeconomically responsible manner when planted in strategic patterns. Agroforestry operations are also a tried-and-true method of providing clean water.

In typical agricultural methods, crops absorb less than half of the supplied nitrogen and phosphorus fertilizer. As a result, surplus fertilizer is carried away from agricultural fields by surface runoff or leached into the subsurface water supply, polluting water sources and lowering water quality [39]. Agricultural surface runoff, for example, can cause excessive sediment, fertilizer, and pesticide delivery to recipient water bodies and is a major contributor to eutrophication in the Gulf of Mexico. Riparian buffers, for example, have been recommended as a way to address non-point source pollution from agricultural areas. Riparian buffers help clean runoff water by slowing it down, allowing for more infiltration, sediment deposition, and nutrient retention. Trees with deep root systems in agroforestry systems can help improve groundwater quality by acting as a "safety net," absorbing excess nutrients leached below the rooting zone of agronomic crops. These nutrients are subsequently recycled back into the system via root turnover and litterfall, boosting the system's nutrient utilization efficiency [40].

4. Agroforestry Solutions for Climate Change

1. Agroforestry for Climate Change Mitigation

Without a doubt, different AF methods can lower atmospheric CO2 levels as fossil fuels are substituted.

AFS may collect ambient carbon and store it in many components, including the bole, branch, foliage, and root. As a result, agroforestry is a form of a low-carbon farming system that combines the provision of food security in a changing climate with the sequestration of ambient carbon in soil and vegetation through the management of natural resources such as light, land, water, and nutrients [41; 42]. Short rotation forestry programs that use fast-growing, high-yield trees result in larger biomass because they absorb more CO2. Raj et al. [43] estimate, that the global storage capacity for C under AFS ranges from 0.3 to 15.2 mega C/ha/year, and according to Nair et al. [44], the storage capacity was shown to be highest in humid tropics in comparison to other high-rainfall regions.

There are numerous ways to calculate how much carbon is stored in agroforestry systems; some of them are based on in-situ measurements, but the use of various assumptions causes significant variations in the data [45]. The reported carbon stocks and carbon sequestration vary greatly among African agroforestry systems. Agro-silver-pastoral systems, for example, combine rich carbon stocks with a high potential for sequestration (Table 2). Agroforestry systems can also significantly reduce the demand for wild forests for energy. According to some authors, increased demand for tree products might encourage farmers to undertake agroforestry [46], especially in areas where the supply of fuel wood is dwindling. The growth of agroforestry for sustainable fuelwood can help replace energy sources and evolve into a significant carbon offset option [47].

Table 2: Potential C stock and C sequestration of some AFS in Africa

Description (source)	C sequestration (Mg C/ha/yr) [range]	C stock (Mg C /ha)	Max rotation period (yr)	Reference
Parklands dominate AFS (Faidherbia albida)	0.2–0.8	5.7–7	50	[48; 49; 50]
Rotational woodlots	2.2–5.8	11.6–25.5	5	[48; 49; 50; 51]
Tree planting-windrows-home gardens	[0.4–0.8]	19.0	25	[48; 52]
Long-term fallows, regrowth of woodlands in abandoned farms	0.22–5.8	15.7	25	[48; 53]
AFS and integrated land use	1.0–6.7	12–228	50	[50; 54; 55]
Soil C in AFS	0.25–1.6	13–300	Ns	[45; 56]

Note: ns: not specified. Source Mbow et al. [2]

2. Agroforestry for Climate Change Adaptation

Tropical agriculture is vulnerable to climate change, especially subsistence agriculture [57]. Due to declining soil fertility, water availability, and biodiversity loss, Africa's agricultural production faces sustainability issues, and yields of significant cereal crops, such as maize, have plateaued at 1 ton ha-1 ([58]. Smallholder farmers' livelihoods are thus seriously threatened by insufficient food production for household use, especially in areas where climate change and variability are more pronounced. Agroforestry has a role to play in assisting smallholder farmers to adapt to climate change because they lack the resources to do so [59].

Agroforestry can increase smallholders' resilience to present and future climatic hazards, such as future climate change, both at the farm and landscape scales [60; 59]. Even in areas where the water, soil, and biodiversity are damaged, they are essential to maintaining homes. Through the provision of several direct and indirect ecosystem goods and services, the trees component of farming has significantly improved land productivity and livelihoods [28]. In the highlands of Eastern Africa, fodder trees in agroforestry systems are especially crucial, according to Franzel et al. [61], primarily to feed dairy cows and satisfy output shortages during periods of harsh climatic circumstances, such as droughts. These fodder trees are simple to grow, need little land, labor, or capital, produce a variety of byproducts, and frequently supply feed within a year of planting. However, several major obstacles prevent the widespread use of fodder trees, including the lack of species suitable for different agroecological zones, a lack of seed, and farmers' lack of knowledge and expertise required to grow them.

Agroforestry techniques, such as parklands, are crucial because they provide soil cover with trees and shrubs, which prevents erosion and mitigates the effects of climate change. In risky regions like the Sahelian zone of West Africa, they give green fodder to supplement crop wastes for livestock feeds, fruits, and leaves for human consumption, as well as help farmers, generate cash. The interactions between diverse agroforestry system components have an impact on the ecosystem service functions of parkland trees (providing, regulating, and sustaining services) in several different ways [62]. By providing woodfuels, agroforestry has also played a significant part in SSA's energy provision and is expected to continue to dominate the region's population's energy portfolio in the future decades [63]. For instance, Asase and Tetteh [64] stated that of the 20 species identified in Ghana's agroforestry, 100% of them were used as fuel wood and 83% as medicines. The presence of trees on farms provides a more readily available, secure, and reliable source of fuelwood for energy and income, according to a study carried out in western Kenya, especially to the benefit of women [65].

According to Syampungani et al. [66], well-designed and well-managed agroforestry have some positive effects on yield and income as well as the possibility of continued production. For example, home garden species are crucial to small-scale household honey production for income [67]. Similar to this, Bachi [68] found that about 24.4 percent and 10% of respondents, respectively, utilized woody plants for income, and beekeeping helped them to acquire market-priced food for subsistence. Agroforestry adopters have improved cash income and food security, according to numerous reports [69; 68; 70]. According to Tadesse [71], 46% of the honey marketed in 2010 in southwest Ethiopia came from agroforestry based on coffee. Mekonen et al. [72] indicate that, in Ethiopia, around 25% of plant species were used for food, 13% for medicine, and 10% for household tools. Fertilized tree species (FTS) are well known to significantly boost maize yields when compared to maize farming without fertilizer in Zambia [73].

The use of trees in agroforestry, which provides social and environmental advantages as a part of farming livelihoods, also contributes to food security in Africa in the face of climate change and variability [2]. The amount of shade has a direct effect on reducing microclimate fluctuation and preserving soil moisture. This reduces the risk of crop failure or a decline in crop output by shielding the crop of interest from extreme climate occurrences. In comparison to crops with modest shading (10–30%), the coffee produced in heavy shadow (60–80%) was kept 2-3°C cooler during the hottest hours of the day [74]. Additionally, according to Lin [75], crops cultivated in open spaces lose between 31 and 41 percent of their moisture from soil evaporation and plant transpiration. Additionally, it was noted that coffee beans grew larger under agroforestry (under trees) than they did in full light, even though full sun produced more fruiting and beans per cluster [76]. Additionally, coffee production and biodiversity preservation under the influence of climate change may be reconciled through the use of agroforestry systems, which may also contribute to some regulating and supporting ecosystem services [77]. The varied traditional cocoa forest gardens may aid in controlling pests and illnesses and enable effective adaptability to shift socioeconomic conditions, according to a study [78].

Kebebew and Urgessa [79] argue that tree-based agricultural systems are more lucrative and less dangerous than other agricultural options because they provide a wider range of goods and are less likely to be infected by pests, allowing farmers to avoid dangers. Through its naturally occurring side effects, such as improved nutrient cycling, integrated pest management, and higher disease resistance, agroforestry can safeguard farm productivity. Agroforestry methods also frequently improve crop diversity inside the systems, which increases the variety of food, fuel, and fodder products produced for smallholder farmers and reduces wind damage by up to twice the height of the windbreak [75]. As a result, a variety of agroforestry systems may enable numerous different kinds of adaptation to take place under a variety of climatic conditions. However, the degree of diversity incorporated into the system will determine the co-benefit levels, with more diversity within the agroforestry system resulting in more co-benefits [80]. As a result, the ecosystem services offered by agroforestry help people and other ecosystems become more resilient to the effects of climatic fluctuation and change.

5. CONCLUSION

The provision of ecosystem services is essential to human welfare. Agroforestry is an integrated land-use system that can be a significant complement to the conservation of biodiversity, the reduction of CO_2 emissions, and the enhancement of livelihood adaptation to climate variability and change. By storing CO_2 in living biomass and soil, it reduces emissions from deforestation and soil erosion while also easing the strain on natural forestation. It is important to recognize and effectively manage the various socioeconomic and environmental factors that prevent agroforestry from reaching its full potential for maintenance, conservation, and CO_2 abatement. Agroforestry's potential must also be understood by decision-makers and the general public, and landowners must get assistance in terms of technical know-how, access to and selection of the right planting species, and management. Future studies should concentrate on identifying the best ways to integrate various agroforestry components, diversifying agroforestry components and management strategies, analyzing so many ecosystem services provided by various agroforestry systems, and the contributions of urban agroforestry to the preservation of ecosystems and the management of climate change.

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