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

Siraj Shekmohammed[1], Fahmina Mahmud[2], Md. Asaduzzaman[3], Umma Hany[4]*, and Md. Mahbub Morshed[2]

[1]East Hararghe, Meta Agricultural Office, Africa Center of Excellence for Climate Smart Agriculture and Biodiversity Conservation, Haramaya University, Ethiopia; [2]Dept. of Biotechnology and Genetic Engineering Mawlana Bhashani Science and Technology University, Bangladesh; [3]Dept. of Biochemistry and Molecular Biology, Gono Bishwabidyalay, Bangladesh; and [4]Dept. of Agriculture Rabindra Maitree University, Bangladesh.

*Correspondence: ummavabna181@gmail.com (Umma Hany, Lecturer, Dept. of Agriculture Rabindra Maitree University, Kushtia, Bangladesh).

ABSTRACT

Agro forestry systems are believed to provide several ecosystem services; however, until recently evidence in the agro forestry literature supporting these perceived benefits has been lacking. This paper aimed to provide empirical information on the role of agro forestry in ecosystem maintenance and climate change adaptation and mitigation provided by agro forestry. Agro forestry has played a greater role in the maintenance of the ecosystem and mitigation of CO_2 than monocropping and open cereal-based agriculture but less than natural forest. Agro forestry is important for preserving biodiversity, CO_2 sequestration, and adapting to climate change. CO_2 sequestration through above and ground biomass, offsetting CO_2 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 agro forestry to contribute considerable benefit to the maintenance of the ecosystem, and climate change mitigation and adaptation next to a forest.

Keywords: Biodiversity, Carbon sequestration, Cleanliness, Soil improvement, and Socio-economic benefits.

INTRODUCTION:

Through the application of agroforestry, crop production can be maintained while providing an alternate solution to ecological problems (Amare *et al.,* 2019; Mbow *et al*., 2014). According to the spatial arrangement or temporal order, this system integrates tree culture, crop cultivation, and/or animal production on the same land management (Santoro *et al*., 2020). 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 (Mbow *et al*., 2014; Bai *et al.,* 2019). Furthermore, the system can support biodiversity by incorporating several plant/crop species that could serve as homes for a variety of wildlife (Assogbadjo *et al*., 2012; Santos *et al*., 2019). Numerous studies have emphasized the socioeconomic advantages of agroforestry for rural populations in addition to its beneficial effects on the environment (Browder *et* *al*., 2005). Implementing a broad agroecosystem with livestock, trees and other crops could increase the community's economic resilience (Maia *et al.,* 2021). Through a variety of food sources, the system may also increase household food security (Duffy *et al.,* 2021; Kiptot *et al.,* 2014; and Ali *et al.,* 2022).

Ripple *et al.* (2019) noted that climate change is currently occurring and that immediate action is needed to keep the global temperature increase to 1.5 degrees (Mbow *et al*., 2017). 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, in-sect 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, 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 (Tengberg *et al.,* 2018; Alam *et al*., 2022).

Although the potential contribution of agroforestry systems to the maintenance of the ecosystem is still in argument and it remains largely unexplored (Harvey and Villalobos, 2007). Furthermore, there is a lack of empirical data on the relationships between agroforestry and household livelihood resilience, particularly concerning mitigating climate change (Lin, 2011; Nair and Garrity, 2012). These are all brought on by a lack of comprehensive empirical data. Therefore, the purpose of this paper is to provide empirical information specific contribution that agroforestry makes to ecosystem services as well as to solutions to climate change.

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 (Mbow *et al.,* 2014). 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 (Gebru *et al.,* 2019). Additionally, in addition to the money generated by yearly crops, some trees with higher economic value can be able to generate income for the comm.-unity. According to research conducted by Roshetko *et al,* (2013) revealed that, in Indonesia, teak-agroforestry (*Tectona grandis*) practices can generate up to 12% of the total household income, even though these systems have a reduced recycling time. Additionally, a study on the agro forestry of damar (*Agathis dammara*) in Pesisir, West Sumatra, revealed that the production of damar contributed up to 50% of the household's overall revenue (Wollenberg and Nawir, 2005). Furthermore, the implementation of coffee agro forestry in Wey-Besay Watershed, Lampung, & increased household income by more than 50% compared toonly 12% from the traditional agriculture method (Suyanto *et al.,* 2007). 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 (Martinelli *et al.,* 2019; Maia *et al.,* 2021). 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 incurrect choice of tree or crop components can result in nutrient competition (Reynolds *et al.,* 2007) which consequently reduces yield and farmers' profit. In rural areas, the implementation of agroforestry may create new employment opportunities for off-farm tasks (**Table 1**) (Iskandar *et al.,* 2016).Women may also benefit from more job opportunities since they can participate directly in production activities, which can increase gender equality in rural areas (Kiptot *et al.,* 2014). Additionally, keeping jobs in rural regions may also reduce rural migration and boost their economy (Ollinaho and Kröger, 2021). Agroforestry can boost food and nutrition security for those living near forests while also generating revenue. Ickowitz *et al*. (2016)'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. Their research revealed that agroforestry raises 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 (Pratiwi and Suzuki, 2019). Other studies, including those undertaken in Sub-Saharan Africa, South Asia, and Latin America, have found a positive association between agroforestry adoption and household food security (Mbo *et al.,* 2014; Kiptot *et al.,* 2014; Sharma *et al.,* 2016).

Table 1: Employment generation potential of agroforestry in India and rates of return from investment in the agroforestry system Source: Dhyan *et al*. (2016).

Agroforestry System	Area (million/ ha)	Additional employment (persons/ha/year)	Total employment (million/days)	The investment rate ratio (%/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

Agroforestry for Ecosystem Services

Agroforestry includes several ecological practices that have the potential to improve ecosystem services for rural areas. These practices include improving soil fertility, reducing erosion, improving water quality, promoting biodiversity, improving aesthetics, and sequestering carbon (Mukhlis *et al.,* 2022). It is widely acknowledged that the services and benefits supplied by agroforestry methods occur at many geographical and temporal ranges.

Biodiversity Conservation

Ecosystems and species critical to human survival and the health of our planet are disappearing at an alarming rate. 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 examined how agroforestry systems contribute to biodiversity (Atangana *et al.,* 2014; Jose, 2012; Harvey *et al.,* 2006). Agroforestry serves critical purposes in biodiversity conservation such as

1) Provides habitat for species that can withstand some disturbance
2) Aids in the preservation of sensitive species' germplasm
3) Reduces the rate of natural habitat conversion by providing a more productive, long-term alternative to typical agriculture techniques that may include destroying natural ecosystems
4) Creates connectivity between habitat remnants, which may help to maintain the integrity of these remnants and the conservation of area-sensitive floral and faunal species and
5) Helps to sustain biological variety by providing additional ecosystem services such as erosion control and water recharge, minimizing habitat degradation and loss.

Agroforestry for Soil Enrichment

Agro forestry has a well-established role in boosting and sustaining long-term soil productivity and sustainability. Nitrogen-fixing trees and crops are widely used in tropical agroforestry systems (Jose, 2009). 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 below-ground organic matter and releasing and recycling nutrients (Udawatta *et al.,* 2011). Agroforestry systems have also been demonstrated to be capable of reclaiming polluted land and lowering soil salinization and acidity (Dhyan *et al.,* 2016). One of the most viable ways for managing land and soil resources is eco-restoration and soil resource sustainability is expected to increase soil organic carbon (SOC) through agro forestry (Aldeen *et al.,* 2013; Dhyan *et al.,* 2016) and rhizospheric effects boost land production (Saha *et al.,* 2010), reduce soil erosion (Udawatta *et al.,* 2011), retain soil moisture, and diversify farm revenue (Dagar *et al.,* 2013).

Agroforestry for Better Air and Water Quality

Windbreaks and shelterbelts, for example, are advertised as having numerous benefits. These benefits include efficiently shielding buildings and streets from drifting snow, cost savings in animal production by lowering wind chills, crop protection, wildlife habitat, absorbing atmospheric carbon dioxide and creating 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. There has been a lot of interest in using shelterbelts as a potential option for dealing with livestock odor in recent years (Tyndall and Colletti, 2007). The bulk of odor-causing chemicals and compounds are carried as aerosols (particulates). Vegetative buffers can filter particles from airstreams by removing dust, gas, and microbial components. They concentrate on swine odor in their extensive review of the subject. When planted in strategic patterns, these authors claim that they effectively manage odor in a socioeconomically reasonable manner. Crops absorb less than half of the nitrogen and phosphorus fertilizer used in conventional farming methods. Surplus fertilizer is either transported away from agricultural fields by surface runoff or leached into the subsurface water supply, contaminating water sources and reducing water quality (Tilman *et al.,* 2011). Agricultural surface runoff, for example, can contribute significantly to eutrophication in the Gulf of Mexico by delivering excessive silt, fertilizer, and pesticides to recipient water bodies. Riparian buffers, for example, have been suggested as a solution to reduce non-point source pollution from agricultural areas. Riparian buffers aid in the cleaning of runoff water by slowing it down, allowing for greater infiltration, sediment deposition, and nutrient retention. In agroforestry systems, trees with deep root systems can help enhance groundwater quality by acting as a "safety net," collecting excess nutrients leached below the rooting zone of agronomic crops. These nutrients are then recycled back into the system through root turnover and litterfall, increasing the nutrient consumption efficiency of the system (Montagnini, 2006).

Agroforestry Solutions for Climate Change

Climate Change Mitigation through Agro forestry without a doubt, different AF methods can lower atmospheric CO_2 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 (Jhariya *et al.,* 2021; Yadav *et al.,* 2017). Short rotation forestry programs that use fast-growing, high-yield trees result in larger biomass because they absorb more CO_2. According to Raj *et al.* (2019), the worldwide storage capacity for C under AFS ranges from 0.3 to 15.2 mega C/ha/year, with the humid tropics having the highest storage capacity compared to other high-rainfall regions. There are different methods for calculating the amount of carbon stored in agro forestry systems; some are based on in-situ measurements, but the application of varied assumptions generates substantial discrepancies in the data (Kumar *et al.,* 2012). 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**).

Table 2: The potential carbon stock & sequestration of some agroforestry in Africa (Source: Mbow *et al.,* 2014).

Description (source)	C sequestration (Mg C/ha/yr)	C stock (Mg C /ha)	Max rotation period (yr)	Reference
Parklands dominate AFS (Faidherbia albida)	0.2–0.8	5.7–7	50	(Thangata *et al.,*2012; Takimoto *et al.,* 2008; Marone *et al.,* 2017)
Rotational woodlots	2.2–5.8	11.6–25.5	5	(Thangata *et al.,* 2012; Takimoto *et al.,* 2008; Marone *et al.,* 2017; Kimaro *et al.,* 2012)
Tree planting-windrows-home gardens	0.4–0.8	19.0	25	(Thangata *et al.,* 2012; Glenday, 2008
Long-term fallows, regrowth of woodlands in abandoned farms	0.22–5.8	15.7	25	(Thangata *et al.,* 2012; Jew *et al.,* 2016)

AFS and integrated land use	1.0–6.7	12–228	50	(Marone *et al.,* 2017; Lal *et al.,* 2007; Gruenewald *et al.,* 2007)
Soil C in AFS	0.25–1.6	13–300	Ns	(Kumar and Nair, 2012; Kim *et al.,* 2016)

Agroforestry systems can also greatly reduce the demand for energy from wild forests. According to some authors, growing demand for tree products may motivate farmers to engage in agro forestry (Sood and Mitchell, 2011), particularly in places where fuel wood supplies are limited. The expansion of agro forestry for sustainable fuel wood can assist in the replacement of energy sources and evolve into a substantial carbon offset alternative (Luedeling *et al.,* 2011).

Climate Change Adaptation through Agroforestry

Climate change threatens tropical agriculture, particularly subsistence agriculture (Verchot *et al.,* 2007). 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 (Carsan *et al.,* 2014). Smallholder farmers' livelihoods are thus seriously threatened by insufficient food production for household consumption, particularly in areas characterized by more changing climate and fluctuation. Agroforestry can help smallholder farmers adapt to changing climate because they lack the resources to do so (Lasco *et al.,* 2014). Agro forestry can increase smallholders' resilience to present and future climatic hazards, such as future climate change, both at the farm and landscape scales (Hoang *et al.,* 2014; Lasco *et al.,* 2014). 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 (Dhyan *et al.,* 2016). In the highlands of Eastern Africa, fodder trees in agroforestry systems are especially crucial, according to Franzel *et al*. (2014), 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. How-ever, several major obstacles prevent the widespread use of fodder trees, including the lack of species sui-table for different agro ecological zones, a lack of seed, and farmers' lack of knowledge and expertise required to grow them. Agro forestry 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 live-stock feeds, fruits, and leaves for human consumption, as well as help farmers, generate cash. The interactions between diverse agro forestry system components have an impact on the ecosystem service functions of parkland trees (providing, regulating, and sustaining services) in several different ways (Bayala *et al.,* 2014). By providing wood fuels, agro forestry has also played a significant part in SSA's energy pro-vision and is expected to continue to dominate the region's population's energy portfolio in the future decades (Iiyama *et al.,* 2014). For instance, Asase and Tetteh, (2010) stated that of the 20 species identified in Ghana's agroforestry, 100% of them were used as fuel wood and 83% as medicines. According to a study conducted in western Kenya, the existence of trees on farms provides a more readily available, secure, and stable source of fuelwood for energy and income, notably to the benefit of women (Thorlakson and Neufeldt, 2012). According to Syampungani *et al.* (2010), 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 (Sileshi *et al.,* 2007). Similar to this Bachi, (2017) 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 (Linger, 2014; Bachi, 2017; Kassa *et al.,* 2018).

According to Eshete, (2013), 46% of the honey marketed in 2010 in southwest Ethiopia came from agroforestry based on coffee. Mekonen *et al.* (2015) 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 (Pretty *et al.,* 2011). The utilization of trees in agroforestry, which provides advantages as part of farming livelihoods, also contributes to food security in Africa in the face of climatic change (Mbow *et al.,* 2014). Shade has a direct impact on minimizing microclimate variability and retaining soil moisture. This decreases the chance of crop failure or a decrease in crop output by protecting the crop of interest from extreme climate occurrences. In comparison to crops with little shading (10-30%), coffee grown in heavy shade (60-80%) was kept 2-3°C cooler during the hottest time (Lin, 2007). According to Lin, (2014), crops cultivated in open spaces lose between 31 and 41 percent of their moisture from soil evaporation and plant transpiration. Furthermore, it was shown that coffee beans grew larger under agroforestry (under trees) than they did in full sun, even though full sun produced more fruiting and beans per cluster (Youkhana and Idol, 2010). Additionally, under the influence of climate change, coffee production and biodiversity preservation may be harmonized through the employment of agroforestry systems, which may also contribute to some regulating and supporting ecosystem services (De Souza *et al.,* 2012). 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 (Bisseleua *et al.,* 2008). Kebebew and Urgessa, (2011) argue that tree-based agricultural systems are more lucrative and less harmful than other agricultural solutions since they supply a broader range of goods and are less likely to be affected by pests, allowing farmers to avoid dangers. Agroforestry can protect farm productivity by providing naturally occurring side effects such as improved nutrient cycling, integrated pest management, and increased disease resistance. Agroforestry technologies usually boost crop diversity within the systems, increasing the range of food, fuel, and fodder products generated for smallholder farmers and reducing wind damage by up to twice the height of the windbreak (Lin, 2014). As a result, a range of agroforestry systems may enable various types of adaptation to occur under a variety of climatic conditions. However, the degree of diversity introduced into the system will influence the co-benefit levels, with greater diversity within the agro forestry system resulting in higher co-benefits (Schoeneberger, 2009). As a result, the ecosystem services provided by agroforestry assist people and other ecosystems are becoming more resilient to the effects of climatic variation and change.

CONCLUSION:

The provision of ecosystem services is essential to human welfare. Agroforestry is an integrated land-use system that can help to conserve the environment, reduce CO_2 emissions, and improve livelihood resilience to climatic variability and change. It minimizes emissions from deforestation and soil erosion while also relieving pressure on natural forestation by storing CO_2 in living biomass and soil. Recognizing and successfully managing the different socioeconomic and environmental constraints that prohibit agroforestry from realizing its full potential for maintenance, conservation, and CO_2 reduction is critical. The potential of agro forestry must also be understood by decision-makers and the general public, and land-owners must be assisted in terms of technical knowhow, access to and selection of appropriate planting species, and management. Future research should focus on determining the optimal ways to combine multiple agro forestry components, diversifying agro-forestry components and management strategies, assessing the multitude of ecosystem services given by various agro forestry systems, and the contributions of urban agroforestry to ecosystem preservation and climate change management.

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