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THE ROLE OF AGROFORESTRY APPROACH AS A POTENTIAL TOOL FOR ATTAINING CLIMATE SMART AGRICULTURE FRAMEWORK: BANGLADESH PERSPECTIVES

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ABSTRACT
The contribution of agroforestry methods in Bangladesh is examined in this review study as a climate-smart agriculture tool, including the aspects of i) Agroforestry as Food Security Capacity and Livelihood Improvement, ii) Sustainable land use through agroforestry for promoting resilience to climate change iii) Agroforestry and Mitigation of Greenhouse Gas Emission. The systematic review was conducted following the framework of PRISMA. The keywords "Agroforestry in Bangladesh", "Agroforestry and Food Security", "Agroforestry and Sustainability", and "climate-smart agriculture practices", “Agroforestry and Climatic Resilience” in the aspect of Bangladesh were entered into databases of PubMed and Scopus. Fifty-two original research articles were selected for systematic review. Agroforestry in Bangladesh produces food, firewood, fodder, and societal flexibility, sustaining output and enhancing livelihoods through revenue opportunity, according to the systematic review. Agroforestry systems boost productivity in several Bangladeshi locations, helping locals meet their food demands and earn more. It promotes carbon sequestration, sustainable land use, and greenhouse gas emission reduction. Many Bangladeshi agroforestry methods benefit the environment, people, and economy but institutional impediments prevent their use. However, the synthesis of Bangladeshi agroforestry literature helps determine how well agroforestry works and its future route and research aims, as it could help achieve sustainable development goals through it’s climate-smart trait.

KEY WORDS
Adaptability, climate resilience, climate smart agriculture, food security, land use practices, mitigation, soil conservation, SDGs.

Bangladesh has observed rapid population growth in the last few decades. The demand for food is increasing alongside the requirements for nutrition security. In contrast, cultivable land is decreasing. About 73.4% of the land area was arable in 1989, which declined to 61.5% in 2020 [1]. Environmental sustainability is at risk as there was 0.3 tons per capita CO_2 emission in 2007, and terrestrial and marine areas cannot be protected [2]. The climatic changes have exposed the Bangladesh delta to face climatic vulnerability, where tidal river mismanagement is a prominent cause of destruction [3]. According to the report of BBS, 40% of the area was found flood affected [4]. Where the world is shifting towards achieving Sustainable Development Goals, Bangladesh is moving backwards due to abruptly caused natural disasters yearly. Women and children are still under nutrition insecurity; most live below the poverty line. The climatic hazards made Bangladesh vulnerable to extreme conditions as people lost their lives in riverine areas yearly. Geographical position combined with excess population, poverty, and lack of management has made Bangladesh vulnerable to climate change. Natural calamities have become a common phenomenon in many districts of Bangladesh, particularly riverine households. Excessive population growth, loss of arable land and flood, drought, and are marked as factors of rapid land degradation. The coastal and hoar areas frequently face the adverse impacts of climate change, including drought, flood, cyclone, and storm surges. Hence, people become exposed to vulnerability, including national food insecurity and agricultural vulnerability [7]. The changes in climatic variables have an impact on crop production, including yield. The inhabitants and farming communities of haor areas are exposed to constraints of hydro-ecological factors comprising monsoon rainfall and drought [9]. The haor areas of Sunamganj districts were found to be exposed to flood hazards [10] though the hoar areas possess the most fertile land that can generate greater agricultural productivity. The rainfall variability, river flow changes, and riverbank erosion cause financial loss. The flash floods in North-eastern haor areas destroy crops every year, causing price inflation and disrupting the cluster of food systems. In this situation, agroforestry practices can help to improve sustainable agriculture in the current era of global climate change by promoting food security, food diversity, and the production of key income streams. In response to the current dwindling situation of continuous land degradation and improper management, agroforestry in Bangladesh is reviewed as a land-use strategy of multifunctional which can uplift soil organic carbon and increase the soil nutrients and microbial dynamics than monocropping system [11]. In this case, agroforestry is a climate-smart practice that can act as a sustainability tool for increasing productivity, adaptability, and climatic resilience [12]. Different agroforestry systems, including homestead agroforestry [13], are practiced in Bangladesh. Homestead-based agroforestry can act as a land use strategy for conserving biodiversity as Bangladesh has twenty million households [14] besides its contribution to food security. The adoption of agroforestry can substantially address nutrient deficiencies, ameliorate soil health, stock soil organic carbon, and consequently conserve biodiversity [15]. In addition to providing various products, it mitigates the effects of climate change by promoting biodiversity, expanding forest cover, bolstering carbon stocks, carbon sequestration, and lowering farmer risk. Most of the agroforestry system is based on productivity mechanisms. More carbon is stored in adjacent soils through photosynthesis in woody plant tissue when agroforestry practices are adopted, and greenhouse gas concentrations in the atmosphere stay lowered. Besides, agroforestry can aid farmers in adjusting to climate change by increasing the resilience of farmland through diversification of output and ecological ecosystem services. In other words, if a crop fails due to unforeseeable weather conditions, farmers will still have access to a tree crop, strengthening the economy. In response to current food demand and climatic vulnerability, farmers in adverse areas have adopted different mechanisms and technologies in response to climate change. But agroforestry is an efficient climate-smart agriculture practice that can minimize the severe impact compared to monocropping agricultural production. It is challenging to supply the country's vast demand for food, lumber, fuel, and fodder while maintaining ecological balance as forest cover degrades. Evidence found that the adaptation of agroforestry helped to achieve rapid transformation in agriculture by introducing the farming system of fruit-dominating trees and breaking the monoculture of rice farming [16]. But it is underrated while it can act as a climate Smart Agriculture technology which is a progressive approach to landscape management that primarily comprises adopting enhanced land use practices, aims at a significant response to climate change, reduces greenhouse gas emissions, and ensures food security. It is quite underrated as a CSA tool, due to which less focus is reflected on this ground. Considering the significance, the purpose of the review is to determine whether the agroforestry system can achieve pillars of CSA through food security capacity and livelihood improvement opportunities, sustainable land use system, and reducing greenhouse gas emissions. It reviewed the prevalence of thriving agroforestry systems in Bangladesh and reviews its capacity to fulfill climate-smart agriculture pillars of increasing productivity, adapting resilience to climate change, and greenhouse gas mitigation.

METHODS OF RESEARCH

The PRISMA methodology [17] was used to conduct the systematic review of peer-reviewed journal papers on agroforestry as a tool of sustainability pillars.

The systematic review was launched using the PRISMA framework. Initially, the keywords selected were "Agroforestry in Bangladesh," " Agroforestry and Food Security," "Agroforestry and Sustainability," and "climate-smart agriculture practices," "Agroforestry and Climatic Resilience." These keywords were entered to search publications in databases of PubMed and Scopus (Science Direct, Wiley, Springer Nature, Taylor and Francis, etc.). The databases were searched for scholarly articles on agroforestry techniques in Bangladesh.

The cited documents were loaded into the Zotero software (Version 6.0.9), where records were 507 in number. In the subsequent phase, the duplicate records (165) were eliminated. A total of 342 records were evaluated for eligibility.

Specific articles were removed from the eligibility area based on specified criteria. Studies of book chapters, review articles, brief communications, not Scopus indexed, conference papers, seminar papers, and others that were not focused on the research topic or provided insufficient information were removed. There was a total of 290 of these articles.

The published research (52) that attempted to demonstrate the potential of agroforestry as a sustainable technology served as the inclusion criterion for the articles. The article's inclusion proceeded based on the original research report and the English language.

A review of selected publications was conducted following the research goals. A systematic review was conducted following the PRISMA framework depicted in Figure 1.

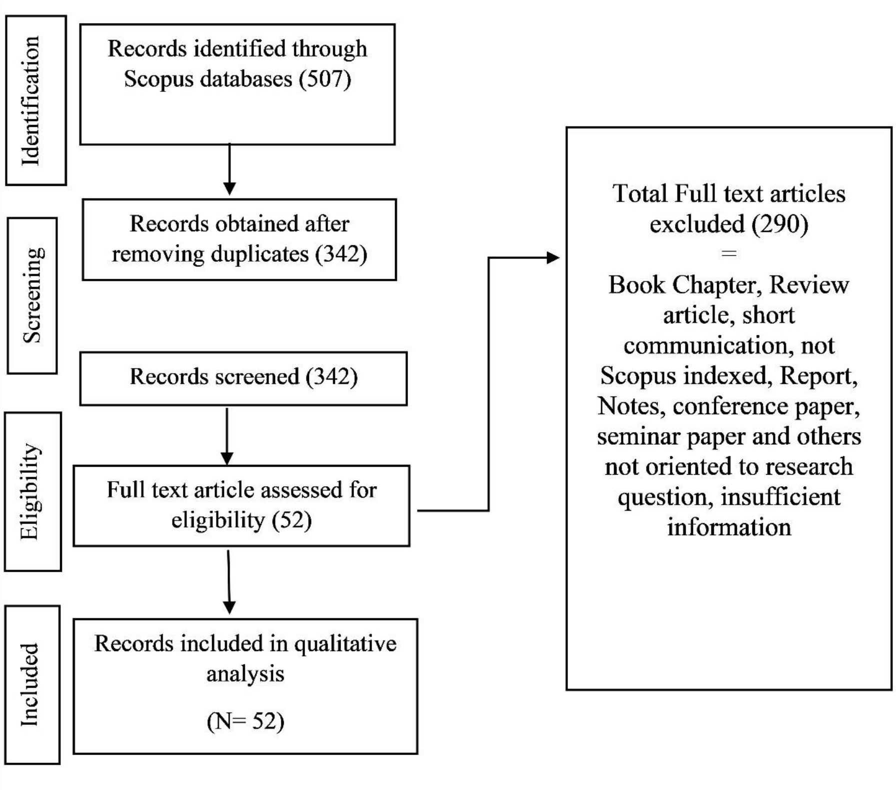

Figure 1 – Methodological Framework (PRISMA)

RESULTS AND DISCUSSION

Agroforestry as Food Security Capacity and Livelihood Improvement. Agroforestry can improve rural livelihoods, including socio-economic status, and provide several environmental advantages, including enhanced water quality, biodiversity conservation, erosion reduction, soil fertility enhancement, and global greenhouse gas emission reduction. Consequently, agroforestry is one of the most efficient means of balancing economic along with, social and environmental benefits. It can suit local requirements while preserving the environment; nevertheless, this technique may displace local food production by facilitating sophistication in traditional production techniques. Consequently, a wide range of species could be introduced through agroforestry; thereby, the function of food security and livelihood improvement becomes flexible among marginal farmers. Agroforestry has long been recognized prominent land-use option for conserving species while meeting the basic requirements of millions of underprivileged people in developing countries such as Bangladesh. Agroforestry practices in the Madhupur Tract (Tangail and Mymensingh) increased farm income significantly and provided rural farmers with additional benefits such as high capital and a variety of plants such as Acacia, Pineapple, Ginger, and Turmeric, indicating its potential to serve as a wildlife corridor and an indicator of breeding and feeding [18]. In Chittagong, hill tracts, agroforestry ranked second beneficial land use system in terms of environmental, social, and economic benefits [19]. Another study conducted in Tangail and Mymensingh district revealed that tribal farmers benefitted from agroforestry systems comprising species of *Acacia auriculiformis*, *Acacia sp*., *Mangifera indica* and *Gmelina arborea*, etc., and opined that they were facilitated through high access to food, timber, fuelwood and fodder, high economic returns, high species diversity [20]. Given the rising demand for fruit, lumber, and fuelwood, the wild mango tree species may be a suitable native tree species for filling a market gap and satisfying farmer needs [21]. Farmers from Chittagong districts choose horticultural species because fruit trees such as *A. catechu*, *C. nucifera*, and *Citrus spp*. provided a quick monetary return and assisted in meeting household nutrition and food demands even though timber species produce a larger economic return [22]. The homestead products delivered alternatives to traditional wood fuel supply in the north-eastern of Bangladesh [23]. The species numbers present revealed that fruit and timber trees (60 to 90 percent of homesteads had Jackfruit, Mango, and Betel nut) were preferred more in the homestead agroforestry system, which is important in Bangladesh's economy as woody species grown in the homesteads are a significant source of fuelwood and energy utilization [24]. The productivity is enhanced when the nutritional status increases when trees of agroforestry system facilitate nitrogen fixation, and mycorrhizal association and deep-rooted trees improve nutrient availability through increasing accessibility to soil nutrients caused by high organic matter levels and cation exchange capacity. Arbuscular mycorrhizal spore population, distribution, and colonization found to occur at significant ranges under different agroforestry plants such as *Albizia procera* Benth., *Curcuma domestica* Vahl., *Gmelina arborea* (Roxb) DC, *Eucalyptus camaldulensis* Dehnn., *D. sissoo, C. domestica, Swietenia macrophylla* King., etc. in Dinajpur which indicated the productivity enhancement dependency on agroforestry practices [25]. Farmers in the Sundarbans region preferred aqua-silviculture practices (87 percent) as an effective form of agroforestry in which trees such as *Psidium guajava*, *Avicennia officinalis*, *Excoecaria agallocha*, *Azadirachta indica*, *Acacia nilotica,* and *Albizia procera* provided timber, fuelwood, and fodder for livestock while also assisting them in increasing their income [26]. The cropland agroforest was proven to be a source of high productivity in Khulna, Satkhira, and Jessore, where the most prevalent or dominant species was identified *Swietenia macrophylla* (20.83 relative prevalence), followed by *Mangifera indica* (15.57 relative prevalence) and *Cocos nucifera* (7.08 relative prevalence) [27]. It is common practice in Bangladesh to cultivate a variety of plants close to homes for both cash income and subsistence. Fifty-six tree species have been identified in homestead agroforestry, which provides fruit, timber, medicinal species, etc., and has been proven to be a parameter for species conservation, stand structure, and biodiversity conservation in the drought-prone region of Bangladesh's northwest [28]. The transformation into Jackfruit based agroforestry with Eggplant and Papaya was found to increase yield by 32.7%, which was higher than monoculture productivity with a contributory benefit–cost ratio (5.47) and land equivalent ratio (2.59) [29]. The adoption of agroforestry systems in Bangladesh revealed that it is a potential source of increased productivity through its food security capacity. Findings from Padma floodplain landscapes revealed that relative poverty decreased as a result of agroforestry's better income compared to other agricultural systems and its greater land distribution among farmers with the least amount of land where income covers basic home requirements such as fuelwood and food security, as well as medical care, housing, and sanitary conditions, as well as tuition [30]. Farmers may choose to use agroforestry since it has been shown to provide higher BCR (benefit-cost ratio), IRR (Internal Rate of Return), and NPV (Net Present Value), where the findings indicated an opportunity to achieve SDG (Sustainable Development Goals) on climate change mitigation (SDG-13) [31]. Another study showed that an agroforestry production system could be the most effective tool for creating income, halting forest degradation, and eventually serving as a model for sustainable land management in a country with a growing population as the benefit-cost ratio of 4.12, the net present value of this land use scheme's benefits was $1,7710 [32]. Even though Pineapple agroforestry has a higher Benefit-Cost ratio (BCR), banana agroforestry was the most profitable system (with a BCR of 4.21 in participatory agroforestry and 3.35 in privately managed land) [33]. Agroforestry can boost economic returns and decrease rural poverty, in addition to alleviating the issue of land degradation caused by shifting farming in hill tracts [34]. Community-based buffer zone management in Bangladesh's Madhupur National Park has shown greater financial success through the adoption of agro-silvo-horticulture than agro-silviculture [35]. The results showed that both the Jackfruit-based and the date palm-based traditional agroforestry system improved farm productivity, with the latter system having a substantially greater benefit-cost ratio than the norm in the agricultural practices of the Mymensingh and Jessore districts of Bangladesh [36]. The financial evaluation from Sandwip Island in the Chittagong District revealed that homestead-based agroforestry generated significant profitability as benefit-cost ratios were greater than one, net present values were positive on average, and internal rates of return were greater than ten percent [22]. It demonstrates that investment in horticulture and timber tree species associated with agroforestry is extremely profitable in the long run. In fact, it can help in improving traditional production techniques. When comparing the benefit-cost ratio and return to labor, net present value (Tk. 22, 139/ha) in hill tracts of Chittagong, agroforestry was found to be more beneficial than Jhum with 25% high gross benefit [37]. Agroforestry is preferable to Jhum for soil conservation and reducing the expense of nutrient depletion [37]. The average annual profit from a betel leaf plantation was anticipated to be Tk. 80979 per hectare, and this betel leaf-based agroforestry technique generated a benefit-cost ratio of 4.47 which determined its efficiency as a profitable practice [38]. The highest tree density of Areca and highest per hectare income was found in the agroforestry plots of poor farmers, and net farm income was inversely correlated with the area dedicated to agroforestry [39]. Traditional agroforestry practices in the Rajshahi district include hedgerows, home gardens, and alley cropping, where the economic study found that the average annual value of a household's agroforestry yield is around TK. 15,400, compared to TK 8,600 from their monocropping agricultural activities [40]. In the Malta-broccoli-turmeric and Malta-broccoli-ginger-based agroforestry systems benefit-cost ratio was found to be 2.92 and 2.01, respectively [41]. The financial analysis proved that agroforestry is profitable and that large-scale production can increase high profitability.

In the Madhapur Sal forest locality, banana and pineapple-based agroforestry systems developed a strengthened market system where pineapple received the greatest market share potential [42]. In pineapple based agroforestry system, farmers were engaged in adopting plantation of Cassava, Taro, Ginger, Turmeric, Jackfruit, Sal, Bamboo, and Banana, from which they were able to fulfil their basic requirements such as economic and ecological sustainability[43]. A study on Gazipur homestead agroforestry practices revealed that homestead is a potential source of diversity and cash generating option as farmers occupy their homestead area for the plantation of major trees such as Jackfruit (*Artocarpus heterophyllus*), Mahogany (*Swietenia mahagoni*), Mango (*Mangifera indica*), Teak (*Tectona grandis*), Coconut (*Cocos nucifera*), Litchi (*Litchi chenensis*) and Guava (*Psidium guajava*) etc. indicating its potentiality alternative to mono-cropping agriculture practice [44]. The products from Betel leaf-based agroforestry systems broaden the scope of exportation in the international market in the United Kingdom from Sylhet and ease the achievement of sustainable attributes [45]. In the Satkhira district, farmers adopted different agroforestry practices responsible for livelihood diversification [46]. The findings revealed that different agroforestry practices have proved profitable in securing food and nutrition requirements. Though agroforestry is underrated compared to monocropping, this sector has performed commendably from marginal to large farm-level households. It indicates that in terms of achieving sustainable development goals (SDGs), agroforestry can act as a tool for zero hunger and livelihood improvement through poverty alleviation.

Sustainable Land Use through Agroforestry

In Bangladesh, a developing nation, most of the population lives in poverty. The nation must continue to handle the challenge of feeding a growing population while preserving the health of natural ecosystems. One of the greatest challenges of the twenty-first century will be preserving food supplies while mitigating climate-induced soil degradation. Land degradation has accelerated in many regions of the world, including Bangladesh. Consequently, it is essential to create alternative strategies that preserve soil or the ecosystem while preserving food security. In northern Bangladesh, farmers were engaged in the cultivation of fruits (90%), timber (79%), and fuelwood (87%) in the agroforestry system for access to food, fuel, and fodder for the successful utilization of land and accessibility to livelihood capitals [47]. The outcomes from the Chittagong hill tracts showed that the integration of agroforestry improved the ecological conditions of the located regions by reducing soil erosion, soil fertility maintenance, and uplifting tree coverage in addition to increasing farmers' income through employment and the sale of farm products [48]. Upland communities observe sustainable land management by adopting rubber-based agroforestry systems [49]. The development of the agroforestry system in Chittagong hill tracts revealed its benefit-cost ratio of 3:1, high seedlings growth and survival rate (over 70%), and the majority of farmers (54%) were enthusiastic regarding the adoption of agroforestry expansion [50]. Another study showed that betel nuts are the most efficient tree for agroforestry with Piper Chaba, and most farmers (64.8% of them) had between 41 and 90 Piper Chaba plants; this agroforestry system has made farmers' lives much more stable by giving them access to food, timber, fruit, fuelwood, livestock feed all year long making farmers’ lives easier with generating capital and optimum land utilization [51]. Jackfruit and date palm's traditional agroforestry system also improved rural farmers' resilience through more efficient water utilization, improving microclimate, enhancing soil fertility, diversifying products and controlling pests and diseases in Jessore and Mymensingh [36]. Hence, sustainable land use becomes prominent through agroforestry adoption depicted in figure 2. Sustainable land use indicates sustainable production through optimum utilization of land and soil conservation. Agroforestry systems can substantially improve soil's physical, biological, and chemical properties. The agroforestry canopy and root systems contribute to soil conservation. The soil organic matter is improved by the decaying of plant parts. The assessment of soil contents such as concentrations of soil organic matter (4.75 percent), available phosphorus (12.17 μgg−1), and exchangeable potassium (0.39 mg/kg) revealed that they were significantly higher in agroforestry plots than in reforestation or slash-and-burn plots which suggests that agroforestry helps to restore soil functions in south-eastern regions [52]. It indicates that agroforestry retains soil fertility, reduces soil erosion, and improves soil physical properties through its root system and maintenance of organic matter and biomass production. The largest tree biomass was found in natural forests (3 078.6 kg/100 m^2), followed by pineapple, lemon, and banana agroforestry, where soil pH, organic matter, phosphorus, organic carbon, moisture content, and total nitrogen were all elevated in Tangail Madhapur Sal forest [33].

The degraded land can be reclaimed by the incorporation of an agroforestry system. The devastated forest area was restored using betel leaf, supari-based agroforestry, and locally available species [39]. The nutrient release becomes synchronized, and nutrient cycling remains efficient under the agroforestry system. A study on the Malta tree-based agroforestry system revealed that less interference occurred for photosynthetically active radiation by the Malta-based agroforestry system with fewer canopies that, causes maximum utilization of natural resources such as land utilization and soil fertility preservation [41]. Globally, tree plantations are regarded as one of the most effective solutions to the climate crisis, and agroforestry plays a crucial role in mitigating climate change by integrating trees into agricultural practices. However, numerous abiotic stresses, such as drought, frequently threaten the productivity and longevity of this commendable solution. Species selection is one of the most challenging aspects of maximizing productivity and preventing tree mortality in drought-prone areas.

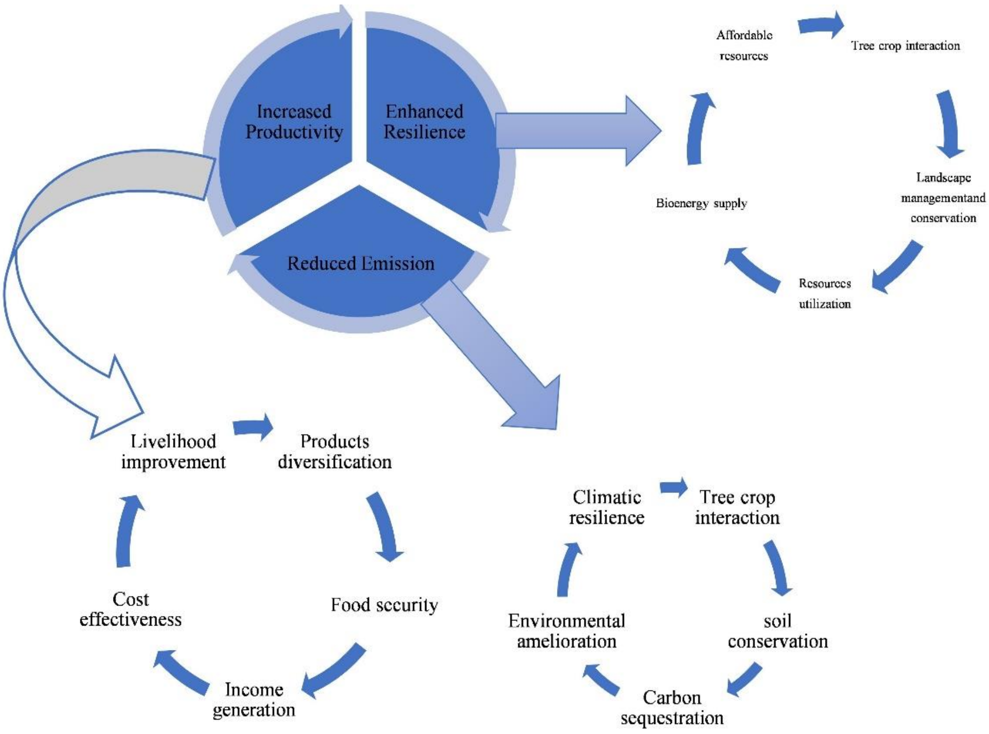

Figure 2 – Role of Agroforestry as Climate Smart Land Management

Agroforestry tree species like *S. macrophylla* had a much higher rate of germination at both soil water content of 100% and 50% whereas *A. nilotica* and *P. dulce* seedlings were able to survive and keep growing at low moisture regimes, which shows that they can adapt to areas that are prone to drought. [53]. Meanwhile, the sustainable land use system uplifts the process of soil conservation, which consequently helps uplift productivity, diversity and species preservation. The combination of above- and below-ground materials in AFs enhances soil quality and creates a habitat for various biota and soil creatures. With agroforestry (AF), it is feasible to preserve and maintain soil while also maintaining local and regional agroecosystems. Sustainable soil management practices provide the foundation for attaining the sustainability objective. The Sylhet region's betel leaf-based agroforestry practices accelerated the conservation of plant diversity because they contained species of wood, medicine, horticulture, annual crops, bamboo, and leafy vegetables [38]. The red list species were identified Morang elachi (*Amomum aromaticum*), kalomegh (*Andrographis paniculate*), bet (*Calamus guruba*), Uri Am (*Mangifera sylvatica*), Sharpagandha (*Rauvolfia serpentina)*, Kosum (*Schleichera oleosa*) in Southwestern of Bangladesh which indicated its capability of resources conservation [54]. Sustainable land use leads to soil conservation, productivity, and species diversity; thereby, SDGs of life on land can be ensured (Figure 3).

As greenhouse gas (GHG) emissions become more concentrated, the global climate is in perpetual flux. Deforestation and forest degradation are significant factors in rising greenhouse gas levels. Maintaining natural forest ecosystems and reforesting deforested, degraded woodlands, as well as newly acquired lands, are the least expensive means of combating climate change. Due to the high potential rates of carbon uptake in developing tropical nations and the cost-effectiveness of emission reduction, tropical forestry is gaining appeal as a method for reducing carbon emissions. By reducing greenhouse gas emissions, agroforestry techniques have increased their capacity to contribute to sustainable forest management. Tree species diversity and density may expedite the decomposition of soil organic carbon. The study found that species-rich home gardens with intensive tree cover can retain more carbon in soil (1.65% on average) than species-poor home gardens, helping to moderate climate change in Sylhet [55]. More soil organic carbon (SOC) may be present in a home garden agroforestry system with a greater diversity of plant species and a higher plant density. These results have relevance for the mitigation of climate change employing tropical backyard agroforestry systems, notably in terms of decreasing greenhouse gases like atmospheric carbon dioxide.

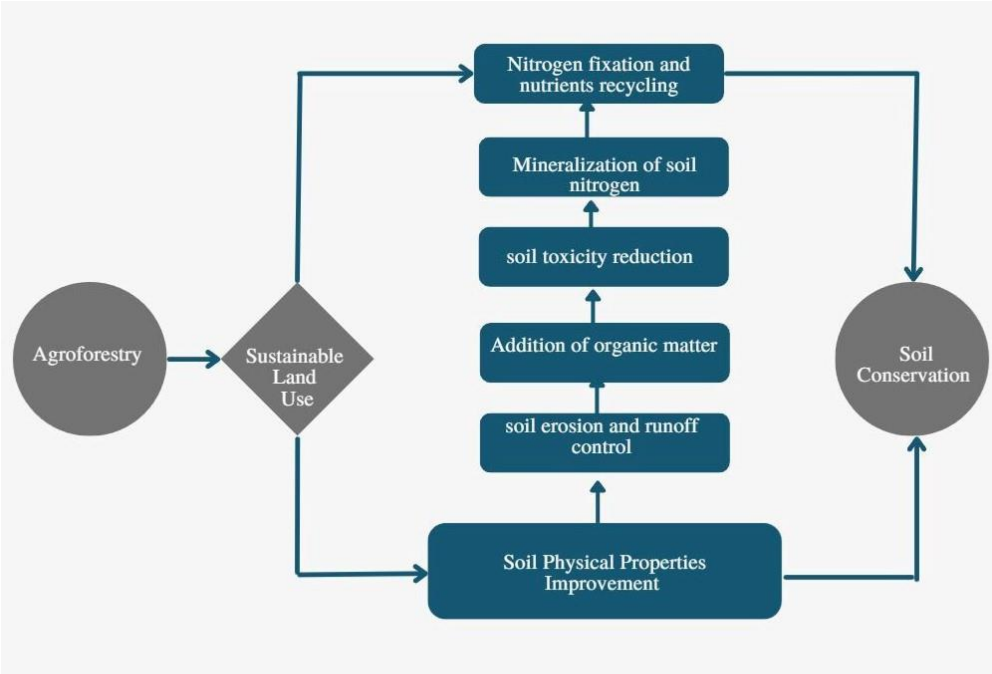

Figure 3 – Agroforestry and Soil Conservation for Adapting Resilience to Climate Change

Agroforestry and Mitigation of Greenhouse Gas Emission. In case determining the ratio of phosphorus (P), nitrogen (N), and carbon (C) in shrub and tree-shrub homesteads, SOC:P was 0.011 (0-10 cm depth), SN: P = 0.023 (0-10 cm depth), and C: N ratio was consistently stronger in the 10-20 cm depth of soil, indicating the potentiality of homestead agroforestry to uplift SOC and SN storage with substantial homestead coverage in Rangpur [56]. Higher tree species richness and diversity indices reflect greater above- and below-ground tree biomass C stocks. It was discovered that a one-unit increase in the tree species richness and diversity index increased the tree biomass carbon stock by 22 mg C/ha and 30 Mg C/ha, respectively in the inland and hillside forests where total soil C stocks were high both in inland (51 Mg ha−1) and hillside forest with increased diversity of tree species and stand density [57]. Although conservation agroforestry based on fruits and trees is ideally suited for managing biologically depleted landscapes with high financial returns, it can also be practiced in shifting cultivation fields near settlements in Khagrachhari District [58]. This allows for the transition from shifting cultivation to multi-strata conservation agroforestry or tree- and fruit-based agroforestry. At the site-specific location, agroforestry species such as *Acacia mangium, Tectona grandis,* and *Eucalyptus camaldulensis* have the capability to sequestrate significant amounts of carbon [59]. A study on leaf litter decomposition of *Dalbergia sissoo* Roxb., *Azadirachta indica* A. Juss, and *Melia azedarach* L. figured out that they released nutrients (potassium, nitrogen and phosphorus) during their decomposition where *D. sisso* showed maximum release of nitrogen and phosphorus and *A. indica* released high potassium nutrients [60]. Another nutrient dynamic study revealed that 48 µg g-1 nitrogen was released from *E. camaldulensis* whereas 0.8 µg g-1 phosphorus and 23 mg g-1 potassium were generated from leaf litter of *S. macrophylla*, both were best at releasing potassium and phosphorus nutrients [61]. Above-ground carbon storage was positively and significantly mediated by biodiversity elements, canopy height, species richness, and structural diversity.

Table 1 – Outputs from Agroforestry Approach in Bangladesh towards CSA Pillars

Agroforestry Approach	Location	Outputs towards CSA pillars	References
Agroforestry	Rajshahi, Naogaon and Chapai Nawabganj	Productivity: food diversity, income opportunity Adaptability: social vulnerability reduction Mitigation: High greeneries, biodiversity protection	[16]
Homestead agroforestry	Chittagong	Productivity: Long-term investment analyzed profitably with a high benefit-cost ratio (>1), positive net present value, greater than 10 percent internal rate of return	[22]
Homestead plantation	North-eastern	Wood fuel supply	[23]
Aqua silviculture	Satkhira	Productivity: supply of fodder and related materials and increased income	[26]
Cropland agroforestry	Khulna, Satkhira, Jessore	Productivity: Facilitation of commercial production	[27]
Homestead agroforestry	Northwestern	Adaptation: Species preservation	[28]
Multistory agroforestry	Narsingdi	Productivity: increased yield, high land equivalent, and benefit-cost ratio Adaptation: utilization of water, fertilizers, light	[29]
Betel leaf-based agroforestry	Sylhet	Productivity: Income generation Mitigation: Biodiversity conservation	[38]
Piper betel leaf-based and Areca-based agroforestry	Panchagarh	Productivity: increased income and profitability Adaptation: Sustainable land utilization	[39]
Malta-based agroforestry	Bangabandhu Sheikh Mujibur Rahman Agricultural University	Productivity: profitability generation Adaptation: increased efficiency of land use	[41]
Banana and pineapple-based agroforestry system	Madhapur Sal forest	Productivity: great market potentialities	[42]
Pineapple based agroforestry	Garo community	Environmental support: Shade, weed control, mulch, fuelwood supply Productivity: Food security, local consumption, income generation, timber supply Others: House poles, live fencing	[43]
Homestead agroforestry	Gazipur	Productivity: fruit, vegetables, timber, fuel, income, Mitigation: soil fertility, protection from natural destruction, biomass energy Adaptation: soil erosion reduction, shade, beautification	[44]
Betel leaf-based agroforestry system	North-eastern hill	Productivity: Income generation and profitability Adaptation: management of soil fertility, disease control.	[45]
Homestead Agroforestry, Aqua-silviculture, Boundary Plantation, Alley cropping, Mixed plantations	Satkhira	Productivity: Livelihood diversification; economic, physical, and natural capital facilities Adaptation: cope with climatic change Mitigation: reduction of dependency on natural forests	[46]
Homestead agroforestry	Chittagong hill tracts	Productivity: Sustainable production, long-term benefit, high market demand Adaptation: Maximum utilization of land, biodiversity conservation Mitigation: Environmentally friendly production	[48]
Rubber based agroforestry	Chittagong hill tracts	Productivity: Employment opportunity	[48]
Jhum cultivation	Chittagong hill tracts	Adaptation: culturally adaptable, easy management, Pest control.	[48]
Ploughland cultivation	Chittagong hill tracts	Productivity: Production Opportunity	[48]
Rubber based agroforestry	Chittagong hill tracts	Productivity: Nutrition and food security, employment opportunity and cash return, fuelwood supply, livestock support Adaptation: 2.12 hectares of land utilization by a farm family Mitigation: Soil conservation through mixed cropping and hedgerows systems	[49]
Agri-Horti-silvicultural agroforestry	Chittagong hill tract	Productivity: High BCR, High seedlings growth	[50]
Choi Jhal-based agroforestry	Kurigram	Productivity: Livelihood sustainability	[51]
Homestead agroforestry	Southwestern	Adaptation: Space utilization Mitigation: Biodiversity conservation	[54]
Home garden agroforestry	Sylhet	Mitigation: High soil organic carbon content with increased tree richness	[55]
Homestead forest	Cox's Bazar	Mitigation: tree species richness contributed to greater carbon stock	[57]
Home garden agroforestry	Khulna	Mitigation: Biomass carbon stock promotion	[62]
Jujube based agroforestry	Bangabandhu Sheikh Mujibur Rahman Agricultural University	Productivity: food support, nutrition support, high yield, economic return, high market value Adaptation: shade, land utilization, water and fertilizer utilization Mitigation: dynamics improvement of soil nutrients	[63]
Agroforestry	Chittagong hill tracts	Productivity: Products supply, Income generation Adaptation: in mountainous regions, an efficient land-use system Mitigation: environmentally sustainable	[64]
Participatory agroforestry	Madhupur Sal forest	Productivity: Poverty alleviation and livelihood improvement	[65]
Homestead agroforestry	Rajbari, Dhaka, Sylhet and Tangail	Productivity: Poverty alleviation, economic benefits, high plantations	[67]
Homestead agroforestry	Rangpur	Adaptation: Greater soil nitrogen content and organic carbon content	[68]

This indicated home garden agroforestry's potential to reduce carbon emissions and be a nature-based solution [62]. Integrating spices and vegetables such as Indian spinach, okra, turmeric, and ginger in Jujube-based agroforestry enriched the nutrient dynamics of soil besides its additional capability of optimum land utilisation with optimum profitability [63]. From an environmental aspect, the superiority and effectiveness of these land-use systems may be shown in the rates of soil formation under agroforestry and wood plantations being higher than the rate of loss in the Chittagong hill tracts study [64]. The findings indicate that carbon sequestration is an essential step of greenhouse gas emission reduction, which could be sustainable by adopting agroforestry at a large scale, and the SDG of climate action can be fulfilled. The Table 1 represents the overall beneficial outputs of agroforestry as a climate smart agriculture tool in aspects of productivity, adaptation and mitigation.

Outlined Barriers behind the Successful Implementation of Agroforestry Approaches. The different hindrances or constraints can make agroforestry unpopular among farmers. One of the major obstacles to agroforestry implementation was the absence of technical support, technical ability, expertise, training, motivation, and information [31]. Indigenous or local organizations have managed several agroforestry systems in the country for many years. Like many other tropical nations, Bangladesh faces the problem of traditional and market-driven agroforestry management systems, rapid economic development, and the need for more food and other products to sustain a rising population's livelihoods. Although agroforestry practices enhance species diversity, generate financial benefits, and assist farmers in preserving their livelihoods, tribal farmers confront a number of obstacles, such as bureaucracy and a shortage of alternative market facilities [20]. Participants in the Participatory Forestry program say that bureaucracy, illegal money demands from forest department officials, an unregulated market system, and insufficient road infrastructure are the main reasons why poverty has not been reduced [65]. Although Aqua silviculture is a climate-smart and eco-friendly aquaculture technique that provides local farmers with benefits by increasing vegetation on fishpond dikes, farmers opined the primary obstacles to the implementation of aqua silviculture were high soil and water salinity levels, inadequate financial resources, and the absence of technical support in Sundarbans region [26]. Unstable land tenure, complicated transit regulations, double taxes on agricultural products, and farmers' precarious socio-economic conditions were identified as major causes of low adoption of agroforestry, despite greater environmental and economic benefits [37]. Lack of resources, such as money, interest, and knowledge of agroforestry systems, as well as the long time required to see a profit, absence of technical support, etc., identified significant impediments to agroforestry integration [40]. Although agroforestry technologies improve species diversity, support farmers' lives, and ensure financial return, pest and disease outbreaks on annual crops and trees have increased [47]. Lack of trust in novel land-use systems, inadequacies in project design in innovation strategy, and land tenure policy obstacles constituted the most significant barriers to further advancements in agroforestry, which could be overcome by enhancing local groups' social capital in order to improve the standard of living in upland areas [48]. Low female engagement, inadequate baseline data, and a lack of funding were the main obstacles preventing farmers from adopting a participatory-based working style in the case of rubber base agroforestry [49]. The study findings indicate that there is an opportunity to promote agroforestry by removing institutional and policy barriers and providing the necessary facilities and support services if constraints are identified structurally.

Recommended Approaches in Response to Barriers. Agroforestry efficiency drivers could be described in technological advancement, market infrastructure improvement, research and good governance and local policies and regulations maintenance illustrated in figure 4. Due to growing land demands for agricultural production, the soil in the mountainous regions of southeast Bangladesh has deteriorated significantly. In recent years, fallow times have been substantially curtailed due to slush and burn techniques, especially in hilly regions, which have significantly impacted soil quality. Agroforestry methods can replace slash-and-burn techniques where agroforestry systems could be modernized by initiatives such as incorporating leguminous plants to uplift nitrogen concentration, providing government incentives, and arranging local NGOs and GOs campaigns [52] for broadening the scope. In Madhupur, the average household income from the Participatory Agroforestry Program (PAP) was 150,691 Taka, and the average per capita income was over the poverty line, demonstrating that the PAP was successful in eradicating poverty and significantly enhancing the local economy [65].

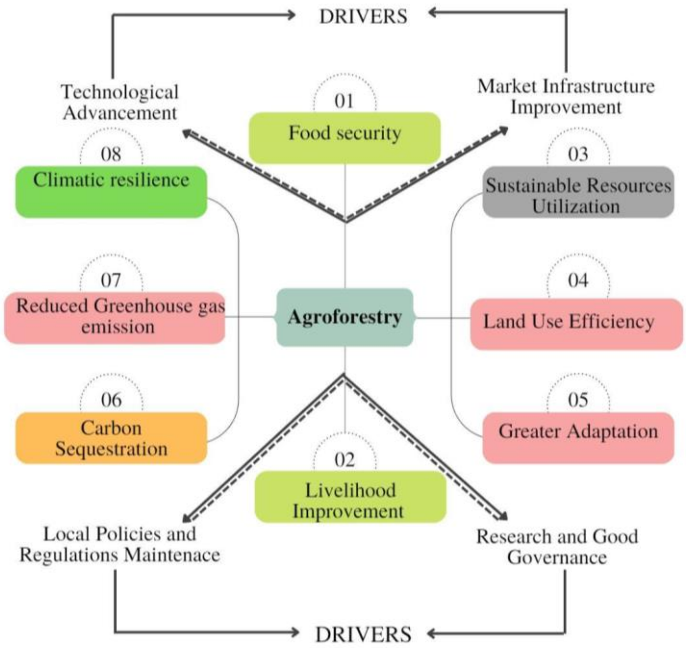

Figure 4 – Agroforestry Efficiency Drivers

Farmers could profit from the Department of Agricultural Extension's initiatives to extend agroforestry technologies across the nation by offering proper training [31]. Research is required for the domestication and assimilation of wild species into agroforestry techniques because of a lack of knowledge concerning the current state, such as wild mango species, uses, and compatibility with other agroforestry tree species[21]. Potential agroforestry practices should be used nationwide, but additional research is required to fully realize the benefits of agroforestry for preserving biodiversity, establishing sustainable livelihoods, and decreasing global warming [18]. To make agroforestry and other sustainable land-use methods more feasible, it is important to reduce trade-offs by improving conservation strategies at the farmer level [36]. Homestead agroforestry systems may have a larger role in carbon sequestration and climate change mitigation than is now understood, but this will only become clear with further research into other aspects of stand form and soil characteristics [55]. Understanding the factors influencing farmers' home garden investment decisions is critical to investigate the links between the human environment and potentially improving livelihoods through better management techniques. It is critical to determine whether there is a quantitative and predictable relationship between homestead garden biophysical conditions and household characteristics in southwestern Bangladesh [54]. Studies on different agroforestry-based practices should be explored and implemented because exploring other agroforestry systems was beneficial. The rapid population growth, water and soil quality degradation, and increased food demand led to the development of advanced farming practices such as homestead gardening and agroforestry practices [66]. To fully realize agroforestry's potential for biodiversity conservation and climate change mitigation, the creation of sustainable livelihoods Piper chaba-based agroforestry systems could be implemented as it was identified as profitable [51]. To increase sustainable production, the marketing barriers should be eased between consumers and farmers by strengthening communication channels [42]. To improve carbon sequestration in home gardens, future plantings should be continued to utilize site-specific dominant species and a small number of additional species with distinctive growth forms, as opposed to a monocultural strategy [62]. A study suggested enhancing the cropping system of multilayered and modernized farming practices to establish ecosystems' equilibrium [44]. Agroforestry has presented a number of difficulties, such as inadequate financial support, a lack of appropriate farm management training, and the possibility of joblessness for the marginal community, highlighting the significance of integrating rural and agricultural development policy by taking into consideration collaboration for sustainable reforestation by agroforestry [16]. It is suggested that extension workers should collaborate with the local population to adopt homestead forestry since correctly managed homestead forestry can reduce rural people's poverty by raising overall household income [67].

CONCLUSION

The overall evidence from the system review supported that agroforestry is a potential tool for achieving pillars (enhanching productivity, promoting resilience to climate change, and GHG mitigation) of climate-smart agriculture practice. Currently, well-managed agroforestry systems are an integral part of scientific investigations that consider ecosystem services. This system boosts biodiversity in concrete and abstract ways by enhancing ecosystem services; thereby, it promotes multi functions such as supplying food, fodder, fuel, and timber to a particular locality. Land management is one of the twenty-first century's most important problems, and AFs can address and recognize these problems while facilitating numerous functions in a sustainable manner. The soil, which is the most plentiful natural resource, supporting billions of living organisms and a wide variety of plant and animal species, can be utilized by agroforestry to ensure soil health, which promotes ecological stability and environmental sustainability. Consequently, scientific AFs guarantee one side's productivity and enhance biodiversity by boosting global environmental services. Carbon sequestration for climate change mitigation is one of the essential services offered by AFs, along with improved soil fertility, enhanced nutrient cycling, and higher resource use efficiency. By reducing GHG emissions and sequestering and storing them in plants and soils, AF decreases its carbon and environmental footprints. An effective strategy and strong governance are more important with outstanding scientific AFs to attain sustainability in tropical Bangladesh. For a more sustainable future, a road map must be developed to implement site-specific AF models for maintaining soil health and quality. Thus, agroforestry can substantially contribute to greater productivity and adaptability through sustainable land use systems and help mitigate greenhouse gas emissions. Therefore, the Sustainable Development Goals could be supported by adopting agroforestry and expanding this tool since it's CSA features. But its flow is interfered with by various constraints, which could be rectified by strategic approaches considering its drivers of technological advancement, infrastructure development related to the market, regulation and local policies maintenance, good governance and research on this ground.

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