



Agroforestry for Sustainable Livelihoods: The Way Forward

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Received: September 30, 2025

Revision Submitted: January 21, 2026

Accepted: February 10, 2026

Abstract: Agroforestry has been a practice since time immemorial but as a scientific discipline, it is relatively new compared to many other agricultural science disciplines. As a scientific discipline of enquiry, agroforestry evolved since the 1970s. It is a sustainable land management system which increases the overall production of the land by combining the production of trees, crops and or animals simultaneously or sequentially on the same unit of land. Agroforestry trees benefit the livelihoods of farmers in multifarious ways, including improved well-being, increased income and savings, decreased susceptibility to various whims, and sustainable resource usage. Furthermore, because of their capacity to store carbon and balance out the losses brought on by deforestation and forest degradation, agroforestry trees have recently gained more attention in the fight against climate change and adaptation. There has been an overall increase in the area under agroforestry at the global level in 2000-2010. The overall population in the world living in an agroforestry landscape has increased from 746.7 million to 837.6 million during 2000-2010, which implies that more farmers have realized the importance of agroforestry and consequently adopted it. Keeping in view the importance of agroforestry, there is a need to further accelerate its adoption and its intensification to increase the area under agroforestry for the overall benefit of the world farming community. In India, agroforestry has received the attention of policy makers as a sustainable land use as evident from the fact that India is the first country in the world to have a dedicated Agroforestry Policy. Despite its numerous benefits, several challenges must be addressed to accelerate the widespread adoption of agroforestry.

Keywords: Livelihood, adoption, Sustainable development goals, Carbon sequestration, Climate change, Adaptation.

1. INTRODUCTION

Sustainable food systems face significant challenges due to expanding populations and declining agricultural land. Nearly 69% of India's population lives in rural areas, which are typified by poor access to safe drinking water, sufficient housing and sanitation, health care, education, and economic resources. Although governments' attempts to ensure sufficient and sustainable access to all means of livelihood have resulted in improvements in living standards, several gaps still exist (Patidar, 2019). Climate variability, water shortages, and declining land quality pose threats to rural livelihoods and global food security. Despite generating necessary meals, conventional agriculture frequently damages the environment by using excessive amounts of chemicals, water, and land, which results in biodiversity loss and climatic impacts. These problems highlight the necessity of multipurpose, sustainable agriculture systems that maintain social and environmental well-being while increasing productivity (Sudomo et al., 2023). The issue of livelihood security is of national importance in India, because a sizable section of the rural population is directly

dependent on natural resources. Renewable resources are under extreme strain due to overexploitation, necessitating immediate action to restore ecological equilibrium. The National Environment Policy 2006, which centres sustainable development on human wellbeing, expressly acknowledges this concern. In order to meet socio-economic demands and mitigate the effects of environmental degradation, agroforestry provides a feasible route to resilience and sustainable resource use (Bansal et al., 2021). Around the world, agroforestry has become an essential land-use system that sustains the livelihoods of millions of rural communities. For small-scale farmers who mostly depend on natural resources for food, fuel, fodder, and additional revenue, it provides several ecological and financial advantages (Sahoo and Wani, 2019). Agroforestry offers a robust and sustainable substitute that improves environmental health and productivity as climate change, soil erosion, water scarcity, and growing input costs continue to pose challenges to traditional agriculture. Agroforestry's conservation and socioeconomic benefits have historically received little attention, despite its increasing significance.

Available online: March 13, 2026

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Comprehensive, long-term data describing the evolution of agroforestry systems and the factors that have shaped their function in preserving biodiversity and improving livelihoods is still lacking (Pandit, 2014). It is essential to comprehend its function in contemporary farming methods, not only to increase output but also to favourably impact rural incomes and environmental sustainability. The demand for sustainable farming methods has been further heightened by population growth and growing competition for land. Deliberate tactics, such as the domestication of beneficial tree species, enhanced market accessibility, and favourable legislative settings, are necessary to strengthen agroforestry systems. By increasing food security and diversifying revenue streams, such systems can strengthen rural resilience, especially in areas susceptible to climatic fluctuation. Reviving rural economies and advancing sustainable land management require the incorporation of synergistic technologies within agroforestry frameworks (Sarveswaran et al., 2023). Agroforestry's potential as a climate-smart and livelihood-enhancing strategy is highlighted by international frameworks like the United Nations Sustainable Development Goals (SDGs), the Convention on Biological Diversity, the United Nations Framework Convention on Climate Change (UNFCCC), and the Convention to Combat Desertification. Although nations with national-level agroforestry programs, such as India and Nepal, have made significant policy strides, governance frameworks remain lacking in many other countries in the global South (Awazi et al., 2024). Agroforestry is becoming more and more acknowledged on a global scale as a means of achieving sustainable development objectives. Scaling up agroforestry as a global answer to climate resilience and rural development will require strengthening governance, policy coordination, and institutional support. This review is carried out to synthesize and interpret the contribution of agroforestry to sustainable livelihoods and to address the limitations in fostering sustainable livelihoods across diverse socio-ecological contexts.

2. ROLES OF AGROFORESTRY IN SUSTAINING LIVELIHOODS

Agroforestry systems play the following important roles in livelihoods of the farmers:

2.1. Increased Well-being

Through subsistence and revenue-generating pathways, farming systems that incorporate agro-ecological practices have been demonstrated to significantly reduce the negative externalities of farming while also improving indicators of

household well-being, such as dietary diversity and nutrition. For instance, long-term research on an agroforestry program in Kenya discovered that the intervention had a favourable impact on revenue creation, fuelwood access, and household asset accumulation, especially in families headed by women (Milheiras et al., 2022). Agroforestry greatly increased financial capital in terms of timber, non-timber, and fuel wood income, according to a study conducted by Ahmad et al. (2021). Additionally, agroforestry farmer households (HHs) had significantly better natural capital (the amount of land and land ownership; the number of HHs growing vegetables, fruit crops, and medicinal crops); social capital (the number of social groups that HHs participated in and the number of HHs sharing crop seeds); and physical capital (buffalo plough, generators, and sprinklers) than conventional farmers. By adding diversity, taste, and nutritional value, as well as providing vital vitamins, minerals, proteins, and calories, tree-based foods improve diets. Fodder from dhama (*Grewia optiva*), cultivated in agroforestry systems of the Western Himalayas, serves as a crucial supplement, reducing the scarcity of green fodder during winter (Sood and Mahajan, 2018). Furthermore, agroforestry reduces the reliance on forest-sourced fuelwood, traditionally collected by women thus, easing their workload and freeing time for leisure or other productive activities while simultaneously conserving natural forests.

2.2. Food and Nutritional Security

Agroforestry enhances food security by fostering ecosystem resilience and services derived from the functional diversity and species interactions within its inherent biodiversity (Nuwarapaksha et al., 2024). Agro-ecological agroforestry systems are more sustainable and capable of restoring degraded ecosystems, in addition to preserving agro biodiversity, allowing farmers and traditional communities to grow more resilient and self-sufficient. Therefore, food production in an agro-ecological system could ensure food sovereignty in developing countries. To ensure food security, rural poverty reduction, and sustainable development, agro-ecological practices by small farmers and vulnerable populations, such as the indigenous population, must be encouraged (Goncalves et al., 2021). By diversifying their crop bases, agroforestry systems lower the likelihood of crop failure due to poor weather conditions. These systems also help farms produce more by promoting beneficial processes like nutrient pumping, weed and pest control, nutrient cycling, biological nitrogen fixation, and increased soil moisture availability

(Sarvade et al., 2014). Combining forestry and agriculture will not only contribute to the availability of more nutrient-dense meals but also to the development of more private food production systems that are more resilient to environmental shocks. When properly implemented, integrating trees into farming methods guarantees that the most disadvantaged groups continue to have access to foods high in nutrients and supports the operation of natural food markets, supply chains, and distribution networks (Sahou and Wani, 2019).

2.3. Employment and Income Generation

Agroforestry gives farmers a comprehensive understanding of ecological principles and climate change-adaptive management strategies, including food production, soil management, and tree and tree product management. It has been discovered that small farm households can improve and restore the rural farmland management system, as well as increase their output and income, by implementing cash trees and agroforestry. Research suggests that compared to arable systems, agroforestry operations yield a greater anticipated gross mixed revenue (Tebkew et al., 2024). In addition to providing essential raw materials for wood-based industries, trees grown in commercial agroforestry systems also increase farmers' incomes. For instance, Poplar cultivated in agroforestry systems across Punjab, Haryana, and parts of Uttar Pradesh serves as a key raw material for the paper industry, generating substantial income for farmers. Furthermore, trading carbon credits is a new source of income to farmers, diversifying their agricultural portfolio further. Policy analysis reveals that at prices of \$100 per MgC, carbon sequestration in agroforestry systems would have the potential to raise per capita incomes of farmers by up to 15% (Antle et al., 2007). As a land use system, agroforestry has enormous potential to support rural development and livelihood security by creating jobs. One of the key ways to address the challenges of the future is to standardise, improve, and distribute agroforestry-based remediation technologies for problematic soils, as well as develop, standardise, and implement agroforestry models connected to the market to increase the productivity and profitability of small-holding farmers (Castle et al., 2021).

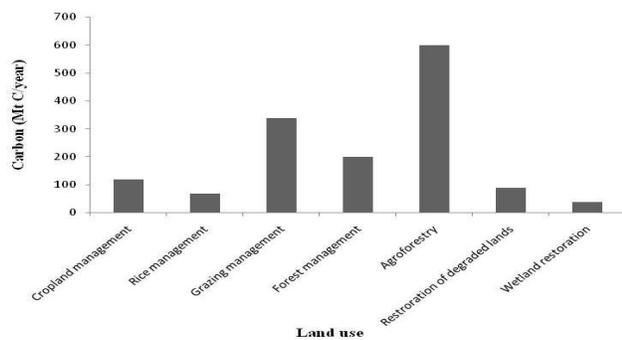
2.4. Sustainable Resource Use

In agricultural landscapes, trees and woodlands can preserve soil, protect crops from the direct or indirect effects of erosion, and help to maintain site productivity. By adding organic matter to the soil's top layer, trees increase the soil's organic matter and nutrient level. Through their deep tap root system, trees absorb nutrients from deeper soil layers and

transfer them to the upper layer through the decomposition of litter. Trees therefore serve as a nutrient pump. Tree cover is essential to many agroforestry systems because it replenishes the soil's top layer with nutrients and increases site productivity (Dhyani et al., 2021). Additionally, tree leaves intercept rainfall, which lowers surface runoff and helps to maintain soil fertility. Further, a variety of tree species fix nitrogen from the atmosphere into the soil, increasing soil fertility. The examples of such nitrogen fixing trees include Khair (*Acacia catechu*), Kikar (*Acacia nilotica*), Shisham (*Dalbergia sissoo*) and Kachnar (*Bauhinia variegata*) etc. The sustainability of agricultural production is aided by these improvements in soil characteristics and nutrient content. Additionally, trees help to moderate extreme weather conditions, such as temperature. As a result of these microclimatic changes the overall crop productivity increases.

2.5. Carbon Sequestration and Climate Change Adaptation

Agroforestry systems serve as effective carbon sinks, with significant potential for climate change mitigation and adaptation (Jose and Bardhan, 2012). Their carbon sequestration capacity is especially notable due to widespread applicability across agricultural and degraded lands. Smallholder tropical agroforestry systems can sequester 1.5–3.5 Mg C ha⁻¹ yr⁻¹ (Montagnini and Nair, 2004). Agroforestry offers significant potential for carbon storage and spans around 630 million hectares worldwide (IPCC, 2000). The many advantages of agroforestry are highlighted in recent IPCC reports, including food security, income creation, biodiversity conservation, carbon sequestration, climate adaptation, and the provision of ecosystem services (Quandt et al., 2023). Among the top 100 climate solutions, Project Drawdown found 11 agroforestry-based strategies, including bamboo, indigenous tree-based systems, silvopasture, intercropping, and multistrata agroforestry. Figure 1 highlights that agroforestry systems have a significantly higher capacity for carbon sequestration compared to conventional land use practices. According to (Zomer et al., 2022), just 10% more trees on agricultural land over ten years might sequester more than 18 PgC (1.83 PgC yr⁻¹). This is significantly higher than the net emissions from land use and forestry (1.6 PgC yr⁻¹ in 2020) and the present annual carbon losses from tropical land-use changes (0.6–1.2 PgC yr⁻¹). According to the UN Decade on Ecosystem Restoration, small-scale improvements in agricultural tree cover can support global restoration objectives. Agroforestry, which offers both economic and



Source: (IPCC, 2007)

Figure 1. Carbon sequestration potential of different land use by 2040

ecological benefits as well as climate benefits, is acknowledged by the (IPCC, 2001) as a "no regrets" approach. Important systems that contribute to carbon sequestration include agrisilviculture (trees plus crops), silvipasture (trees plus livestock), and agri-silvipasture (trees plus crops plus livestock). Additionally, it has been discovered that agroforestry stores more carbon in deeper soil layers than treeless farming systems (Prabha et al., 2014).

2.6. Evolution of Agroforestry Research Over Decades

Since the late 1970s, when the term "agroforestry" gained international popularity, the number of publications has significantly expanded. Over the last four decades, most of the literature on agroforestry has focused on ecological issues; the field's ecological foundation is indicated by the prevalence of terms like forest, species, soil, and land. However, the language used to describe social dimensions has been extremely limited (Hastings et al., 2023). Trends in study topics have drastically changed throughout time. Early studies in the 1990s focused on traditional systems and biophysical assessments. Research has shifted to system structure and interactions by the 2000s, especially the competition between crops and trees for light, water, and nutrients. Studies examined how species interactions, such as those with shade trees or plants that repel pests, could enhance ecosystem productivity and services. In response to concerns about climate change, carbon sequestration became a significant issue with the aid of international frameworks like the Kyoto Protocol. The increasing loss of biodiversity has also led to the promotion of agroforestry as a strategy for habitat conservation. Since then, studies have expanded to examine ecosystem services, which are currently a major focus of agroforestry research (Liu et al.,

2019). Over the years, important research clusters have been found using analytical techniques like LDA and HJ-Biplot. From 1993 to 2022, issues including biodiversity, climate change, food security, and organic soil carbon have not gone out of style. On the other hand, there is less attention in topics like aerial biomass and alley cropping (Montes et al., 2023). Even though agroforestry research has been conducted in India for over a century, the formal incorporation of agroforestry into national agendas began in 1983 when the Indian Council of Agricultural Research (ICAR) initiated the All India Coordinated Research Project (AICRP) on Agroforestry. Established at Jhansi in 1988, the National Research Centre on Agroforestry was renamed the Central Agroforestry Research Institute (CAFRI) in 2014. With 37 centres dispersed throughout 27 State Agricultural Universities and 9 ICAR institutes, AICRP currently covers a range of agro-climatic zones. The Indian Council of Forestry Research and Education (ICFRE) also contributes through its network of institutes (Handa et al., 2015). These changes show how agroforestry research has dynamically evolved from regional studies to globally important, multidisciplinary subjects centred on development, resilience, and sustainability.

2.7. Adoption of Agroforestry

Since its institutionalisation, agroforestry has been advocated as a significant sustainable land use choice by numerous national and international organisations. It has been a traditional land use in many regions of the world for ages. Despite this, until 2009, there was hardly any effort to calculate the global area covered by agroforestry adoption (Zomer et al., 2009). Agroforestry was divided into three groups by (Zomer et al., 2014) viz; tree cover > 10%, tree cover > 20%, and tree cover > 30%. Global Increase in Agroforestry Area by Tree Cover Density (2000–2010) suggests that there is a considerable increase in area adopted under agroforestry systems of varying tree cover densities (Figure 2). It has been estimated that a total of 1.8 billion people (24.6% of world's population) all over the world live in agricultural landscape (Zomer et al., 2014). Of these 746 million (41%) lived in agroforestry landscape with tree cover > 10% in 2000–2002 which increased to 837.6 million in 2000–2010. This represents an increase of 90.9 million (5%) during the period 2000–2010. The highest number of people lived in agroforestry landscape in East Asia, South Asia and Southeast Asia respectively.

Therefore, it is implied that throughout the 2000–2010 decade, the area covered by agroforestry and its intensification with tree cover has grown. Additionally, there

are now more people living in agroforestry landscapes worldwide. This suggests that farmers all around the world are becoming more and more interested in agroforestry as a land use method. Nevertheless, in order to improve farmer livelihoods and increase the environmental benefits at the local, regional, and global levels, efforts are needed to develop, accelerate, and intensify the adoption of agroforestry in all parts of the world. Various constraints need to be overcome to develop and promote agroforestry. These limitations differ not only across nations but also between regions of the world (Sood and Mitchell, 2011). The barriers to agroforestry adoption in India differ from one state to the next. There is limited additional research on the global, regional, and local trends in the area covered by agroforestry options after 2010.

Some of risks that landowners may face due to climate change and how agroforestry practices might be used to adapt to those risks (Table 1).

3. CONSTRAINTS IN PROMOTION AND CONDITIONS FOR

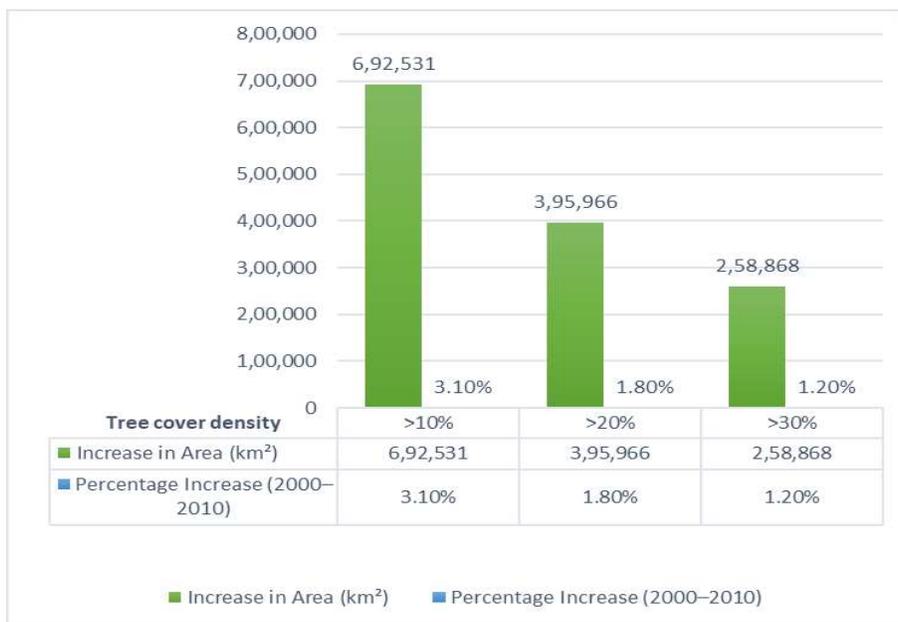
AGROFORESTRY ADOPTION:

The broad constraints, especially with reference to India, in the development and promotion of agroforestry are as:

- Lack of institutional set up solely devoted to developing, managing and encourage agroforestry land use as a whole and there is a lack of coordination amongst various

departments and organizations working individually and in isolation on different aspects (agriculture, forestry, and livestock) of agroforestry (Chavan et al., 2015).

- Poor or partial implementation of Indian National Agroforestry Policy (2014) by various states.
- Insufficient funding for agroforestry research and development due to lack of technical and economic data on different agroforestry models.
- Legal restrictions imposed by the governments on harvesting and intra and inter-state and inter country transport of agroforestry produce and inadequate attempts to ease out these restrictive regulations (Sood et al., 2018). A number of states have *de-jure* exempted several tree species from harvesting and transport restriction, however, *de-facto* such restrictions exist.
- Dearth of certified quality planting material and lack of certified tree nurseries
- Poor market linkages and infrastructure for proper sale of agroforestry produce.
- Insufficient work on standardization of post-harvest processing technologies for tree produce.
- Non-availability of economic data of different agroforestry models
- Poor extension mechanisms for the promotion of agroforestry.



Source: (Zomer et al., 2014)

Figure 2. Global increase in agroforestry area by tree cover density (2000–2010)

- Apprehension amongst the farmers that their land use will be changed after planting trees.
 - Long time taken by the trees to produce desired tree product (long gestation period) compared to agricultural crops.
 - Lack of research on reducing gestation period of many forest tree species and their poor domestication.
 - Lack of institutional mechanisms to link agroforestry practitioners to carbon credits
 - There are a number of conditions under which farm households may or may not adopt agroforestry implies that conditions like land tenure, tree ownership, management arrangements, security of future produce, right to harvest, transport and sell, prices and marketing conditions must be favorable to encourage agroforestry adoption (Table 2).
- 4. PROMOTION OF AGROFORESTRY: WAY FORWARD**
- The following strategies need to be adopted for promotion of agroforestry:
- Quantification of contribution of existing agroforestry to farmers' income. This will help in the framing strategies to promote agroforestry models which enhance the income of the farmers.
 - Identification of superior germplasm of agroforestry tree species for production of quality planting stock having short gestation periods (GOI, 2014).
 - Domestication of forest tree species
 - Studies on tree-crop interactions, management practices and development of post-harvest technologies for tree produce and their value addition (Sood and Mahajan, 2018). This will assist the farmers in adopting better tree-crop combinations and management practices on their farms to enhance overall productivity of the land in a sustainable manner.
 - Creation of awareness about agroforestry amongst the farmers and popularization of success stories on agroforestry adoption amongst the farmers and policy planners.
 - Setting up of a separate institutional mechanism at global, regional and national levels for promotion of agroforestry and ensuring coordination amongst the stakeholders.
 - Adoption of the recommendation of National Agroforestry Policy (2014) in India to promote agroforestry. Similar policies need to be framed at state levels.
 - Liberalization of legal restrictive regime on harvesting, transport and sale of tree produce. Also, the officials or staff need to be made aware of already *de-jure* exemptions of various species from felling and transport rules so that this exemption can be *de-facto* implemented.
 - Integrating agroforestry development with other rural

Table 1. Risks due to climate change and role of agroforestry in its adaptation

Risk	Adaptation	Agroforestry practice
Intense precipitation events	Slow water runoff to reduce flooding, soil erosion, and water pollution	Riparian forest buffers, alley cropping
Increased temperatures	Reduce heat stress on animals by providing shade	Silvipasture, Agrisilvipasture
Increased frequency and intensity of drought	Reduce evapotranspiration by reducing windspeed	Windbreaks (Agri-silviculture)
Increased storm intensity (wind & precipitation)	Protect crops from wind damage	Windbreaks (Agri-silviculture), alley cropping (Agrisilviculture)
Changes in growing season due to temperature and precipitation	Protect crops by creating microclimates	Windbreaks (Agri-silviculture), Agrisilvipasture, alley cropping (Agri-silviculture)
Winter storms and cold temperature extremes	Reduce cold stress on animals by providing shelter	Silvipasture, windbreaks (Agri-silviculture)
Increased insect and disease problems	Control pests by providing habitat for beneficial insects	Windbreaks (Agri-silviculture), riparian forest buffers, alley cropping (Agri-silviculture)
Increased possibility of crop failure due to other risks	Reduce total crop loss by increasing crop diversity	All agroforestry practices

Adapted and modified after: (USDA, 2015)

Table 2. Conditions for agroforestry adoption

Conditions	Adopt	Do not adopt
Land tenure	Secure	Insecure
Access to usufruct	Vested primarily in household	Subject to government control or taxation or ambiguous
Choice of tree species	To meet farmer's priority	To meet official's priority
Tree ownership	Owned by household by law or in practice	Owned by or shared with government or local authority or ambiguous
Management arrangements	Participative or semi-autonomous	Centralised and prescriptive
Security to future produce	Provided and binding	Uncertain
Rights to cut and fell trees	Unrestricted and practiced at will by owners	Restricted or believed to be restricted
Rights of transit to market	Unrestricted and practiced by at will by owners	Restricted or believed to be restricted
Marketing	Competitive	Monopolistic
Prices of tree produce	Known, stable or rising	Not known, unstable or dropping
Target concerns	Specific household needs	Social welfare
Production goal	Immediate household needs	Conservation

Based on: (Chambers et al., 1989); (Pasicolonet et al., 1997); (Sood, 2003);(Sood et al., 2018)

development plans.

- Estimation of economics of different models of agroforestry so that it can help farmers to avail loans.
- Quantification and modeling of carbon sequestration potential of agroforestry at global level, regional and farm level. This will help in estimating the revenue potential to be earned through carbon credits.

5. CONCLUSION

In addition, production of tree and food products from the same area of land, agroforestry has gained popularity because of its role in climate adaptation and carbon sequestration. Compared to other land uses, agroforestry has the greatest potential to sequester carbon by 2040. This is due to the vast amount of land (630 x 106 hectares) that is accessible for agroforestry globally (IPPC, 2000). Globally, the amount of land covered by agroforestry has been trending upward since the 1990s. In India, the promotion of agroforestry has been viewed seriously as evident from the fact that India is first country in the world to adopt the National Agroforestry Policy. Despite this, obstacles to agroforestry's growth and intensification must be removed globally in order to enhance farmers' livelihoods and fulfil the practice's promise for local, regional, and global carbon sequestration. As a result, the loss from deforestation and degradation would be balanced, leading to sustainable land use and the adaptation and mitigation of climate change. To determine the size of the agroforestry area, investigations utilising remote sensing and GIS technology must be conducted on a regular basis. The policies solely devoted to

agroforestry need to be enunciated by each nation to provide scaffolding to agroforestry development and research.

Acknowledgement

The authors acknowledge the facilities provided by SKUAST, Jammu for writing this review paper.

Authors' Contributions

K.K Sood – Conceptualization, Resources, Writing-original draft, Supervision

Sandeep Sehgal – Conceptualization, Reviewing and Editing, Visualization

Vibhuti Rathore – Reviewing and Editing, Visualization

Conflict of Interest

The authors declare that they have no known competing financial or personal relationships that could have influenced the work reported in this paper.

Data Availability

Not Applicable

Declaration about Use of AI Tools

No use of AI tools have been used in the writing process.

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