Indian Journal of Ecology (2025) 52(5) (SI): 1281-1287
DOI: https://doi.org/10.55362/IJE/2025/4646

Manuscript Number: 4646
NAAS Rating: 5.38

Agroforestry Systems in the North-Western Himalayas: A Nexus of Biodiversity Conservation, Livelihood Enhancement, and Ecosystem Services

Ritika Maurya, Naresh Kumar[1], Meenakshi Gupta, K.K. Sood and Chandramohan Singh[2]

Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu-180 009, India
[2]ICAR-Central Agroforestry Research Institute, Jhansi-248 003, India
[3]College of Forestry VCSG Uttarakhand University of Horticulture and Forestry, Ranichauri-249 199, India
E-mail: mauryaritu2000@gmail.com

Abstract: The North-Western Himalayn Region (NWHR) spanning Uttarakhand, Himanchal Pradesh and Jammu & Kashmir supports diverse agroecological zones and traditional agroforestry systems thereby conserving biodiversity, enhancing livelihood and improving other ecosystem services. Agroforestry systems emerge as a multifunctional land use strategy in these fragile landscapes offering various provisioning, regulating, supporting and cultural services. Integrating trees, crops and livestock in these systems enhances food and fodder security, sequesters carbon, regulates hydrology and buffer communities against climate variabilities. In Garhwal Himalayas, agroforestry provides 0.5-0.68 kg of fuelwood per capita daily and 4.70-5.57 kg fodder per animal unit reducing the reliance on natural forests. Traditional agroforestry systems ranging from Homesteads and Silvipastoral models to Sea buckthorn-based agroforestry demonstrates deep cultural integration and resilience. However, challenges such as land fragmentation, land tenure issues, restrictive forest laws etc. constraints its wider adoption. Supportive framework and policies like National Agroforestry Policy, Nationally Determined Contributions, Convention on Biodiversity, Land Degradation Neutrality etc. helps to strengthen agroforestry in North Western Himalayan Region.

Keywords:

The North-Western Himalayan Region (NWHR) comprising regions of Indian states of Uttarakhand, Himanchal Pradesh and Jammu & Kashmir have varying agroecological conditions. It not only supports rich biodiversity but also helps to sustain a large population depending on the existing natural resources for their livelihood (Rawat 2023) including food, fodder, fibre, timber, medicine as well as drinking water (Sharma and Chettri 2021). Agroforestry systems in this context emerge as a multifunctional and multipurpose land use strategy which contributes to diverse ecosystem services including provisioning, regulating, supporting and cultural services by maintaining ecological stability, food and fodder security, climate resilience, carbon storage etc. (Borelli et al., 2018). This region consists of various traditional and evolved agroforestry systems over time ranging from silvipastoral and agrisilvicultural combinations to home gardens and alley cropping models developed through indigenous knowledge and community adaptation to wide range of physical and socio-cultural conditions (Verma et al., 2024). It acts as dynamic link between conservation and development offering different pathways to reduce increasing pressure on natural forests and enhance sustainability of agricultural farming systems (Nair et al., 2022). As the world is facing issues like global warming, climate change, food insecurity, biodiversity and land degradation etc., agroforestry acts as a mitigation and adaptation strategy to restore ecosystems, ensure and support environmental sustainability while maintaining the land use productivity (Saikia et al., 2017). This review aims to provide the information regarding currently existing agroforestry systems in NWHR analysing their ecological functions, livelihood implications, biodiversity conservation and other ecosystem services contribution. It also reviews the prevailing challenges faced by the or practitioners of the agroforestry systems outlining policy gap and research constraints for strengthening agroforestry as a sustainable land use strategy in NWHR.

Agroforestry systems across varying agroclimatic zones of the North-Western Himalayan region: The NWHR encompasses a wide range of agroclimatic zones (Table 1), covering an area of approximately 0.33 million km^2 varying from subtropical foothills to temperate mid-hills and alpine highlands lying above 3000 m amsl and shaped by diverse climatic conditions, soil types and altitudinal gradients (Sharma et al., 2017). It significantly influences the local farming systems and land use practices leading to depletion of resources and reduced productivity. In this context, agroforestry systems in these regions have naturally evolved as an adaptive strategy for sustaining productivity, ensure resource conservation while maintaining the ecological balance. Over centuries, it has evolved to address food insecurity, forest degradation, and climate issues

(Verma et al., 2024). Despite modernization and pressure of land fragmentation, many traditional systems persist and offer solutions for developing climate resilient agroforestry models.

Diverse agroforestry systems prevalent across North-Western Himalayan region: The NWHR region exhibits rich indigenous knowledge systems that foster sustainable land use practices. Local communities have developed region-specific agroforestry models like homestead in Garhwal and Himanchal including multilayered planting of vegetables, fruit trees, medicinal plants and fodder trees reflecting biodiversity conservation and household food security (Kumar 2022) while the silvi-pastoral systems are common in high altitude and slopy areas where these systems integrate fodder trees (eg. *Bauhinia variegata, Grewia optiva*) with grazing lands, supporting livestock and preventing soil erosion (Rawat 2023). The major prevalent agroforestry systems in North-Western Himalayan region have been summarized in the Table 2 and some traditional agroforestry systems have been shown in Table 3.

Agroforestry based Ecosystem services in the North Western Himalayan Region: Ecosystem services are the set of diverse ecological purposes or the direct and indirect contributions of an ecosystem to the human well-being (TEEB 2010). The Millennium Ecosystem Assessment (MES) provides a globally recognized classification into four types, viz. provisioning services, regulating services, supporting services and cultural services (Tallis and Kareiva 2005, Haines-Young and Potschin 2012) (Fig. 1). The following are some significant ecosystem services that NWHR agroforestry systems offer:

Agroforestry for biodiversity conservation: Agroforestry as a natural habitat ensures in-situ conservation of native flora and fauna offering a sustainable land use model. Mountain regions are rich source of biodiversity due to their diverse gene pools. However, several anthropogenic activities such as hunting, timber extraction, extensive grazing, forest conversion, and climate change, pose a danger to these ecosystems' biodiversity. By reducing anthropogenic pressure, agroforestry mitigates forest degradation while providing protection for a variety of species. Well integrated agroforestry landscapes serve as ecological corridors that facilitate habitat connectivity and species movement across fragmented Himalayan topography. Various fruit trees like *Malus, Prunus, Pyrus,* and *Morus* species and fodder tree species like *Grewia, Grevillea,* and *Gmelina* are frequently planted in lower elevations. Another significant tree species in the higher altitude Himalayan region is *Hippophae salicifolia*, which is grown for its fruit, which can be utilized locally as fuelwood,

Table 1. Zonal classification of agro-climatic zones of the North-Western Himalayan states

States	Agro-climatic zones	Altitudinal ranges (m amsl)	Districts/ Part of the state
Jammu and Kashmir	Low altitudinal subtropical zone	≤1000	Jammu, Kathua, Udhampur, and parts of Doda and Rajouri districts
	Mid to high altitude intermediate zone	1000-2000	Poonch and major part of Rajouri, Anantnag, Pulwama, part of Doda district
	Valley temperate zone and mid to high altitude zone	2000-3000 (<1200 Kashmir valleys)	Srinagar, Baramulla, Kupwara and part of Anantnag, Pulwama, Budan, and Poonch
	Cold arid zone	>3000	Kargil, Leh, upper parts of Doda, Anantnag, Baramulla and Kupwara districts
Himanchal Pradesh	Low altitudinal subtropical zone	≤1000	Una, Hamirpur, Bilaspur and parts of Kangra, Chamba, Mandi, Sirmour, and Solan districts
	Mid-hills subhumid zone	1000-2000	Part of Chamba, Solan, Shimla, Mandi, Sirmour districts
	High hills temperate wet zone	2000-3000	Parts of Chamba, Kangra, Mandi, Sirmour, Shimla, and Kullu districts
	High hills dry temperate zone	>3000	Kinnaur, Lahaul Spiti, and parts of Kangra and Chamba districts
Uttarakhand	Babhar and tarai zone and subtropical low hills zone	<1000	Haridwar, Udham Singh Nagar, and parts of Nainital, Dehradun, Pauri Garhwal districts
	Hill zone Mid-hill subhumid zone	1000–2000	Parts of Garhwal, Nainital, Dehradun, and Champawat districts
	High hills temperate zone	2000–3000	Almora, Bageshwar, Tehri Garhwal, parts of Chamoli, Champawat, Rudraprayag, Nainital, and Uttarkashi districts
	High hill dry temperate zone	>3000	Parts of Chamoli, Rudraprayag, Pithoragarh, and Uttarkashi districts

Source: Ghosh (1981), Kashyap et al. (2013)

fodder and nutraceutical properties providing farmers with a high income. Because of the ability to endure the shock and strain of environmental and climatic change, agroforestry has been recognized as one of the resilient farming systems to guarantee food security (Panda 2025). Nair et al. (2022) emphasizes the role of these strategically located agroforestry systems in maintaining ecological continuity and enhancing biodiversity conservation outside recognized protected areas. One of the main international initiatives to emphasize the advantages of biodiversity and the rising costs of ecosystem degradation and biodiversity loss is the Economics of Ecosystems and Biodiversity (TEEB). All ecosystem services are regulated by biodiversity, but it can also function as a service in and of itself (Mace et al., 2012). As it offers resilience against present or upcoming changes in ecosystems and the benefits they offer, biodiversity is sometimes thought to have insurance value.

Climate resilience and other ecosystem services: Agroforestry systems affect climatic patterns and absorb carbon from the atmosphere. Climate regulation describes how ecosystems affect the earth's temperature by releasing greenhouse gases (GHGs) into the atmosphere. These systems enhance soil processes and properties, which are crucial for regulating the climate by lowering GHGs emissions and sequestering carbon, as well as for supplying water by controlling soil properties. The potential for agroforestry systems to reduce climate change and global warming has been estimated at around 26 million metric tons of carbon, which will rise to 45 million metric tons by 2040 as they include woody species that develop quickly (IPCC 2001). Furthermore, in both low-lying and high-altitude regions, agroforestry serves as a substitute for the traditional farming system in order to lessen deforestation and CO_2 emissions and slow down climate change and global warming (Mbow et al., 2014). The World Agroforestry Centre (WAC) states that agroforestry systems can boost yield up to 50% and can help sequester as much as 3.5 tons of C ha^{-1} yr^{-1}. The various agroforestry types found in NWHR are capable of capturing and storing carbon in soil and vegetation, with values ranging from 0.02-54 Mg C ha^{-1}. In agriculture-based agroforestry systems, the majority of the biomass is removed for human consumption resulting in a lesser vegetation carbon compared to horticulture agroforestry since plant parts extraction is limited. However, differences in elevation, agroforestry components, and management strategies led to variances in carbon stock in both vegetation and soil (Chisanga et al., 2018, Vikrant et al., 2020). In addition to these, the age and growth pattern of plants, as well as the

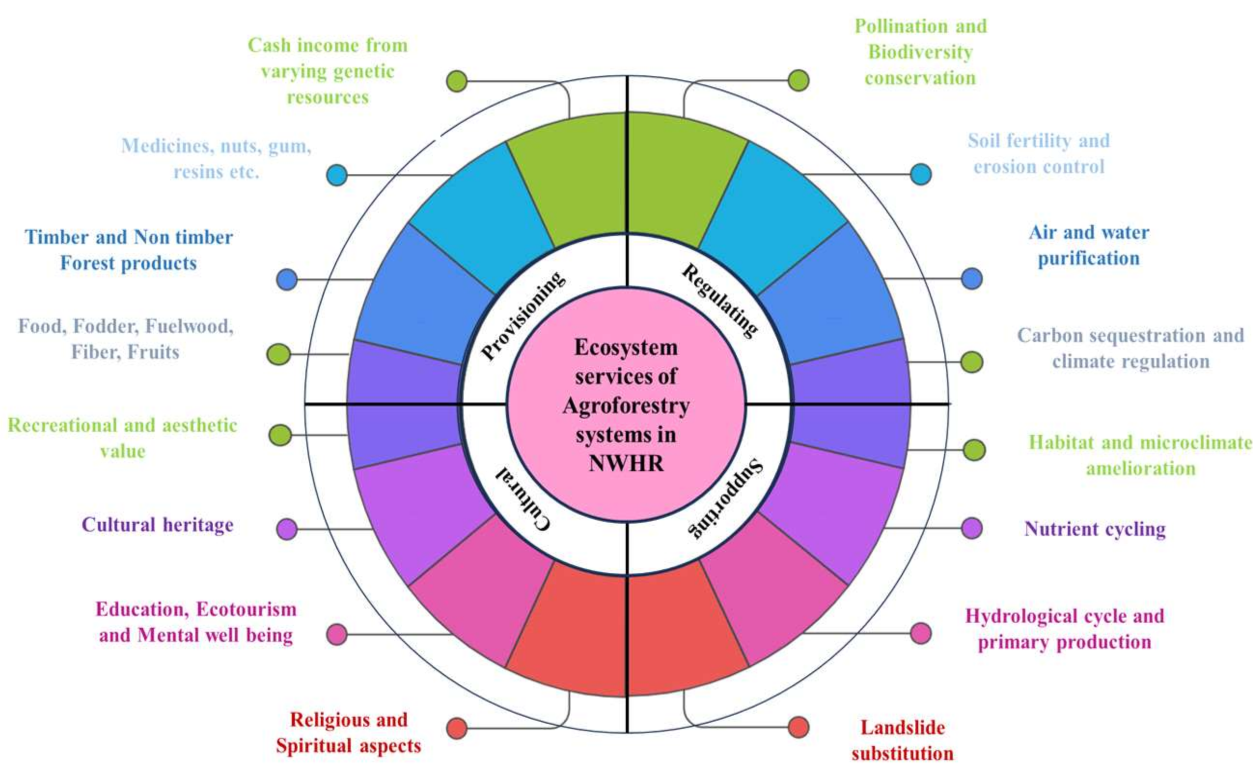

Fig. 1. Major Ecosystem services provided by agroforestry systems in North-Western Himalayan Region

interactions between crops and trees, affect the carbon stock and biomass accumulation in agroforestry systems (Kanime et al., 2013). This helps to lock in more carbon and improve CO_2 mitigation. Data indicates that by taking appropriate mitigation measures, soil carbon emissions might be lowered by 50% by 2050 compared to 2010 levels (Xu et al., 2020). Agroforestry techniques can reduce farmers' susceptibility to climate change, according to a study conducted in the Western Himalayan region (Pandey et al., 2017). This is because agroforestry is a sustainable land-use system for the mountains because it is self-regulating, adaptive, and incorporates a variety of crops and livestock.

Culture and Supporting services: Agroforestry systems in the North Western Himalayas play a critical role in enhancing ecosystem services and bolstering climate resilience. In addition to the primary services listed above, it also offers supporting and cultural ecosystem services. The integration of trees with crops and livestock improves carbon sequestration potential, acting as a natural sink and aiding in climate change mitigation (Pandey and Ghosh 2023). These systems contribute significantly to soil health by promoting organic matter accumulation and microbial diversity, thus enhancing nutrient cycling (Rawat et al., 2023). Furthermore, agroforestry helps regulate the hydrological cycle by enhancing water infiltration, reducing surface runoff, and facilitating spring recharge in the ecologically fragile Himalayan terrain (Sharma et al., 2024). Himalayan region's agroforestry systems provide an increase in pollinator species (Sharma et al., 2020), provide fodder for livestock, conserve water and improve water use efficiency (Chauhan et al., 2013), regulate nutrient cycling, provide aesthetic value, and provide ritual plants. Furthermore, various ethnic communities that live in the mountains consider the mountain landscapes, including the agroforestry systems of the Himalayan region, to be sacred and culturally significant because they offer spiritual and recreational services (Sharma et al., 2007). Additionally, agroforestry systems have helped certain communities preserve their traditional

Table 2. Prevalent agroforestry systems and species diversity in NWHR (Modified from Sharma et al. 2024)

Region	Agroforestry systems	Species composition
Himanchal Pradesh	Agri-silviculture, Agri-horticulture, Silvi-pastoral, Pastoral-silviculture, Pastoral-Horti silviculture, Horti-agriculture, Horti-pastoral, Agri-Horti silviculture, Agri-Silvi horticulture, Agrisilvopastoral	Forest trees: *Abies pindrow, Acacia catechu, Ailanthus altissima, Albizia chinensis, Bauhinia variegata, Cedrus deodara, Celtis australis, Dalbergia sissoo, Diospyros kaki, Grewia optiva, Melia composita, Picea smithiana, Pinus gerardiana, Pinus wallichiana, Populus alba, Populus ciliata, Quercus semecarpifolia, Quercus ilex, Robinia pseudoacacia, Salix alba, Toona ciliata, Ulmus villosa*
		Fruit trees: *Carica papaya, Citrus spp., Juglans regia, Litchi chinensis, Malus domestica, Mangifera indica, Morus alba, Phyllanthus emblica, Prunus amygdalus, Prunus armeniaca, Prunus domestica, Prunus persica, Psidium guajava, Punica granatum, Pyrus communis*
		Crops: *Abelmoschus esculentus, Allium cepa, Allium sativum, Avena sativa, Beta vulgaris, Brassica juncea, Brassica oleracea, Capsicum annuum, Cicer arietinum, Glycine max, Hordeum vulgare, Oryza sativa, Phaseolus vulgaris, Pisum sativum, Solanum lycopersicum, Solanum lycopersicum, Solanum smithiana, Triticum aestivum, Vigna mungo, Zea mays*
Uttarakhand	Agrisilviculture, Agrisilvihorticulture, Agrisilvopastural, Silvipastoral, Agrihorticulture, Agrihortisilviculture, Silvi horticulture, Hortipastoral	Forest trees: *Cedrus deodara, Celtis australis, Ficus auriculata, Ficus palmata, Grewia oppositifolia, Melia azedarach, Pinus roxburghii, Pinus wallichiana, Quercus leucotrichophora, Rhododendron arboretum, Toona ciliata,*
		Fruit trees: *Carica papaya, Citrus spp., Emblica officinalis, Juglans regia, Malus domestica, Mangifera indica, Morus serrata, Musa paradisiacal, Myrica esculenta, Prunus armeniaca, Prunus cerasoides, Prunus domestica, Prunus spp., Psidium guajava, Punica granatum, Pyrus pyrifolia*
		Crops: *Abelmoschus esculentus, Amaranthus caudatus, Amaranthus spinulosa, Brassica campestris, Brassica juncea, Cajanus cajan, Eleusine coracana, Glycine max, Hordeum vulgare, Lens culinaris, Lycopersicon esculentum, Oryza sativa, Phaseolus vulgaris, Pisum sativum, Spinacea oleracea, Triticum aestivum, Vigna mungo, Vigna umbellate, Zea mays*
Jammu and Kashmir	Agrisilviculture, Agrihorticulture, Horti agriculture, Horti-silviculture, Horti-silvipastoral, Horti-agrisilviculture, Silvipastoral, Hortipastoral, Agrisilvipastoral, Agri-Horti silviculture, Homesteads	Forest trees: *Abies pindrow, Acacia catechu, Aesculus indica, Ailanthus altissima, Albizzia lebbeck, Cedrus deodara, Dalbergia sissoo, Picea smithiana, Pinus wallichiana, Populus deltoids, Populus nigra, Robinia pseudoacacia, Salix alba, Ulmus wallichiana*
		Fruit trees: *Cydonia oblonga, Juglans regia, Malus spp., Morus alba, Prunus amygdalus, Prunus avium, Prunus persica, Punica granatum*
		Crops: *Abelmoschus esculentus, Allium cepa, Allium sativum, Brassica juncea, Brassica oleracea, Brassica rapa, Cucumis sativus, Daucas carota, Glycine max, Lagenaria siceraria, Oryza sativa, Phaseolus vulgaris, Pisum sativum, Raphanus sativus, Solanum lycopersicum, Solanum tuberosum, Triticum aestivum, Vigna radiata, Zea mays*

knowledge and germplasm of native and heirloom crop and tree species, as well as culturally significant plants including *Ocimum sanctum, Ficus reliogiosa*, and *Thysanolaena maxima* (Islam et al., 2017). As climate variability intensifies, the adaptive capacity of agroforestry, through diversified land use and species richness, offers a buffer against extreme events and supports both ecological stability and sustainable livelihoods (Hussain et al., 2024).

Livelihood and socio-economic benefits: The socio-economic status of a society is determined by combining its social and economic standing in relation to others, having a broad impact on the availability of resources, the pattern of social livelihood, food security, etc. (Roy et al., 2013). Ignoring socioeconomic issues causes various developmental programs to suffer, thus, knowledge of these factors is crucial for farming systems and aids in the formulation of policies for the welfare of society (Sood et al., 2008). Agroforestry and socioeconomic factors are interlinked as these encourage tree integration on farms while improving livelihoods, especially benefitting vulnerable groups including marginal and small farmers, women, and children emphasizing its potential to enhance society (Murthy et al., 2016). Numerous studies conducted nationwide demonstrate its beneficial effects on the socioeconomic status of farmers in terms of women welfare, advancement of marginalized groups, food security, enhanced financial resilience, decreased crop failure, consistent employment and income, increased land productivity etc. Agroforestry can generate around 5.76-million-man days annually, spanning 75,500 hectares, demonstrating the potential for employment as well as a rural development in the tough Himalayan terrains (Arunachalam et al., 2020). Agroforestry contributes directly to household provisioning of fodder, fuelwood, and non-timber forest products (NTFPs). In Garhwal Himalaya, agroforestry was found to supply 0.5−0.68 kg fuelwood per capita per day and 4.70-5.57 kg fodder per animal unit per day, depending on altitude, fulfilling substantial proportions of household energy and livestock feed needs, while reducing dependency on natural forests (Nagar et al., 2018). Crucially, agroforestry systems also buffer households against climate and market shocks. This correlation between socio-economic indicators and the extent of agroforestry adoption reinforces its role as a risk mitigation strategy amid climatic variability and market fluctuations.

Challenges and research gap: India has surpassed China as the most populated nation, and while the agricultural sector employs about half of the workforce, its contribution to GDP has decreased since independence to roughly 17.8% (Sharma and Raina 2021). NWHR ecosystems are delicate due to its steep and rocky terrain, geological dangers, biodiversity, land degradation, land use and land cover, and topography (Saha and Kumar 2019). However, inconsistency in its adoption arises due to different land tenure systems, market access and changing socio-economic priorities across different agroecological zones of the NWHR (Gyau et al., 2014, Kumar et al., 2024). In addition, a several anthropogenic activities, such as deforestation, excessive resource use, poor farming techniques, etc., have led to land fragmentation (Shukla et al., 2018), soil erosion, the depletion of land resources, decreased productivity, etc. NWHR's biophysical

Table 3. Traditional agroforestry systems of NWHR

Agroforestry systems	Description	Species
Homesteads or Kyaroo in Kangra, Hamirpur and Jammu districts	Farm unit or multitier canopy structure that raises a variety of species for fuelwood, timber, and fodder etc, primarily to meet the fundamental needs of the farmers.	Upper storey: Fodder trees like *Celtis australis*, *Bahaunia variegata*, *Grewia optiva*, and bamboo species particularly *Dendrocalamus hamiltonii* and *D. strictus* Middle storey: Bushes like medicinal *Adhatoda vasica*, *Vitex negundo*, etc. Fruit trees: pear, plum, lemon, citrus, etc., are grown along with *Colocasia esculanta*, *Dioscoria spp*, and *Curcuma domestica* grown for domestic uses.
Plantation crop combination	Generation of national economy by value added products for different international markets by growing species on waste and marginal lands.	Tea is the important plantation crop of the Himalayan region. Traditionally, it is grown with indigenous species. In Himachal Pradesh, tea gardens in Kangra, Palampur, and Baijnath valleys are managed under *Albizia chinensis.*
Sea-Buck-Thorn Based Agroforestry Systems in Cold Desert Areas	Sea-buck-thorn is a fast-growing shrub accounting for <5% plantation cover which fixes 180 kg ha^{-1} yr^{-1} ofnitrogen and has calorific value of 4,785 calories kg^{-1}.	*Hippophae rhamnoides* renowned for restoring land in cold and dry fragile ecosystems, preventing desertification.
Bamboo groves	Cultivation is done to utilize it for making a variety of domestic products such as fishing rods, baskets, mates, cow huts, miniature farmhouses, and water conveyers etc. Additionally, it is used as feed for the cattle in winter season.	*Dendrocalamus hamiltonii, D. structus,* and *Bambusa nutans* are cultivated in high rainfall subtropical and mid-hill moist regions (Himachal Pradesh regions of Palampur, Hamirpur, Una, Bilaspur, Jammu, J&K and Dehradun, Uttarakhand).

characteristics' susceptibility, sustainable land use practices are crucial for ecosystem resilience. Agroforestry can aid in stabilizing these landscapes but its full potential appears to be constrained by the available area as the average size of land holdings has decreased, averaging around 1 hectare. So, there is less opportunity for farmers with small land areas to include trees as an overabundance of agriculture. The cold desert region in NWHR makes the area more vulnerable to climatic fluctuations (Tewari and Kapoor 2013). However, as the population grows, people are also cultivating sloppy areas, which has harmed the ecology. The ecological rehabilitation requires integrated land use and management strategies for which agroforestry appears to be the solution to all issues. Despite their ecological and socio-economic significance, substantial challenges occur in scaling and institutionalization. The implementation of National Agroforestry Policy (2014) in the hilly terrains remains constrained due to issues such as unclear land tenure, restrictive forest laws, and fragmented holdings. Decentralized forest governance mechanisms such as Van Panchayats, Joint Forest Management Committees (JFM), and the Forest Rights Act (FRA) and schemes like MNREGA, RKVY, and PMKSY include provisions for agroforestry components have not been effective and have limited field level impact (Pandey and Ghosh 2023). Institutions such as ICAR, ICFRE, and State Forest Departments play a crucial role in research and policy implementation, yet region-specific data, participatory models, and adaptive technologies are still lacking (Hussain et al., 2024). Several other policies like Convention on Biological Diversity (CBD), Nationally Determined Contributions (NDCs) under the Paris agreement (2015), and Land Degradation Neutrality (LDN) and UN Sustainable Development Goals have reinforced its importance in addressing land degradation, climate change and alleviating rural poverty etc. (Gichuki et al., 2019). Addressing these multifaceted challenges calls for enhanced institutional coordination, inclusive policy reforms, improved extension services, and recognition of the role of smallholders and women in sustaining traditional agroforestry landscapes across the Himalayas.

CONCLUSION

Agroforestry systems in NWHR represent different ecologically sound and socio-economically viable land use strategies, harmonizing biodiversity conservation with rural livelihoods and other associated ecosystem services. The region's unique agroecological gradients have nurtured a diversity of traditional agroforestry practices ranging from silvipastoral and home gardens and alley cropping are deeply rooted in local knowledge system and are adaptive to site-specific conditions. Despite its potential, the systems remain under recognized in policy and land use planning frameworks with implementation barriers like insecure land tenure, restrictive forest regulations, poor market access and limited region-specific research continues to hinder its wider adoption. However, different policies like National Agroforestry Policy, Nationally Determined Contributions, Land Degradation Neutrality etc. strengthen the participation to some extent. A holistic and integrated approach is thus needed to mainstream agroforestry for sustainable development, climate resilience and biodiversity conservation in this fragile landscape.

REFERENCES

Arunachalam A, Handa AK, Dev I, Kaushal R, Panwar P and Dhyani SK 2020. Alternate land use and agroforestry systems for resource conservation and enhanced productivity in the hills. *Indian Journal of Hill Farming* **33**(1): 176-193.

Borelli S, Conigliaro M, Quaglia S, and Salbitano F 2018. Urban and Peri-urban agroforestry as multifunctional land use, pp 705-724. In *Agroforestry: anecdotal to modern science*. Springer Singapore.

Chauhan S K, Dhillon W S, Singh N and Sharma R 2013. Physiological behaviour and yield evaluation of agronomic crops under agri-horti-silviculture system. *International Journal of Plant Research* **3**: 1-8.

Chisanga K, Bhardwaj DR, Pala NA and Thakur CL 2018. Biomass production and carbon stock inventory of high-altitude dry temperate land use systems in North-Western Himalaya. *Ecological Processes* **7**: 22.

Ghosh SP 1981. *Agroclimatic zone specific research*. Indian Council of Agricultural Research, New Delhi, p 539.

Gichuki L, Brouwer R, Davies J, Vidal A, Kuzee M, Magero C and Gilbey B 2019. *Reviving land and restoring landscapes*. IUCN, Gland, Switzerland, p 7-34.

Gyau A, Franzel S, Chiatoh M, Nimino G and Owusu K 2014. Collective action to improve market access for smallholder producers of agroforestry products: Key lessons learned with insights from Cameroon's experience. *Current Opinion in Environmental Sustainability* **6**: 68-72.

Haines-Young R and Potschin M 2012. Common international classification of ecosystem services (CICES, Version 4.1). *European Environment Agency* **33**: 107.

Hussain A, Elkarmout AF, Mansour EZ, Awais M, Usman M, Ahmad H and Ahmad T 2024. An environment friendly practice, the climate smart agriculture crop production and soil management systems: A review. *Journal of Sustainable Agricultural and Environmental Sciences* **3**(3): 101-124.

IPCC 2001. Climate Change 2001: the scientific basis. In: Houghton JET, Ding Y, Griggs D, Noguer M, Van der Linden P, Dai X, Maskell M, Johnson C (eds), *Contribution of Working Group I to the third assessment report of the Intergovernmental Panel on Climate Change* (IPCC), p 881.

Islam M, Quaiser K and Bhatt G 2017. Indigenous knowledge in traditional agroforestry systems of Kashmir valley: current challenges and future opportunities. *International Journal of Forestry and Crop Improvement* **8**: 68-77.

Kanime N, Kaushal R, Tewari S, Raverkar K, Chaturvedi S and Chaturvedi OP 2013. Biomass production and carbon sequestration in different tree-based systems of Central Himalayan Tarai region. *For Trees Livelihoods* **22**: 38-50.

Kashyap SD, Dagar JC, Pant KS and Yewale AG 2013. Soil conservation and ecosystem stability: natural resource management through agroforestry in Northwestern Himalayan region, pp 21-55. In *Agroforestry systems in India: livelihood security & ecosystem services*, Springer, New Delhi, India.

Kumar M 2022. *Traditional Agroforestry and Livelihood Support: A study in Upper Yamuna Valley of Uttarkashi district of Garhwal Himalaya, India*, Doctoral dissertation, College of Forestry, Ranichauri Campus, VCSG Uttarakhand University of Horticulture and Forestry.

Kumar RV, Tiwari P, Daniel S, Kumar KR, Mishra I and Shah DG 2024. Agroforestry Systems: A Pathway to Resilient and Productive Landscapes. *International Journal of Environment and Climate Change* **14**(12): 177-193.

Lepcha NT and Devi NB 2020. Carbon cycling and balance in a traditional cardamom-based agroforestry system of Sikkim Himalayas. *Tropical Ecology* **61**: 527-537.

Mace GM, Norris K and Fitter AH 2012. Biodiversity and ecosystem services: a multilayered relationship. *Trends in Ecology and Evolution* **27**: 19-26.

Mbow C, Smith P, Skole D, Duguma L and Bustamante M 2014. Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. *Current Opinion in Environmental Sustainability* **6**: 8-14.

Murthy IK, Dutta S, Varghese V, Joshi P and Kumar P 2016. Impact of agroforestry systems on ecological and socio-economic systems: a review. *Global Journal of Science Frontier Research* **16**(5): 15-27.

Nagar B, Kumar M, Pandey R and Rawat S 2018. Fuelwood and fodder consumption from agroforestry at different altitudinal zones of Garhwal Himalaya. *Journal of Plant Development Sciences* **10**(12): 659-668.

Nair PR, Kumar BM and Nair VD 2022. Agroforestry for biodiversity conservation, pp 539-562. In *An introduction to agroforestry: four decades of scientific developments*. International Publishing, Cham: Springer.

Panda S 2025. *Agroforestry: Nature Based Solution for Climate Change and Food Security,* pp 189-238. Springer Nature.

Pandey R, Aretano R, Gupta AK, Meena D, Kumar B and Alatalo JM 2017. Agroecology as a climate change adaptation strategy for smallholders of Tehri-Garhwal in the Indian Himalayan Region. *Small-Scale Forestry* **16**: 53-63.

Pandey B and Ghosh A 2023. Urban ecosystem services and climate change: a dynamic interplay. *Frontiers in Sustainable Cities* **5**: 1281430.

Rawat D, Mukhopadhyay D, Khanduri VP, Singh B, Riyal MK and Sati SP 2023. Harnessing soil ecosystem services for achieving soil-based SDGs in Indian Himalaya, pp 147-169. In *Soil Carbon Dynamics in Indian Himalayan Region,* Springer Nature, Singapore.

Roy B, Rahman M and Fardusi MJ 2013. Status, diversity, and traditional uses of homestead gardens in Northern Bangladesh: A means of sustainable biodiversity conservation. *International Scholarly Research Notices* 1–11.

Sharma S, Joshi R, Pant H and Dhyani P 2017. Climate Change & North-West Himalaya: Prioritization of Agriculture based Livelihood Actions. *G.B. Pant National Institute of Himalayan Environment and Sustainable Development, Kosi-Katarmal, Almora*, pp 27.

Saha SK and Kumar AS 2019. Northwest Himalayan ecosystems: issues, challenges and role of geospatial techniques, pp 3–14. In: Navalgund RR et al (eds) *Remote Sensing of Northwest Himalayan Ecosystems,* Springer, Singapore.

Saikia P, Kumar A and Khan ML 2017. Agroforestry: A sustainable land use system for livelihood security and climate change mitigation, pp 61-70. In *Climate Change and Agroforestry. New India Publishing Agency, New Delhi, India*.

Sharma J, Sharma SD, Sharma K and Sharma D 2021. Appraisal of biological yield and economic returns of existing agroforestry systems in Tehsil Bangana of Unda District of Himachal Pradesh, India. *Biological Forum- An International Journal* **13**(2): 413-419.

Sharma K, Acharya BK, Sharma G, Valente D, Pasimeni MR, Petrosillo I and Selvan T 2020. Land use effect on butterfly alpha and beta diversity in the Eastern Himalaya, India. *Ecological Indicators* **110**: 105605.

Sharma R, Xu J and Sharma G 2007. Traditional agroforestry in the eastern Himalayan region: land management system supporting ecosystem services. *Journal of Tropical Ecology* **48**: 1-12.

Sharma E and Chettri N 2021. Biodiversity conservation and ecosystem services in the Hindu Kush Himalaya. *Journal of Graphic Era University* 1-18.

Sharma H, Pant KS, Bishist R, Prakash P and Gautam KL 2024. An insight into prevalent agroforestry land use systems of North Western Himalayan Region, India: Challenges and future prospects. *Agroforestry to Combat Global Challenges: Current Prospects and Future Challenges* 419-439.

Sharma R, Singh, S, Huria A, Chauhan A and Barman T 2024. Sustainable land management practices for healthy ecosystem services: A cornerstone of biodiversity sustenance in the Indian Northwestern Himalaya, pp 235-252. In *Sustainable Land Management in India,* Springer, Singapore.

Shukla R, Chakraborty A, Sachdeva K and Joshi PK 2018. Agriculture in the western Himalayas – an asset turning into a liability. *Development in Practice* **28**(2): 318-324.

Sood KK, Najiar C, Singh KA, Handique P, Singh B and Rethy P 2008. Association between socioeconomic parameters and agroforestry uptake: evidences from eastern Himalaya. *Indian Journal of Forestry* **31**(4): 559-564.

Stobdan T, Angchuk D and Singh SB 2008. Seabuckthorn: an emerging storehouse for researchers in India. *Current Science* **94**(10): 1236-1237.

Tallis, H., and Kareiva P 2005. Ecosystem services. *Current Biology* **15**(18): 746-748.

Tewari VP and Kapoor KS 2013. Western Himalayan cold deserts: Biodiversity, eco-restoration, ecological securities and concerns. *Annals of Arid Zone* **52**(3&4): 223-230.

Verma K, Sharma P, Bhardwaj DR, Singh MK, Verma T and Thakur P 2024. Traditional agroforestry practices in the Indian Himalayas, pp 135-162. In *Learning 'from' and 'with' the Locals: Traditional Knowledge Systems for Environmental Sustainability in the Himalayas*, Springer Nature, Switzerland.

Vikrant K, Chauhan DS and Rizvi R 2020. Carbon stock assessment along altitudes in agrisilviculture systems of Tehri District, Uttarakhand, North-Western Himalaya-case study of Pratapnagar block. *Indian Forester* **146**(3): 202-207.

Xu S, Sheng C and Tian C 2020. Changing soil carbon: influencing factors, sequestration strategy and research direction. *Carbon Balance and Management* **15**(2): 1-9.

Received 12 November, 2025; Accepted 20 November, 2025