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Carbon sequestration potential and economic benefits of agroforestry in Shiwalik region of Himalaya in India

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Abstract
Agroforestry is a classical long-standing technique and a significant aspect of subsistence farming, which gained popularity as a commercial and beneficial land use throughout the world in recent years. Approximately, 1.2 billion people depend directly on agroforestry products and services *viz*. fuelwood, timber, poles, food, fodder etc. In Shiwalik Himalayan region, traditional agroforestry practices play significant role in sustainable livelihoods of the people through fulfilling their daily needs. The current article provides concise description of the different agroforestry systems practiced in the Shiwalik Himalayan region, together with information on their biomass production, economic benefits and carbon sequestration potential. The various agroforestry systems that farmers prefer and practiced in the region are Agri-Silviculture (AS), Agri-Horticulture (AH), Agri-Silvi-Horticulture (ASH), Agri-Silvi-Pastoral (ASP), Silvi-Pastoral (SP), Pastoral-Silviculture (PS), Agri-Horti-Silviculture (AHS), Pastoral-Horticulture (PH), Horti-Pastoral (HP) and Pastoral-Horti-Silviculture (PHS). In terms of biomass production, the production potential of agroforestry systems ranged from 4.24 t ha^{-1} to 47.45 t ha^{-1} whereas the net economic returns varied from Rs 5,772 ha^{-1} yr^{-1} to Rs 2,97,953 ha^{-1} yr^{-1} and the B:C ratio from 1.38 to 3.55 based on the types of components used, associated costs incurred and returns realized. Moreover, the carbon stock capacity among practiced agroforestry systems expands from 1.91 t ha^{-1} to 21.35 t ha^{-1}. Overall, agroforestry is a prominent land use system in Shiwalik region of Himalayan in India which is gaining more interest among farmer due to its higher net returns in all the three categories of farmers. Nevertheless, agroforestry usually stores more carbon than monoculture farming and farmers can also earn carbon credits by trading the carbon captured in agroforestry systems on international markets in the climate change scenario.

Keywords: Sustainability, biological productivity, economic returns, benefit cost ratio, climate change, carbon sequestration potential and carbon credit

Introduction
Agroforestry, as a public intervention for safeguarding long term sustainability of farming, may be of a recent origin, but it has been practiced by the farmers in one form or the other since time immemorial (Sharma *et al*. 2022) [23]. In developing nations, approximately 1.2 billion people (20% of the world's population) relies directly on agroforestry goods and services in rural and urban regions (Leakey, 1997) [14]. Various types of agroforestry systems have been identified in recent studies and most distinguished ones are the agroforestry systems with trees and annual crops, with trees and livestock on wooded pasture & rangeland and with trees, crops and livestock. However, the most widely adopted form of hill agroforestry systems is the practice of planting and retaining trees and shrubs on agricultural field bunds (boundary plantation and wind breaks) and on pasture lands (scattered trees). Agroforestry is also called as mixed cropping, has been embraced as a way of life and a source of income in India since ancient times (Dhyani *et al*. 2016) [4]. Land use practices in the Shiwalik Himalayas encompass agricultural ecosystems, with 90% of the population living in rural areas where agriculture, horticulture and raising livestock are the main sources of income (Atul *et al*. 1994) [2]. Agroforestry is a unique and prominent land use practice in the Shiwalik region of Himalayas, India (Dhyani *et al*. 2016) [4]. The area under Shiwalik zone of Himachal Pradesh, India is 3,514 square km which ranges between 900 m-1200 m in elevation (DOA, 2009) [6].

Due to the complexity, fragility and distinctive topography of Himalayan ecosystems, the region has a wide range of land use patterns and rapid changes in its landscape ecology (Palni *et al*. 1998) [18]. Traditional agroforestry systems in the Himalayan region are essential for meeting the fundamental needs of the rural population, enhancing overall productivity and meeting farmers daily needs by providing a variety of products (Tiwari, 2018) [32]. Agroforestry systems in the Shiwalik hills of Himalaya are backbone of native farming community for livelihood stabilization (Yadav *et al*. 2016) [34]. The projected reduction in agricultural area and rising need for food grain and fuel (2 times), timber production (3 times) and fodder (1.5 times) emphasize the importance of agroforestry in present system of farming (Dhyani and Handa, 2014) [5]. In addition to its benefits for the environment, agroforestry meets nearly half of the requirement for fuelwood, 65% of the demand for small timber, 70 - 80% of the demand for raw material for plywood, 60% of the need for raw materials for paper pulp and 10-11% of the demand for green fodder for livestock (NRCAF, 2013) [17]. One of the major problems facing the world right now is the current climate change, which is being exacerbated by emissions from the burning of fossil fuels (Lorenz and Lal, 2014) [15]. A large and constantly growing population need for fuel, food, lumber and other forest products is being met from a smaller area of forest at a slower rate, which makes it more challenging (Singh, 2020) [29]. Agroforestry, which is the concept of integrating forest tree species with agricultural crops for the benefit of both humans and nature as a whole, appears to be the solution in the present scenario (Singh, 2020) [29]. To combat the erratic nature of the monsoon, preserve food security and to reduce environmental impact, farmers rely on agroforestry systems having diversified outputs, preserved agricultural productivity and various incomes (Sharma et at. 2023) [23]. Agroforestry shows significant promise for sequestering carbon both below and above ground (Goswami *et al*. 2017) [7]. Agroforestry systems have better biological productivity and will become more significant as biomass yield potential influences the extent of impact of climatic changes at the regional and / or worldwide levels (Rajput *et al*. 2017) [19]. Agroforestry ecosystem services are significant for their beneficial contributions to the water, carbon and nitrogen cycles, as well as their cultural and financial potential in treacherous mountainous environments. Increasing the area under agroforestry in the nation can help to solve some of the primary difficulties posed by climate change (CAFRI Vision 2015; Dhyani *et al*. 2016) [4, 3]. According to Mercer (1993) [16], agroforestry schemes have two main goals: first, to improve the efficiency of rural utilization of resources by reducing or eliminating environmentally destructive land-use practices and by incorporating new or improved agroforestry organisations in order to bring about sustainable increases in incomes and standard of living and second, to offer opportunities for social equity. Estimating an agroforestry system's socioeconomic impact is one way to assess its success in achieving the primary goals of social and economic equity or distributive efficiency. Thus, the different agroforestry systems were identified, the biomass production, economic benefits and carbon stock of agroforestry in Shivalik Himalayan of India were described in three different categories of farming community (Medium, Small and Marginal Farmers).

Prevalent agroforestry systems in Himachal Pradesh

There is great altitudinal variation present in Himachal Pradesh that varies up to 6,965 m above mean sea level. Agroforestry is widely accepted form of farming practices in Shiwalik region of Himachal Pradesh and is gaining interest of farmers through its high profitability nature. Farmers are practicing various forms of agroforestry systems on their farm land according to their different needs which also diversifies the farmers income through delivering different products at different times from single unit of land. Various studies have been carried out in Shiwalik region of Himachal Pradesh (Kumar 2016; Singh 2017; Singh 2019; Thakur 2021; Verma 2021; Sharma 2022a; Sharma 2022b) [13] as shown in the table 1. Kumar (2016) [13 27, 28, 31, 33, 26, 22] identified the agroforestry systems in Kandaghat block of Solan district that included Agri-Silviculture (AS), Agri-Silvi-Pastoral (ASP), Agri-Silvi-Horticulture (ASH), Agri-Horti-Silviculture (AHS), Horti-Pastoral (HP) and Silvi-Pastoral (SP) systems. Singh (2019) [28] conducted survey in three different altitudinal zones of Kangra district and revealed that six agroforestry systems types were prevalent among different categories of farmers in three altitudinal zones namely: Agri-Silviculture (AS), Agri-Silvi-Horticulture (ASH), Agri-Horticulture (AH), Agri-Silvi-Pastoral (ASP), Pastoral Silviculture (PS) and Silvi Pastoral (SP). In Shiwalik region of Shimla district, Singh (2019) [28] found six different agroforestry systems practiced by the farmers namely: Agri-Silviculture (AS), Agri-Silvi-Pastoral (ASP), Agri-Silvi-Horticulture (ASH), Agri-Horti-Silviculture (AHS), Silvi-Pastoral (SP) and Horti-Pastoral (HP). Thakur (2021) [31] performed the survey of agroforestry systems in Nadaun tehsil of Hamirpur district of Himachal Pradesh and revealed that five different agroforestry systems were practiced by the farmers in the study area namely, Agri-Silviculture (AS), Agri-Horticulture (AH), Agri-Silvi Horticulture (ASH). Agri-Horti-Silviculture (AHS) and Pastoral-Silviculture (PS). Verma (2021) [33] carried out the diagnostic survey of agroforestry systems and finds that six agroforestry systems were prevalent among different categories of farmers in the study area *viz*. AS, ASH, AH, ASP, PS and SP. Sharma (2022a) performs the survey of agroforestry systems in Sujanpur tehsil of Hamirpur district and revealed that seven different agroforestry systems were practiced by the farmers in the study area namely, Agri-Silviculture (AS) Agri-Horticulture (AH), Agri-Silvi-Horticulture (ASH), Agri-Silvi-Pastoral (ASP) and Silvi-Pastoral (SP) were identified. In medium and small category of farmers all five agroforestry systems were present while in marginal category of farmers Silvi-Pastoral (SP) system was absent. In Shiwalik region of Mandi, Sharma (2022b) [22] conducted survey of agroforestry systems in the Jogindernagar tehsil of Mandi district and identifies six agroforestry systems among different categories of famers namely: Agri-Silviculture (AS), Agri-Silvi-Horticulture (ASH), Agri-Horticulture (AH), Agri-Silvi-Pastoral (ASP), Pastoral-Silviculture (PS) and Pastoral-Horticulture (PH). Rice, maize, soyabean, tomato, brinjal, etc. were crops grown during kharif season and wheat, cauliflower, peas, mustard, onion, potato, etc. were grown during rabi season in the Jogindernagar Tehsil. These prevalent and existing systems fulfills different needs of the local farmers and therefore is practiced by the famers for their timber, fuelwood, fodder and other needs.

Biological productivity potential of agroforestry

The population of India have increased continuously from the past, which will continue to increase in the future as well and this ever-increasing population needs are going to be increase also. These needs are directly or indirectly being derived from the land which is a limited resource and cannot be expended at all. Agroforestry systems are more productive than other

conventional farming practices through cultivation of productive trees with the crops on the farmland. Use of proper trees will increase the overall biomass production and economics returns from the system (Sharma *et al*. 2023). Different studies are performed in Shiwalik region of Himachal Pradesh to estimates the biological productivity of different agroforestry systems (Kumar 2016; Singh 2017; Singh 2019 [28]; Thakur 2021; Verma 2021; Sharma 2022a; Sharma 2022b) [13, 27, 28, 31, 33, 26, 22] as summarized in the Table 2. Kumar (2016) [13] carried out study in Kandaghat block of Solan district and revealed that among all the existing agroforestry systems highest (24.88 t ha^{-1} yr^{-1}) grand total biomass was observed in Silvi-Pastoral (SP) system and lowest (12.16 t ha^{-1}) in Agri-Horti-Silviculture (AHS) irrespective of farmers categories of the studied area. Singh (2017) carried out study in Shimla district of Himachal Pradesh and found highest above ground biomass was recorded under Horti-Agriculture (HA) system (22.16 t ha^{-1}) in altitudinal zone-IV, while among three farmers category, it was recorded highest under marginal farmers category (18.40 t ha^{-1}) in altitudinal zone-IV. Thakur (2021) [31] performed the survey of agroforestry systems in Nadaun tehsil of Hamirpur district of Himachal Pradesh and revealed that the highest grand total biomass 26.39 t $ha^{-1}$was observed in Agri-Silviculture system (AS) and lowest (18.74 t ha^{-1}) in Pastoral-Silviculture system (PS). Verma (2021) [33] carried out study in Barsar tehsil of Hamirpur district and revealed that the highest biological yield was recorded under Agri Silvi Horticulture (ASH) system i.e. (25.09 t ha^{-1}) respectively. While, the lowest biological yield was recorded under Pastoral-Silviculture (PS) system i.e. (16.61 t ha^{-1}). Sharma (2022a) carried out survey in Sujanpur tehsil of Hamirpur district and find out that the highest grand total biomass (23.89 t ha^{-1}) was observed in Agri-Silvi-Horticulture system (ASH) and lowest (16.03 t ha^{-1}) in Agri-Silviculture system (AS). Sharma (2022b) [22] conducted survey of agroforestry systems in Jogindernagar tehsil of Mandi district and revealed that the maximum total biomass production of agroforestry systems among different farmers categories were recorded in ASH system i. e 23.42 t ha^{-1}.

Economic benefits potential of agroforestry

Different studies are performed in Shiwalik region of Himachal Pradesh to estimates the biological productivity of different agroforestry systems (Kumar 2016; Singh 2017; Singh 2019; Thakur 2021; Verma 2021; Sharma 2022a; Sharma 2022b) [13] as summarized in the Table 3. Kumar (2016) [13, 27, 28, 31, 33, 26, 22] carried out study in Kandaghat block of Solan district and revealed that maximum net returns (Rs. 297952 $ha^{-1}yr^{-1}$) was reported from Agri-Horti-Silviculture (AHS) and least (Rs. 33232 $ha^{-1}yr^{-1}$) from Silvi-Pastoral (SP) system among all the existing agroforestry systems of the studied area irrespective of all the farmers categories. Singh (2017) carried out study in Shimla district of Himachal Pradesh and found highest benefit cost ratio under different agroforestry systems was recorded under Horti-Agriculture (HA) system in altitudinal zone-V (2.36), while among three farmers category, it was recorded highest in Agri-Horticulture (AH) system under medium farmers category (2.22). Among five Altitudinal zones highest net return was recorded under Horti-Agriculture (HA) system (Rs. 108786.62 $ha^{-1}yr^{-1}$), in altitudinal zone-IV while among three farmers category, it was recorded highest (Rs. 119955.09 $ha^{-1}yr^{-1}$) under medium farmers category in altitudinal zone-V. (Kaler *et al*. 2017) studied the economic returns from existing agroforestry systems in Kangra district of Himachal Pradesh and reported that highest net returns (Rs 240734.32 $ha^{-1}yr^{-1}$) was recorded under Agri-Silviculture (AS) systems among large farmers category whereas maximum B:C ratio (2.00) was observed under Agri-Silvi-Horticulture (ASH) system among same category of farmers. Thakur (2021) [31] performed the survey of agroforestry systems in Nadaun tehsil of Hamirpur district of Himachal Pradesh and revealed that among all the categories of farmers, the maximum net returns (Rs 1,41,532 $ha^{-1}yr^{-1}$) was reported from Agri-Horti-Silviculture (AHS) and least (Rs 7875 $ha^{-1}yr^{-1}$) from Pastoral-Silviculture (PS) system. Sharma (2022a) carried out survey in Sujanpur tehsil of Hamirpur district and find out that among all the category of farmers the maximum net returns (Rs 297,581.20 $ha^{-1}yr^{-1}$) was reported from Agri-Silvi-Horticulture (ASH) and least (Rs 5,772.50 $ha^{-1}yr^{-1}$) from Silvi-Pastoral (SP) system. Sharma (2022b) [22] conducted survey of agroforestry systems in Jogindernagar tehsil of Mandi district and revealed that the higher net returns (Rs 99,405 $ha^{-1}yr^{-1}$) were observed in Agri-Silvi-Horticulture (ASH) system. Maximum benefit cost ratio is 2.83 was recorded under Agri-Horticulture (AH) system.

Carbon stock / sequestration potential of agroforestry

Climate change is one of the major issues that require immediate attention. Sequestering carbon through agroforestry is one of the ways to contribute to global climate change mitigation. Agroforestry has a huge potential as mitigation strategy to the changing climate because of its potential to sequester carbon in its several agricultural components, tree components and soil (Albrecht and Kandji, 2003; ICAR, 2006). It involves the physical and biological processes of removing and storing carbon from the atmosphere and acting as a potential carbon sink. Compared to a monoculture field of agricultural plants or pasture, the quantity of carbon sequestered can rise with an addition of trees or shrubs to agroforestry systems (Kirby and Potvin, 2007) [11]. Sharma (2022b) [22] conducted a survey of agroforestry systems in Jogindernagar tehsil of Mandi district (HP) and found that the maximum carbon storage potential (10.54 t ha^{-1}) was recorded under Agri-Silvi-Horticulture (ASH) system. In Shiwalik region of Himalayas, the carbon storage potential of various agroforestry systems is shown in the table 4 which varies between 1.91 t ha^{-1} to 21.35 t ha^{-1} among the different categories of farmers. The above ground carbon stock, below ground carbon stock and total carbon stock is derived by multiplying the respective biomass with a factor of 0.45 (Kaul and Panwar, 2008) [10].

Table 1: Agroforestry systems practiced and their major components in Shiwalik region of Himachal Pradesh, India.

Farmer Categories	Agroforestry Systems	Major Agricultural Crops	Major Forest Trees	Major Fruit Trees	Major Grasses	References
Medium	Agri-Silviculture, Agri-Silvi-Horticulture, Agri-Horticulture, Agri-Silvi-Pastoral, Agri-Horti-Silviculture, Pastoral-Horticulture, Pastoral-Silviculture, Silvi-Pastoral, Horti-Pastoral, Pastoral-Horti-Silviculture	Wheat, Rice, Maize, Soyabean, Mustard, Onion, Garlic, Peas, Ladyfinger, Potato, Garlic, Tomato, Turmeric, Spinach, Capsicum, Beans, Cabbage, Ginger, Blackgram	Mulberry, Beul Kachnar, Khirak, Tooni, Pajja, Gurpatraj, Khair, Peepal, Chir, Darek, Poplar, Pistacia, Ficus	Lemon, Pear, Mango, Orange, Papaya, Walnut, Litchi, Guava, Peach, Mosambi, Banana, Plum, Apricot	Doob grass, Chari, Bermuda grass, Seteria, Elephant grass, *Apluda mutica*, *Heteropogon contortus*, *Chrysopogon montanus*, *Dichanthium annulatum*, *Cymbopogon martini*, *Chrysopogon martini*, *Panicum maximum*	Kumar (2016) [13]; Singh (2017) [27]; Singh (2019) [28]; Thakur (2021) [31]; Verma (2021) [33]; Sharma (2022a) [26]; Sharma (2022b) [22]
Small	Agri-Silviculture, Agri-Silvi-Horticulture, Agri-Horticulture, Agri-Silvi-Pastoral, Agri-Horti-Silviculture, Pastoral-Silviculture, Silvi-Pastoral, Horti-Pastoral	Wheat, Rice, Maize, Soyabean, Mustard, Beans, Potato, Peas, Garlic, Onion, Cauliflower, Beans, Arbi, Ginger, Capsicum, Barley, Turmeric, Blackgram, Cabbage	Mulberry, Beul Kachnar, Tooni, Gurpatraj, Khirak, Poplar, Darek, Shisham, Pistacia, Ficus, Myrica, Pyrus, Chir	Lemon, Pear, Mango, Orange, Papaya, Guava Mosambi, Walnut, Peach, Apricot, Plum	Doob grass, chari, *Chrysopogon montanus*, *Dichanthium annulatum*, *Cymbopogon martini*, *Heteropogon contortus*, *Chrysopogon martini*, *Panicum maximum*	Kumar (2016) [13]; Singh (2017) [27]; Singh (2019) [28]; Thakur (2021) [31]; Verma (2021) [33]; Sharma (2022a) [26]; Sharma (2022b) [22]
Marginal	Agri-Silviculture, Agri-Silvi-Horticulture, Agri-Horticulture, Agri-Silvi-Pastoral, Agri-Horti-Silviculture, Pastoral-Silviculture, Silvi-Pastoral	Wheat, Rice, Maize, Soyabean, Pea, Garlic, Mustard, Blackgram, Cauliflower, Tomato, Brinjal, Turmeric, Arbi, Barley, Cabbage, Capsicum, Coriander	Mulberry, Beul Kachnar, Tooni, Khirak, Gurpatraj, Poplar, Darek, Ficus, Pistacia, Chir, Pyrus, Salix Alba, *Juglans Regia*	Lemon, Pear, Mango, Orange, Papaya, Pajja, Guava, Litchi, Walnut, Orange, Banana, Plum, Apricot	Doob grass, *Chrysopogon montanus*, *Dichanthium annulatum*, *Cymbopogon martini*, *Heteropogon contortus*	Kumar (2016) [13]; Singh (2017) [27]; Singh (2019) [28]; Thakur (2021) [31]; Verma (2021) [33]; Sharma (2022a) [26]; Sharma (2022b) [22]

*Farmer categories = Medium (>2 ha), Small (1-2 ha) and Marginal (<1 ha).

Table 2: Biomass production potential of existing agroforestry systems in Shiwalik region of Himachal Pradesh, India.

Agroforestry Systems	Medium			Small			Marginal			References
	AGB (t ha^{-1})	BGB (t ha^{-1})	Total (t ha^{-1})	AGB (t ha^{-1})	BGB (t ha^{-1})	Total (t ha^{-1})	AGB (t ha^{-1})	BGB (t ha^{-1})	Total (t ha^{-1})	
Agri-Silviculture	10.47-24.04	3.37-7.53	13.97-31.57	10.45-23.05	3.06-7.03	13.51-30.08	10.31-20.38	2.83-6.72	13.47-27.1	Kumar (2016) [13]; Singh (2017) [27]; Singh (2019) [28]; Thakur (2021) [31]; Verma (2021) [33]; Sharma (2022a) [26]; Sharma (2022b) [22]
Agri-Silvi-Horticulture	14.37-25.64	2.46-10.71	16.83-36.35	14.82-26.55	2.97-10.34	20.46-35.24	13.5-28.92	3.98-9.92	17.48-38.84	Kumar (2016) [13]; Singh (2017) [27]; Thakur (2021) [31]; Verma (2021) [33]; Sharma (2022a) [26]; Sharma (2022b) [22]
Agri-Horticulture	9.68-17.49	3.22-6.70	12.90-23.96	9.61-16.86	2.68-6.08	12.29-22.94	10.15-13.82	3.09-7.24	13.24-20.61	Singh (2017) [27]; Singh (2019) [28]; Thakur (2021) [31]; Verma (2021) [33]; Sharma (2022a) [26]; Sharma (2022b) [22]
Agri-Silvi-Pastoral	15.94-19.08	3.90-7.7	19.84-26.78	14.51-16.98	2.95-5.38	17.46-22.36	14.11-20.68	3.97-8.63	18.47-29.31	Kumar (2016) [13]; Singh (2017) [27]; Verma (2021) [33]; Sharma (2022a) [26]; Sharma (2022b) [22]
Agri-Horti-Silviculture	11.55-19.38	2.24-5.81	13.79-25.19	10.26-17.64	1.90-5.93	12.16-23.57	11.47-16.95	1.65-5.64	13.12-22.59	Kumar (2016) [13]; Thakur (2021) [31]
Pastoral-Horticulture	16.45	3.79	20.24	-	-	-	-	-	-	Sharma (2022b) [22]
Pastoral-Silviculture	3.77-15.39	1.36-4.32	5.13-18.74	3.98-15.36	1.28-4.54	5.26-19.90	9.9	2.95	12.85	Singh (2017) [27]; Singh (2019) [28]; Thakur (2021) [31]; Verma (2021) [33]; Sharma (2022b) [22]
Silvi-Pastoral	15.75-30.60	2.55-10.88	18.30-41.48	13.51-33.04	2.74-14.41	16.25-47.45	16.24-28.94	6.09-7.77	22.33-36.71	Kumar (2016) [13]; Singh (2017) [27]; Verma (2021) [33]; Sharma (2022a) [26]
Horti-Pastoral	12	3.36	15.36	10.33	2.98	13.31	-	-	-	Kumar (2016) [13]
Pastoral-Horti-Silviculture	3.15	1.09	4.24	-	-	-	-	-	-	Singh (2019) [28]

*Farmer categories = Medium (>2 ha), Small (1-2 ha) and Marginal (<1 ha).

Table 3: Economic benefits of different agroforestry systems in Shiwalik region of Himachal Pradesh, India.

Agroforestry Systems	Medium			Small			Marginal			References
	Production Costs (Rs. ha^{-1} yr^{-1})	Gross Returns (Rs. ha^{-1} yr^{-1})	B:C Ratio	Production Costs (Rs. ha^{-1} yr^{-1})	Gross Returns (Rs. ha^{-1} yr^{-1})	B:C Ratio	Production Costs (Rs. ha^{-1} yr^{-1})	Gross Returns (Rs. ha^{-1} yr^{-1})	B:C Ratio	
AS	39049.99-233439.36	83754.04-446885.09	1.51-2.44	55520.95-200169.71	113950.15-398401.00	1.64-3.27	29140.60-194761.00	64632.45-429820.00	1.66-2.28	Kumar (2016) [13]; Singh (2017) [27]; Singh (2019) [28]; Thakur (2021) [31]; Verma (2021) [33]; Sharma (2022a) [26]; Sharma (2022b) [22]
ASH	64278.00-199125.00	161370.00-422350.00	1.81-2.51	78370.00-236586.00	177775.30-506330.00	1.69-2.27	101337.00-165238.00	196990.00-390585.00	1.58-2.36	Kumar (2016) [13]; Singh (2017); Thakur (2021) [31]; Verma (2021) [33]; Sharma (2022a) [26]; Sharma (2022b)[22]
AH	45837.00-171994.80	104646.33-319499.00	1.57-2.83	35866.53-220035.00	83632.52-304416.00	1.38-2.33	28882.03-144621.00	65166.51-227691.00	1.57-2.26	Singh (2017 [27]); Singh (2019) [28]; Thakur (2021) [31]; Verma (2021) [33]; Sharma (2022a) [26]; Sharma (2022b) [22]
ASP	61956.00-175495.18	108781.00-355422.00	1.76-2.38	56271.00-188970.00	105900.00-399492.00	1.88-2.11	37703.00-145290.00	66004.00-341432.00	1.39-2.35	Kumar (2016) [13]; Singh (2017) [27]; Verma (2021) [33]; Sharma (2022a) [26]; Sharma (2022b) [22]
AHS	161265.00-208610.00	300698.00-459480.00	1.86-2.20	154747.00-200691.00	274631.00-460027.00	1.77-2.29	165848.00-223302.00	307380.00-521255.00	1.85-2.33	Kumar (2016) [13]; Thakur (2021) [31]
PH	40079.00	70432.00	1.76	-	-	-	-	-	-	Sharma (2022b) [22]
PS	8235.00-19436.00	14857.00-37832.29	1.70-1.95	7875.00-18828.06	11346.00-37949.68	1.44-2.36	10950.00	26913.16	2.46	Singh (2017) [27]; Singh (2019) [28]; Thakur (2021) [31]; Verma (2021) [33]; Sharma (2022b) [22]
SP	6684.00-22251.00	15089.00-61323.00	2.00-2.76	5084.00-29245.81	11897.00-60582.00	1.74-3.46	14723.00-16287.62	30002.89-47956.00	1.84-3.26	Kumar (2016) [13]; Singh (2017) [27]; Verma (2021) [33]; Sharma (2022a) [26]
HP	91388.00	324607.00	3.55	111294.00	353335.00	3.17	-	-	-	Kumar (2016) [13]
PHS	19286.97	41371.34	2.15	-	-	-	-	-	-	Singh (2019) [28]

*AS- Agri-Silviculture, ASH- Agri-Silvi-Horticulture, AH- Agri-Horticulture, ASP- Agri-Silvi-Pastoral, AHS- Agri-Horti-Silviculture, PH- Pastoral-Horticulture, PS- Pastoral-Silviculture, SP- Silvi-Pastoral, HP- Horti-Pastoral and PHS- Pastoral-Horti-Silviculture

* Farmer categories = Medium (>2 ha), Small (1-2 ha) and Marginal (<1 ha).

Table 4: Carbon sequestration potential of prevalent agroforestry systems in in Shiwalik region of Himachal Pradesh, India

Agroforestry Systems	Medium			Small			Marginal			References
	AGB (t ha^{-1})	BGB (t ha^{-1})	Total (t ha^{-1})	AGB (t ha^{-1})	BGB (t ha^{-1})	Total (t ha^{-1})	AGB (t ha^{-1})	BGB (t ha^{-1})	Total (t ha^{-1})	
Agri-Silviculture	4.71-10.82	1.52-3.39	6.29-14.21	4.70-10.37	1.38-3.16	6.08-13.54	4.64-9.17	1.27-3.02	6.06-12.20	Kumar (2016) [13]; Singh (2017) [27]; Singh (2019) [28]; Thakur (2021) [31]; Verma (2021) [33]; Sharma (2022a) [26]; Sharma (2022b) [22]
Agri-Silvi-Horticulture	6.47-11.54	1.11-4.82	7.57-16.36	6.67-11.95	1.34-4.65	9.21-15.86	6.08-13.01	1.79-4.46	7.87-17.48	Kumar (2016) [13]; Singh (2017) [27]; Thakur (2021) [31]; Verma (2021) [33]; Sharma (2022a) [26]; Sharma (2022b) [22]
Agri-Horticulture	4.36-7.87	1.45-3.02	5.81-10.78	4.32-7.59	1.21-2.74	5.53-10.32	4.57-6.22	1.39-3.26	5.96-9.27	Singh (2017) [27]; Singh (2019) [28]; Thakur (2021) [31]; Verma (2021) [33]; Sharma (2022a) [26]; Sharma (2022b) [22]
Agri-Silvi-Pastoral	7.17-8.59	1.76-3.47	8.93-12.05	6.53-7.64	1.33-2.42	7.86-10.06	6.35-9.31	1.79-3.88	8.31-13.19	Kumar (2016) [13]; Singh (2017) [27]; Verma (2021) [33]; Sharma (2022a); Sharma (2022b)
Agri-Horti-Silviculture	5.20-8.72	1.01-2.61	6.21-11.34	4.62-7.94	0.86-2.67	5.47-10.61	5.16-7.63	0.74-2.54	5.90-10.17	Kumar (2016) [13]; Thakur (2021) [31]
Pastoral-Horticulture	7.40	1.71	9.11	-	-	-	-	-	-	Sharma (2022b)
Pastoral-Silviculture	1.70-6.93	0.61-1.94	2.31-8.43	1.79-6.91	0.58-2.04	2.37-8.96	7.31-13.02	2.74-3.50	10.05-16.52	Singh (2017) [27]; Singh (2019) [28]; Thakur (2021) [31]; Verma (2021) [33]; Sharma (2022b) [22]
Silvi-Pastoral	7.09-13.77	1.15-4.90	8.24-18.67	6.08-14.87	1.23-6.48	7.31-21.35	4.46	1.33	5.78	Kumar (2016) [13]; Singh (2017) [27]; Verma (2021) [33]; Sharma (2022a) [26]
Horti-Pastoral	5.40	1.51	6.91	4.65	1.34	5.99	-	-	-	Kumar (2016) [13]
Pastoral-Horti-Silviculture	1.42	0.49	1.91	-	-	-	-	-	-	Singh (2019) [28]

*Farmer categories = Medium (>2 ha), Small (1-2 ha) and Marginal (<1 ha).

Conclusion

Agroforestry systems promise number of benefits to enhance nature contribution to people and plays crucial role in well-being of farmers by providing various products from the single land unit. Agroforestry systems multifunctional nature is critical for preserving biodiversity, providing goods and services to society, enhancing carbon storage, increasing soil fertility and promoting human well-being. From the above study, it can be concluded that the agroforestry is a prominent land use system in Shiwalik region of Himalayan in India and is gaining more interest of farmer due to its higher net returns and B:C ratio in all the three categories of farmers. Agroforestry usually stores more carbon than monoculture farming system and farmers can earn carbon credits by trading the carbon captured in agroforestry systems on international markets.

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