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Carbon stock potential of agroforestry systems in low hills of north-western Himalayas

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ABSTRACT

The present experiment was conducted at Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh during 2019–21 to study the prevalent agroforestry systems and to assess their carbon stock potential. Sub-montane low hill zone of Chamba district of Himachal Pradesh was the study area with 15 farmers selected from each marginal, small and medium categories to carry out the study. Results of the investigation revealed that five agroforestry systems, viz. agrisilviculture, agrihorticulture, agrisilvihorticulture, silvopastoral and pastoralsilviculture were prevalent in the studied area. Maximum aboveground and belowground biomass production was recorded for the silvopastoral system among all the identified systems with least under pastoralsilviculture. Carbon stock potential among all the systems was recorded highest for the silvopastoral system (60.92 Mg/ha) and generally followed the order silvopastoral>agrisilvihorticulture>agrisilviculture>pastoralsilviculture>agrihorticulture. Farmer categories didn't affect the carbon storage potential of the different agroforestry systems significantly. Soil carbon stock contributed more as compared to vegetation carbon stock with pastoralsilviculture having maximum soil:plant carbon ratio of 2.59. The study highlights the importance of the tree based land uses and offers the basis for selection of the potential system from the climate change mitigation point of view in the susceptible Himalayan region.

Keywords: Agroforestry, Carbon, Himalayas, Productivity, Sub-montane

Himachal Pradesh (HP) is a mountainous state located in western part of Himalayas and is characterized by the diverse agro-ecosystems with altitude varying from 350–6975 m amsl (Gupta *et al.* 2017). Agriculture is the main occupation of the people of the state with 69% of the main workers engaged in the agricultural activities and 75% of the total reporting area is available for cultivation. Hill farming systems are dominated by small-scale and subsistence agricultural groups as about 89% of the landholdings in HP are constituted by marginal and small farmers (GoHP 2021). In comparison to larger and more financially oriented farms, these farmers have distinct land management goals and limits. Planting trees on farms helps farmers to satisfy their multifarious needs, which leads to increase in tree cover and thereby reducing the burden on existing forests. Being influenced by physiography, the climate within state varies greatly with some areas being warmed significantly during summers, while, some being covered with snow during winters resulting in the state being classified in four agro-ecological zones. In recent years, changing climate, population increase and decreased land holdings has called for the development of land use systems that reconcile agricultural production with the provisioning of ecosystem services, including climate change mitigation. Agroforestry provides end-to-end link between sustainability and profitability along with greater opportunities for the sustained productivity to tackle such problems. However, the adoption of agroforestry technologies depends on the edapho-climatic, socioeconomic status and farmer needs, and management is influenced by physical, demographic and institutional factors (Bayard *et al.* 2007). Studies report that low lying areas of HP are highly exposed to the changing climatic conditions (GoHP 2012). Chamba district of HP is categorized by mountainous landscape ranging from 2000 feet to 21000 feet and is least explored for its agroforestry resources. So, keeping in mind the extent of exposure to climate change and the role of agroforestry in addressing the climate change effects, the study was carried out with the objectives of identifying the prevalent agroforestry systems (AFS) and to assess their carbon stock potential.

MATERIALS AND METHODS

The present experiment was conducted during 2019–2021 at Dr Y S Parmar University of Horticulture and

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Forestry, Nauni, Solan (32°11′30” to 33°13′6”N and 75°49 to 77°3′30”E), Himachal Pradesh. Three village panchayats were selected and from each panchayat 15 farmers were selected randomly comprised 5 farmers each from marginal, small and medium category. The AFS being practised by the selected farmers were identified on the structural and functional basis (Nair 1985) and named on the basis of the prime importance of the functional components.

For the estimation of biomass in the AFS, sampling was done by laying out the standard plots of 50 cm × 50 cm for herbage, 1 m × 1 m for agricultural crops, 5 m × 5 m for shrubs and 30 m × 10 m for the trees. For the biomass estimation of the herbage, agricultural crops and shrubs, the destructive method of sampling was used. In case of agricultural crops and herbage, the vegetation found within the sample plot was uprooted and the aboveground and belowground portions were separated and oven dried at 70ºC till a constant weight was obtained. For the estimation of shrub biomass, the shrubs were uprooted and the branches were categorized into different size classes. Three branches from each size class were selected to assess the oven dried weight of the branches which on multiplying with the number of branches in each size class gave the total oven dried weight. For trees, non-destructive method of biomass estimation based on volume equations was used (FSI 1996). The aboveground biomass (AGB) of the trees was estimated as:

$$\text{Stem biomass (Mg/ha)} = \text{VOB} \times \text{WD}$$

where VOB, volume over bark (from volume equations); WD, wood density. The AGB of a tree was calculated by formula:

$$\text{AGB (Mg/ha)} = \text{Stem biomass (Mg/ha)} \times \text{BEF}$$

where BEF, Biomass expansion factor. Belowground biomass (BGB) of tree was calculated by multiplying its AGB with a standard factor of 0.26 (Cairns *et al*. 1997). Biomass carbon stock was calculated by multiplying the biomass with the standard factor 0.5 (IPCC 2003). For the estimation of soil carbon stock, five soil samples, one from the centre and four from the corners, were collected from the depth of 0-30 cm from the sample plot laid to form a composite sample. Soil samples were then shade dried, grinded to pass through 2 mm sieve and stored in cloth bags for further analysis. Soil organic carbon density was calculated by multiplying % organic carbon with bulk density and soil depth and expressed in Mg/ha.

$$\text{C (Mg/ha)} = \text{Soil bulk density (g/cm}^3) \times \text{soil depth (cm)} \times \text{OC (\%)} \times 100$$

where C, soil organic carbon density; OC, soil organic carbon (%) expressed in decimal fraction. Vegetation carbon stock along with soil carbon stock was expressed as total carbon stock of the system. The data were subjected to two way ANOVA using SPSS software and least significant difference (LSD) was calculated where data exhibited significant results.

RESULTS AND DISCUSSION

Identification of AFS: The findings revealed that five AFS were prevalent in the study area, viz. agrisilviculture (AS), agrihorticulture (AH), agrisilvihorticulture (ASH), silvopastoral (SP) and pastoralsilviculture (PS). Depending upon the functional components AFS can take numerous forms which are generally the result of primary needs of the society, topography, climate, edaphic conditions, biotic factors as well as economic aspects. The tree density and proportionate area under tree component in different systems varied from 50 (pastoralsilviculture) to 157 (silvopastoral) per ha and 0.20 (agrihorticulture) to 0.65% (silvopastoral), respectively. Among the prevalent AFS in the study area, the specific agricultural components consisted of *Zea mays* (Makki), *Triticum aestivum* (Kanak), *Hordeum vulgare* (Jau), *Oryza sativa* (Dhaan), *Avena sativa* (Jauvi), *Capsicum annuum* (Shimla mirch), *Solanum lycopersicum* (Tamatar), *Solanum tuberosum* (Baingun), *Allium sativum* (Lahsun), *Coriandrum sativum* (Ben), *Brassica juncea* (Sarson), *Trigonella foenumgraecum* (Methi) and *Capsicum frutiscens* (Pipli). In the present era when we are facing the adverse climatic conditions agroforestry in the form of traditional systems is cushioning our agroecosystems implicitly. The systems prevalent in the farmer field were mostly traditional having the higher proportion of forest species fulfilling the needs of the fodder, i.e. *Grewia optiva* (Beul), *Leucaena leucocephala* (Leucena), *Ficus palmata* (Dagla), *Bauhinia variegata* (Kachnar), *Morus serrata* (Toot), *Prunus cerasoides* (Paaja), *Celtis australis* (Khirak), timber, *i.e. Toona ciliata* (Tooni), *Bombax ceiba* (Semal), *Melia composita* (Drek), *Dalbergia sissoo* (Shisham), *Punica granatum* (Dadu), *Tectona grandis* (Sagwan), *Celtis australis* and fuel, i.e. *Albizia chinensis* (Black siris/Olha), *Celtis australis, Leucaena leucocephala, Ficus palmata, Morus serrata, Grewia optiva, Bauhinia variegata, Pyrus pashia* (Kainth) and *Pistacia integerrima* (Kakarsingi). However, with the changing scenario horti-based systems are being preferred by the farmers owning to the economic benefits, perennial nature, less management which also results in positive ecological benefits side by side. In the study area, various horti-based systems comprised *Mangifera indica, Citrus limon, Litchi chinensis, Citrus aurantifolia, Prunus persica, Prunus domestica, Psidium guajava, Carica papaya* and *Pyrus communis.* Although, farmers are not much bothered about the climatic hazards as they are by the returns from the investment, so, if farmers can be motivated to adopt suitable agroforestry technologies based on their economic profitability and dual goals of raising farmer economy and addressing climate change can be fulfilled simultaneously. Topographically being hilly terrain, the conservation of the soil against erosion as well as stabilization of the farm bunds becomes important. Natural grasses retained on the farm bunds as well as adoption of the pasture based systems locally known as ghasnis, on the land left fallow is also of utmost importance. Major grasses present in the pasture based systems were *Chrysopogon montanus, Heteropogon contortus, Chloris* *gayana, Cymbopogon martini, Setaria* spp*, Saccharum spontanum, Panicum maximum, Desmostachya bipinnata, Pennisetum* spp and *Cynodon dactylon.* The results of the study were in line with the findings of several workers (Gupta *et al.* 2017, Tiwari *et al.* 2018, Sharma *et al.* 2021 and Sharma *et al.* 2023) who reported agrisilviculture, agrisilvihorticulture, agrihortisilviculture, agrihorticulture, silvipastoral, pastoralsilviculture, agrisilvipastoral and pastoralsilvihorticulture as the prevalent systems in low hills of HP. Fulfilment of fodder requirements and fuel wood demand, poor soil conditions, prevention of soil erosion as well as availability of the diversified products were attributed as the main reasons for adopting these systems.

Biomass production potential of AFS: The AGB was significantly influenced by the type of AFS ($P<0.001$) and the interaction of farmer category with AFS ($P=0.043$) (Table 1). However, effect of farmer category on AGB production was found to be non-significant. Among different AFS, the AGB production ranged between 19.79–38.40 Mg/ha, which is in line with the AGB reported (4.58–70.91 Mg/ha) in the study area by several workers. The AGB reported is higher than that reported by Tiwari *et al.* (2018), while, lower compared to the AGB reported by Gupta *et al.* (2017) and Panwar *et al.* (2022) in low hill zone of HP. Among all the systems, the maximum (38.40 Mg/ha) AGB was obtained for silvopastoral which was at par with the agrisilvihorticulture (36.03 Mg/ha), while, minimum (19.79 Mg/ha) was obtained for pastoralsilviculture which was at par with agrihorticulture (22.32 Mg/ha). Maximum biomass under silvopastoral system may be ascribed to tree density contributing to more biomass production along with structural and compositional differences of the system as reported by Singh (2018) and Sharma *et al.* (2021). For interaction, maximum (41.89 Mg/ha) AGB was obtained for silvopastoral system under small category, while, minimum (15.76 Mg/ha) for pastoralsilviculture under marginal category. Results obtained can be ascribed to the tree densities under different farmer categories and were similar to the findings of Singh (2018) attributed to the structural differences, management, edaphic conditions, age, growth of the vegetation etc.

Similarly, AFS ($P<0.001$) and the interaction between farmer category and AFS ($P=0.027$) significantly affected BGB production (Table 1). The BGB ranged between 5.11 to 9.88 Mg/ha which is higher than that reported (0.59–21.21 Mg/ha) by Tiwari *et al.* (2018) and Sharma *et al.* (2021), while, lower compared to the that reported by Gupta *et al.* (2017) and Panwar *et al.* (2022) in Himalayan region. Among all the systems, maximum (9.88 Mg/ha) BGB was obtained for silvopastoral which was at par with the agrisilvihorticulture (9.04 Mg/ha), while, minimum (5.11 Mg/ha) was obtained for pastoralsilviculture which was at par with agrihorticulture (5.39 Mg/ha). Results obtained were similar to the findings of Sharma *et al.* (2021) and Panwar *et al.* (2022) attributed to the species diversity, density, frequency, age of vegetation, management regimes, tree growth characteristics etc. Further, being a fraction of AGB, variations in BGB becomes inevitable and may depend on type of plant, root system, management practices as well as ecological conditions prevailing in the area (Rajput *et al.* 2015, Chaturvedi *et al.* 2016). For interaction, maximum (10.84 Mg/ha) and minimum (4.05 Mg/ha) BGB was obtained for silvopastoral and pastoralsilviculture system respectively, under small and marginal farmer category.

Data in Table 2 reflected that biomass carbon stock was significantly influenced by the AFS ($P=0.000$) and the interaction ($P=0.039$) between AFS and farmer category. Among all the systems, biomass carbon stock was obtained maximum (24.14 Mg/ha) for silvopastoral at par with the agrisilvihorticulture (22.54 Mg/ha) system, while, minimum (12.45 Mg/ha) was obtained for pastoralsilviculture which was at par with agrihorticulture (13.85 Mg/ha) system. The biomass carbon stock is in line with findings of Singh *et al.* (2019) in low hills of HP, while, lower as compared to that reported by Gupta *et al.* (2017) and Singh *et al.* (2018).

Maximum biomass carbon under silvopastoral system may be because of higher tree density contributing more biomass production and consequently higher carbon stock retention. Similarly, maximum total biomass carbon have been reported under silvopastoral (Singh *et al.* 2018) and

Table 1 Biomass production (Mg/ha) in different AFS among farmer categories

AFS	AGB			Mean	BGB			Mean
	Farmer Category (FC)				Farmer Category (FC)			
	Marginal*	Small	Medium		Marginal*	Small	Medium	
AS	32.43	26.40	33.45	30.76^{b}	8.11	6.21	8.28	7.53^{b}
AH*		25.51	19.12	22.32^{a}		6.30	4.48	5.39^{a}
ASH	37.48	34.39	36.22	36.03^{c}	9.39	8.66	9.09	9.04^{c}
SP	34.89	41.89	38.42	38.40^{c}	9.01	10.84	9.78	9.88^{c}
PS	15.76	22.21	21.40	19.79^{a}	4.05	5.44	5.84	5.11^{a}
Mean	30.14	30.08	29.72		7.64	7.49	7.49	
$\text{LSD}_{0.05}$	FC- NS, AFS- 4.12, FC×AFS- 7.14				FC- NS, AFS- 1.09, FC×AFS- 1.88			

Mean values in respective row and column followed by different alphabet are statistically different at $P<0.05$, NS, Non-significant, *: Based on modified population marginal mean.

Table 2 Biomass carbon stock (Mg/ha) and soil carbon density (Mg/ha) in different AFS among farmer categories

AFS	Biomass carbon stock			Mean	Soil carbon density			Mean
	Farmer Category (FC)				Farmer Category (FC)			
	Marginal*	Small	Medium		Marginal*	Small	Medium	
AS	20.27	16.31	20.86	19.15^{b}	26.25	27.18	26.31	26.58^{ab}
AH*		15.91	11.80	13.85^{a}		22.51	24.43	23.47^{a}
ASH	23.43	21.52	22.65	22.54^{c}	27.00	34.67	29.97	30.55^{bc}
SP	21.95	26.37	24.10	24.14^{c}	34.08	37.42	38.83	36.78^{d}
PS	9.90	13.82	13.62	12.45^{a}	28.61	34.41	31.90	31.64^{c}
Mean	18.89	18.79	18.60		28.99	31.24	30.29	
$LSD_{0.05}$	FC- NS, AFS- 2.50, FC×AFS- 4.33				FC- NS, AFS- 4.52, FC×AFS- NS			

Mean values in respective row and column followed by different alphabet are statistically different at $P<0.05$, NS, Non-significant.
*: Based on modified population marginal mean.

agrisilvihorticulture (Singh 2018) systems attributed to the structural differences, management, edaphic conditions, growth of the vegetation etc. For interaction, maximum (26.37 Mg/ha) biomass carbon was obtained for silvopastoral system under small farmer category, while, minimum (9.90 Mg/ha) for pastoralsilviculture under marginal category farmers.

Soil carbon density was found to have significant (P=0.000) influence of the AFS (Table 2). Highest soil carbon density (36.78 Mg/ha) was recorded under silvopastoral system, while, minimum under agrihorticulture which was at par with the soil carbon density under agrisilviculture. Higher soil organic carbon in silvopastoral system may be due to the litter addition as well as decayed root material in the soil as compared to the other systems. Soil organic carbon is also influenced by litter quality, geographic location, land use and management. Systems which are relatively older and undisturbed have potential to store higher carbon (Panwar *et al.* 2022) which may be the cause behind the higher carbon accumulation in soil under silvopastoral system. Similarly, higher soil carbon pool was reported under silvopastoral (Goswami *et al.* 2014) in Himalayan region. However, the results were contrary to the findings of the Singh *et al.* (2015) and Singh *et al.* (2018) where silvopastoral system resulted in minimum soil carbon density. Further, it was also found that soil organic carbon density in pastoralsilviculture was also higher which otherwise have lower biomass organic carbon stock that may be due to intensive root cycling taking place in grassland ecosystem.

Total carbon stock potential was significantly affected by the AFS (P=0.000), while, the farmer category as well as interaction between both didn't affected the total carbon stock significantly (Table 3). Silvopastoral system was found to have highest total carbon stock potential which may be due to the dominance of the tree component along with the tree density in the system.

Panwar *et al.* (2022) and Sharma *et al.* (2023) also reported higher carbon stock under silvopastoral system attributed to tree density as well as management practices**.** However, important point to note here is that under pasture dominated system the carbon stock stored in soil was more as compared to vegetation carbon stock as can be seen from the higher soil:plant carbon ratio of 2.59 under pastoralsilviculture system. Higher soil organic carbon may also be due to the dominance of broadleaved tree species having deep anchored root system (Kumar *et al.*

Table 3 Total carbon stock (Mg/ha) and soil:plant carbon ratio in different AFS among farmer categories

AFS	Total carbon stock			Mean	Soil:plant carbon			Mean
	Farmer Category (FC)				Farmer Category (FC)			
	Marginal*	Small	Medium		Marginal*	Small	Medium	
AS	46.53	43.48	47.17	45.73^{b}	1.31	1.84	1.26	1.47^{a}
AH*		38.42	36.23	37.33^{a}		1.43	2.04	1.74^{a}
ASH	50.44	56.19	52.63	53.09^{c}	1.15	1.61	1.34	1.37^{a}
SP	56.03	63.79	62.93	60.92^{d}	1.61	1.42	1.64	1.56^{a}
PS	38.51	48.23	45.51	44.09^{b}	2.92	2.49	2.36	2.59^{b}
Mean	47.88	50.02	48.89		1.75	1.76	1.73	
$LSD_{0.05}$	FC- NS, AFS- 5.23, FC×AFS- NS				FC- NS, AFS- 0.37, FC×AFS- NS			

Mean values in respective row and column followed by different alphabet are statistically different at $P<0.05$, NS, Non-significant.
*Based on modified population marginal mean.

2021). Similarly, Goswami *et al.* (2014) also reported higher soil:plant carbon ratio in non-arable land uses, viz. silvipasture and pure grassland, highlighting the protective role of these systems on soil on one hand, while the vulnerability towards higher carbon emissions under degraded conditions on the other hand. However, Rajput *et al.* (2017) reported higher soil:plant carbon ratio under cultivated systems as compared to perennial tree based systems emphasizing the conservation needs of soil resources under these ecosystems.

In the study area, five AFS were prevalent, viz. agrisilviculture, agrihorticulture, agrisilvihorticulture, silvipastoral and pastoralsilviculture. Biomass production as well as carbon stock potential was not influenced significantly by the type of the farmer category, but, agroforestry system. Biological productivity of the agroforestry land use was found higher for the system dominated by perennial component with silvipastoral system being most productive among all the systems and having maximum carbon stock emphasizing the potential role towards climate change mitigation. Further, carbon stock potential of the agrisilvihorticulture shows that diversified composition can be beneficial from economical as well as ecological perspectives.

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