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K K Vikrant *, D S Chauhan, R H Rizvi

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CO_2 Mitigation Potential of Traditional Agroforestry Systems along Elevations in Tehri District of North West Himalaya, India

Vikrant K.K [1,*], Chauhan D.S [2] and Rizvi R.H [3]

[1] Department of Agriculture, Sai Nath University, Jirawar,Chandway-Kuchhu Road Ranchi, Jharkhand – 247667, India, kundankumarvikrant@gmail.com
[2] Department of Forestry & Natural Resources, HNB Garhwal University, Srinagar, Garhwal, Uttarakhand – 246174, India, chauhands2008@gmail.com
[3] ICAR-Central Soil Salinity Research Institute, Lucknow, Uttar Pradesh-226002, India, rhrizvi@gmail.com
* Correspondence: kundankumarvikrant@gmail.com, +917857920157

Abstract: Agroforestry has a sustainable attributes with both tangible and nontangible benefits. In this study carbon mitigation and credits potential of traditional agroforestry systems at different elevations were evaluated. These traditional systems are: Agrihortisilviculture system (AHS), Agrihorticulture system (AH) and Agrisilviculture system (AS). Stand density, living biomass carbon and soil carbon were measured in each sample plot. The results were that stand density of woody perennials varied from 61 to 233 tree ha^{-1} across t elevations and systems, and , *Grewia oppositifoila* was the predominant tree species occupying most of the agroforestry land use system. Plant and soil organic carbon were significantly different ($P \leq 0.05$) among systems and elevations. Total carbon including plant and soil was significantly higher in the AH system at upper elevations. Total carbon emmision mitigation varied with changing elevations and systems, being highest at lower elevation with AHS system. The total carbon credits was also recorded high at lower elevation, whereas the total value of C credits was higher at mid elevation due to the estimated agroforestry area. The total value of C credits from all agroforestry systems was observed (128977.59 **€**) of the study area.

Keywords: agroforestry systems; biomass; carbon credits; climate change; carbon mitigation

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1. Introduction

Climate change is now impacting agricultural production, food stability and nutritional security across the world. Agricultural systems, such as agroforestry, that integrate trees with livestock and crops on the same land has been adopted in developing countries to strengthen the climate change resilience of small stakeholders who have limited resources. In tropical countries such as Kenya, Brazil and Indonesia, government programs are run to cultivate trees plus crops on farmland to reduce the effect of climate change [1]. India became the first country in the world to adopt an agroforestry policy (10 February 2014). The "Trees Outside Forests in India" programme has been launched as a joint initiative of the Ministry of Environment, Forest and Climate Change, Government of India and the United States Agency for International Development (USAID). The initiative is mainly to expand the area under trees outside of forests and to mitigate climate change [2]. The current area under agroforestry is estimated from LISS III satellite data to be 13.75 M ha of the total geographical area of the country using by the Central Agroforestry Research Institute (CAFRI) [3]. Increasing temperature is mainly due to rising CO_2 levels in the atmosphere and there is need to take necessary action to reduce the effect of climate change. Agroforestry can play a significant role to sequester atmospheric CO_2 which may help to mitigate climate change. A proposal has been approved by the Cabinet Committee on Economic Affairs as a National Mission for a green India as a centrally sponsored scheme. The main objective of the mission includes increased

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forest/tree cover and improved quality of forest cover across in two to eight million hectares, along with improved ecosystem services including biodiversity, hydrological services, and an increased forest-based livelihood income for households that live in and around the forests, and enhanced annual CO_2 sequestration [4]. India is the third highest country in the world for in green house gas emissions after China and the United States. India promises to reduce green house gas emission intensity by 33 to 35 percent by 2030 [5]. If the agroforestry technique is to be used for climate change mitigation through carbon sequestration, then accurate data is required on living biomass [6]. Therefore, the main objective of the study was to examine the CO_2 mitigation efficiency of agroforestry systems across different elevations in North Western Himalaya, in the Tehri District, Uttarakhand, India.

2. Materials and methods

2.1. Study area

The present study was carried out from 2014-2018 in the Tehri Garhwal district of Uttarakhand (Figure 1) which is the part of North Western Himalayan region . The district lies between latitude of $30^0$03' and 30^0 53' North l and longitudes 77^0 56' and 79^0 04' East and has an area of 3,642 km^2 [7]. The area under forest cover is 2236 km^2 and 1142.42 km^2 is under cultivation [7] .The Tehri district has been divided into three agro-climatic zones viz: sub-tropical zone (300-1200m), sub-temperate zone (1200-2000m) and temperate zone (2000-2800 m) on the basis of topography, elevation and temperature condition [8].

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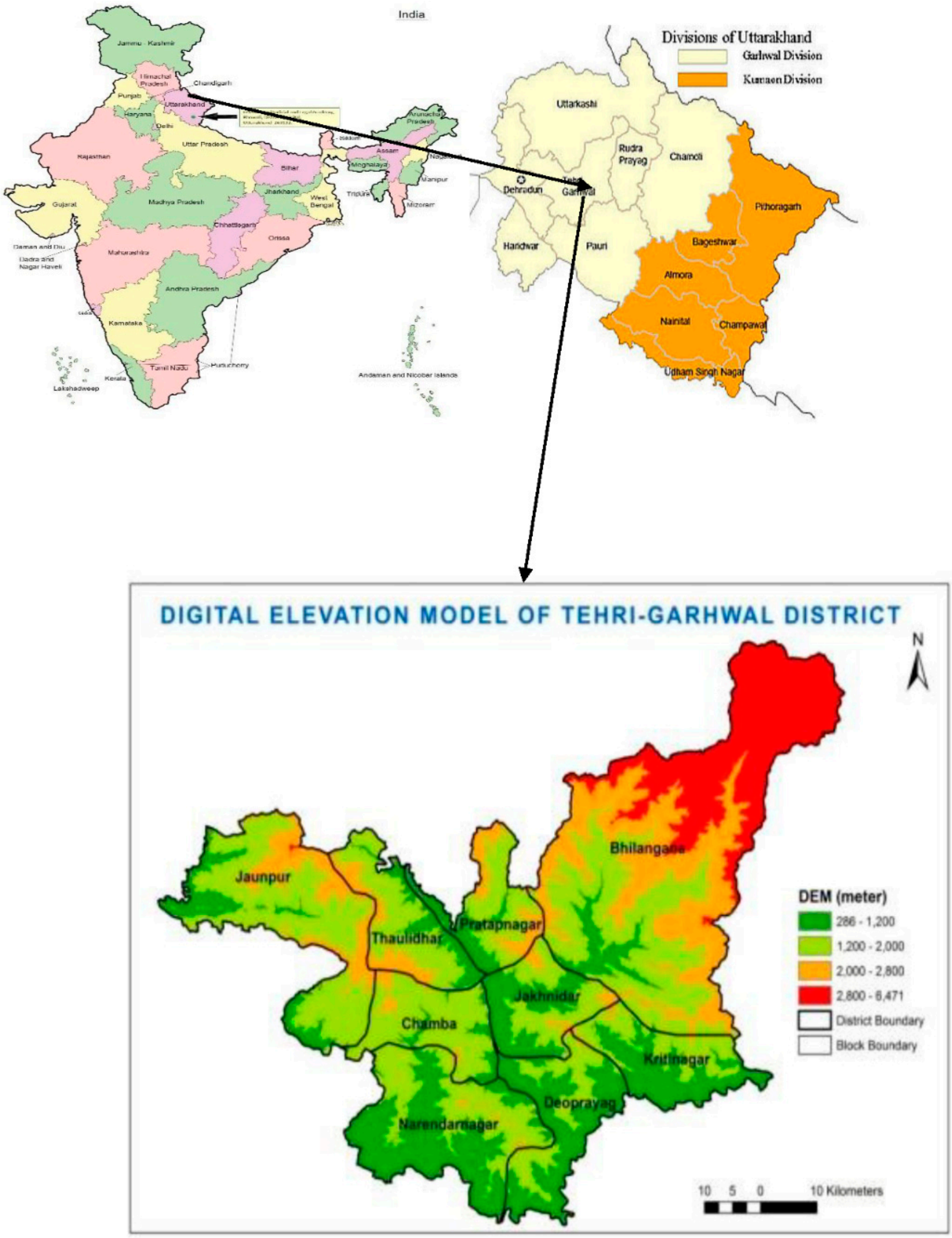

Figure 1. Map of Study area.

2.2. Methodology

Stratified random sampling techniques were used for this study. Out of nine blocks, six blocks on three elevations i.e. 286-1200m, 1200-2000m and 2000-2800m were selected in the district for first stage sampling. Thirty two villages were selected randomly from six blocks, seven villages from Deoparayag block, six villages each from Kirtinagar & Chamba blocks, five villages from Pratapnagar block and four villages each from Thauldhar & Jakhnidhar blocks. Considering the elevations, 14 villages were situated in lower elevation (286-1200m), 13 villages were in middle elevation (1200-2000m) and five villages were in upper elevation (2000-2800m). In the second stage of sampling, list of farmers of each villages were prepared on the basis of concerned block office records. Total, 540 farmers were selected randomly. Most of agroforestry systems have been identified at each elevation of each block. On the basis of structure and function of different land use systems, most important components were identified. Ten sample plots of 100 m^2 size were randomly marked in each village. All individual trees, shrubs and fruits species were recorded within 100 m^2 size plot and crops, grasses and weeds species were recorded in 1m^2 size nested plot and density was estimated by formula given by Muller-Dombios and Ellenberg (1974) [9]. Tree height was determined by Haga altimeter and DBH was measured by tree caliper. Collected data was in unequal replication and analyzed by analysis of variance (ANOVA) and least significant difference (LSD) statistical tools. Stem volume was measured using the Pressler 1985 [10] and Bitterlich 1984 [11] formula $V=f \times h \times g$ (where V is volume, f is form factor, h is total height and g is basal area). Stem biomass was estimated by multiplying the stem volume with wood specific gravity [12] using the maximum moisture content method [13]. Branch and leaf biomass was estimated using the fresh and dry weight ratio [14]. Factor of 0.25 for broad-leaved species and 0.20 for coniferous species were multiplied with above ground biomass for below ground biomass [15]. 0.45 Factor was multiplied with biomass for value of carbon stock [16]. Destructive method was used for crop and grass biomass using 1m^2 quadrate. Fresh weight was converted into dry weight on the basis of plant samples kept in the oven for drying at 80^{O}C for 24 hours. Total carbon was converted in to CO_2 mitigation by multiplied carbon stock value with the factor of 3.67 [17]. One tone of sequestrated CO_2 in the form of living biomass is equal to one C credit. One carbon credit is equal to €3.00 [18]. Soil carbon in same agroforestry sites was also estimated. 10 pre-existing sample plots of 100m^2 were also selected for soil carbon estimation. Composite samples were obtained for three soil layers, 0-10, 10-20 and 20-30 cm. Weighing bottle method were used for determining bulk density [19]. Walkley and Black (1934) method [20] were used for estimating soil organic carbon percentage. Soil carbon stock (Mg ha^{-1}) was calculated by using the Pearson et al. (2007) [17] equation.

3. Results

The three common agroforestry systems were identified in Tehri district which are agrisilviculture system-AS (includes trees and agriculture crops), agrihorticulture system-AH (includes edible fruit trees and agriculture crops), and agrihortisilviculture system-AHS (trees including edible fruit trees, forest trees and agriculture crops) (Table 1). In different agroforestry systems, predominant forestry species were *Grewia oppositifoila, Celtis australis, Melia azedarach, Bauhinia variegata, Ficus roxburghii, Boehmeria regulosa, Quercus leucotrichophora, Myrica esulenta*, whereas, *Mangifera indica, Musa pradisica, Citrus sinensis, Prunus persica, Pyrus cuminis, Malus domestica, Psidium guajava, Punica grantum* and *Emblica officinalis* were the common fruit species (Table 1). Predominant annual crops were *Triticum aestivum* (Wheat), *Oryza sativa* (Rice), *Ehinochloa frumentacea* (Barnyard millet), *Eleusine coracana* (Finger millet), *Hordeum vulagare* (Barley), *Zea mays* (Maize), *Cajanus* spp. (Pigeon pea), *Glycine max* (Soyabean), *Amarnathus blitum* (Chaulai), *Pisum sativum* (Pea), *Allium cepa* (Onion), *Solanum tuberosum* (Potato), *Vigna mungo* (Urd) and *Brassica compestris* (Sarson). Considering the agroforestry systems across elevations, *G. oppositifolia, C. australis, M. azedarach, B. variegata, F. roxburghii* and *T. ciliata* were the most common tree species present across two elevations (286-1200 & 1200-2000m) in AS and AHS, whereas, *Q. leucotrichophora* also common tree species present across two altitiudes (1200-2000 & 2000-2800m) in AS and AHS. However, *Grewia oppositifolia* was one of the species thriving in the diverse altitudinal range in AS and AHS. The most common fruit tree species *Citrus limon, C. sinensis, C. aurentium, Mangifera indica, Musa prasdisica, Psidium guajava* and *Emblica officinalis* were present across two elevations (286-1200 & 1200-2000m) in AHS and AH, while *Malus domestica, Juglans regia, C. limon* and *C. sinensis* were also common fruit tree species present across two elevations (1200-2000 & 2000-2800m) in AHS and AH. *Triticum aestivum, Echinochloa frumentacea,* and *Eleusine coracana* were the most common annual crops grown by the farmers across the three elevations under agroforestry systems (Table 1). The vegetables, oil and pulses crops viz. *Solanum tuberosum, Allium cepa, Brassica compestris, Glycine max, Cajnus spp. and Vigna mungo* were also grown by most of the farmers across the elevations.

Table 1. Existing agroforestry systems and its functional components along elevations.

Elevations (m)	Components					
	Dominants tree species (forest tree + fruit)			Dominants annual crops (crop+ grass+ weed)		
	Agrisilviculture system (AS)	Agrihortisilviculture system (AHS)	Agrihorticulture system (AH)	Agrisilviculture system (AS)	Agrihortisilviculture system (AHS)	Agrihorticulture system (AH)
286-1200	*Grewia oppositifolia, Melia azedarach, Celtis australis, Boehmeria regulosa, Ficus auriculata,Toona ciliata, Prunus cerasoides, Bauhinia variegata, Ficus roxburghii*	*Citrus limon, Psidium guajava, Mangifera indica, Musa paradisica, Citrus sinensis, Grewia oppositifolia, Melia azedarach, Toona ciliata, Celtis australis, Ficus roxburghii*	*Mangifera indica, Citrus limon, Carica papaya, Citrus aurentium, Embilica officinalis, Prunus persica, Psidium guajava, Punica granatum*	*Echinochloa frumentacea, Eleusine coracana, , Zea mays, ,Triticum aestivum , Agreatum cenozoides, Cynodon dactylon, Lantana camara*	*Echinochloa frumentacea, Eleusine coracana, Oryza sativa, Glycine max, Cajanus spp., Cynodon dactylon, Lantana camara, Allium cepa, Solanum tuberosum, Brassica compestris, Raphanus sativus*	*Glycine max, Pisum sativum, Ehinochloa frumentacea, Eleusine coracana, Allium cepa, Solanum tuberosum, Brassica compestris, Raphanus sativus*
1200-2000	*Celtis australis, Bauhinia variegata, Ficus roxburghii, Grewia oppositifolia, Melia azedirach, Morus alba, Quercus leucotrichophora, Toona ciliata*	*Celtis australis, Ficus roxburghii, Grewia oppositifolia, Melia azedirach, Morus alba, Citrus aurentium, Psidium guajava, Embilica officinalis, Mangifera indica, Musa paradisiacia, Malus domestica*	*Citrus aurentium, Psidium guajava , Embilica officinalis, Mangifera indica, Musa paradisiaca, Malus domestica*	*Amarnathusblitum, Ehinochloa frumentacea, Eleusine coracana, Oryza sativa, Glycine max, Cicer arientinum, Cajanus spp., Triticum aestivum , Cynodon dactylon, Lantana camara*	*Fagopyrumesculentum, Oryza sativa, Ehinochloa frumentacea, Eleusine coracana, Chenopodium album, Allium cepa, Solanum tuberosum, Brassica compestris, Raphanus sativus, Cynodon dactylon, Lantana camara*	*Glycine max, Pisum sativum, Ehinochloa frumentacea.Eleusine coracana, Allium cepa, Solanum tuberosum, Brassica compestris, Raphanus sativus.*
2000-2800	*Quercus leucotrichophora, Rhododendron arboretum, Myrica esculenta, Grewia oppositifolia*	*Grewia oppositifolia ,Quercus leucotrichophora, Rhododendron arboreum, Myrica esculenta, Citrus limon, C. sinensis, Juglans regia, Malus domestica.*	*Pyrus communis, Prunus persica, Prunus armenica, Juglanse regia, Pyrus communi, Citrus limon, C. sinensis, Malus domestica*	*Triticum aestivum, Eleusine coracana, Fagopyrum esculentum, Amarnathusblitum, Ehinochloa frumentacea, Lantana camara*	*Triticum aestivum, Amarnathus blitum, Fagopyrum esculentum, Ehinochloa frumentacea, Eleusine coracana, Solanum tuberosum, Amranthus virdius*	*Triticum aestivum, Amarnathus blitum, Ehinochloa frumentacea, Eleusine coracana, Solanum tuberosum, Cynodon dactylon*

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Tree density both forest and fruit trees varied from 61 tree ha^{-1} in AHS system to 233 tree ha^{-1} in AH system across the elevations (Table 2). The tree densities including fruit trees at lower elevation of AS, AHS and AH systems were 227, 230 and 181 ha^{-1}, respectively, whereas at middle elevation of AS, AHS and AH systems were 216, 243 and 233 ha^{-1}, respectively. At upper elevation tree densities of AS, AHS and AH systems were 152, 206 and 148 ha^{-1}, respectively. The density was higher at middle elevation as compared to lower and upper elevation, whereas, density value was higher in AHS system as compared to AS and AH systems across the elevations. *Grewia oppositifolia* was dominant forest tree species having maximum density (90 trees ha^{-1}) in AHS system (77 trees ha^{-1}) in AS system as compared to AH system at middle elevation followed by *Ficus roxburghii* (45 trees ha^{-1}) in AS system at middle elevation and *Celtis australis* (41 trees ha^{-1}) in AHS system at lower elevation. Whereas, dominant fruit trees are *Mangifera indica* with maximum density (37 trees ha^{-1}) and (35 trees ha^{-1}) respectively at lower and middle elevation in AH system as compared to AHS system followed by *Citrus sinensis* (35 trees ha^{-1}) in AH system at middle elevation and *Musa paradisiaca* (34 trees ha^{-1}) in same system at lower elevation (Table 2). Similarly, *Quercus leucotrichophora* was dominant forest tree having maximum density (58 trees ha^{-1}) in AS system and (51 trees ha^{-1}) in AHS system followed by *Grewia oppositifolia* (40 trees ha^{-1}) in AS system at upper elevation, while dominant fruit trees species were *Citrus sinensis* and *Malus domestica* have maximum density (32 trees ha^{-1}) respectively in AH system as compared to AHS system at upper elevation (Table 2). Across the elevations, AHS system contained maximum density followed by AS system, while, higher density were recorded at middle and lower elevations.

Table 2. Tree species density in different agroforestry systems along elevations.

		Density (trees ha^{-1})		
Elevations	**Forest species**	**Agrisilviculture system (AS)**	**Agrihortisilviculture system (AHS)**	**Agrihorticulture system (AH)**
286- 1200 m	*Adina cardifolia*	6	NA	NA
	Anogeissus latifolia	6	NA	NA
	Acacia catechu	4	8	NA
	Bahunia verigata	5	NA	NA
	Bombax ceiba	8	NA	NA
	Celtisaustralis	40	41	NA
	Ficus palamata	11	NA	NA
	Ficus roxburghii	10	NA	NA
	Ficus semicordata	6	NA	NA
	Grewia oppositifolia	60	55	NA
	Hoplia integrifolia	5	10	NA
	Melia azedirach	20	22	NA
	Morus alba	5	10	NA
	Pinus roxburghii	7	6	NA
	Prunus cerasoides	6	NA	NA
	Pyrus pashia	8	9	NA
	Rhus parviflora.	4	NA	NA
	Toona ciliata	5	8	NA
	Woodfordia fruticosa	3	NA	NA
	Total	**227**	**169**	**NIL**
1200- 2000 m	*Celtis australis*	32	25	NA
	Ficus roxburghii	45	24	NA
	Grewia oppositifolia	77	90	NA
	Melia azedirach	15	22	NA
	Morus alba	11	NA	NA

	Pinus roxburghii	6	NA	NA
	Quercusleucotrichophora	15	17	NA
	Rhus parviflora	5	NA	NA
	Toona ciliata	6	NA	NA
	Woodfordia fruticosa	4	NA	NA
	Total	**216**	**178**	**NIL**
2000-2800 m	*Grewia oppositifolia*	40	18	NA
	Myrica esculenta	35	32	NA
	Quercus leucotrichophora	58	51	NA
	Rhododendron arboreum	19	19	NA
	Total	**152**	**120**	**NIL**
	Fruit species			
286- 1200 m	*Carica papaya*	NA	7	24
	Citrus aurentium	NA	NA	22
	Citrus limon	NA	NA	25
	Embilica officinalis	NA	15	NA
	Mangifera indica	NA	12	37
	Musa paradisiacia	NA	11	34
	Psidium guajava	NA	10	17
	Punica granatum	NA	6	22
	Total	**NIL**	**61**	**181**
	Grand total (forest + fruit)	**227**	**230**	**181**
1200- 2000 m	*Citrus aurentium*	NA	5	14
	Citrus limon	NA	NA	14
	Citrus sinensis	NA	10	35
	Embilica officinalis	NA	5	18
	Mangifera indica	NA	13	35
	Musa paradisiacia	NA	15	23
	Prunus armenica	NA	7	19
	Prunus persica	NA	7	23
	Psidiumguajava	NA	NA	12
	Punica granatum	NA	3	11
	Pyrus communis	NA	NA	29
	Total	**NIL**	**65**	**233**
	Grand total (forest + fruit)	**216**	**243**	**233**
2000-2800 m	*Citrus limon*	NA	NA	21
	Citrus sinensis	NA	25	32
	Juglanse regia	NA	17	12
	Malus domestica	NA	28	32
	Prunus armenica	NA	NA	13
	Prunus persica	NA	NA	22
	Pyrus communis	NA	16	16
	Total	**NIL**	**86**	**148**
	Grand total (forest + fruit)	**152**	**206**	**148**

The total biomass and carbon stock was found comparatively higher at lower elevation than middle and upper elevations across the systems. Whereas, across the elevations AHS system contained higher biomass accumulation and carbon stock than AS and AH systems (Table 3). CO_2 mitigation showed significant difference ($P \leq 0.05$) at lower elevation across the system. Whereas, across the elevations AHS system showed significant difference ($P \leq 0.05$) and estimated higher CO_2 mitigation than AS and AH system (Table 3).

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Table 3. Total Biomass (Mg ha^{-1}), Biomass Carbon stocks (Mg ha^{-1}) and CO_2 mitigation (Mg ha^{-1}) in different agroforestry systems along elevations.

AFS	Elevations (m)								
	286-1200 m			1200-2000 m			2000-2800 m		
	Total Biomass	Biomass Carbon stocks	CO_2 Mitigation	Total Biomass	Biomass Carbon stocks	CO_2 Mitigation	Total Biomass	Biomass carbon stocks	CO_2 Mitigation
AS	3.81	1.71	6.27	3.62	1.62	5.94	2.45	1.10	4.03
AHS	6.36	2.86	10.49	4.37	1.96	7.19	3.77	1.69	6.20
AH	3.54	1.59	5.83	2.69	1.21	4.44	1.81	0.81	2.97
LSD	0.86	0.39	1.43	0.77	0.35	1.28	0.60	0.27	1.11

*Significance at the level of probability of 5% ($P \leq 0.05$).

The Net carbon stock of different agroforestry land systems, including soil organic carbon and plant biomass carbon is given in Table 4. Carbon pools compared with plant and soil indicated that soil organic carbon was significantly higher ($P \leq 0.05$) than that of plant C pools across the elevations. Total C pools including plant and soil recorded significantly higher ($P \leq 0.05$) in AH system as compared to AHS and AS system across the elevations. Statistically lowest C pool was recorded in AS system across the elevations. In general, total C pools were recorded statistically higher at upper elevation than middle and lower elevations. In the soil layer (0–30 cm, AS system exhibited, statistically the highest total C pool (46.53 Mg ha^{-1}) at upper elevation followed by AHS system (27.71 Mg ha^{-1}), however, statistically alike at lower elevation.

Table 4. Carbon pool (Mg ha^{-1}) in different agroforestry systems along elevations.

AFS	Carbon (Mg ha^{-1}) Elevations (m)								
	286-1200 m			1200-2000 m			2000-2800 m		
	Plant	Soil (0-30 cm)	Total	Plant	Soil (0-30 cm)	Total	Plant	Soil (0-30 cm)	Total
AS	1.71	19.78	21.49	1.62	23.07	24.69	1.10	23.78	24.88
AHS	2.86	24.85	27.71	1.96	23.11	25.07	1.69	24.98	26.67
AH	1.59	25.97	27.56	1.21	25.03	26.24	0.81	45.72	46.53
LSD	0.39	17.21	19.60	0.35	20.21	20.56	0.27	21.29	21.56

*Significance at the level of probability of 5% ($P \leq 0.05$).

At upper elevation, plant soil carbon ratio was found statistically higher than middle and lower elevations, irrespective of agroforestry systems, whereas in AH system plant soil carbon ratio was statistically higher than AHS and AS systems across the elevations (Figure 2). Plant soil carbon pool ratio was also recorded maximum (56.44) in AH system followed by (21.62) in AS system at upper elevation.

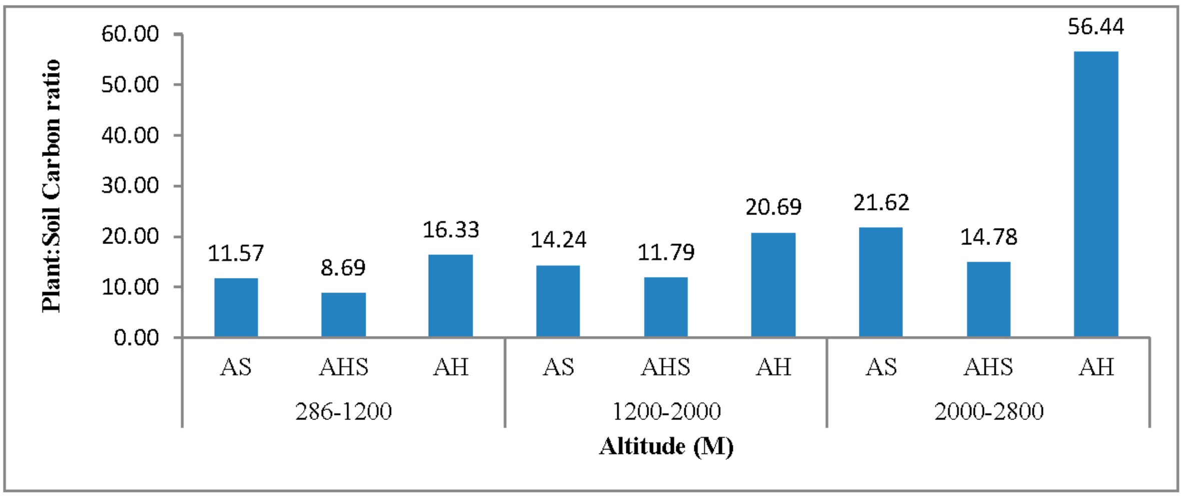

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Figure 2. Plant: Soil carbon ratio in different agroforestry systems along elevations.

C mitigation differs significantly ($P \leq 0.05$) with changing elevations. It was estimated that the total agroforestry land use area contributed mostly biomass C mitigation (5894.13Mg) at middle elevation followed by (4574.08 Mg) at lower elevation (Table 5).

Table 5. Carbon credit production potential in different agroforestry systems along elevations.

Elevations (m)	Estimated agroforestry area (ha)*	Mitigated carbon (Mg)	Carbon credits Total	ha^{-1}	Value of carbon credits (€)^{c}
286-1200	2231.26	4574.08	16786.87	7.52	50360.61
1200-2000	3707.36	5894.13	21631.45	5.83	64894.35
2000-2800	1038.65	1246.38	4574.21	4.40	13722.63
2800-6471	52.11	Not estimated			
Total	7029.06	11714.59	42992.53		128977.59

* Source: Vikrant et al. 2018.

It shows that the C mitigation reduces approximately at the rate of 38% at upper elevation from lower elevation. C mitigation capacity followed the order Middle >lower > upper elevations. The total C mitigated by agroforestry systems was 11714.59 Mg in the district (Table 5). Moreover, rate of C mitigation was more at mid elevation with AHS system. Total C credits of agroforestry of Tehri district were estimated at 42992.53 in which highest number (21631.45) was from the middle elevation and lowest number (4574.21) was from the upper elevation of Tehri district. Whereas, the C credits per ha produced greatest number (7.52 ha^{-1}) at lower elevation, while upper elevation produced the lowest (5.83 ha^{-1}) C credit. Total calculated values of carbon credit were 128977.59 € (Table 5).

6. Discussion:

Dadhwal et al. (1989) [20] and Toky et al. (1989) [21] have also observed similar agroforestry systems across the elevations in North Western Himalayan region.Value of tree density was higher than the value reported by Goswami et al. (2014) [22] at mid-hill region of the Himachal Pradesh of India. . In the present study, *Grewia oppositifolia* occupied in highest density across agroforestry systems of Tehri district as compared to other forest species. *Grewia oppositifolia* occupied 0.64% area followed by 0.40% area by *Celtis australis* through Remote Sensing in Tehri district [23]. *Grewia oppositifolia* is a multipurpose tree which is most adopted by local farmers [20]. Total biomass and carbon stock in AHS was statistically alike but differed significantly from AS and AH systems. The higher biomass and carbon stock from the fruit and tree based system can be attributed to the presence of vegetable crops and trees as the dominant component in the system along with fruit trees. Biomass carbon has been found maximum at lower elevation because of abundance of tree species such as, *Grewia oppositifolia, Celtis australis, Ficus roxbughii, Morus alba, Citrus spp, Malus domestica* and *Psidium guajava* which were planted at high density. Agrihortisilviculture land management systems have good dominance of species with diverse growth habits, better root systems and good mineral requirements, which enable them to optimize available space & resources and lesser intensity of weeds as compared to other systems [21]. It was also indicated that total tree biomass was decreased with increasing elevations across systems. This variation can mainly be due to difference in the nature of the agro-climatic region. The comparison of three agroforestry land use systems showed the maximum CO_2 mitigation potential in AHS system followed by AS system. Higher CO_2 mitigation in horticulture and tree based system can be attributed to the maximum removal of harvesting biomass of fruits, fodder, fuel wood and vegetables. CO_2 mitigation depends on total carbon storage level which is positively correlated with elevations. However, higher CO_2 mitigation was found in lower elevation due to the adequate management of tree component. Results suggested that soil C pool is exploited in agrisilviculture systems due to regular tilling of soil for crop production and also attributed to the uptake of nutrients by annual crops [24]. Higher C pool were found in under fruit tree-based system (AH and AHS) which may be due to regular addition of litter biomass in the soils [25]. Soil carbon stock exceeds by a factor of 5 from Plant carbon stock [26]. As per LISS IV satellite data, area under agroforestry estimated as 7029.06 ha of total geographical area of Tehri district. Highest area under agroforestry was found in 1200-2000 m elevation i.e. 3707.36 ha followed by 288-1200 m elevation i.e. 2231.26 ha [23]. Considering agroforestry systems, C mitigation differs significantly ($P \leq 0.01$) with respect to systems which was estimated maximum (7.98 Mg ha^{-1}) in AHS system followed by (5.42 Mg ha^{-1}) in AS system it is nearly 30% less [27]. Mid elevation/subtropical zone consists maximum number of trees biomass and carbon stock, this variation is mainly due to difference in the nature of agroclimatic region. C mitigation depends on biomass and carbon stock level which increases with elevations. Age, structure and management of the system are an important factor for C variability in plant biomass [28]. In mountain agroforestry, farmers collect the fodder and fuelwood for livelihood by lopping the trees. Requirement of timber has been fulfilled by sometimes harvesting after rotation period. Commercial felling is totally banned.

7. Conclusion

The traditional agroforestry system in Himalayan region is an alternative choice towards carbon storage for atmospheric CO_2 sequestration and carbon credit. Middle elevation/sub-temperate zone with AHS system has the capacity for maximum CO_2 mitigation and carbon credit. However, lower elevation contained maximum number of carbon credit per ha^{-1}. Plant: Soil carbon pool ratio was observed highest at upper elevation in AH system. Traditional agroforestry system should be promoted for environment and economic benefit as a carbon credit for improving the livelihood of rural people in Tehri district of Uttrakhand due to ban of green felling in Himalayan region.

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