Chapter

Assessment of Biomass and Carbon Stock along Altitudes in Traditional Agroforestry System in Tehri District of Uttarakhand, India

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Abstract

Agroforestry represents an integration of agriculture and forestry to increase productivity and sustainability of farming systems and farm income. It has been recognized as carbon sinks due to the need of climate change mitigation. The objective of this study was to compare the carbon stock in living biomass between altitudes and agroforestry system in Tehri district, Uttarakhand. The system compared was: Agrihortisilviculture system (Trees, crops and fruits), Agrihorticulture system (Trees and Fruits) and Agrisilviculture system (Trees and crops.). 1350 sample plots were selected in three altitudes. Three altitudes were: Lower (286-1200 m), Middle (1200-2000 m) and Upper (2000-2800 m). Results indicated that carbon was influenced by the altitudes. Carbon stock in the lower altitude (286-1200 m) was higher compared to the middle and upper altitudes. Agrihortisilviculture system contained maximum carbon stock compare than other system. It is concluded that agroforestry systems are playing an important role in the biodiversity conservation, soil enrichment and carbon storage in Tehri district of Uttarakhand.

Keywords: Agroforestry system, Climate change, Altitudes, Carbon storage

1. Introduction

The third IPCC Assessment Report on climate change (IPCC 2000) contains an endorsement of the potential for agroforestry to contribute to increase in carbon stock in agriculture lands. Agroforestry can both sequester carbon and produce a range of economic, environmental, and socioeconomic benefits. Trees in agroforestry farms improve soil fertility through control of erosion, maintenance of soil organic matter and physical properties, increase N, help in extraction of nutrients from deep soil horizons, and promotion of more closed nutrients cycling. Agroforestry is an ideal option to increase productivity of wasteland, increase tree cover outside the forest and reduce human pressure on forests under different agro-ecological regions, and is thus a viable option to prevent and mitigate climate change effect [1]. Most, if not all, agroforestry systems have the potential to sequester carbon for a short period, say 6–8 yrs. [2]. With adequate management of trees under agroforestry systems, a significant fraction of the atmospheric C could be captured and stored in plant biomass and in the soils [2]. An IPCC special report [3] (IPCC 2000) indicates that conversion of unproductive croplands and grasslands to agroforestry have the best potential to soak up atmospheric C. In agroforestry, soil restoration process involves recovery of organic based nutrients cycle through replenishment of soil organic matters, about half of which is C [4]. Removing atmospheric carbon (C) and its storage in the terrestrial biosphere is vital for compensating the emission of greenhouse gases. Agroforestry, a land- use system has an integral relationship with the farm community to supplement fuel, fodder, fruits, fibers and organic fertilizers on one hand and capture abundant amounts of carbon on the other. Agroforestry systems are believed to have good potential to sequester carbon [5] and thus immensely important in the era of climate change. Human activities change carbon stocks in terrestrial ecosystems through rapid land-use transformations [6]. At the moment, agroforestry has generated much enthusiasm as a result of the National Action Plan for Climate Change [7] which, under its Green India mission, has exclusively emphasized the agroforestry interventions. It is proposed that under agroforestry, 0.80 m ha of area would involve improved agroforestry practices on the existing lands under agroforestry and that 0.70 m ha would involve additional lands under agroforestry. There is now consensus that the agroforestry systems and practices hold viable potential to meet the present basic human needs, besides addressing several major agro-ecological, carbon sequestration and socioeconomic issues. Moreover, National Agroforestry Policy 2014 of India has also focused on encouraging fast growing tree species for carbon sequestration and environmental amelioration. The C sequestration potential of agroforestry systems is estimated to be between 12 and 228 Mg, with a median value of 95 Mg. Therefore, based on the earth's area that is suitable for the practice, 1.1–2.2 Pg C could be stored in the terrestrial ecosystems over the next 50 years [8]. Long rotation systems such as agroforestry, home gardens and boundary plantings can sequester sizeable quantities of C in plant biomass and in long-lasting wood products. Soil C sequestration constitutes another realistic option achievable in many agroforestry systems. The potential of agroforestry for CO_2 mitigation is well recognized. There are a number of short comings however, that need to be emphasized such as the change in vegetation under agroforestry systems, *etc*. [8] (Albrecht and Kandji 2003). Significance of agroforestry with regard to C sequestration and other CO_2 mitigating effects is being widely recognized, but there is still paucity of quantitative data on agroforestry systems with varying altitude in Himalayan region. This study was conducted to determine the carbon stock capacity of different agroforestry system in Indian Himalaya along altitudes.

2. Materials and methods

2.1 Study area

The present study was undertaken in Tehri l district of Uttarakhand state which lies in the Northern region of India. Of the total 8,479,562 human population of the state, 78% lives in rural areas. The agriculture land in the hills of Uttarakhand is scattered and fragmented and the per capita land holding of Uttarakhand farmers is 0.2 ha, and about 36% of rural families live below the poverty line and agriculture contributes around 37% to state gross domestic production [9]. The Tehri district lies between 30^0 03′ and 30^0 53' North latitude and 77^0 56′ and 79^0 04′ East longitude having geographical area of 3,642 km^2 [10]. Geographical area of the district is 3642 km^2, of which forest area is 3221.56 km^2 [11]. Tehri district lies in the hilly areas of the state and agriculture is the major occupation of its in habitants. Total population in the district is 616409, population density is 169 person/km^2 and the rate of increase in population is 2.37% per ten years [12]. The location map showing the details of the study area is presented in **Figure 1**. The land use pattern shows 2,236 km^2 areas under forest cover (including reserve forest, civil soyam forest, community land and community forest), 1142.42 km^2 under cultivation and the rest are wasteland, barren land, Pastureland and grooves and snow-covered mountains [13] with 58,569 ha area under cultivation, of which irrigated land in only 12.21% [11]. Average rainfall of this district is 1395 mm and means average temperature varies from1 14.8 ^{0}Cto 29.5^{0}c with average relative humidity of 60.5%. On the basis of different altitudes and agro-climatic zone [14], the district was divided into three zones *viz*. foot hill/subtropical zone is lower altitude (286–1200 m), middle altitude i.e. Sub temperate zone (1200–2000 m) and upper altitude *i.e* temperate zone (2000–2800 m) and above 2800 m area there are no habitation in the district therefore this area is not under study. Out of nine developmental blocks, six blocks representing three zones were selected for present study villages in Tehri district. The details of the villages studied are given in **Table 1**.

2.2 Description of Systems

Farmers practices mainly three agroforestry systems *viz*. agrisilvicultural system (trees and agriculture crops are growing in same pieceof land), agrihorticultural

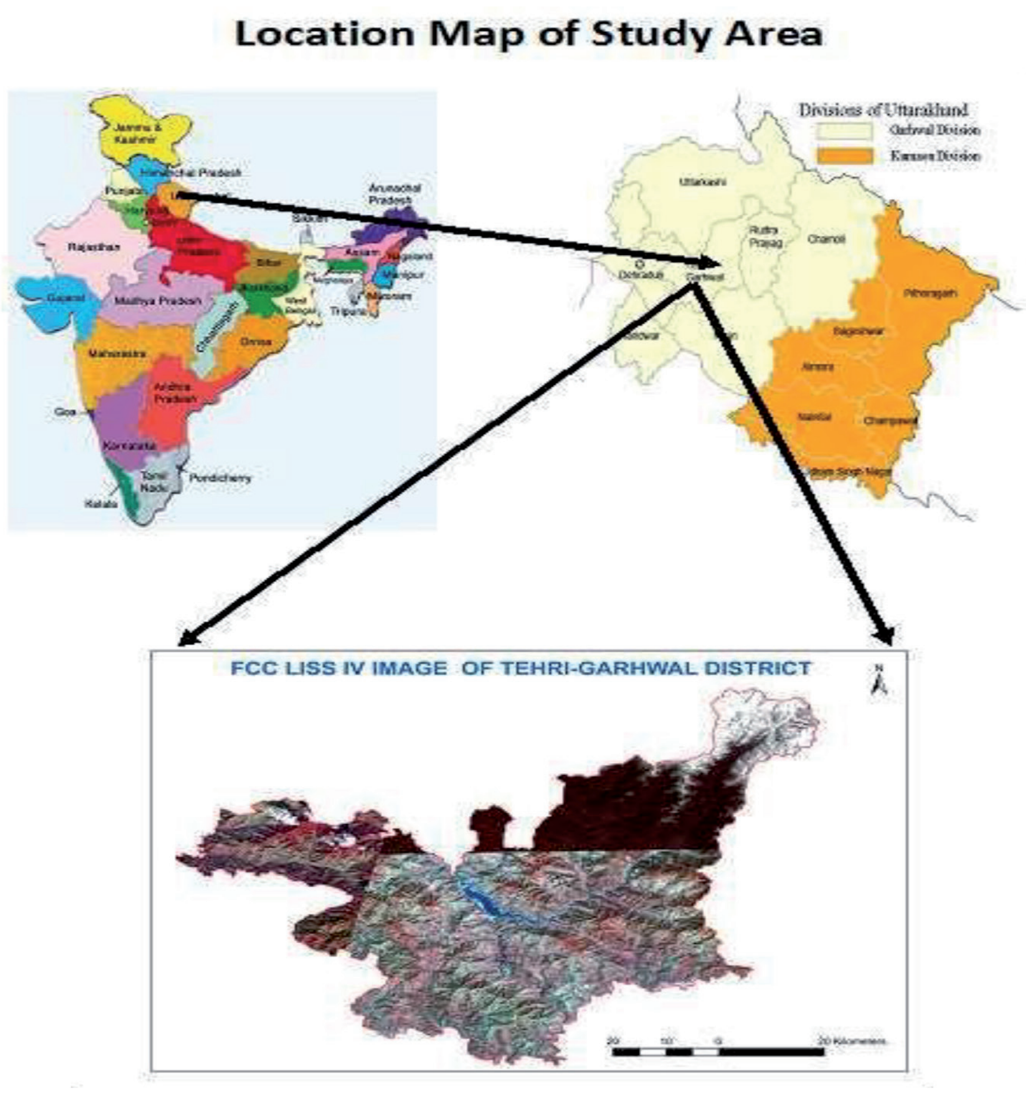

Figure 1.
Location map of study area.

Blocks	Altitudes (m)		
	Lower (286–1200 m)	**Middle (1200–2000 m)**	**Upper (2000–2800 m)**
Devprayag	Bagi, Grothikhanda, Palisen, Bachhendrikhal	Langur, Dungi	Juranaa
Kritinagar	Maikhandi, Jakhnand, Dhaulangi	Timal gaon, Dagar, Riskoti	No settlement area
Chamba	Kyari, Pali	Guldi, Purshal	Saud, Chopriyal gaon
Thauldhar	Dharwal, Jaspur	Indra, Sonara	No settlement area
Jakhnidhar	Raswari, Undoli	Manthal, Chah	No settlement area
Pratapnagar	Bausari	Kothaga, Kandakhal	Kualgarh, Banali

Table 1.
Study villages in Tehri district.

system (edible fruit trees and agriculture crops are growing in same Piece of land) and agrihortisilvicultural system (trees including edible fruit trees, forest trees and agricultural crops are growing in same Pieceof land) in the district. The characteristics of each system are as follows:

2.3 Agrisilviculture system (AS)

It is quite common throughout the district. This system is managed for the production of fuel, fodder, fibre and small timber trees with the agricultural corps. Agriculture crops such as wheat (*Triticum aestivum*), peas (*Pisum sativum*), potato (*Solanum tuberosum*), cauliflower (*Brassica oleracea*) and mustard (*Brassica compestris*) *etc*. during the winter season; and maize (*Zea mays*), tomato (*Lycopersicon esculentum*), pepper *(Pepper nigrum)* and french bean (*Phaseolus vulgaris*) *etc*. during the summer season are grown in monoculture or mixed cropping on the permanent terraces prepared across the hill slopes, while fodder, fuel and timber trees such as *Grewia oppostifolia, Celtis australis, Bauhinia variegata, B. purpuera, Albizia leeback etc.* are deliberately left or grown on the bunds of terraces.

2.4 Agrihorticulture system (AH)

This system is commonly practicedin those areas where fuel and fodder is easily available from other sources, and or size of the land holding is large. Agriculture crops mainly leafy and rhizomatous cropsare grown within space of horticulture trees such as *Mangifera indica* (Mango), *Citrus limon* (Nimbu), *Musa paradisica* (Kela), *Psidium guajava* (Amrud), *Mallus domestica* (Apple), *Prunus domestica* (Plum), *Prunus armeniaca* (Apricot), *Prunus persica* (Peach), *Prunus dulcis* (Almond) and *Pyrus communis* (Pear) *etc.*

2.5 Agrihortisilviculture system (AHS)

This system is managed for production of fruits, grains, fodder and fuelwood. Fruit trees are planted at regular space with in the fields, and fodder or small timber trees are left on the field bunds while the annuals are grown as intercrop. Species grown are same as that in the other two systems.

2.6 Plot selection & Forest Inventory

Ten sample plots of (100 m^2) size each were randomly laid out in each agroforestry system in each altitude. The shape of the plot is trapezoidal, with the short parallel to the contours at the top of the site. All three agroforestry system covered in each block on each altitude. The (100 m^2) size plot was used for tree (woody perennials) enumeration and 1x1m size plot was used for (annuals *i.e.* agricultural crop, grass and weeds). All trees falling in the plot (100 m^2) were enumerated. The DBH (diameter at breast height (i.e. 1.37 m) was measured with tree caliper and height with Haga altimeter.

2.7 Estimation of biomass

Bole volume was measured with bark using the following formula was given by (Presselar 1865) [15]:

$$\boldsymbol{V = f\ X\ h\ X\ g} \tag{1}$$

V = Volume
f = form factor
h = height
g = basal area
Form factor was calculated using formula as given in Eq. (2) (Pressler 1865; Bitterlich 1984) [15, 16] was used for calculating the form factor.

$$\boldsymbol{f = 2\, h_1 / 3h} \tag{2}$$

Where f = form factor
h_1 = is the height at which diameter is half of the diameter at breast height and
h = is the total height
Stem biomass was estimated by multiplying the stem volume with wood specific gravity [17] (IPCC 2006). The value of wood specific gravity of different agroforestry species in Garhwal Himalaya were used as reported by various authors (Kumar *et al.* 1989 [18]; Sheikh *et al.* 2011 [17]; Choudhry and Ghosh 1958 [19]; Rajput *et al.* 1985 [20]; Raturi *et al.* 2002 [21]; Purkashyatha 1982 [22] *etc.* was given in **Table 2**. For Branch biomass total number of branches irrespective of size were counted on each of the sample tree, then these branches were categorized on the basis of basal diameter into three groups viz. < 6 cm, 6-10 cm and > 10 cm. From each of sampled tree two branches from each group were randomly selected and were weighed for obtaining fresh weight. Sub samples of each component were oven dried to constant weight at 650 C. The following formula (Chidumaya 1990) [36] Eq. (3) was used to determine the dry weight of branches:

$$\boldsymbol{B_{dwi} = B_{fwi} / 1 + M_{cbdi}} \tag{3}$$

Where B_{dwi} - oven dry weight of branch, B_{fwi} - fresh/green weight of branches, M_{cbdi} - moisture content of branch on dryweight basis. Leaves from the sampled branches were also removed, weighed and oven dried separately to a constant weight at 65°C to determine leaf biomass Eq. (4) (Chidumaya 1990, [36]).

Sl. No	Species	Specific gravity	Source
1	*Quercus leucotrichophora*	0.826	Raturi et al. (2002) [21]
2	*Grewia oppositifolia*	0.606	Purkayastha (1982) [22]
3	*Melia azedirach*	0.491	Raturi et al. (2002) [21]
4	*Celtis australis*	0.444	Rajput et al. (1985) [20]
5	*Toona ciliata*	0.424	Raturi et al. (2002) [21]
6	*Adina cardifolia*	0.583	Raturi et al. (2002) [21]
7	*Mangifera indica*	0.588	Chowdhury and Ghose (1958) [19]
8	*Citrus limon*	0.91	Ting and Blair (1965) [23]
10	*Pyrus communis*	0.676	Tumen (2014) [24]
11	*Ficus roxburghii*	0.443	Sheikh et al. (2011) [17]
12	*Prunus cerasoides*	0.69	Kumar (1989) [18]
13	*Anogeissus latifolia*	0.757	Purkayastha (1982) [22]
14	*Psidium guajava*	0.59	Sheikh et al. (2011) [17]
15	*Morus alba*	0.603	Purkayastha (1982) [22]
16	*Citrus sinensis*	0.916	Joseph and Abdullahi (2016) [25]
17	*Juglanse regia*	0.59	Wani et al. (2014) [26]
18	*Bahunia verigata*	0.55	Kanawajia et al. (2013) [27]
19	*Ficus palmate*	0.578	Sheikh et al. (2011) [17]
20	*Malus domestica*	0.67	Miles and Smith (2009) [28]
21	*Prunus armenica*	0.50	Miles and Smith (2009) [28]
22	*Prunus persica*	0.90	Babu et al. (2014) [29]
23	*Myrica esculenta*	0.737	Sheikh et al. (2011) [17]
24	*Pyrus pashia*	0.70	Kumar (1989) [18]
25	*Ficus auriculata*	0.443	Sheikh et al. (2011) [17]
26	*Punica granatum*	0.99	Felter and Lloyd (1898) [30]
27	*Carica papaya*	0.918	Afolabi, I. S. and Ofobrukweta, K (2011) [31]
28	*Bombax ceiba*	0.33	Troup (1921) [32]
29	*Rhododendron arboreum*	0.512	Rajput et al.(1985) [20]
30	*Pinus roxburghii*	0.491	Rajput et al.(1985) [20]
31	*Embilica officenalis*	0.614	Sheikh et al. (2011) [17]
32	*Psidium guajava*	0.59	Kanawjia et al. (2013) [28]
33	*Celtis australis*	0.444	Rajput et al. (1985) [20]
34	*Albizia leeback*	0.69	Mani and Parthasarathy (2007) [33]
35.	*Rhus Parviflora*	0.620	Chowdhury and Ghose (1958) [19]
36.	*Wood fructicosa*	0.55	Chaturvedi et al. (2012) [34]
37	*Musa Paradisica*	0.29	Omotosa and Ogunsile (2010) [35]
38	*Acacia catechu*	0.825	Purkayastha (1982) [22]

Table 2.
Specific gravity of agroforestry species.

$$L_{dwi} = L_{fwi} \,/\, 1 + M_{cbdi} \tag{4}$$

Where L_{dwi} - oven dry weight of Leaves, L_{fwi} - fresh/green weight of Leaves, M_{cbdi} - moisture content of leaves on dry weight basis.

Total above ground biomass was the sum of stem biomass, branch biomass and leaves biomass [37]. Below ground biomass of tree was calculated by multiplying the aboveground biomass by a factor of 0.25 for broad-leaved species and 0.20 for coniferous species [38]. The biomass carbon of tree was estimated from the sum of above ground biomass and below ground biomass of tree.

Crop biomass was estimated using 1 m X 1 m quadrates by a destructive method. During 2015–2016, when the crops were at their peak biomass in March to April for *Rabi* (winter) and August to September for *Kharif* (summer) seasons. All the agricultural crops, grasses and weeds plants occurring within the border of the quadrats were harvested at ground level and sorted out and collected samples were weighted. Fresh weight was converted into dry weight on the basis of plant samples kept in the oven for drying at 80 °C for 24 hours. The crop biomass was converted into carbon by multiplying with a factor of 0.45 [39]. In annual crops, below ground biomass was estimated by multiplying with reference root: shoot ratio for each crop species [40]. Total biomass carbon stock of agroforestry system was the sum of total biomass carbon of trees and total biomass carbon of crops. The biomass carbon was estimated from total biomass by multiplying biomass with a factor of 0.45 [39].

2.8 Statistical analysis

The data was analyzed applying two-way analysis of variance (ANOVA) Wherever the effects exhibited significance $P \leq 0.0\ 5$ probabilities, all analysis was performed using GEN STATISTICS 32 version [41] (VSN International 2017).

3. Results and discussion

In the Himalayan region, a number of indigenous agroforestry systems have been known from Himachal Pradesh [42] (Atul and Khosla, 1990) and Uttarakhand [42] (Dadhwal *et al.,* 1989) out of which agrihortisilviculture system, agrisilviculture system and agrihorticulture system are very common and frequent. Dadhwal *et al.,* (1988) [42] and Toky *et al.,* (1989) [43] have recognized these three agroforestry systems with their multifarious benefits to the hill farmers. Existing agroforestry systems and its components in Tehri district has reported in Vikrant *et al*. 2015 [44]. In lower altitudes, the agroforestry system differed significantly in Above ground biomass, Below ground biomass (AGB), Total tree biomass (TTB), Total biomass (TB) and Total carbon (TC) ($P \leq 0.05$). In general, T0tal carbon were higher in agrihortisilviculture system (2.44 Mg ha^{-1}) followed by agrisilviculture system (1.60 Mg ha^{-1}) (**Table 3**). At middle altitudes, agroforestry system shows significantly difference in AGB, BGB TTB, TB and TC ($P > 0.05$). Total carbon storage were found maximum in agrihortisilviculture system (2.22 Mg ha^{-1}) followed by agrisilviculture system (1.53 Mg ha^{-1}) (**Table 4**). Agroforestry system differed significantly in AGB, BGB TTB, TB and TC ($P \leq 0.05$) at upper altitudes. Agrihorticulture system shows maximum (1.64 Mg ha^{-1}) carbon stock followed by agrisilviculture system (1.3 Mg ha^{-1}) (**Table 5**). Effect of interaction between altitudes and systems is depicted in **Table 6**. Crop biomass (CB)

Parameters	System			DF	Type III	Mean square	F	Pr > F
	AHS	AS	AH					
AGB	2.79	2.45	1.84	2	202.25	101.12	16.89	0.00
BGB	0.7	0.62	0.47	2	50.56	25.28	4.22	0.00
TTB	3.49	3.07	2.31	2	269.67	134.83	22.53	0.00
CB	1.95	0.37	0.28	2	5.04	2.52	29.97	0.00
TB	5.44	3.44	2.59	2	348.32	174.16	28.02	0.00
TC	2.44	1.60	1.16	2	15.41	7.7	8.24	0.00

Significance at the level of probability of 5% ($P < 0.05$).
AGB = Above ground biomass BGB = Below ground biomass CB = Crop biomass TB = Total biomass TTB = Total tree biomass TC = Total carbon.

Table 3.
Comparison among system for AGB, BGB, TTB, CB, TB and TC, in (Mg C ha^{-1}) along lower altitudes of Tehri district, Uttarakhand (n = 60).

Parameters	System			DF	Type III	Mean square	F	Pr > F
	AHS	AS	AH					
AGB	3.64	2.43	2.19	2	202.17	101.122	16.91	0.00
BGB	0.91	0.60	0.54	2	50.54	25.205	4.22	0.00
TTB	4.55	3.03	2.73	2	269.67	134.83	22.55	0.00
CB	0.39	0.37	0.56	2	5.049	2.524	9.97	0.00
TB	4.94	3.40	3.29	2	454.34	207.17	34.6	0.00
TC	2.22	1.53	1.48	2	204.45	93.22	15.57	0.00

Significance at the level of probability of 5% ($P < 0.05$).
AGB = above ground biomass BGB = below ground biomass CB = Crop biomass TB = Total biomass TTB = Total tree biomass TC = Total carbon.

Table 4.
Comparison among system for AGB, BGB, TTB, CB, TB and TC, in (Mg C ha^{-1}) along middle altitudes of Tehri district, Uttarakhand (n = 60).

Parameters	System			DF	Type III	Mean square	F	Pr > F
	AHS	AS	AH					
AGB	2.37	1.85	1.48	2	20.87	10.43	4.26	0
BGB	0.8	0.51	0.49	2	5.21	2.6	1.32	0
TTB	3.17	2.46	1.97	2	27.83	13.91	5.68	0
CB	0.46	0.42	0.42	2	0.03	0.01	0.13	0.87
TB	3.64	2.88	2.4	2	29.68	14.84	5.58	0
TBC	1.64	1.3	1.08	2	6.01	3.006	5.58	0

Significance at the level of probability of 5% ($P < 0.05$).
AGB = Above ground biomass BGB = Below ground biomass CB = Crop biomass TB = Total biomass TTB = Total tree biomass TC = Total carbon.

Table 5.
Comparison among system for AGB, BGB, TTB, CB, TB, and TC, in (Mg C ha^{-1}) along upper altitudes of Tehri district, Uttarakhand (n = 30).

are significant differences between altitudes and agroforestry sytem ($P \leq 0.05$), While CB showed nonsignificant difference with altitude andsystem.Biomass and carbon stock was found maximum in agrihortisilivculture system followed by agrisilivculture system and minimum in agrihorticulture system (**Tables 3–5**). It was observed that

Source	Stock	DF	Type III SS	Mean square	F	Pr > F
Altitude	AGB	2	136.54	68.27	19.35	0.00
	BGB	2	45.51	22.75	6.45	0.00
	TTB	2	182.066	91.033	25.817	0.000
	CB	2	0.451	0.226	2.696	0.069
	TB	2	198.887	99.443	27.047	0.000
	TC	2	40.275	20.137	27.047	0.000
System	AGB	2	88.26	44.13	12.51	0.00
	BGB	2	29.42	14.71	4.17	0.00
	TTB	2	117.697	58.848	16.689	0.000
	CB	2	0.451	0.226	2.696	0.069
	TB	2	165.417	82.708	22.495	0.000
	TC	2	33.497	16.788	22.495	0.000
System x Altitudes	AGB		12.66	3.16	0.89	0.00
	BGB		4.22	1.055	0.29	0.00
	TTB	4	16.887	4.222	1.197	0.312
	CB	4	2.321	0.580	6.934	0.000
	TB	4	25.577	6394	1.739	0.142
	TC	4	5.179	1.295	1.739	0.142

Significance at the level of probability of 5% ($P \leq 0.05$).
AGB = above ground biomass BGB = below ground biomass CB = Crop biomass TB = Total biomass TTB = Total tree biomass TC = Total carbon.

Table 6.
Analysis of variance for AGB, BGB TTB, CB, TB, and TC by altitudes, system and the interaction of both variables of Tehri district, Uttarakhand.

agrihortisilviculture system yields higher biomass carbon stock than other agroforestry systems across the altitudes may be due to adequate management of trees under agroforestry systems of the atmospheric carbon capture and stored in plant. It is indicated that as the biomass carbon was decreased with increasing altitudes across systems is m. The similar results are also reported by (Kaur *et al*. 2000 [45]; Maikhuri *et al.* 2000 [46]). Albert and Kandiji (2003) [8] reported that carbon variability in plant biomass can be high within complex systems and productivity depends on several factors including the age, structure and the management of the system. Among agroforestry systems, biomass carbon stock followed the order agrihortisilviculture>agrisilviculture> agrihorticulture. There was no significant difference between biomass carbon stock with altitudes and systems (**Table 2**). The main reasons for higher carbon density in tree based systems as exhibited by perennial components, is attributed to continuous accumulation of biomass in the woody component [47]. Moreover, from the agriculture fields and grasses almost all of the above ground biomass carbon stock is removed annually.

4. Carbon stock contribution by trees species in agroforestry across altitudes

Total thirty eight agroforestry trees species were observed in different agroforestry systems of the district. Out of thirty eight, *Grewia oppositifolia, Celtis australis*, *Melia azedirach*, *Quercus leucotrichophora*, *Ficus roxburghii*, *Myrica* *esculenta, Rhododendron arboretum, Citrus limon, Juglans regia* accumulated maximum biomass carbon stock in the district (**Figure 2**). **Figure 3** represents that among the dominant tree species *Quercus leucotrichophora* contributed maximum (15.11%) biomass carbon stock followed by *Ceitis australis* (6.94%), *Grewia oppositifolia* (6.45%) and rest of species contributes (49.34%). In the present study, *Quercus leucotrichophora* contributed maximum biomass then other tree species. Biomass in *Quercus leucotrichophora* was higher as reported by (Devi *et al.* 2013 [48]; Sharma *et al*. 2010 [49]) for lower Western Himalaya. *Grewia opposoitifoila* contributed maximum number of trees but biomass contribution was lower than *Quercus leucotrichophora,* may be due continous lopping of its branches for fuel and fodder during lean period by local people therefore stunting and bushy growth of *Grewia* was noticed in agroforestry field. Kumar *et al.* (2012) [50] reported that overexploitation of resources from traditional agroforestry trees reduce input biomass.

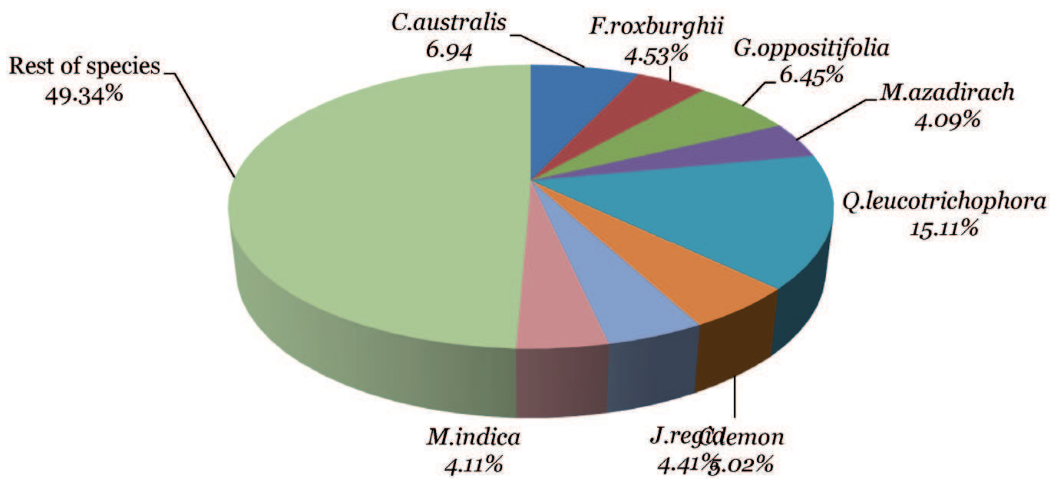

Figure 2.
Carbon stock contributed by trees species in agroforestry of Tehri district.

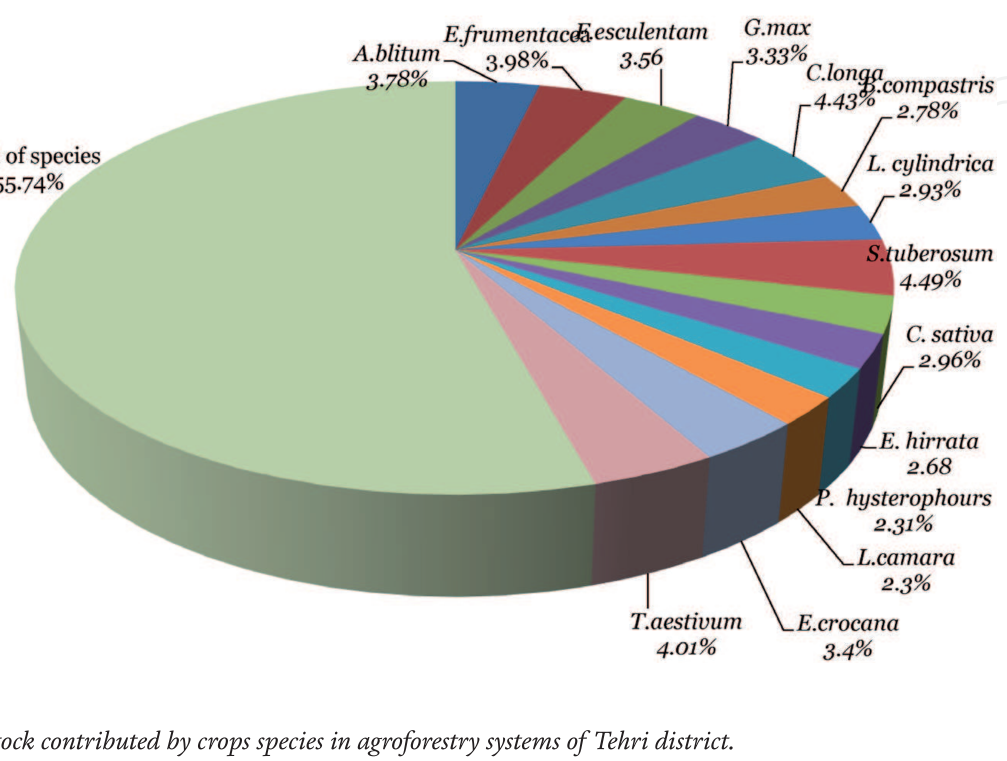

Figure 3.
Carbon stock contributed by crops species in agroforestry systems of Tehri district.

5. Carbon stock contribution by crop in agroforestry across altitudes

Forty crops species associated in agroforestry systems were observed in the district. Out of forty, maximum biomass carbon containing crop species are *Solanum tuberosum* (4.49%), *Curcuma longa* (4.43%), *Tetricum estivum* (4.01%),*Ehinochloa frumentacea* (3.98%), *Amarnathus blitum* (3.78%), *Fagopyrum esculenta* (3.56%), *Eleusine coracana* (3.4%)and *Glycine max* (3.33%) and rest of the species contributes (55.74%) biomass carbon stock (**Figure 3**). In the present study *Solanum tuberosum* contributed maximum biomass as compared to other crop species. It may be attributed that *Solanum tuberosum* had maximum leaf area and dry weight as compare to other crop species. Due to large leaf area, it is capable for absorption of maximum sunlight and has a maximum amount of CO_2 fixation [51, 52].

6. Conclusion

Agrihortisilviculture system had maximum biomass carbon stock at lower altitudes. Across the altitudes, farmers mostly adopted agrihortisilviculture system. Considering biomass and carbon stock, lower altitude (286–1200 m) subtropical zone have more potential for carbon sequestration in agroforestry. *Grewia oppositifoila*, *Quercus leucotrichophora* and *Celtis australis* were dominant agroforestry tree species which contributed more biomass carbon stock as compared to other species and are mostly adopted by the farmers in agroforestry. Therefore, these three species were considered suitable agroforestry tree species in the district. In agroforestry systems, particularly agrisilviculture and agrihortisilviculture land use systems are playing an important role in the carbon storage an Tehri district of Uttarakhand. Hence these systems need to be promoted further for economic and environmental security. Due to ban of green/live trees felling in the entire Indian Himalayan region, agroforestry systems can be a good source of earning significant carbon credit to thefarmers. Therefore understanding and implementation of carbon sequestration will help to maintain climate change mitigation from agroforestry.

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