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Biomass production and carbon stock potential of natural vegetation, agroforestry and cultivated land use systems along altitudinal gradient in north western Himalaya

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Abstract
The present study was undertaken in two altitudinal ranges 365-635 m and 636-914 m above mean sea level covering sub-montane, low hills and sub-tropical regions of Himachal Pradesh, India. The two altitudinal ranges were selected because of having common eight land use systems *viz.,* agriculture (T_1), horticulture (T_2), agrisilvicultural (T_3), silvopastoral (T_4), agrihorticulture (T_5), agrihortisilvicultural (T_6), forest (T_7) and grassland (T_8). The experiment was carried out to identify variation in different land use systems in terms of biomass production and carbon stock potentials. The maximum value of aboveground biomass (184.75 t ha^{-1}), belowground biomass (47.84 t ha^{-1}) and total biomass (232.59 t ha^{-1}) was recorded in forest land use system. All traits of biomass followed the order of $T_6>T_2>T_5>T_3>T_4>T_1>T_8$.. Among the agroforestry systems maximum aboveground (66.46 t ha^{-1}), belowground (20.84 t ha^{-1}) and total biomass (86.48 t ha^{-1}) were accumulated in agrihortisilviculture system. The values of above, below and total biomass showed declining trend with increase in altitude. Vegetation carbon density also decreased with increasing altitudinal range. Among agroforestry systems, maximum (90.10 t ha^{-1}) total carbon stock was observed in agrihortisilviculture, which was 2.45, 4.42, 10.67 and 44.80% higher than agrihorticulture, silvopastoral, agrisilviculture and agriculture land use system.

Keywords: Agroforestry, Altitude, Biomass, Carbon pool, Land use

Introduction
The role of forests (or trees) in carbon cycles is well recognized (Singh and Lal, 2000; Pala *et al.,* 2012) and forests area is considered as large sink of carbon (Dixon *et al.,* 1994; Wang *et al.,* 2001). There is considerable interest to increase the carbon storage capacity of terrestrial vegetation through land-use practices such as afforestation, reforestation, and natural regeneration of forests, grasslands, silvicultural and agroforestry systems (Brown, 1996; Ghosh and Mahanta, 2014; Chatuvedi *et al.*, 2016). Finding low-cost methods to sequester carbon is emerging as a major international policy goal in the context of increasing concerns about global climate change (Montagnini and Nair, 2004). Agroforestry has been recognized to be of special importance as a carbon sequestration strategy because of its applicability in agricultural lands as well as in reforestation programs (Cairns and Meganck 1994; Ruark *et al.,* 2003; Roy, 2016). Conceptually trees are considered to be a terrestrial carbon sink (Houghton *et al.,* 1998). Therefore, managed forests can, theoretically, sequester carbon both *in situ* (biomass and soil) and *ex-situ* (products). By including trees in agricultural production systems, agroforestry can, arguably, increase the amount of carbon stored in lands devoted to agriculture, while still allowing for the growing of food crops (Kursten, 2000).

In India, average sequestration potential in agroforestry has been estimated to be 25 t C per ha over 96 million ha (Sathaye and Ravindranath, 1998) but there is a considerable variation in different regions depending upon the biomass production. Several studies from forests of Indian Himalayan region (Shah *et al.,* 2014; Pala *et al.,* 2012; Iqbal *et al.,* 2014) and agroforestry (Rajput *et al.,* 2015; 2016) have been carried out in the recent past to explore the compatibility regarding carbon stock storage. In recent years, the farmers and field professionals of sub-montane and low hills, sub-tropical zone of Himachal Pradesh have developed various agroforestry systems integrating with timber, fodder, fruit trees and field crops and can store more carbon than monoculture land use. The main components of these land use systems are cereal crops, legumes, vegetable crops, fruit trees etc. The main forest tree species which dots the landscape of this agro-climatic zone are *Poplar, Eucalyptus, Grewia, Morus, Toona, Siris* and *Bamboos* etc. These agroforestry systems and other land use systems need to be tested for their carbon storage potential and environmental suitability in order to quantify the relative importance of these land use systems in today's contest. Therefore, the present study was undertaken in different land use systems of sub-montane and low hills, sub-tropical zone of Himachal Pradesh to estimate the biomass and carbon stocks in different land use systems.

Materials and Methods

Study area: The study was carried out (during 2015-2016) in agro-climatic zone of Himachal Pradesh, which was divided in two altitudinal ranges A_1 (365-635 m) and A_2 (636-914 m). The zone covers an area of 55,673 km^2 over six districts *viz.,* Kangra, Hamirpur, Una, Bilaspur, Solan and Sirmaur. The area is located between 32° 50' to 30° 22' North latitude and 76° 18' to 77° 47' East longitude and 365 to 914 m above sea level altitudinal range (Fig 1). For the selection of sites, three districts were randomly selected for sampling. Each district was further stratified in two altitudinal range (365-635 m) and (636-914 m). At each altitudinal range three sites were selected randomly on the basis of altitude and from each site three villages were selected for further sampling. In both altitudinal ranges A_1 and A_2 eight different land use systems viz., agriculture, horticulture, agrisilvicultural, silvopastoral, agrihorticulture, agrihortisilviculture, forest and grassland denoted by T_1, T_2, T_3, T_4, T_5, T_6, T_7 and T_8 were selected (Table 1).

The climate of study area varied within different altitudinal ranges. This zone was affected by all three extreme climatic conditions, high temperature in summers (18-35° C), very low in winter (5-21° C) and heavy rainfall in rainy season. The average annual rainfall varied from 1400-1800 mm and most of which was concentrated during July- August, receiving about 80 percent of total annual rainfall. There was a vast variation in vegetation type in zone first. In forest ecosystem (land use) and tree based land use systems had huge variation in vegetation; grasslands had only herbs and shrubs. Important flora constituted in this zone was *Acacia catechu*, *Grewia optiva, Pinus roxburghii, Shorea robusta, Toona ciliata, Dalergia sissoo in trees, common shrubs were Murraya koenigii, Pyrus pashia, Lantan camara, Artemisia vulgaris, Adhatoda vasica, Carrisa carandas* and common herbs were *Bidens pilosa, Xanthium strumar-ium, Cynodon dactylon, Cyperus rotundus, Chrysopogon montanus, Themeda anathera* etc.

***Above ground tree biomass*:** For measurement of above ground tree biomass in each land use system 0.1 ha plots (50 × 20 m^2) were laid down. The volume estimation of all the trees falling in the plot was enumerated. The diameter at breast height (dbh) was measured with calliper and height with Ravi's multimeter. Local volume equation developed for specific tree species and region were used for calculating the volume of the forest trees of the sample plot (FSI, 1996). Where volume equation was not available for the concerned species, the general volume equations were used for volume (FSI, 1996).The estimation of above ground biomass of woody trees was estimated by using expansion factors and specific gravity. The expansion factors for different species were available from previous literature (IPCC 2003; Rai *et al.,* 2000). Specific gravity was determined from the available literature (IPCC, 2003; Kaul and Sharma, 1983). Wherever the specific gravity values were not available in that case the stem cores were taken to find out specific gravity which was used further to determine the biomass of the stem using maximum moisture method (Smith, 1954).

Below ground biomass: Below ground biomass of trees was calculated by using the guidelines of IPCC (1996) and Cairns *et al.* (1997). Below ground biomass of trees were calculated by multiplying above ground biomass with a factor of root: shoot ratio of particular tree (Rajput *et al.,* 1985; Kumar, 1998). Below ground biomass = above ground biomass × root: shoot ratio

***Fruit tree biomass*:** For estimation of fruit tree biomass, we developed diameter-dry biomass based equations. For this purpose, we visited orchard fields from time to time, when they were uprooting their orchards during winter. For each fruit tree crop we selected 20 trees. Each selected tree was then sectioned into secondary branches and main stem. The diameter of basal portion (with tree calliper) and fresh weight of each branch was determined in the field with the help of balance. After estimating the dry biomass of the each secondary branch, we developed non-linear regression equation between diameter and dry biomass of the branches. This regression equation was then used to estimate the dry weight of secondary branches of the sample trees of the sample plot.

$$\text{Dry weight of the sample tree} = \text{Biomass of the main stem log} + \text{Cumulative weight of all the secondary branches}$$

Table 1. Tree-crop combinations and their distribution under land use systems of sub-montane and low hills, sub-tropical zone of Himachal Pradesh

Land use systems /elevation range	Code	Tree- crop combination	Plot size (m^2)	Net cropped area (ha^{-1})	Area under trees (ha^{-1})	Area under grass (ha^{-1})	No. of tree ha^{-1}
Agriculture	T_1	Maize-wheat, black gram-mustard					
365-635 m asl		Maize-wheat, paddy- wheat	50×20	1.00	-	-	-
636-914 m asl				1.00	-	-	-
Horticulture	T_2	Mango, kinnow					
365-635 m asl		Mango	50×20	-	1.00	-	160, 520
636-914 m asl				-	1.00	-	230
Agrisilviculture	T_3	Popular + toona + maize-barley, toona + sissoo + paddy- wheat					
365-635 m asl		Toon + morus + celtis + black gram-wheat, grewia +	50×20	0.60	0.40	-	450,180,70
636-914 m asl		sissoo + maize – pea	50×20	0.60	0.40	-	130, 20, 20, 150, 70
Silvopastoral	T_4	Eucalyptus, toona, morus+ natural grass					
365-635 m asl		Khair+sissoo+grewia+natural grass	50×20	-	0.30	0.70	160, 80,40
636-914 m asl			50×20	-	0.30	0.70	100, 110, 20
Agrihorticulture	T_5	Kinnow + tomato-wheat, kinnow + maize- mustard					
365-635 m asl		Mango + maize –wheat, mango + tomato-mustard	50×20	0.60	0.40	-	230
636-914 m asl			50×20	0.60	0.40	-	160
Agrihortisilviculture	T_6	Maize-wheat + kinnow + toona + popular, paddy- wheat + mango					
365-635 m asl		+ toona, black gram-onion + kinnow+toona	50×20	0.40	0.60	-	160,150,220,120
636-914 m asl		Paddy-wheat + mango + eucalyptus, maize-galic + mango +toon	50×20	0.40	0.60	-	80, 100, 80
Forest	T_7	*Shorea robusta, Albizia lebbeck, A. procera, Terminelia arjuna,*					
365-635 m asl		*D. sissoo, Toona ciliata, Acacia catechu, Leucaena leucocephala.*	50×20	-	1.00	-	330
636-914 m asl		*Pinus roxburghii + A. catechu*	50×20	-	1.00	-	400, 150
Grassland	T_8	Natural grass					
365-635 m asl		Natural grass	50×20	-	-	1.00	-
636-914 m asl			50×20	-	-	1.00	-

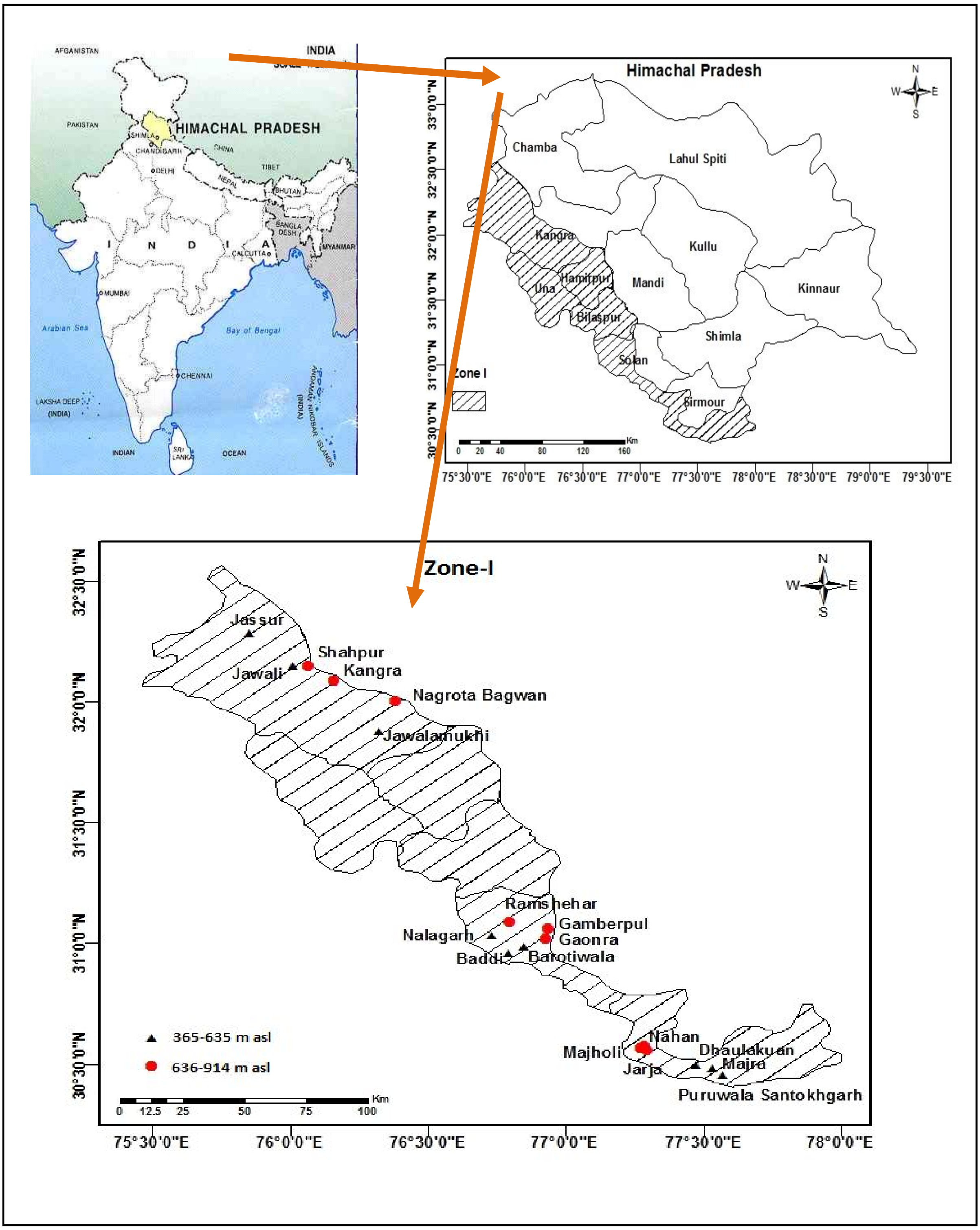

Fig 1. Study site in Himachal Pradesh, India

Fruit tree root biomass:
The uprooted fruit trees by the farmers during their orchard replacement time were used to develop the diameter-biomass equations on dry biomass. The same trees were used for the estimation of the fruit tree root biomass and shoot-root ratio. Five plots of 1 x 1 m^2 were used for estimation of crop biomass. All the crop biomass occurring within the borders of the quadrates were cut at ground level and collected samples were weighed, sub-sampled and oven dried at 65 $\pm$ 5 ^oC to a constant weight. The crop biomass was converted into carbon by multiplying with a factor of 0.5 (IPCC default value). Below ground biomass of crops and grasses was calculated by multiplying above ground biomass of crops/grasses with a factor of root: shoot ratio of particular crop/grass.

Below ground biomass = above ground biomass × root: shoot ratio

Litter and soil carbon stock: To quantify standing floor mass, standing floor litter were randomly collected at five points using a 1m x 1m quadrates size. The standing floor litter inside the quadrate was collected and oven dried at 60 °C to a constant weighed. The litter biomass was converted to carbon by multiplying a default value of 0.370 (Smith and Heath, 2001). Above and below ground carbon stock in vegetation was determined by vegetation biomass by multiplying with default value 0.5 (IPCC, 1996).

Carbon stock = biomass × 0.5 (IPCC default value)

Soil samples were also collected, air dried in shade, grinded with wooden pestle, passed through 2 mm sieve, and stored in cloth bags for further laboratory analysis. Organic carbon content was estimated following Walkley and Black (1934) method. Soil mass for a particular soil depth was then computed from the bulk density and soil C stock was calculated for that soil depth by multiplying soil mass with soil organic C-content (Nelson and Sommers, 1996).

***Statistical analysis*:** The data obtained were subjected to statistical analysis as per the procedure suggested by Gomez and Gomez (1984).

Results and Discussion

***Above ground, below ground and total tree biomass production*:** Trees play an important role in soil C sequestration (Takimoto *et al*., 2009); with an increase in the number of trees (high tree density) in a system, the overall biomass production per unit area of land will be higher, which in turn might promote more C storage in soils. In the interaction effect between land use systems and altitudinal range, the above ground biomass declined with the increasing altitudinal range from A_1 to A_2 except in grassland in the present study. However, this decline was significant in agrisilviculture and silvopastoral systems only. Maximum (184.75 t ha^{-1}) above ground biomass was found under forest land use system followed by agrihortisilviculture (66.46 t ha^{-1}), horticulture (62.99 t ha^{-1}), agrihorticulture (58.37 t ha^{-1}), agrisilviculture (45.01 t ha^{-1}), silvopastoral (34.49 t ha^{-1}), agriculture (17.09 t ha^{-1}) and grassland (2.43 t ha^{-1}), respectively. Agrihortisilviculture system had 3.88 times higher above ground biomass over agriculture system. Irrespective of land use systems, A_1 (63.33 t ha^{-1}) had significantly higher biomass than A_2 (54.57 t ha^{-1}) (Table 2). Higher biomass production at lower altitude might be due to higher density of tree species in the systems, local climatic factors, higher fertility status because of their proximity to plains, management practices and differences in species composition (Rajput *et al.,* 2015; 2016).

The maximum below ground biomass was found in forest (47.84 t ha^{-1}), which was significantly higher than other land use systems, and it was minimum in grassland (1.09 t ha^{-1}). Among agroforestry systems, maximum below ground biomass production (20.02 t ha^{-1}) was exhibited by agrihortisilviculture, and it was significantly higher than agrihorticulture (13.18 t ha^{-1}), agrisilviculture (12.47 t ha^{-1}) and silvopastoral (9.01t ha^{-1}) systems (Table 2). Agroforestry systems (AFS) produced 1.84 to 4.09 times higher below ground biomass than agriculture land use system. In fact, recent studies indicated higher soil C stock (amount of carbon stored in soil) under deeper soil profiles in AFS compared to treeless agricultural or pasture land systems under similar ecological settings (Haile *et al*., 2008; Nair *et al.,* 2009). In this connection, AFS are expected to have a great impact on the flux and long term storage of C in the terrestrial biosphere (Dixon, 1995) as the area of the world under AFS will hopefully increase substantially in the near future.

The maximum total biomass (232.59 t ha^{-1}) was accumulated in forest land use followed by agrihortisilviculture (86.48 t ha^{-1}), horticulture (74.25 t ha^{-1}), agrihorticulture (71.56 t ha^{-1}), agrisilviculture (57.48 t ha^{-1}), silvopastoral (43.51 t ha^{-1}), agriculture (21.98 t ha^{-1}) and grassland (3.52 t ha^{-1}) use systems (Table 2). The total tree biomass production declined at all land use

Table 2. Effect of land use systems, altitudinal gradient and their interaction on above ground, below ground, total and litter biomass production (t ha^{-1})

Land use system	Above ground biomass production			Below ground biomass production			Total biomass production			Litter biomass production		
	A_1 (365-635 m)	A_2 (636-914 m)	Mean	A_1 (365-635 m)	A_2 (636-914 m)	Mean	A_1 (365-635 m)	A_2 (636-914 m)	Mean	A_1 (365-635 m)	A_2 (636-914 m)	Mean
T_1 (Agriculture)	21.96	12.21	17.09	5.06	4.72	4.89	27.02	16.94	21.98	0.07	0.04	0.06
T_2 (Horticulture)	64.85	61.14	62.99	11.55	10.96	11.25	76.4	72.1	74.25	0.60	0.44	0.52
T_3 (Agrisilviculture)	53.29	36.73	45.01	13.47	11.47	12.47	66.76	48.2	57.48	0.49	0.35	0.42
T_4 (Silvopastoral)	45.04	23.94	34.49	11.3	6.73	9.01	56.35	30.67	43.51	0.32	0.25	0.28
T_5 (Agrihorticulture)	60.58	56.17	58.37	13.51	12.85	13.18	74.1	69.02	71.56	0.42	0.26	0.34
T_6 (Agrihortisilviculture)	70.91	62.01	66.46	21.21	18.83	20.02	92.12	80.84	86.48	0.34	0.33	0.34
T_7 (Forest)	188.05	181.45	184.8	56.77	38.92	47.84	244.82	220.37	232.59	2.64	1.11	1.87
T_8 (Grassland)	1.92	2.94	2.43	0.86	1.31	1.09	2.78	4.26	3.52	0.13	0.14	0.14
Mean	63.33	54.57		16.71	13.22		80.04	67.78		0.63	0.36	
	SEm±	CD (P<0.05)		SEm±	CD (P<0.05)		SEm±	CD (P<0.05)		SEm±	CD (P<0.05)	
T	2.31	6.70		0.55	1.59		2.84	8.24		0.046	0.133	
A	1.15	3.35		0.27	0.79		1.42	4.12		0.023	0.067	
T×A	3.27	9.48		0.77	2.25		4.01	11.66		0.065	0.189	

systems, except in grassland. The carbon sequestration potential of the vegetation component (above and belowground) also varied from 0.29 Mg ha-^{1} yr-^{1} in a fodder bank agroforestry system of West African Sahel to 15.21 Mg ha^{-1} yr^{-1} in mixed species stands of Puerto Rico (Nair *et al.,* 2009).

Litter biomass production: Maximum litter biomass (1.87 t ha^{-1}) was accumulated in forest, followed by horticulture (0.52 t ha^{-1}), agrisilviculture (0.42 t ha^{-1}), agrihortisilviculture (0.34 t ha^{-1}), agrihorticulture (0.34 t ha^{-1}), silvopastoral (0.28 t ha^{-1}) and grassland (0.14 t ha^{-1}), respectively. The minimum (0.06 t ha^{-1}) litter biomass was recorded in agriculture system (Table 2). The litter biomass declined significantly with increasing altitudinal range. Lower altitude (A_1) recorded 1.75 times higher litter biomass than higher altitude (A_2).The litter biomass production declined significantly with increase in altitude (from A_1 to A_2 altitude) in respect of land use systems viz., horticulture, agrisilviculture and forest.

Above ground, below ground and total biomass carbon stock: Forest land use system showed highest above ground biomass carbon stock (92.37 t ha^{-1}). The above ground biomass carbon stock in horticulture (31.50 t ha^{-1}) was statistically at par with agrihortisilviculture (33.23 t ha^{-1}) and agrihorticulture (29.19 t ha^{-1}) land use system (Table 3). The minimum above ground biomass carbon stock (1.21 t ha^{-1}) was observed in grassland system. Among the agroforestry systems, agrihortisilviculture recorded maximum (33.23 t ha^{-1}) above ground carbon stock and it was 12.61%, 32.27 %, 48.09% and 74.3% more than agrihorticulture, agrisilviculture, silvopastoral and agriculture. Significantly higher above ground carbon stock (31.66 t ha^{-1}) was found at lower (A_1) altitude than higher (A_2) (27.29 t ha^{-1}). The role of forests (or trees) in carbon cycles is well recognized (Singh and Lal, 2000) and forests are considered a large sink of carbon (Dixon *et al.,* 1994; Wang *et al.,* 2010). Now efforts are being made to increase the carbon storage capacity of terrestrial vegetation through land-use practices such as afforestation, reforestation, and natural regeneration of forests, silvicultural systems and agroforestry (Brown, 1996; Canadell and Raupach, 2008).

The maximum below ground carbon stock was observed at A_1T_7 treatment combination (28.38 t ha^{-1}), which differed significantly with other combinations. It was observed that the below ground carbon had no significant difference in respect of land use systems at both the altitudinal ranges, except in silvopastoral and forest land use

Table 3. Effect of land use systems, altitudinal gradient and their interaction on above ground, below ground and total vegetation carbon stock (t ha^{-1})

Land use system	Above ground carbon stock			Below ground carbon stock			Total vegetation carbon stock		
	A_1 (365-635 m)	A_2(636-914 m)	Mean	A_1 (365-635 m)	A_2(636-914 m)	Mean	A_1 (365-635 m)	A_2(636-914 m)	Mean
T_1 (Agriculture)	10.98	6.11	8.54	2.53	2.36	2.44	13.51	8.47	10.99 f
T_2 (Horticulture)	32.42	30.58	31.50	5.78	5.48	5.63	38.20	36.05	37.12 c
T_3 (Agrisilviculture)	26.65	18.37	22.51	6.73	5.74	6.23	33.38	24.10	28.74 d
T_4 (Silvopastoral)	22.52	11.97	17.25	5.65	3.36	4.51	28.17	15.34	21.75 e
T_5 (Agrihorticulture)	30.29	28.09	29.19	6.76	6.42	6.59	37.05	34.51	35.78 c
T_6 (Agrihortisilviculture)	35.45	31.01	33.23	10.60	9.41	10.01	46.06	40.42	43.24 b
T_7 (Forest)	94.03	90.72	92.37	28.38	19.46	23.92	122.41	110.18	116.30 a
T_8 (Grassland)	0.96	1.47	1.21	0.43	0.66	0.54	1.39	2.13	1.76 g
Mean	31.66	27.29		8.36	6.61		40.02	33.90	
	SEm±	CD (P<0.05)		SEm±	CD (P<0.05)		SEm±	CD (P<0.05)	
T	1.15	3.35		0.27	0.79		1.42	4.12	
A	0.57	1.67		0.13	0.40		0.71	2.06	
T×A	1.63	4.74		0.38	1.13		2.01	5.83	

systems. Maximum below ground carbon stock (23.92 t ha^{-1}) was observed in forest system followed by agrihortisilviculture (10.01 t ha^{-1}), agrihorticulture (6.59 t ha^{-1}), agrisilviculture (6.23 t ha^{-1}), horticulture (5.63 t ha^{-1}), silvopastoral (4.51 t ha^{-1}) and agriculture (2.44 t ha^{-1}), respectively (Table 3). Minimum value of below ground carbon stock (0.54 t ha^{-1}) was recorded in grassland system. Below ground carbon stock showed decreasing trend with increase in altitudinal range.The results were in agreement with the findings of Rajput *et al.* (2015), who reported that the biomass in forest ecosystem decreases with increasing altitude. Similar findings were also reported earlier by Minj (2008), where all categories of biomass *viz.*, aboveground, belowground and total biomass in different land use systems decreased with increase in altitude.

Maximum mean total carbon stock (116.30 t ha^{-1}) was observed in forest land use system followed by agrihortisilviculture (43.24 t ha^{-1}), horticulture (37.12 t ha^{-1}), agrihorticulture (35.78 t ha^{-1}), agrisilviculture (28.74 t ha^{-1}), silvopastoral (21.75 t ha^{-1}) and agriculture system (10.99 t ha^{-1}). Among agroforestry systems, agrihortisilviculture showed quite higher values of total biomass carbon stock than other systems and followed the trend of agrihortisilviculture > agrihorticulture > agrisilviculture > silvopastoral (Table 3). With respect to the effect of altitudinal gradient on total carbon stock, higher total carbon stock was also recorded in A_1 (44.00 t ha^{-1}) than A_2.

***Litter carbon density and soil carbon density*:** Litter carbon pool was found significantly higher under forest (0.69 t ha^{-1}) followed by horticulture (0.19 t ha^{-1}), agrisilviculture (0.15 t ha^{-1}), agrihorticulture (0.13 t ha^{-1}), agrihortisilviculture (0.12 t ha^{-1}), silvopastoral (0.10 t ha^{-1}), grassland (0.05 t ha^{-1}) and agriculture (0.02 t ha^{-1}), respectively. The litter carbon pool was found statistically at par in silvopastoral, horticulture and agrihortisilviculture. Irrespective of the land use systems, the litter carbon declined significantly with increasing altitudinal range. Maximum (80.44 t ha^{-1}) soil carbon density was observed in forest land use system followed by silvopastoral (64.25 t ha^{-1}), agrihorticulture (51.99 t ha^{-1}), grassland (39.48 t ha^{-1}) and agriculture (38.72 t ha^{-1}) (Table 3-4). The incorporation of trees or shrubs in agroforestry systems increased the amount of carbon sequestered when compared to a monoculture field of crop plants or pasture (Sharrow and Ismail, 2004; Kirby and Potvin, 2007).The above results indicated that biomass components *viz.,* above and belowground biomass and total biomass produced by particular land use system was influenced by the age of the components-annual or perennial, type of crop, structure of the system, nature and number of woody components, etc. Nayak (1996) observed that aboveground biomass was influenced by the plant species and their densities. Deshmukh (1998) reported that management practices also affected the biomass production of tree grown under different agroforestry systems.

Total ecosystem carbon density and vegetation carbon pool: Maximum (197.43 t ha^{-1}) total carbon density was recorded in forest land use system, which was significantly higher than all other land use systems. The land use systems of horticulture (96.38 t ha^{-1}), agrihortisilviculture (90.10 t ha^{-1}), agrihorticulture (87.89 t ha^{-1}), Silvopastoral (86.11 t ha^{-1}) and agrisilviculture (80.48 t ha^{-1}) remained statistically at par with one another (Table 4). Trees are known for their high potential for converting radiant energy into organic matter as compared to the annuals. Forest ecosystems store carbon in large, long-lived species and in species with dense wood (Bunker *et al.*, 2005). Agrihortisilviculture land management systems had several species with diverse growth habits, root systems, mineral requirements enabling optimum use of available space and resources (Huxley, 1983) and lesser intensity of weed as compared to other systems (Toky *et al.,* 1989). The variability in the productivity of agroforestry system as recorded in our study was in agreement with the observations of Albrecht and Kandji (2003).

Table 4. Carbon pool (t ha^{-1}) in different components of the system as influenced by average effect of land use system and altitudinal gradient

Treatment	Vegetation carbon pool	Litter carbon pool	Soil carbon pool	Total carbon pool
T_1 (Agriculture)	10.99	0.02	38.72	49.73
T_2 (Horticulture)	37.12	0.19	59.06	96.38
T_3 (Agrisilviculture)	28.74	0.15	51.58	80.48
T_4 (Silvopastoral)	21.75	0.10	64.25	86.11
T_5 (Agrihorticulture)	35.78	0.13	51.99	87.89
T_6 (Agrihortisilviculture)	43.24	0.12	46.74	90.10
T_7 (Forest)	116.29	0.69	80.44	197.43
T_8 (Grassland)	1.75	0.05	39.48	41.29
SEm±	1.42	0.017	5.469	5.805
CD (P<0.05)	4.12	0.049	15.872	16.846
Altitudinal range (A)				
A_1 (365-635 m a.s.l.)	40.02	0.23	48.86	122.73
A_2 (636-914 m a.s.l.)	33.90	0.13	59.21	129.26
SEm±	0.71	0.008	2.735	1.652
CD (P<0.05)	2.06	0.025	7.936	NS

Maximum vegetation carbon pool (116.29 t ha ^{1}) was observed in forest land use and minimum (1.42 t ha^{-1}) in grassland (Table 4). Carbon pool under agrihortisilviculture and horticulture systems was found to be statistically at par. Further it was observed that vegetation carbon declined with increasing altitudinal range. Biomass carbon (aboveground, belowground and total carbon) density was significantly influenced by altitudinal range. The lower altitude showed maximum vegetation carbon in all categories. It was approximately half of the vegetation biomass and also affected by the factors of the vegetation biomass. The higher values of these traits in this treatment combination might be ascribed to higher average age diameter of the tree component at this altitudinal range, nature of the functional component in question and intensity of management involved. Indeed, the average age of the timber trees was quiet higher than agricultural crop, fodder and fruit based land use systems. In addition to it, the biomass production and its removal was quiet high in field crops.

Conclusion

Different land use systems had significant influence on production of above, below and total biomass. All traits of biomass followed the order of T_6>T_2 >T_5 >T_3>T_4 >T_1>T_8. Whereas, among the agroforestry systems maximum aboveground (66.46 t ha^{-1}), belowground (20.84 t ha^{-1}) and total biomass (86.48 t ha^{-1}) was accumulated by agrihortisilviculture system followed by agrihorticulture, agrisilviculture and silvopastoral system, respectively. Agriculture land use showed 74.28, 75.57 and 74.58% lower aboveground, belowground and total biomass than the agrihortisilviculture system, respectively. The values of above, below and total biomass showed declining trend with increasing altitude. The altitudinal range also had significant influence on vegetation carbon density. The study, therefore, indicated that the forest land use system had higher (197.43 t ha^{-1}) carbon stock (vegetation + litter + soil) among all land use systems, but agrihortisilviculture system had higher carbon stock (90.10 t ha^{-1}) than agriculture and all other agroforestry systems. Hence, increase in tree cover seems to be a viable option for mitigation of carbon increase in atmosphere.

References

Albrecht, A and S.T. Kandji. 2003. Carbon sequestration in tropical agroforestry systems. *Agriculture, Ecosystem and Environment* 99: 15-27.

Brown, S. 1996. Present and potential roles of forests in the global climate change debate. *Unasylva* 185: 3-10.

Bunker, D. E., F. DeClerk., J. C. Bradford., R. K. Colwell., I. Perfecto., O. L. Philips., M. Sankaran and S. Naeem. 2005. Species loss and aboveground carbon storage in a tropical forest. *Science* 310: 1029-1031.

Cairns, M. A. and R. A. Meganck. 1994. Carbon sequestration, biological diversity, and sustainable development: integrated forest management. *Environ Management* 18: 13-22.

Cairns, M. A., S. Brown., E. N. Helmer and G. A. Baumgardener. 1997. Root biomass allocation in the world's upland forests. *Oecologia* 111: 1-11.

Canadell, J. G. and M. R. Raupach.2008. Managing forests for climate change mitigation. *Science* 320: 1456-1457.

Chaturvedi, O.P., A.K. Handa, R. Kaushal, S. Sarvade and P. Panwar. 2016. Biomass production and carbon sequestration through agroforestry. *Range Management and Agroforestry* 37: 116-127.

Deshmukh, H. K. 1998. Studies on the performance of wheat and soybean as intercrop with *Grewia optiva* pollarded at different heights. M.Sc. Thesis, Dr. Y.S. Parmar University of Horticulture and Forestry, Solan, India. pp. 1-90.

Dixon, R. K. 1995. Agroforestry systems: sources or sinks of greenhouse gases? *Agroforestry Systems* 31: 99-116.

Dixon, R. K., J. K. Winjum., K. J. Andrasko., J. J. Lee and P. E. Schroeder. 1994. Integrated systems: assessment of promising agroforest and alternative land-use practices to enhance carbon conservation and sequestration. *Climatic Change* 30: 1–23.

Dixon, R. K., S. Brown., R. A. Houghton., A. M. Solomon and M. C. Trexler. 1994. Carbon pools and fluxes of global forest ecosystems. *Science* 263: 185-190.

FSI. 1996. Volume equations for forests of India, Nepal and Bhutan. Forest Survey of India, Ministry of Environment and Forests, Government of India.

Ghosh, P.K. and S.K. Mahanta. 2014. Carbon sequestration in grassland systems. *Range Management and Agroforestry* 35: 173-181.

Gomez, K. A. and A. A. Gomez. 1984. *Statistical Procedure for Agriculture Research*. 2nd edn. Johan Willey and Sons, Inc. New York. pp. 1-680.

Haile, S. G., P. K. R. Nair, and V.D. Nair. 2008. Carbon storage of different soil-size fractions in Florida silvopastoral systems. *Journal of Environmental Quality* 37: 1789-1797.

Houghton, R. A., E. A. Davidson and G. M. Woodwell. 1998. Missing sinks, feedbacks and understanding the role of terrestrial ecosystems in the global carbon balance. *Global Biogeochemical Cycles* 12: 25-34.

Huxley, P. A. 1983. Phenology of tropical woody perennials and seasonal crop plants with reference to their management in agroforestry systems. In: P.A. Huxley (ed). *Plant Research and Agroforestry.* International Council for Research in Agroforestry, Nairobi, Kenya. pp. 503-526.

IPCC.1996. Impacts, adaptations and mitigation of climate: scientific-technical analyses. In: Contribution of the second assessment report of the Intergovernmental Panel on Climate Change. 1995. Cambridge University.

IPCC. 2003. Good practice guidance for land use, land-use change and forestry, IPCC National Greenhouse Gas Inventories Programme, Hayama, Japan. pp. 1-295.

Iqbal, K., J. A. Bhat., N. A Pala, A. Hussain and A. K. Negi. 2014. Carbon and biomass density of trees in Duggada area of Garhwal Himalaya, India. *Indian Forester* 140: 18-22

Kaul, O. N. and K. K. Sharma. 1983. Biomass production systems of poplars and willows in India. *Indian Forester* 109: 645-654.

Kirby, K. R and C. Potvin. 2007. Variation in carbon storage among tree species: implications for the management of a small scale carbon sink project. *Forest Ecology and Management* 246: 208-221.

Kumar S. 1998. Dimensional stabilization of wood factors influencing shrinkage-swelling behaviour. *Journal of Timber Development Association of India* 25: 31-44.

Kursten, E. 2000. Fuelwood production in agroforestry systems for sustainable land use and CO_2 mitigation. *Ecological Engineering* 16: S69–S72.

Minj, A. V. 2008. Carbon sequestration potential of agroforestry systems- an evaluation in low & mid hills of western Himalayas. Ph. D. Thesis, Dr. Y. S. Parmar University of Horticulture and Forestry, Solan, India. pp. 1-124.

Montagnini, F and P. K. R. Nair. 2004. Carbon sequestration: An underexploited environmental benefit of agroforestry systems. *Agroforestry Systems* 61: 281–295.

Nair, P. K. R., B. M. Kumar and V. D. Nair. 2009. Agroforestry as a strategy for carbon sequestration. *Journal of Plant Nutrition and Soil Science* 172: 10-23.

Nayak, B. K. 1996. Studies on biomass productivity and nutrient content in *Eucalyptus tereticornis, Leucaena leucocephala* and *Melia azedarach* under high density plantation. M. Sc. Thesis, Dr Y. S. Parmar University of Horticulture and Forestry, Solan, India. pp. 1-112.

Nelson, D.W. and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. In: A.L. Page (ed). *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*. Agronomy Series 9. American Society of Agronomy, Madison, WI. pp. 961-1010.

Pala, N. A., A. K. Negi., K. K. Vikrant., Y. Gokhale., S. Aziem and N. P. Todaria. 2012. Carbon stock estimation in tree species of Sem Mukhem sacred forest in Garhwal Himalaya. *Journal of Forestry Research.* DOI-10.1007/s11676-013-0341-1

Rai, P., K. R. Solanki and U. P. Singh. 2000. Survival, growth and production of multipurpose trees under silvipastoral system. *Annals of Forestry* 8: 279-281.

Rajput, B. S., D. R Bhardwaj and N. A. Pala. 2015. Carbon dioxide mitigation potential and carbon density of different land use systems along an altitudinal gradient in north-western Himalayas. *Agroforestry System.* DOI 10.1007/s10457-015-9788-8 Springer.

Rajput, B. S., D. R. Bhardwaj and N. A. Pala. 2016. Factors influencing biomass and carbon storage potential of different land use systems along an elevational gradient in temperate northwestern Himalaya. *Agroforestry System.* DOI 10.1007/s10457-016-9948-5

Rajput, S. S., N. K. Shukla and V. K. Gupta. 1985. Specific gravity of Indian timbers. *Journal of Timber Development Association of India* 3: 12-41.

Roy, M.M. 2016. Agroforestry on dry and degraded lands: present status and future prospects. *Range Management and Agroforestry* 37: 1-11.

Ruark, G. A., M. M. Schoeneberger and P. K. R. Nair. 2003. Agroforestry–helping to achieve sustainable forest management. *In: Proceedings of UNFF (United Nations Forum for Forests) Intercessional Experts Meeting on 'Role of Planted Forests in Sustainable Forest Management'*, March 24-30, 2003, New Zealand. www.maf.govt.nz/unff-planted-forestry-meeting.

Sathaye, J. A. and N. H. Ravindranath. 1998. Climate change mitigation in the energy and forestry sectors of developing countries. *Annul Review of Energy and Environment* 23: 387–437.

Shah, S., D. P. Sharma, P. Tripathi and N. A. Pala. 2014. Carbon partitioning in subtropical *Pinus roxburghii* sergant, forest Solan, India. *Journal of Tropical Forest Science* 26: 355-361.

Sharrow, S. H. and S. Ismail. 2004. Carbon and nitrogen storage in agroforests, tree plantation and pastures in western Oregon, USA. *Agroforestry Systems* 60: 123-130.

Singh, R and M. Lal. 2000. Sustainable forestry in India for carbon mitigation. *Current Science* 78: 563-567.

Smith, D. M. 1954. Maximum moisture content method for determining specific gravity of small wood samples.*U.S. Forest Products Laboratory Report.* 8 pp.

Smith, J. E. and L. S. Heath. 2001. Identifying influences on model uncertainty: an application using a forest carbon budget model. *Environmental Management* 27: 253-267.

Takimoto, A., V.D. Nair and P.K.R. Nair. 2009. Contribution of trees to soil carbon sequestration under agroforestry systems in the West African Sahel. *Agroforestry Systems* 76: 11-25.

Toky, O. P., P. Kumar and P. K. Khosla. 1989. Structure and function of traditional agroforestry systems in the Western Himalayan. I. Biomass and productivity. *Agroforestry Systems* 9:47-70.

Walkley, A. and I. A. Black. 1934. An examination of the degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. *Soil Science* 63: 251-263.

Wang X., Z. Feng and Z. Ouyang. 2001. The impact of human disturbance on vegetative carbon storage in forest ecosystems in China. *Forest Ecology and Management* 148: 117-123.