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Aboveground Carbon Sequestration Potential of Agroforestry Systems of Western Himalaya

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ABSTRACT

Agroforestry landuse systems have been perceived as a potential carbon sinks and can contribute substantially to mitigate the global climate change hence the study involving five agroforestry systems viz. horti-pastoral (HP), silvi-pastoral (SP), agri-horticulture (AH), agri-silviculture (AS), agri-horti-silviculture (AHS) and one natural grassland (NG) system of Western Himalaya were undertaken at Nauni (30^{0} 51' N and 76^{0} 11'E), Solan (H.P.). The region represents sub-humid sub-tropical to sub temperate climate with an altitude of 1250 m amsl. The experiment was laid in split plot design. Each landuse system was replicated thrice. Existing carbon stocks and relative carbon sequestration potential of six landuse systems were evaluated. Different land use systems had significant variation in their total biomass production levels over natural grassland. The SP system produced the highest biomass whereas minimum in NG. the AHS system produced the second highest biomass among the different systems despite having less number of trees. The total carbon stocks (Plant + soil) revealed the superiority of SP system followed by AHS system with their respective value of 101.69 and 54.31 t ha^{-1}.The finding evinced that silvi-pastoral system can be a better option for carbon sequestration in general. However, in arable lands, agri-horti-silviculture system shall be a better system for this purpose.

Keywords:

Bulk density, carbon stocks, Himalaya, landuse systems,soil

INTRODUCTION

Climate change is a complex alteration of climate, subtle and continuous, yet extremely important through its consequences on vegetation of various types that thrived under constant or relatively unchanged climates (IPCC 2001). Over the past few decades, acceleration in the human-induced changes in the climate of the earth has become the focus of scientific and social scrutiny. Scientific evidences suggest that increased atmospheric CO_2 could have some positive effect such as improved plant productivity (Idso and Kimball 2001; Keutgen and Chan 2001). However negative changes in the global climate are often the most consequential processes associated with an increased concentration of CO_2 in the atmosphere

(Smith 1993; Dixon 1995, USDA NRCS 2000). Current terrestrial carbon is estimated at 2000±500 Pg, which represents 25 per cent of global carbon stocks (DOE 1999). The sink option of CO_2 mitigation is based on the assumption that this figure can be significantly increased if various biomes are judiciously managed and/or manipulated. Among these the carbon sequestration potential of three biomes viz., agricultural lands, biomass croplands and deserts have been estimated as 0.85-0.90, 0.50-0.80 and 0.80-1.30Pg year^{-1}, respectively, that might be sustained for a period of 25-50 years. The primary method to increase carbon sequestration in agricultural land biomes has been advocated as high level management whereas for biomass croplands as well as deserts and degraded lands, high level manipulation (DOE 1999). The carbon sequestration potential of tropical agroforestry systems is estimated between 12 and 228 Mg ha^{-1} with a mean value of 95 Mg ha^{-1}. Therefore bases on earth's area that is suitable for practices (585-1215×10^{6} ha), 1.1-2.2 Pg C could be stored in the terrestrial ecosystems over the next 50 years (Albrecht and Kandji2003). Removing atmospheric carbon and storing it in terrestrial biosphere is one of the options, which have been proposed to compensate greenhouse gas emission. Agricultural lands are believed to be a major potential sink and could absorb large quantities of carbon if trees are reintroduced to these systems and judiciously managed together with crops and/or animals. Thus the importance of agroforestry as a landuse system is receiving wide recognition not only in terms of agricultural sustainability but also in issues related to climate change or carbon sequestration. In India agroforestry is being promoted as an alternate landuse system to deal with the problems related to landuse sustainability and environmental amelioration. Numerous agroforestry systems both natural as well as planted developed in different agroclimatic regions of India have been found highly productive and environmentally suitable. North-West Himalayan region also have variety of land management practices and systems of agroforestry nature. Promising among these have been modified and planted in the farms of Dr. Y.S.Parmar University of Horticulture and Forestry. Therefore, present study was carried out over these systems with the objectives to determine existing biomass carbon stocks and to find out their relative carbon sequestration potential.

MATERIALS AND METHODS

The investigation was conducted at the Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh India. The site Nauni is located at 30^{0}51' N latitude and 76^{0}11' E longitudes, 15 Km south east of Solan at an elevation of 1250 m asl representing transitional zone between subtropical and sub-temperate region. The soils of the site were gravely sandy loam and classified as inceptisols and typic entrochrepts. Parent material was a mix of sand stone, conglomerate and dolomite. pH was about 7.0.

Experimental design and sampling

The experimental design consisted of six agroforestry system (Table 1). Each agroforestry systems were taken as one treatment. The experiment was laid in split plot design using six land use systems viz. natural grassland (NG), horti-pastoral (HP), silvi-pastoral (SP, agri-silviculture (AS), agri-horticulture (AH) and agri-horti-silviculture (AHS). Each agroforestry landuse system was replicated thrice. The data for biomass of tree, crop, grasses and surface litter was recorded following the standard procedures. The tree biomass was portioned into stem branch and leaf and recorded separately. For the crop and grass biomass 1mx1m quadrates were laid out and the crop plants and grasses occurring within the borders of the quadrates were cut at ground level and collected samples were weighed, sub sampled and oven dried at 65^{0}C temperature to a constant weight. The biomass was converted into carbon by multiplying with a factor of 0.45 (Woomer 1999).The data obtained were analyzed using split plot design by Gomez and Gomez (1984). Analysis was carried out on computer using the package "STATISTICS".

RESULTS AND DISCUSSION

Six agroforestry systems including natural grasslands studied have shown significant variations in their total biomass production levels.

The biomass produced has been apportioned among different above-and belowground parts for each component of a system.

Aboveground biomass

The data in table 2 shows the variations in biomass levels of stem, branch, leaf and whole tree for the woody perennial component as well as for crop, grass and litter. Stem biomass was highest in SP system followed by AHS. Agroforestry system types: AS and AH as well as AH and HP showed statistically non-significant biomass values between themselves. However, HP system produced the minimum stem biomass. Branch biomass was also significantly higher in SP system, but reflected a trend different to that of stem biomass among the different systems. Contrary to stem biomass the second highest value for branch biomass was shown by HP system, as in case of stem biomass AHS system showed the second highest value. Similar to stem and branch biomass, leaf biomass was also highest in SP system. It was followed by AHS. However, minimum amount of leaf biomass was in AH system.

Whole tree biomass was significantly higher in SP system with a value of 53.48 t ha^{-1}. It was followed by AHS, AS, HP and AH. Agroforestry systems namely AS, AH, and HP showed statistically alike biomass values. The AHS and AS did not show any statistically significant difference with each other. The stem, branch and leaf biomass of a tree depends upon the number of factors viz., growth habit of the tree species, soil on which it grows, age of the tree, its management and also its compatibility with the associated crop plant species. The highest stem, branch and leaf biomass obtained under SP system can be explained to the fact that in this system the tree species namely *Leucaena* and *Grewia* were planted at high density in mixture and were managed using pollarding techniques. Therefore more number of stems per hectare in SP system over the remaining systems resulted into higher stem, branch and leaf biomass. The second highest biomass value was obtained for AHS system integrating plum and mulberry as woody perennial which reflected the influence of system structure. The variation in crop and grass biomass can be explained due to the tree-crop interaction effects. The reduced biomass may be due to more competition for resources like nutrients, moisture and light compared to the tree species. The higher amount of surface litter may be due to

Variations in crop (wheat) biomass were statistically significant yet AH and AHS systems produced exactly equal amount (2.87 t ha^{-1}) of biomass. The variations in the crop biomass can be explained due to tree-crop interaction effectsGrass biomass was significantly higher in NG system than the biomass. It produced under agroforestry system types namely HP and SP. Litter biomass was significantly higher in SP system followed by NG and HP with their respective value of 3.34, 2.74 and 2.64 t ha^{-1}. AH system showed the minimum litter biomass (1.42 t ha^{-1}), which was statistically similar to the value shown by AHS. Similarly litter biomass levels were also statistically non-significant between AS and AHS.

The total aboveground biomass followed the trend almost similar to the stem biomass among the different systems. It was significantly higher in SP system followed by AHS, AS, HP and AH, with their respective values of 58.74, 21.93, 19.59, 17.22 and 16.70 t ha^{-1}. NG system produced the lowest value of 4.83 t ha^{-1}.

Belowground biomass

The belowground biomass observed as fine roots was highest in AHS followed by HP with their respective values of 1.04 and 1.03 t ha^{-1}, although statistically alike. The remaining systems also showed almost similar amounts of fine roots biomass, which were statistically non-significant with one another.Total above and belowground biomass was highest in SP system having a value of 59.72 t ha^{-1}. It was followed by AHS (22.97) and AS (20.53) whereas the minimum was observed under natural grasslands (5.79 t ha^{-1}). The results clearly quantify the influence of agroforestry system structure, land type and management on biomass production levels.

Carbon stocks in different agroforestry systems

Carbon in plant biomass obtained from a particular agroforestry system type through both

Table 1: Experimental details indicating specific tree-crop combination and their distribution.

Agroforestry system type	Code	Tree-crop combination	Plot size(*m)	Net cropped area(ha)	Area under trees (ha)	Area under grasses	No. of trees (ha^{-1})	Year of planting
Natural grass land	NG	Grass	50 x 10	_	_	1.0	_	_
Horti -Pastoral	HP	Plum + grass	50 x 10	_	_	_	286	1985
Silvi -Pastoral	SP	Leuceana + Grewia + Grass	50 x 10	_	0.2	0.8	2500 (1:1)*	1990
Agri - silviculture	AS	Grewia + Bauhinia + Wheat	50 x 10	0.9	0.1	_	400 (1:1)*	1990
Agri - horticulture	AH	Peach + Wheat	50 x 10	0.9	0.1	_	200	1990
Agri -horti- silviculture	AHS	Plum + Morus + wheat	50 x 10	0.9	0.1	_	332	1990

above and belowground components has been termed as current carbon stock of the system. The variability in carbon stocks, among the different systems has been described agroforestry system wise in both above and belowground components separately, while considering the variations in total i.e. whole system value.

Aboveground carbon stocks

The data presented in Table 3 shows the present carbon stocks in different plant part i.e. tree stem, branch, leaf and fine roots as well as whole tree and other components of a system like crop and grasses including litter. For different plants parts viz. tree stem, branch and leaf. SP system had the highest stem carbon, which was followed by AHS, AS, AH, and HP systems. All the systems showed significantly higher carbon stock values over HP (1.89 t ha^{-1}). The variation in stem carbon between AS and AH as well as AH and HP was however, non-significant between themselves. Branch carbon was significantly higher in SP system followed by HP, AS, AH and AHS with their respective values 9.33, 3.30, 2.92, 2.24 and 1.99 t ha^{-1}. The minimum value was under AHS system. Similar to branch carbon, leaf carbon was also highest in SP system (2.41 t ha^{-1}) which was followed by HP. The minimum value (0.46 t ha^{-1}) was under AH system, although statistically alike to HP, AS and AHS.

Whole tree carbon stocks were significantly higher in SP system with a value of 24.07 t ha^{-1}. It was followed by AHS, AS, HP and AH systems. Agroforestry system type namely AH showed the lowest value of 5.59 t ha^{-1} which was statistically similar to the carbon stock values shown by system types viz. HP, AS, and AHS. The respective values for later three systems were 5.88, 6.97 and 7.63 t ha^{-1}, respectively (Table 3).

Among the six agroforestry system types studied, crop (wheat) component was present in three arable landuse system viz. AS, AH, and AHS only. The carbon stocks varied significantly between these three landuse systems. AS system had significantly lowest value of 1.10 t ha^{-1}, whereas AH and AHS systems depicted the same value of 1.29 t ha^{-1}. The grass component was also present in the three agroforestry system types in non-arable lands only. All the three systems had significantly varied carbon stock values with respect to the minimum value. The maximum was in NG (0.94 t ha^{-1}) in HP system. Agroforestry system types NG and SP behaved statistically alike.

Litter carbon stock was significantly higher in SP system with its maximum value of 1.50 t ha^{-1} (Table 3). It was followed by NG and HP showing the values of 1.23 and 1.19 t ha^{-1}. Agroforestry system types NG and HP albeit were statistically similar but significantly lower than SP in their carbon stock

Table 2: Biomass production levels of different agroforestry system (t ha^{-1}).

System Component	Natural grassland (NG)	Horti pastoral (HP)	Silvi-pastoral (SP)	Agri-silviculture (AS)	Agri-horticulture (AH)	Agri-horti-silviculture (AHS)	CD 0.05
Above ground							
Stem	0	4.20	27.02	7.83	6.41	11.19	2.27
Branch	0	7.34	20.73	6.49	4.98	4.41	2.58
Leaf	0	1.51	5.36	1.51	1.03	1.79	1.21
Whole Tree	0	13.07	53.48	15.49	12.41	17.31	4.28
Crop	0	0	0	2.44	2.87	2.87	0.28
Grass	2.08	1.52	1.93	0	0	0	0.38
Litter	2.74	2.64	3.34	1.66	1.42	1.44	0.21
Total (a)	4.83	17.22	58.74	19.59	16.70	21.93	0.27
Below ground							
Fine roots (b)	0.97	1.03	0.98	0.94	0.93	1.04	NS
Grand Total (a+b)	5.79	18.25	59.72	20.53	17.63	22.97	4.22

Table 3: Carbon stocks in different agroforestry system (t ha^{-1}).

System Component	Natural grassland (NG)	Horti-pastoral (HP)	Silvi-pastoral (SP)	Agri-silviculture (AS)	Agri-horticulture (AH)	Agri-horti-silviculture (AHS)	CD 0.05
Above ground							
Stem	0	1.89	12.16	3.52	2.89	5.04	1.02
Branch	0	3.30	9.33	2.92	2.24	1.99	1.16
Leaf	0	0.68	2.41	0.68	0.46	0.81	0.55
Whole Tree	0	5.88	24.07	6.97	5.59	7.63	1.93
Crop	0	0	0	1.10	1.29	1.29	0.13
Grass	0.94	0.68	0.87	0	0	0	0.17
Litter	1.23	1.19	1.50	0.75	0.64	0.65	0.09
Total (a)	2.17	7.75	26.43	8.82	7.52	9.87	1.92
Below ground							
Fine roots (b)	0.44	0.46	0.44	0.42	0.42	0.47	NS
Grand Total (a+b)	2.61	8.21	26.87	9.24	7.93	10.34	1.90

values. The remaining three system types viz. AS, AH and AHS compared to NG, HP, and SP showed lower carbon stock values. The carbon stock values for former three systems were 0.75, 0.64 and 0.65 t ha^{-1}, wherein the later two were statistically alike.

A perusal of the data on total carbon stocks for different system types (Table 3) further revealed highest carbon storage through SP system. It was 26.43 t ha^{-1}. This system stored about 12 times more carbon than NG and about 3.4 times of HP system. Similarly, carbon stored in SP system was about 3.00, 3.51 and 2.55 times higher over AS, AH and AHS systems, respectively. The variations in total current carbon stored in HP, AS and AH system showed statistically non-significant differences with one another. The minimum

Table 4: CO_2 mitigation levels of different agroforestry system (t ha^{-1}).

System Component	Natural grassland (NG)	Horti-pastoral (HP)	Silvi-pastoral (SP)	Agri-silviculture (AS)	Agri-horticulture (AH)	Agri-horti-silviculture (AHS)	$CD_{0.05}$
Above ground							
Stem	0	6.92	44.50	12.90	10.56	18.43	3.74
Branch	0	12.09	34.14	10.69	8.20	7.26	4.25
Leaf	0	2.49	8.83	2.49	1.70	2.95	1.99
Whole Tree	0	21.53	88.08	25.51	20.44	29.00	7.05
Crop	0	0	0	4.03	4.72	4.72	0.45
Grass	3.44	2.49	3.17	0	0	0	0.62
Litter	4.50	4.37	5.49	2.74	2.34	2.38	0.36
Total (a)	7.94	28.36	96.75	32.26	27.50	36.12	7.03
Below ground							
Fine roots (b)	1.60	1.68	1.62	1.55	1.54	1.71	NS
Grand Total (a+b)	9.54	30.06	98.36	33.81	29.04	37.83	6.95

Table 5: Relative* loss or gain in the system carbon stocks (t ha^{-1}) of different agroforestry systems.

Agroforestry systems	Relative loss or gain
Natural grassland (NG)	100.00 (±0.00)
Horti - pastoral (HP)	315.19 (+215.19)
Silvi - pastoral (SP)	1031.43 (+931.43)
Agrisilviculture (AS)	354.58 (+254.58)
Agrihorticulture (AH)	304.49 (+204.49)
Agrihortisilviculture (AHS)	396.71 (+296.71)

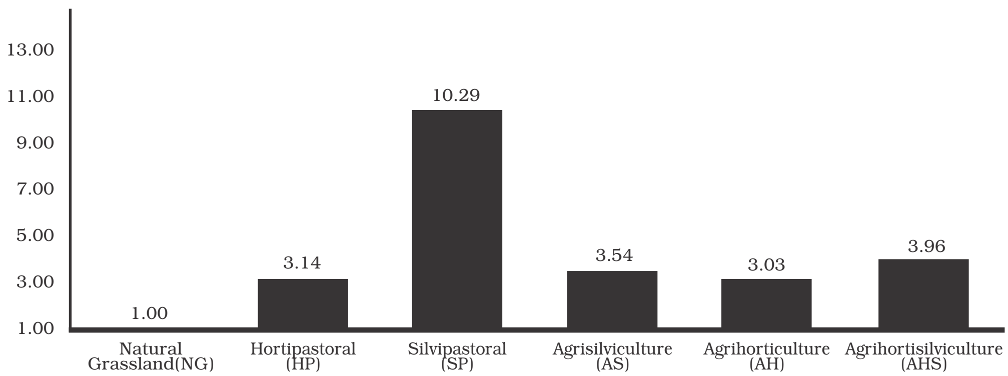

Fig .1. Relative Carbon Sequestration Potential of different agroforestry systems.

amount (2.17 t ha^{-1}) of carbon stored was in NG system, which was significantly lower than all the remaining systems total carbon.

Belowground carbon stocks

Data on carbon stored through fine roots referred to as below ground carbon stock of a systems (Table 3) revealed least and non-significant differences between the system types. The highest current carbon stored value was albeit, shown by AHS (0.47 t ha^{-1}) system and the lowest (0.42 t ha^{-1}) by both AH and AS systems.Further examination of the data for whole system carbon stocks depicted maximum value (26.87 t ha^{-1}) in SP system, which was significantly higher than the values obtained for remaining systems. NG system showed the lowest value of 2.61 t ha^{-1}. Carbon stored in system types viz. HP, AS and AH, having their respective values of 8.21, 9.24 and 7.93 t ha^{-1} showed statistically non-significant differences with one another and hence, were found statistically similar. System types AS and AHS were also statistically similar. It is deduced from the above discussion that variability in the carbon stocks of different agroforestry system depends primarily on its complexity. Albrecht and Kandji (2003) have also reported that carbon variability in plant biomass can be high within complex systems and productivity depends on several factors including the age, the structure and the management of the system. Similar findings of carbon storage were observed by the Beer et al.(1990), Kursten and Burschel (1993) and Jensen (1993).

CO_2Mitigation by agroforestry systems

The amount of CO_2mitigated by an agroforestry system depicted maximum value (98.36 t ha^{-1}) in SP system, which was significantly higher than the values obtained for remaining systems. NG system showed the lowest (9.54 t ha^{-1}) value. The system types viz. HP, AS, AH and AHS having their respective values of 30.06, 33.81, 29.04 and 37.83 t ha^{-1} showed statistically non significant differences with one another (Table 4). In India a number of studies have indicated that the tree component in agroforestry has a capacity for biomass production at least as great as that of natural vegetation. The results obtained are similar to as reported by Montagini and Nair 2004; Kaur et al. 2002; Puri and Swami 2001; Kaur et al. 2000; Maikhuriet al. 2000; Samara et al. 1999. With adequate management of trees under agroforestry systems a significant fraction of the atmospheric carbon could be captured and stored in plant biomass.

Relative Loss or gain in system

The net loss or gain in total carbon stocks of different agroforestry systems has been calculated over the actual value of NG system considering as 100 and presented in Table 5. It was observed from the figure that SP AHS AS HP and AH system had net gains in the total above ground carbon stocks with respect to NG. It indicates that agroforestry system involving woody perennial species either fruit or fodder or any other tree have higher potential to sequester the carbon. The finding also revealed that carbon stocks can be enhanced by integrating woody perennial species along with the annual or herbaceous component as shown by the study.

Relative Carbon sequestration potential

Therelative net gain and loss in total carbon stocks of different agroforestry systems were further used to find out the carbon sequestration potential (CSP) of each system taking the value of NG system as 1. The data thus obtained (Fig 1) have inferred that CSP of SP system was 10 times higher than the NG followed by AHS, AS and HP systems. The lowest was observed in case of AS system however it was also three times higher than the NG system. On the basis of Carbon Sequestration Potential different agroforestry systems showed the following descending order: Silvi-pastoral>agri-horti-silviculture>hortipastoral>agri-silviculture>agri-horticulture.

CONCLUSIONS

The study revealed that different landuse systems had significant variations in their total biomass production levels. Comparing the various landuse systems for their biomass production levels over natural grasslands, it was 3.15 times more in horti-pastoral , 10.31 times in silvipastoral, 3.55 times in agri-silviculture, 3.05 times in agri-horticulture and 3.97 times in agri-horti-silviculture systems. Thus silvi-pastoral system gave higher biomass over all the systems. agri-horti-silviculture systems produced the second highest biomass value among all the landuse systems. The whole system biomass carbon stocks depicted maximum value (26.87 t ha^{-1}) in SP system which was significantly higher than the remaining systems. The amount of CO_2 mitigated by an agroforestry landuse system depicted higher values in silvi-pastoral systems followed by agri-horti-silviculture, agri-silviculture, horti-pastoral and agri-horticulture. Natural grasslands showed the least amount of CO_2 mitigation.

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