Exploring the capability of Carbon Sequestration and Biomass generation in diverse Silvipastoral systems across Sindh range of forest division Ganderbal, India

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Abstract

The present investigation was carried out in Sindh range, Ganderbal forest division in of Kashmir Province to identify variation in different silvopastoral systems (T_1-*Cedrus deodara*, T_2- *Robinia pseudoacacia,* T_3- *Cupressus torulosa,* T_4- *Prunus arminiaca* , T_5- *Ailanthus altissima*, T_6- mixed plantations and T_7- grassland) in terms of biomass production and carbon stock potential. The maximum value of above ground tree biomass (80.57 t ha^{-1}), belowground tree biomass (20.14 t ha^{-1}) and total tree biomass (100.70 t ha^{-1}) was recorded in *Ailanthus altissima* stand and follows the trend $T_5>T_1>T_3>T_2>T_6>T_4$. In case of shrubs, the maximum value of aboveground, belowground and total shrub biomass (4.17 t ha^{-1}, 1.75 t ha^{-1} and 5.92 t ha^{-1}respectivey) was found in grassland and minimum values were found under *cedrus deodara* stand, as it contains only one shrub i.e. *Berberis lycium*. The highest aboveground herb biomass production (13.58 t ha^{-1}) was recorded under T_4- *Prunus arminiaca*, below ground biomass was recorded under grassland with a value of 3.24 t ha^{-1} and the total herb biomass production follows the trend $T_4>T_7>T_5>T_2>T_3>T_6>T_1$. The total vegetational carbon stock in terms of tons per hectare varied between 8.18 t ha^{-1} to 52.39 t ha^{-1} and follows trend: *Ailanthus altissima* (52.39 t ha^{-1}) > *Cedrus deodara* (45.13 t ha^{-1}) > *Cupressus torulosa* (30.44 t ha^{-1}) > *Robinia pseudoacacia* (22.77 t ha^{-1}) > *Prunus arminiaca* (13.90 t ha^{-1}) > T7- grassland (9.68 t ha^{-1}) > mixed stand (8.18 t ha^{-1}).

1. Introduction

Integrating trees, shrubs, and herbs in various ways presents a viable solution for counteracting grassland degradation processes (Nair et al., 2009). This approach enhances soil protection and fertility recovery by incorporating nitrogen-fixing legumes and taprooted trees that utilize deep soil layers, thus recycling nutrients (Alonso, 2011). The primary aim of silvopastoral systems is to enhance sustainable productivity, which hinges on biomass production and carbon storage within their components—trees, shrubs, and herbs (Chaturvedi et al., 2016). Research indicates that silvopastoral systems generally yield higher biomass production compared to monocultures. Moreover, these systems serve as carbon sinks, with aboveground biomass contributing significantly to total carbon stocks and nutrient reserves, making expanding plantation areas an effective means of mitigating global warming and reducing atmospheric carbon dioxide levels (Sharma et al., 2011). Notably, they not only directly store carbon in trees and soil but also mitigate greenhouse gas emissions resulting from deforestation and shifting agriculture. However, factors such as grass and tree species, woody tree density, spatial distribution, and management practices can influence biomass production and carbon sequestration in these systems (Shibu, 2009). Consequently, there is a need to assess the biomass production and carbon sequestration potential of various silvopastoral systems in the Sindh range of the Ganderbal forest division.

2. Materials and Methods

2.1. Study area: The study was carried out during 2019-20 in the Sindh range of forest division Ganderbal. The experimental site covers an area of 21807 hectares with 39 compartments. Geographically the site lies between 74º 42 to 75º 26 East longitude to 34º 28 North latitude with an altitude ranging from 1600m to 5200m above sea level within the central Circle of Kashmir Province. The study employed a stratified random sampling method, using quadrates measuring 10m x 10m for trees. These quadrants were further subdivided into 5m x 5m and 1m x 1m quadrants for shrubs and herbs, respectively. Mature, even-aged stands were chosen for assessing biomass and carbon sequestration potential, including Cedrus deodara, Robinia pseudoacacia, Cupressus torulosa, Prunus arminiaca, Ailanthus altissima, and a mixed stand comprising Cupressus torulosa, Robinia pseudoacacia, and Ailanthus altissima, along with a grassland area denoted as T1, T2, T3, T4, T5, T6, and T7, each with three quadrants per treatment, arranged in a randomized block design.

2.2. Aboveground tree biomass: For assessing the aboveground tree biomass within each stand, 10m x 10m quadrants were established. The volume of all trees within each quadrant was calculated using a specific formula.

Volume = Form factor × basal area × Height

F = $\frac{2\varvec{h}}{3\varvec{H}}$

Basal area = $\frac{\varvec{\pi}\varvec{d}^2}{4}$

d = diameter at breast height

h = height at which diameter is half of dbh

H = total height

F = form factor (Bitterlich, 1984)

The diameter at breast height was measured using a caliper, while tree height was measured using Ravi's multimeter. To estimate aboveground tree biomass, the volume was multiplied by a specific gravity value obtained from literature (Kaul and Sharma, 1983).Biomass = Volume × specific gravity

2.3. Below ground tree biomass: Below ground biomass for all species was determined by multiplying aboveground biomass with 0.25 (FAO, 1997).

2.4. Shrub biomass: For assessing shrub biomass, the 10m x 10m quadrants designated for trees were subdivided into 5m x 5m quadrants to specifically target shrubs. Representative samples from each category were chosen to ascertain the number of stems, branches, and leaves. These samples were carefully stored in paper bags and then subjected to drying in an oven at 70°C for 72 hours to determine their dry biomass. The total aboveground biomass was calculated by multiplying the number of stems in each category by their respective dry biomass. Belowground biomass of the shrub was determined by extracting the entire root system from the soil, washing the roots, and then drying them in an oven at 72°C for 42 hours to measure their dry weight.

2.5. Herb biomass: To evaluate herb biomass, the 5m×5m quadrants designated for shrubs were subdivided into 1m×1m quadrants specifically for herb assessment. Herb samples were collected and transported to the laboratory for a phytosociological study, where they were sorted by species and thoroughly washed with fresh running water. Subsequently, the samples were segregated into different paper bags. Afterward, the samples underwent drying in an oven at 80°C for 48 hours until reaching a constant weight. Each sample was then individually weighed to estimate its biomass, following the methodology outlined by Gupta and Dutt (2005).

2.6. Carbon stock under different silvopastoral systems: The calculation of aboveground carbon stock in trees involved multiplying the aboveground biomass by a carbon conversion factor of 0.5, as outlined by Koach (1989). Similarly, the belowground tree carbon stock was determined by multiplying the belowground biomass by a carbon conversion factor of 0.45, following the methodology established by Woomer (1999). Additionally, the carbon stock of understorey vegetation was assessed by multiplying the biomass by a carbon conversion factor of 0.45, also based on the research by Woomer (1999).

3. Result and discussion

3.1. Above ground, below ground and total tree, shrub and herb biomass production

The maximum tree biomass both above and below ground (80.57 t ha^{-1} and 20.14 t ha^{-1} respectively) was recorded in the *Ailanthus altissima* stand followed by *Cedrus deodara* stand (72.95 t ha^{-1} and 18.24 t ha^{-1} respectively), Whereas, minimum above and below ground tree biomass (3.66 t ha^{-1} and 0.92 t ha^{-1} respectively) was recorded in *Prunus arminiaca* stand (Table-1).. The total tree biomass follows the trend $T_5 > T_1 > T_3 > T_2 > T_6 > T_4$. Highest biomass of trees can be related to higher density and total basal area of trees (Sheikh and Kumar, 2010). In addition the higher biomass production can also be explained on the basis of height, age and number of trees ha^{-1} that varied between stands. These results are similar to the findings of Swamy et al. (2010); Uma et al. (2011) and Fonseca et al. (2012).

The maximum above and below ground shrub biomass (4.17 t ha^{-1} and 1.75 t ha^{-1} respectivey) was recorded in grassland (T_7) whereas, minimum above and belowground shrub biomass (0.31 t ha^{-1}and 0.25 t ha^{-1} respectively) was recorded in T_1- *Cedrus deodara* stand (Table-1) The total shrub biomass was also recorded maximum in T_7-Grassland (control) i.e. 5.92 t ha^{-1} and minimum in T_1-*Cedrus deodara* stand i.e. 0.56 t ha^{-1} (Table 1 and 3). In case of *Cedrus deodara* stand, only one shrub i.e. *Berberis lycium* was present. The presence of only one shrub might have resulted in minimum biomass in T_1. In case of herbs, the highest above ground biomass (13.58 t ha^{-1}) was recorded under T_4- *Prunus arminiaca* stand and below ground biomass was recorded under T_7- grassland with a value of 3.24 t ha^{-1} whereas, lowest above and below ground herb biomass (0.33 t ha^{-1} and 0.12 t ha^{-1}) was recorded under T_1-*Cedrus deodara* stand (Table-1). The total herb biomass followed the trend: T_4- *Prunus arminiaca* (16.73 t ha^{-1}) > T_7- grassland (15.61 t ha^{-1}) > T_5- *Ailanthus altissima* (4.84 t ha^{-1}) > T_2- *Robinia pseudoacacia* (3.51 t ha^{-1}) > T_3- *Cupressus torulosa* (3.25 t ha^{-1}) > T_6- mixed stand (2.63 t ha^{-1}) > T_1-*Cedrus deodara* (0.45 t ha^{-1}). These variations in biomass production can be owed to variation in the light interception, moisture regime and nutrient dynamics etc. In general, shrub and herb biomass were maximum under the stands which have got higher humus and organic content of soil and also low density of trees due to which the increased light interception might be responsible for increased biomass production (Anderson et al., 1968). In addition, the release of allelochemicals by trees might be responsible for inhibitory effects and low phytosociological attributes of herbs which in turn alters the under storey biomass. Allelopathy and interference of needle biomass to grass species under conifers have also been advocated by Dass (1995). Variation in the shrub and herb density has also been reported by Adhikari *et al.* (1995) and Zhu et al. (2010) for temperate ecosystem of Indian Himalayas and Chinese temperate region, respectively.

Table 1
Effect of different silvipastoral systems on above ground, below ground and total biomass production

Silvopastoral systems	Aboveground biomass production (t/ha)				Below ground biomass production (t/ha)				Total biomass production (t/ha) Aboveground + belowground			
	Tree	**shrub**	**herb**	**mean**	**Tree**	**Shrub**	**Herb**	**mean**	**Tree**	**Shrub**	**Herb**	**mean**
T_1 *Cedrus deodara*	72.95	0.31	0.33	**24.53**	18.24	0.25	0.12	**6.20**	91.19	0.56	0.45	**30.73**
T_2 *Robinia pseudoacacia*	32.54	1.94	2.61	**12.36**	8.14	0.86	0.90	**3.30**	40.68	2.80	3.51	**15.66**
T_3 *Cupressus torulosa*	45.07	1.93	2.57	**16.52**	11.27	1.11	0.68	**4.35**	56.34	3.04	3.25	**20.88**
T_4 *Prunus arminiaca*	3.66	3.16	13.58	**6.80**	0.92	1.95	3.14	**2.00**	4.58	5.12	16.73	**8.81**
T_5 *Ailanthus altissima*	80.57	1.21	3.78	**28.52**	20.14	0.69	1.06	**7.29**	100.7	1.90	4.84	**35.82**
T_6 Mixed stand	9.07	2.28	2.14	**4.49**	2.27	0.92	0.49	**1.23**	11.34	3.20	2.63	**5.72**
T_7 Grassland	-	4.17	12.37	**5.51**	-	1.75	3.24	**1.66**	-	5.92	15.61	**7.18**
mean	**34.84**	**2.14**	**5.34**		**8.71**	**1.08**	**1.38**		**43.55**	**3.22**	**6.72**	

Table 2
Carbon stock contribution by trees in seven silvipastoral systems

Silvopastoral systems	**Carbon stock**		
	Above ground (t/ha)	**Below ground (t/ha)**	**Total tree carbon stock (t/ha)**
T_1- *Cedrus deodara*	36.48	8.21	**44.68**
T_2- *Robinia pseudoacacia*	16.27	3.66	**19.93**
T_3- *Cupressus torulosa*	22.54	5.07	**27.61**
T_4- *Prunus arminiaca*	1.83	0.41	**2.24**
T_5- *Ailanthus altissima*	40.29	9.06	**49.35**
T_6- Mixed stand	4.54	1.02	**5.56**
T_7- Grassland (control)	-	-	**-**

Table 3
Total biomass and carbon stock contribution by shrubs in different silvopastoral systems

Shrub species	Treatments							Treatments						
	Total biomass (t/ha) (AGB + BGB)							Total carbon stock (t/ha) (AGC + BGC)						
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_1	T_2	T_3	T_4	T_5	T_6	T_7
Berberis aristata	-	-	1.50	0.24	-	-	0.72	-	-	0.68	0.11	-	-	0.32
Berberis lycium	0.56	0.71	0.66	0.85	1.17	0.16	1.24	0.25	0.32	0.30	0.38	0.53	0.07	0.56
Cotoneaster nummularius	-	-	0.25	0.09	-	-	0.47	-	-	0.11	0.04	-	-	0.21
Daphne mucronata	-	-	0.63	0.87	-	-	-	-	-	0.28	0.39	-	-	-
Indigofera heterantha	-	0.15	-	0.13	-	-	-	-	0.07	-	0.06	-	-	-
Parrotiopsis jacquemontiana	-	-	-	1.18	-	-	-	-	-	-	0.81	-	-	-
Rubus bramble	-	0.47	-	0.06	0.40	-	0.05	-	0.21	-	0.03	0.18	-	0.02
Rubus ellipticus	-	0.61	-	0.82	-	-	0.23	-	0.27	-	0.37	-	-	0.10
Rubus niveus		0.28	-	0.25	0.33	-	0.20		0.13	-	0.11	0.15	-	0.09
Spartium junceum	-	-	-	-	-	1.44	-	-	-	-	-	-	0.65	-
Spirea arcuata	-	0.26	-	-	-	-	-	-	0.12	-	-	-	-	-
Ziziphus jujuba	-	0.32	-	-	-	1.60	3.02	-	0.14	-	-	-	0.72	1.36
Total contribution	**0.56**	**2.80**	**3.04**	**5.12**	**1.90**	**3.20**	**5.92**	**0.25**	**1.26**	**1.37**	**2.30**	**0.86**	**1.44**	**2.66**

T_1-*Cedrus deodara;*T_2- *Robinia pseudoacacia;*T_3- *Cupressus torulosa;*T_4- *Prunus arminiaca;* T_5-*Ailanthus altissima;* T_6- mixed stand *(Cupressus torulosa, Robinia pseudoacacia, Ailanthus altissima);* T_7- grassland(control); '-' means absence; AGB = Aboveground biomass; BGB = Belowground biomass; AGC = Aboveground carbon; BGC = Belowground carbon

Table 4
Total biomass and carbon stock contribution by herbs in different silvopastoral systems

Herb species	Treatments							Treatments						
	Total biomass (t/ha) AGB + BGB							Carbon stock (t/ha) AGC + BGC						
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_1	T_2	T_3	T_4	T_5	T_6	T_7
Achillea millefolium	-	-	-	0.05	-	-	0.05	-	-	-	0.02	-	-	0.02
Agrimonia eupatoria	-	-	-	0.31	-	0.13	0.35	-	-	-	0.14	-	0.06	0.16
Amaranthus caudatus	-	-	-	1.35	-	-	1.58	-	-	-	0.61	-	-	0.71
Amaranthus viridis	-	0.56	-	0.53	-	-	0.69	-	0.25	-	0.24	-	-	0.31
Arctium lappa	-	-	-	5.49	2.20	-	-	-	-	-	2.47	0.99	-	-
Artemisia absinthium	-	-	-	0.16	-	-	0.22	-	-	-	0.07	-	-	0.10
Arnebia hispidissima	-	-	-	1.33	-	-	1.64	-	-	-	0.60	-	-	0.74
Asplenium species	0.06	0.012	-	0.07	-	-	-	0.03	0.05	-	0.03	-	-	-
Bothriochloa ischaemum	-	0.11	-	0.14	-	0.04	0.16	-	0.05	-	0.06	-	0.02	0.07
Centaurea iberica	-	0.12	0.46	-	0.37	-	0.86	-	0.05	0.21	-	0.17	-	0.39
Chenopodium album	-	-	0.59	-	0.61	-	1.13	-	-	0.27	-	0.27	-	0.51
Chenopodium axanthum	-	0.27	-	-	0.29	-	2.45	-	-	-	-	-	-	1.10
Cichorium intybus	-	-	-	0.49	-	0.14	0.69	-	-	-	0.22	-	0.06	0.31
Conyza canadensis	-	0.24	-	0.59	-	-	0.52	-	0.11	-	0.27	-	-	0.23
Cynodon dactylon	0.07	0.69	0.51	0.88	0.44	0.30	1.09	0.03	0.31	0.23	0.40	0.20	0.14	0.49
Cymbopogan nardus	-	-	-	-	-	-	0.06	-	-	-	-	-	-	0.03
Daucus carota	-	-	-	0.64	-	-	0.07	-	-	-	0.29	-	-	0.03
Fragaria nubicula	-	-	0.02	0.26	-	-	-	-	-	0.01	0.12	-	-	-
Frageria vesca	-	-	-	0.04	0.05	-	0.09	-	-	-	0.02	0.02	-	0.04
Lespedeza species	-	-	-	0.10	0.06	0.04	0.15	-	-	-	0.05	0.03	0.02	0.07
Lolium perenne	-	0.67	-	0.62	-	0.27	0.58	-	0.30	-	2.11	-	0.12	0.26

Herb species	Treatments							Treatments						
	Total biomass (t/ha) AGB + BGB							Carbon stock (t/ha) AGC + BGC						
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_1	T_2	T_3	T_4	T_5	T_6	T_7
Malva neglecta	-	-	-	0.04	-	-	0.04	-	-	-	0.02	-	-	0.02

Table 5
Effect of different silvopastoral systems on total vegetation biomass and carbon stock

Silvopastoral systems	Total vegetation biomass (t/ha)	Total vegetation carbon stock (t/ha)
	(trees + shrubs + herbs)	(trees + shrubs + herbs)
T_1 - *Cedrus deodara*	92.2	45.13
T_2- *Robinia pseudoacacia*	46.99	22.77
T_3- *Cupressus torulosa*	62.63	30.44
T_4- *Prunus arminiaca*	26.43	13.90
T_5- *Ailanthus altissima*	107.45	52.39
T_6- Mixed stand	17.17	8.18
T_7- Grassland	21.53	9.68
Mean	**53.48**	**26.07**

Tree, shrub and herb biomass carbon stock: The highest tree biomass carbon stock (49.35 t ha^{-1}) was found in *Ailanthus altissima* system whereas, the lowest (2.24 t ha^{-1}) was observed in *Prunus arminiaca* stand (Table-2). Considering the shrub component of different silvopastoral systems, the highest biomass carbon stock (2.66 t ha^{-1}) was recorded in grassland and lowest (0.25 t ha^{-1}) in *Cedrus deodara* stand (Table-3). In case of herbs, the highest carbon stock (9.36 t ha^{-1}) was observed in *Prunus arminiaca* stand and lowest (0.20 t ha^{-1}) in *Cedrus deodara* stand (Table-4). The total vegetation carbon stock in terms of tons per hectare varied between 8.18 to 52.39 and the following trend was observed: *Ailanthus altissima* (52.39 t ha^{-1}) > *Cedrus deodara* (45.13 t ha^{-1}) > *Cupressus torulosa* (30.44 t ha^{-1}) > *Robinia pseudoacacia* (22.77 t ha^{-1}) > *Prunus arminiaca* (13.90 t ha^{-1}) > T7- grassland (9.68 t ha^{-1}) > mixed stand (8.18 t ha^{-1}). The effect of different silvopastoral systems on the vegetation carbon stock was significant. Vegetation carbon stock range as reported in our case is more or less in line as reported by Sharma et al. (2010) and Singh et al. (1985) for adjoining central Himalayan forest ranges. The difference in carbon storage capacity of different stands depends upon nature and components of system.

Conclusion

Different silvopastoral systems had significant influence on production of above, below and total biomass. The total tree biomass follows the trend $T_5 > T_1 > T_3 > T_2 > T_6 > T_4$, shrub biomass follows the trend $T_7 > T_4 > T_6 > T_3 > T_2 > T_5 > T_1$ and the herb biomass follows the trend $T_4 > T_7 > T_5 > T_2 > T_3 > T_6 > T_1$.The total vegetation biomass and biomass carbon stock in terms of tons per hectare was found maximum (107 45 t/ha and 52.38 t/ha) in *Ailanthus altissima* based silvopastoral system, wheras, minimum vegetation biomass and carbon stock was found in grassland. This study indicates that carbon sequestration potential of different silvopastoral systems is higher than grassland and also the potential varies with tree species. Therefore increase in tree cover seems to be a viable option for mitigation of carbon increase in atmosphere.

Declarations

Author Contribution

Author 1 conducted this research under the guidance of 2 author and from author 3 to 4 helped author 1 in writing the paper

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