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Short communication

Biomass production and carbon sequestration potential of agroforestry systems in Sindh forest division of Kashmir, India

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Abstract

This study aimed to evaluate biomass production and carbon stock potentials of different silvipastoral systems (T_1: *Cedrus deodara*, T_2: *Robinia pseudoacacia*, T_3: *Cupressus torulosa*, T_4: *Prunus armeniaca*) in the Sindh forest division of Kashmir. The highest values 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}) were recorded in *Ailanthus altissima* stand and followed the trend of T_5>T_1>T_3>T_2>T_6>T_4. The highest values of aboveground, belowground and total shrub biomass (4.17 t ha^{-1}, 1.75 t ha^{-1} and 5.92 t ha^{-1}, respectively) were found in grassland and minimum under *Cedrus deodara* stand. The total herb biomass production followed the trend of T_4>T_7>T_5>T_2>T_3>T_6>T_1. The total vegetational carbon stock varied between 8.18 t ha^{-1} to 52.39 t ha^{-1} with a trend of T_5 (52.39 t ha^{-1}) > T_1 (45.13 t ha^{-1}) > T_3 (30.44 t ha^{-1}) >T_2 (22.77 t ha^{-1}) > T_4 (13.90t ha^{-1}) > T_7 (9.68 t ha^{-1}) > T_6 (8.18 t ha^{-1}).

Keywords: Biomass, Carbon stock, Ganderbal, Herbs, Shrubs, Silvipastoral systems, Trees

The Ganderbal forest division spans 37,901 hectares, with 21,507 hectares of commercial forests and 16,394 hectares of non-commercial areas. It comprises three main forest ranges Sindh (21,807 hectares), Manasbal (14,856 hectares), and Harran/Shalbugh (1,238 hectares). The study aims to analyze the diversity, biomass production, and carbon stock of various agroforestry systems within the Sindh range. Integrating trees, shrubs, and herbs effectively combats grassland degradation, enhances soil fertility, and boosts sustainable productivity (Nair *et al.*, 2009; Alonso, 2011; Chaturvedi *et al.*, 2016). Our study indicated that silvipastoral 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). Factors like plant species, tree density, and management practices influence biomass production and carbon sequestration (Shibu, 2009). Hence, evaluating the biomass production and carbon sequestration potential of various silvipastoral systems is crucial for their sustainable management in the Sindh range of Ganderbal forest division.

The study was carried out during 2017-2019 in the mature and even-aged stands aged >10 years of Sindh range of forest division Ganderbal for assessing biomass and carbon sequestration. Seven systems were selected for the study in which T_1: *Cedrus deodara*,T_2: *Robinia pseudoacacia*, T_3: *Cupressus torulosa*, T_4: *Prunus armeniaca*, T_5: *Ailanthus altissima*, and T_6: Mixed stand (comprising of *Cupressus torulosa, Robinia pseudoacacia*, and *Ailanthus altissima*) were compared with T7: Grassland (without trees) system. Monthly average temperature of district Ganderbal during 2017-2019 varied from hot summers to harsh winters. The study area has a temperate climate experiencing four distinct seasons: a severe winter (December to February), a cold spring (March to May), a mild summer (June to August) and a pleasant autumn (September to November). The site falls in a mid to high altitude characterized by hot summer and very cold winters. The average precipitation is 690-1150 mm most of which is received from December to April in the form of snow and rains. The climate is generally temperate type, winter is severe extending from December to

March. The region faces a wide temperature range from -8 °C in winter to maximum of 33 °C in summer. Winter frost is common and medium to heavy snowfall is also witnessed.

Soils were composed of mainly pale, drab coloured, thin bedded slate shale's and fine compacted earthy sandstones. The soils in lower zone are shallow in depth and poor in fertility, while soils in upper reaches are formed under coniferous vegetation, are rich in organic matter and show varying degree of metamorphism. The rocks of this formation are exposed near different sites of Ganderbal district like Rangil, Sonamarg, Naranag, Lar, Shuhama etc.

The vegetation analysis was carried out by stratified random sampling; random quadrates of 10 m × 10 m for trees and within each of these quadrates 5 m × 5 m for shrubs and 1 m × 1 m for herbaceous plants was laid down on all treatments. Indeed, samplings were carried out by stratified random sampling, where Site: 01; Treatments: 07; Quadrates: 03 numbers per treatment; Design: RBD. The volume of all trees within each quadrant was calculated using a specific formula, Volume = Form factor × Basal area × Height;

$$F = \frac{2h}{3H}; \text{ Basal area } = \frac{\pi d^2}{4}$$

where, 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 (dbh) was measured using a caliper, while tree height was measured using Ravi's multimeter; Finally, Biomass = Volume × specific gravity (Kaul and Sharma, 1983). Again below ground biomass for all species was determined by multiplying above ground biomass with 0.25 (FAO, 1997). Shrub 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 above ground biomass was calculated by multiplying the number of stems in each category by their respective dry biomass. Below ground 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.

Herb samples were collected 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. Each sample was then individually weighed to estimate its biomass, following the methodology of Gupta and Dutt (2005).

The calculation of above ground carbon stock in trees involved multiplying the above ground biomass by a carbon conversion factor of 0.5, as outlined by Kaoch (1989). Similarly, the below ground tree carbon stock was determined by multiplying the below ground biomass by a carbon conversion factor of 0.45, following the methodology established by Woomer (1999). Above and below ground carbon stock of understorey vegetation was assessed by multiplying the biomass by a carbon conversion factor of 0.45, also based on the methodology adopted by Woomer (1999).

The *Ailanthus altissima* stand (T_5) exhibited the highest tree biomass, both above (80.57 t ha^{-1}) and below ground (20.14 t ha^{-1}) followed by the *Cedrus deodara* stand with 72.95 t ha-1 above ground and 18.24 t ha^{-1} below ground (Table 1). Conversely *Prunus armeniaca* stand recorded

Table 1. Above ground and below ground biomass of plant community under different silvipastoral systems

Silvipastoral systems	Pooled AGB production (t/ha)				Pooled BGB production (t/ha)				Total vegetation biomass (t/ha) AGB + BGB
	Trees	Shrubs	Herbs	Mean	Trees	Shrubs	Herbs	Mean	(trees+ shrubs+herbs)
T_1	72.95	0.31	0.33	24.53	18.24	0.25	0.12	6.20	92.2
T_2	32.54	1.94	2.61	12.36	8.14	0.86	0.90	3.30	46.99
T_3	45.07	1.93	2.57	16.52	11.27	1.11	0.68	4.35	62.63
T_4	3.66	3.16	13.58	6.80	0.92	1.95	3.14	2.00	26.43
T_5	80.57	1.21	3.78	28.52	20.14	0.69	1.06	7.29	107.45
T_6	9.07	2.28	2.14	4.49	2.27	0.92	0.49	1.23	17.17
T_7	-	4.17	12.37	5.51	-	1.75	3.24	1.66	21.53
Mean	34.84	2.14	5.34	-	8.71	1.08	1.38	-	53.48
S E±	13.02	0.48	2.01	3.60	3.25	0.22	0.48	0.88	13.46
CD (P<0.05)	3.01	0.18	1.33	-	2.87	0.14	0.27	-	6.32

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); AGB: Above ground biomass; BGB: Below ground biomass

Table 2. Carbon stock contribution by trees in different agroforestry systems

Silvipastoral systems	Total carbon stock			
	Pooled above ground (t/ha)	**Pooled below ground (t/ha)**	**Pooled tree carbon stock (t/ha)**	**Total vegetation carbon stock (t/ha) (trees+ shrubs+herbs)**
T_1	36.48	8.21	44.68	45.13
T_2	16.27	3.66	19.93	22.77
T_3	22.54	5.07	27.61	30.44
T_4	1.83	0.41	2.24	13.90
T_5	40.29	9.06	49.35	52.39
T_6	4.54	1.02	5.56	8.18
T_7	-	-	-	9.68
Mean	20.32	4.57	24.90	26.07
S E ±	6.51	1.47	7.98	6.59
CD ($p < 0.05$)	2.21	1.09	3.38	4.13

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

Shrub species	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
Mean	0.28	0.40	0.76	0.50	0.63	1.07	0.85	0.13	0.18	0.34	0.26	0.29	0.48	0.38
S E ±	0.28	0.08	0.26	0.14	0.27	0.46	0.39	0.13	0.03	0.12	0.09	0.12	0.21	0.18
CD (P<0.05)	0.10	0.14	0.51	0.42	0.39	0.77	0.64	0.03	0.01	0.12	0.05	0.11	0.26	0.14

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: Above ground biomass; BGB: Below ground biomass; AGC: Above ground carbon; BGC: Below ground carbon

the lowest above and below ground biomass with values 3.66 t ha^{-1} and 0.92 t ha^{-1}, respectively. Indeed, the total tree biomass order was $T_5>T_1>T_3>T_2>T_6>T_4$ with higher biomass correlating with greater tree density and basal area (Sheikh and Kumar, 2010). Variations in biomass production were related to stand-specific factors such as height, age, and tree density (Swamy *et al*., 2010; Uma *et al*., 2011; Fonseca *et al.*, 2012). For shrubs, the grassland (T_7) displayed the highest above (4.17 t ha^{-1}) and below ground (1.75 t ha^{-1}) biomass, while *Cedrus deodara* stand (T_1) had the lowest above (0.31 t ha^{-1}) and below ground (0.25 t ha^{-1}) biomass (Table 1). Total shrub biomass was highest in T_7 (5.92 t ha^{-1}) and lowest in T_1 (0.56 t ha^{-1}). In *Cedrus deodara* stand, the presence of only one shrub species, *Berberis lycium*, likely contributed to the minimal biomass in T_1.

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

Herb species	Treatments Total biomass (t/ha) AGB+BGB							Treatments 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
Malva neglecta	-	-	-	0.04	-	-	0.04	-	-	-	0.02	-	-	0.02
Marrubium vulgare	-	-	0.04	0.05	-	-	-	-	-	0.02	0.02	-	-	-
Medicago minima	-	0.07	-	1.07	0.51	-	0.16	-	0.03	-	0.48	0.23	-	0.07
Oxalis acetosella	0.04	-	0.36	-	-	-	-	0.02	-	0.16	-	-	-	-
Oxalis corniculata	0.06	-	0.38	-	-	0.32	-	0.03	-	0.17	-	-	0.14	-
Plantago lanceolata	0.06	0.03	-	0.04	-	-	0.05	0.03	0.01	-	0.02	-	-	0.02
Plantago major	-	0.09	-	0.13	-	-	0.47	-	0.04	-	0.06	-	-	0.21
Poa annua	-	0.04	-	-	0.07	-	0.05	-	0.02	-	-	0.03	-	0.02
Poa bulbosa	-	0.06	-	-	0.04	-	0.07	-	0.03	-	-	0.02	-	0.03
Poa pretense	-	-	-	-	-	-	0.03	-	-	-	-	-	-	0.01
Rumex nepalensis	-	-	-	0.16	-	-	0.28	-	-	-	0.07	-	-	0.13
Salvia moorcroftiana	0.09	-	0.15	0.18	0.11	-	0.23	0.04	-	0.07	0.08	0.05	-	0.10
Setaria viridis	-	-	-	0.05	-	-	0.05	-	-	-	0.02	-	-	0.02
Solanum nigrum	-	-	-	0.24	-	-	-	-	-	-	0.11	-	-	-
Sorghum helpense	-	-	-	0.09	-	-	0.11	-	-	-	0.04	-	-	0.05
Stipa sibirica	0.03	0.37	0.74	0.44	-	1.39	0.33	0.01	0.17	0.33	0.20	-	0.63	0.15
Taraxicum officinale	-	-	-	0.21	-	-	0.22	-	-	-	0.09	-	-	0.10
Trifolium pratense	0.04	0.04	-	0.03	0.06	-	0.05	0.02	0.02	-	0.01	0.03	-	0.02
Trifolium repens	-	-	-	0.05	-	-	0.04	-	-	-	0.02	-	-	0.02

Urtica dioica	-	-	-	0.47	-	-	0.58	-	-	-	0.21	-	-	0.26
Viola odorata	-	-	-	0.36	-	-	0.39	-	-	-	0.16	-	-	0.18
Total contribution	0.45	3.51	3.25	16.73	4.84	2.63	15.61	0.20	1.58	1.46	9.36	2.18	1.18	7.02
Mean	0.06	0.22	0.36	0.50	0.40	0.33	0.44	0.03	0.10	0.16	0.28	0.19	0.15	0.20
S E ±	0.01	0.06	0.08	0.17	0.17	0.16	0.09	0.00	0.03	0.04	0.09	0.09	0.07	0.04
CD (P<0.05)	0.01	0.14	0.07	0.42	0.21	0.15	0.31	0.01	0.03	0.08	0.11	0.06	0.03	0.01

Similarly for herbs the highest above ground biomass (13.58 t ha^{-1}) was recorded under T_4-*Prunus armeniaca* and below ground biomass peaked under T_7-grassland (3.24 t ha^{-1}). The lowest above and below ground biomass was recorded in T_1-*Cedrus deodara* 0.33 t ha^{-1} and 0.12 t ha^{-1}, respectively.

The total herb biomass followed the trend of T_4- *Prunus armeniaca* (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}). Biomass variations could be attributed to factors like light interception, soil moisture, and nutrient dynamics. Shrub and herb biomass tended to be higher in stands with higher soil humus and organic content and lower tree density, possibly due to increased light interception (Anderson *et al.,* 1968). Allelopathy from trees and interference with needle biomass might also affect herb biomass (Dass, 1995). Shrub and herb density variations were also observed in similar ecosystems (Adhikari *et al.*, 1995; Zhu *et al.*, 2010).

The highest tree biomass carbon stock (49.35 t ha^{-1}) was recorded in T5-*Ailanthus altissima*, while the lowest (2.24 t ha^{-1}) was in *Prunus armeniaca* stand (Table 2). In shrubs, T7-grassland had the highest biomass carbon stock (2.66 t ha^{-1}) whereas T1-*Cedrus deodara* stand had the lowest (0.25 tha^{-1}; Table 3). Among herbs, the highest carbon stock (9.36 t ha^{-1}) was in T4-*Prunus armeniaca* stand and the lowest (0.20 t ha^{-1}) in T2-*Cedrus deodara* stand (Table 4). Total vegetation carbon stock ranged from 8.18 to 52.39 t ha^{-1}, with an order of $T_5 > T_1 > T_3 > T_2 > T_4 > T_7 > T_6$.

The influence of silvipastoral systems on vegetation carbon stock was significant, with reported ranges aligning with prior studies in adjacent central Himalayan forest ranges (Sharma *et al.*, 2010; Singh *et al.*, 1985). Carbon storage capacity variations across stands depended on system nature and components. Homegardens and block plantation agroforestry systems were reported to have higher carbon contents than other land uses in an agricultural landscape with higher net gains in carbon stocks (Chauhan *et al.,* 2019). While in other study, they found a mean of 55.69 Mg ha^{-1} (both TBC + SOC) in agrisilviculture systems. agroforestry systems are complex and heterogeneous and, the more the heterogeneity, the more efficiently the carbon is sequestered compared to simpler systems (Bandana *et al.,* 2013). Impact of different silvipastoral systems on understorey vegetation and soil properties was also reported earlier (Rather *et al.,* 2023).

Different silvipastoral systems had significant influence on production of above, below and total biomass. The total tree biomass followed the trend of $T_5>T_1>T_3>T_2>T_6>T_4$, shrub biomass followed the trend of $T_7> T_4>T_6>T_3>T_2>T_5>T_1$and the herb biomass followed the trend of $T_4> T_7>T_5>T_2>T_3>T_6>T_1$.The total vegetation biomass and biomass carbon stock in terms of tons per hectare was found maximum (107 45 t $ha^{-1}$and 52.38 t ha^{-1}) in *Ailanthus altissima* based silvipastoral system, whereas, minimum vegetation biomass and carbon stock was found in grassland. This study indicated that carbon sequestration potential of different silvipastoral systems was higher than grassland and also the potential varied with tree species. Therefore, increase in tree cover could be a viable option for mitigation of carbon increase in the atmosphere.

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