Biomass, productivity and carbon sequestration of *Tectona grandis* and *Gmelina arborea*-based silvipastoral system

Preeti Toppo[1], P. R. Oraon[1], Bijay Kumar Singh[2] and Abhay Kumar[1,*]

[1]Department of Silviculture and Agroforestry, College of Forestry, Birsa Agricultural University, Ranchi 834 006, India
[2]Forest Research Center for Eco-Rehabilitation, Prayagraj 211 002, India

This study was conducted in 2009 at Birsa Agricultural University, Ranchi, Jharkhand, India with *Tectona grandis* (teak), *Gmelina arborea* (gamhar) and forage crops such as Sudan grass (*Sorghum sudanense*) and Hybrid Napier grass (*Pennisetum glaucum* × *Pennisetum purpureum*) which were grown under silvipastoral system. Total biomass and total productivity potential of silvipastoral system were found highest with the combination of *Tectona grandis* and Hybrid Napier, i.e. 29.14 tonne ha^{-1} and 21.0 tonne ha^{-1} year^{-1} respectively, while minimum total biomass was found in sole Sudan grass (2.42 tonne ha^{-1}) and maximum total productivity in *T. grandis* (2.09 tonne ha^{-1} year^{-1}). The total carbon sequestration potential under silvipastoral system was maximum in T_1: teak and Hybrid Napier grass (88.64 tonne ha^{-1}) followed by T_3: gamhar + Hybrid Napier (84.72 tonne ha^{-1}), T_2: teak + Sudan grass (77.68 tonne ha^{-1}), and T_4: gamhar + Sudan grass (77.42 tonne ha^{-1}), while the minimum was found in T_{12}: (33.38 tonne ha^{-1}). Annual contribution of total litter production was 505.16 g m^{-2}. Leaf litter in the species accounted for 95.40% and wood (branches and twigs) contributed 4.49% to total litter. The highest litterfall of 156.30 g m^{-2} was recorded in February followed by 151.72 g m^{-2} in January, while the least litterfall of 4.83 g m^{-2} was recorded in August.

Keywords: Biomass, carbon sequestration, forage crop, productivity, silvipastoral system.

INDIA accounts for 15% of the world's total livestock population, but faces a net deficit of green fodder to the extent of 61.1%, dry fodder 21.9% and feeds 64% (ref. 1). To support such a huge livestock population and to fulfil its large forage needs, silvipastoral systems seems to be the most viable option besides meeting the diverse needs of fuel and timber, and the socio-economic requirements of the farmers. A silvipastoral system designed with the combination of suitable native and exotic grass/legume species with trees providing fodder would ensure year-round supply of quality fodder[2].

Jharkhand having only 2.4% land share of the total geographical area of India consists of both plateau and sub-plateau regions and accounts for 29.61% area under forest. The current scenario of agriculture is challenging due to problems such as rainfed condition, heavy but erratic rainfall, soil erosion, soil acidity, moisture deficiency due to poor water retention capacity and permeability of soil, low organic carbon and availability of nutrients, mainly phosphorus, resulting in low agricultural productivity.

Agroforestry is a sustainable land-use system involving a combination of trees, agricultural crops and/or animals on the same land management unit in some form of spatial arrangement or temporal sequence[3]. In agroforestry, the high productivity potential might be due to the availability of more resources, e.g. light, water, space and nutrients with improved soil fertility resulting from litterfall. Several studies in different parts of the country suggested that agroforestry is more profitable than agriculture or forestry alone for a given area of land[4]. Silvipasture, an agroforestry system that combines trees and livestock with forage crops has gained popularity in recent years as an environment-friendly alternative land use system that is also economically viable[5]. Silvipastoral system is specially designed to optimize the use of time, space and physical resources, by maximizing positive interactions (facilitation) and minimizing negative interactions (competition, allelopathy) among the components[6]. It also provides valuable leaf fodder during scarcity/lean periods[7,8].

The productivity of any vegetation system mainly depends on biomass production and carbon storage potential in different components like tree, crops, grasses, etc., which are affected by nature and age of the plants, and other climatic, edaphic, topographic and biotic factors. The productivity of stands is based on the height, diameter and total aboveground biomass, and is influenced by the association of different vegetation components, area coverage, age, site factors and growth characteristics[9]. However, the biomass and productivity estimates of tree species vary from place to place due to variation in climate, soil, temperature and rainfall[10].

The biomass produced and its storage rate in vegetation systems play an important role in quantifying the system output and determining the carbon sequestration rate for mitigating and adapting to climate change[11]. Silvipastoral system is one of the most promising land-use systems

*For correspondence. (e-mail: abhayzimi@gmail.com)

which can sequester carbon in soil and biomass better and help improve soil conditions. The most important benefit of the silvipastoral system is carbon sequestration or storing atmospheric carbon dioxide in the form of tree biomass, as added tree cover on pasturelands is expected to increase carbon storage[12].

Material and methods

The present study was conducted in the agroforestry research field situated in the main campus of Birsa Agricultural University, Kanke, Ranchi during 2017–18. The experimental design adopted was randomized block design (RBD) with 12 treatments and three replications – T_1: teak + Hybrid Napier, T_2: teak + Sudan grass, T_3: gamhar + Hybrid Napier, T_4: gamhar + Sudan grass, T_5: teak + gamhar + Hybrid Napier, T_6: teak + gamhar + Sudan grass, T_7: teak, T_8: gamhar, T_9: teak + gamhar, T_{10}: sole Hybrid Napier, T_{11}: sole Sudan grass, T_{12}: control.

Estimation of biomass

Biomass was estimated as follows:

- Girth at breast height (GBH): This was measured at 1.37 m height from the base of the tree using measuring tape.
- Diameter at breast height (DBH) was calculated as follows

$$\text{DBH} = \text{GBH}/3.14.$$

- Basal area (BA) of the tree was calculated using the formula given by Chaturvedi and Khanna[13]

$$\text{BA} = \pi d^2/4.$$

where d is the diameter.

- Volume: To calculate volume of the tree, basal area was multiplied by height of the tree.

$$\text{Volume (m}^3) = \text{Basal area (m}^2) \times \text{height (m)}.$$

- Specific gravity of wood

$$= \frac{\text{Oven dry weight of wood sample}}{\text{Green volume of wood sample}}.$$

- Aboveground biomass: To estimate this, volume was multiplied by the specific gravity of wood of the tree.

$$\text{Aboveground biomass (kg)} = \text{Volume (m}^3) \times \text{specific gravity}.$$

- Belowground biomass: This was estimated by multiplying the aboveground biomass with 0.26 (ref. 14).

$$\text{Belowground biomass (kg)} = \text{Aboveground biomass} \times 0.26$$

- Total biomass: This was estimated by adding biomass of all the components (belowground and aboveground).

$$\text{Total biomass} = \text{Aboveground biomass} + \text{belowground biomass}.$$

Estimation of productivity

$$P = B_2 - B_1,$$

where P is the productivity, B_1 the biomass of the first year and B_2 is the biomass of the second year.

Estimation of carbon stock in trees

The carbon storage for each tree was computed by multiplying biomass values with carbon concentration generally taken as 0.50 (default value in ref. 15). Else, the amount of carbon in a standing tree was calculated by dividing its biomass by 2, according to the guidelines given in Eggelston *et al.*[16] and expressed in tonne tree^{-1} and tonne ha^{-1}. Total carbon content (tonne ha^{-1}) was estimated by the same method[17–19].

$$\text{Carbon stock (tonne ha}^{-1}) = \text{total tree biomass (tonne ha}^{-1}) \times 0.50 \text{ (conversion factor)}.$$

Estimation of carbon stock in forage crops

Aboveground and belowground carbon stocks in herbs and shrub species were determined by multiplying their respective aboveground and belowground biomass values with the carbon conversion factor of 0.45 (refs 20, 21). Total carbon stock was determined by adding aboveground and belowground carbon.

$$\text{Carbon stock (tonne ha}^{-1}) = \text{Total forage crop biomass (tonne ha}^{-1}) \times 0.45.$$

Estimation of soil carbon stock

Soil has greater carbon storage capacity than vegetation and atmosphere[22], giving it a major role in global carbon sequestration[23]. The carbon stock in soil was calculated as follows[24,25].

$$\text{Soil carbon stock (Mg C ha}^{-1}) = \text{Bulk density (g cm}^{-3}) \times \text{soil sampling depth (cm)} \times \text{soil organic carbon (\%)}.$$

Bulk density is usually expressed in Mg m^{-3}. However, the numerically equivalent unit of bulk density, i.e. g cm^{-3} is also used.

Table 1. Total biomass (tonne ha^{-1}) of tree species and forage crops under silvipastoral system

Treatment	Particulars	Components of the system			Total
		Tree species	Forage crop	Litterfall	
T_1	Teak + Hybrid Napier	21.30	7.16	0.68	29.14
T_2	Teak + Sudan grass	18.85	2.10	0.67	21.62
T_3	Gamhar + Hybrid Napier	19.24	7.18	0.47	26.89
T_4	Gamhar + Sudan grass	19.13	2.09	0.48	21.70
T_5	Teak + gamhar + Hybrid Napier	10.77	7.35	0.46	18.58
T_6	Teak + gamhar + Sudan grass	13.04	2.02	0.46	15.52
T_7	Teak	15.45	0.00	0.67	16.12
T_8	Gamhar	16.94	0.00	0.49	17.43
T_9	Teak + gamhar	8.62	0.00	0.46	9.08
T_{10}	Sole Hybrid Napier	0.00	7.76	0.00	7.76
T_{11}	Sole Sudan grass	0.00	2.42	0.00	2.42
T_{12}	Control	–	–	–	–

Estimation of total carbon sequestration (tree + fodder crops + soil)

Carbon sequestration was estimated by adding all the components (tree + fodder crops + soil). Carbon stock was then multiplied by 44/12 to estimate CO_2. It can be also estimated as follows

$$\text{Total carbon sequestration (tonne C ha}^{-1}) = \text{carbon stock (tree + fodder crops + soil)} \times 3.667.$$

Estimation of litterfall

Litter of standing crops was collected at monthly intervals for one year. In each plot, quadrates of 1 m × 1 m size of litter trap were placed in each treatment to collect litter. The collected litter was sorted into (i) leaves, (ii) twigs and branches. It was brought to the laboratory to determine fresh and oven dry weight (80°C) from each quadrate. All results were expressed as oven dry weight basis.

Results and discussion

Estimation of total biomass under silvipastoral system

Table 1 presents the total biomass (tonne ha^{-1}) of all the components under silvipastoral system. It was observed that the total biomass of the system was maximum in teak + Hybrid Napier (29.14 tonne ha^{-1}) where teak accounted for 21.30 tonne ha^{-1}, Hybrid Napier 7.16 tonne ha^{-1} and litterfall 0.68 tonne ha^{-1}. This followed by gamhar + Hybrid Napier (26.89 ha^{-1}), where gamhar, Hybrid Napier and litterfall contributed 19.24, 7.18 and 0.47 tonne ha^{-1} respectively. Minimum was found in sole Sudan grass (2.42 tonne ha^{-1}).

Negi *et al.*[26] studied biomass production in 20-year-old plantations of *Tectona grandis* and *Gmelina arborea* in Tripura, North East India, using mean tree technique. They reported that dry matter content was 138.37 and 164.4 tonne ha^{-1} respectively. The percentage contribution of bole, bark, branch, twig and leaf was 65.30, 9.10, 16.80, 3.40, 5.40 and 73.70, 9.40, 9.50, 5.00, 2.40 respectively, for *T. grandis* and *G. arborea*. Indeed, the biomass production and allocation of biomass for bole, branch, twig, foliage and roots vary with species, site, density and management practices. Swamy *et al.*[27] reported aboveground biomass and belowground biomass values of 56.62 and 20.25 tonne ha^{-1} respectively in *T. grandis*. Giri *et al.*[28] calculated the total biomass of *T. grandis* as 147.50 tonne ha^{-1} with above-ground biomass of 121.88 tonne ha^{-1} and belowground biomass of 25.62 tonne ha^{-1}. Bohre *et al.*[18] estimated the net biomass accumulation in 10-year-old plantations of *T. grandis* and *G. arborea* to be 279.89 and 371.54 tonne ha^{-1} respectively, with corresponding carbon of 139.91 and 185.77 tonne ha^{-1} respectively. Sahu *et al.*[29] reported total biomass of 206.48 Mg ha^{-1} in a 23-year-old teak plantation, of which aboveground biomass contributed 173.53 Mg ha^{-1} and belowground biomass 32.92 Mg ha^{-1}.

Estimation of total productivity under silvipastoral system

Table 2 presents the total productivity (tonne ha^{-1} $year^{-1}$) of all the components under silvipastoral system. It was maximum in teak + Hybrid Napier (21.0 tonne ha^{-1} $year^{-1}$), where teak accounted for 3.5 tonne ha^{-1} $year^{-1}$ and Hybrid Napier 17.5 tonne ha^{-1} $year^{-1}$. This was followed by gamhar + Hybrid Napier (20.3 tonne ha^{-1}), where gamhar contributed 3.2 tonne ha^{-1} $year^{-1}$ and Hybrid Napier 17.1 tonne ha^{-1} $year^{-1}$. Minimum was found in teak (T_7; 2.7 tonne ha^{-1} $year^{-1}$). Tokey *et al.*[30] reported maximum biomass productivity up to 25.8 tonne ha^{-1} $year^{-1}$, of which 68% was contributed by trees in the agri-horti-silvicultural system. The minimum productivity of 20.4 tonne ha^{-1} $year^{-1}$ was observed in agri-silvicultural system, which contributed to 27% of the total productivity.

Table 2. Total productivity (tonne ha^{-1} year^{-1}) of tree species and forage crops under silvipastoral system

Treatment	Particulars	Components of the system		Total
		Tree species	Forage crop	
T_1	Teak + Hybrid Napier	3.5	17.5	21.0
T_2	Teak + Sudan grass	3.4	5.0	8.4
T_3	Gamhar + Hybrid Napier	3.2	17.1	20.3
T_4	Gamhar + Sudan grass	3.3	5.0	8.3
T_5	Teak + Gamhar + Hybrid Napier	2.1	17.2	19.3
T_6	Teak + Gamhar + Sudan grass	2.5	4.9	7.4
T_7	Teak	2.7	0.0	2.7
T_8	Gamhar	3.1	0.0	3.1
T_9	Teak + Gamhar	2.1	0.0	2.1
T_{10}	Sole Hybrid Napier	0.0	18.3	18.3
T_{11}	Sole Sudan grass	0.0	5.8	5.8
T_{12}	Control	–	–	–

Table 3. Total carbon sequestration potential (tonne ha^{-1}) under silvipastoral system

Treatment	Particulars	Tree carbon stock	Forage crop carbon stock	Litterfall carbon stock	Soil carbon stock	Total carbon stock	Carbon sequestration
T_1	Teak + Hybrid Napier	10.65	3.22	0.31	9.96	24.15	88.64
T_2	Teak + Sudan grass	9.43	0.95	0.30	10.49	21.17	77.68
T_3	Gamhar + Hybrid Napier	9.62	3.23	0.21	10.02	23.08	84.72
T_4	Gamhar + Sudan grass	9.57	0.95	0.22	10.37	21.10	77.42
T_5	Teak + gamhar + Hybrid Napier	5.39	3.31	0.21	10.05	18.95	69.55
T_6	Teak + gamhar + Sudan grass	6.52	0.91	0.21	10.18	17.81	65.36
T_7	Teak	7.73	0	0.30	9.11	17.14	62.90
T_8	Gamhar	8.47	0	0.22	9.32	18.01	66.08
T_9	Teak + gamhar	4.31	0	0.207	9.05	13.56	49.77
T_{10}	Sole Hybrid Napier	0	3.49	0	9.96	13.47	49.42
T_{11}	Sole Sudan grass	0	1.09	0	10.45	11.5	42.36
T_{12}	Control	0	0	0	9.095	9.09	33.38

Total carbon sequestration potential under silvipastoral system

Table 3 presents the total carbon sequestration potential (tonne ha^{-1}) under silvipastoral system. By combining all the components which include tree species, forage crop and soil maximum total carbon sequestration potential was found in T_1: teak and Hybrid Napier 88.64 tonne ha^{-1} followed by T_3: gamhar + Hybrid Napier (84.72 tonne ha^{-1}), T_2: teak + Sudan grass (77.68 tonne ha^{-1}) and T_4: gamhar + Sudan grass (77.42 tonne ha^{-1}) and the lowest in T_{12}: (33.38 tonne ha^{-1}).

Dhyani *et al.*[31] also reported carbon sequestration potential of agroforestry system to be between 0.25–19.14 and 0.01–0.60 Mg C ha^{-1} year^{-1} for tree and crop components respectively, in India. The contribution of agroforestry in soil carbon sequestration varied between 0.003 and 3.98 Mg C ha^{-1} year^{-1}. Nair *et al.*[32] reported that global scenario on an average carbon storage in agroforestry system ranged from 0.29 to 15.21 Mg C ha^{-1} year^{-1} in aboveground, and from 30 to 300 Mg C ha^{-1} up to a depth of 1 m in the soil (the age varied from 4 to 35 years). Kakkar *et al.*[33] studied the carbon storage potential in *Syzygium cumini*, *G. arborea*, *T. grandis*, *Acacia auriculiformis*, *Dalbergia latifolia*, *Terminalia chebula* and *Hardwickia binnata* plantations at Hosakote Research Station. Total carbon sequestration (tonne ha^{-1}) was in the order *A. auriculiformis* (21.3 tonne C ha^{-1}) > *G. arborea* (19.28 tonne C ha^{-1}) > *T. chebula* (7.7 tonne C ha^{-1}) > *D. latifolia* (7.67 tonne C ha^{-1}) > *H. binata* (5.35 tonne C ha^{-1}) > *T. grandis* (5.31 tonne C ha^{-1}) gradual decrease in total carbon sequestration. Kumar *et al.*[34] reported that total carbon stock in the silvipastoral system was 102.81–138.23 Mg ha^{-1} in *Acacia nilotica* + *Cenchrus cilaris* and 112.53–181.51 Mg ha^{-1} in *Salvadora persica* + mixed-grass system. For the silvipastoral system, organic carbon up to 0–30 cm soil depth was 20.50–19.48 mega gram ha^{-1}. The increase in organic carbon was 64–66% compared to native grassland system.

Total litterfall production under silvipastoral system

Figure 1 shows the annual average litterfall production of *T. grandis* and *G. arborea*-based silvipastoral system. Annual contribution towards total litter production of

Table 4. Average yearly amount of litterfall production (g m^{-2} year^{-1}) in *Tectona grandis* and *Gmelina arborea*

	T. grandis		*G. arborea*	
Litterfall component	Amount	Percentage of total	Amount	Percentage of total
Leaf	291.88	95.32	190.57	95.78
Wood (twigs and branches)	14.32	4.68	8.39	4.22
Bark	0.00	0	0.00	0
Total	306.20	100	198.96	100

Table 5. Correlation matrix between biomass, productivity, carbon stock and carbon sequestration

Component	Biomass	Productivity	Carbon stock	Carbon sequestration
Biomass	1.000			
Productivity	0.577	1.000		
Carbon stock	0.995	0.586	1.000	
Carbon sequestration	0.995	0.586	0.999	1.000

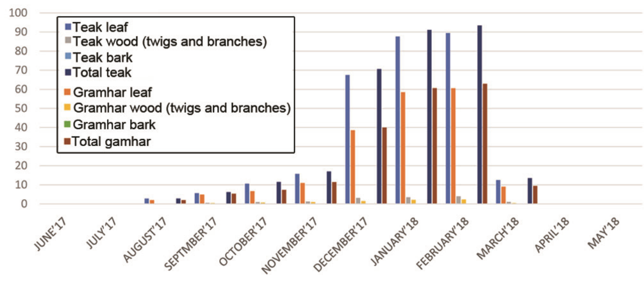

Figure 1. Average litterfall production under silvipastoral system (g m^{-2}).

T. grandis and *G. arborea* was 306.2 and 198.96 g m^{-2} year^{-1} respectively. Leaf litter accounted for 291.88 and 190.57 g m^{-2} followed by wood (twigs and branches) 14.32 and 8.39 g m^{-2} for *T. grandis* and *G. arborea* respectively.

Bark production was absent in both species because the plants under study were comparatively young. The highest litterfall of 93.42 g m^{-2} was recorded in February followed by 91.12 g m^{-2} in January, while the least litterfall of 2.83 g m^{-2} was recorded in August. The same trend was observed in *G. arborea* with the highest litterfall of 62.88 g m^{-2} in February followed by 60.60 g m^{-2} in January while the least litterfall of 2.00 g m^{-2} was recorded in August. Hosur and Dasog[35] observed that in *T. grandis* plantation, leaf litter contributed 96.98% while twigs and fruits contributed only 1.74% and 1.27% respectively. Lower contribution from twigs and fruits was due to the younger age of *T. grandis*.

The average annual litterfall production of *T. grandis* was 306.20 g m^{-2}. Component-wise estimates of the species revealed that leaves accounted for maximum contribution to total litterfall which was higher than wood (twigs and branches; Table 4). The maximum annual leaf fall recorded in *T. grandis* was 95.32% followed by wood (twigs and branches) 4.68% and the least was from bark twigs (nil).

The average annual litterfall production of *G. arborea* was 190.57 g m^{-2}. Component-wise estimates of the species leaves accounted for maximum contribution to total litterfall which was higher than wood (twigs and branches; Table 4). The maximum annual leaf-fall recorded in *G. arborea* was 95.78% followed by wood (twigs and branches) 4.22% and the least was from bark (nil).

Correlation between biomass, productivity, carbon stock and carbon sequestration

Table 5 shows the correlation matrix between biomass, productivity, carbon stock and carbon sequestration in *T. grandis* and *G. arborea*-based silvipastoral system. Productivity was significantly correlated with biomass (0.577). Carbon stock was significantly correlated with biomass (0.995) and productivity (0.586), whereas carbon sequestration was statistically significantly correlated with biomass (0.995), productivity (0.586) and carbon content (0.999).

Conclusion

Silvopastoral system has been practised for hundreds of years by dryland farmers to meet the fodder requirement of their livestock. The ever increasing grazing pressure and energy demand have degraded these traditional pasturelands, and thus a huge gap exists between fodder demand and supply drylands. There are conclusive evidences to suggest that improved silvopastoral system with suitable tree species and management practices such as pruning, lopping, fertilizer applications, germplasm improvement, quality of seedling have scope to improve the productivity of existing pasturelands. There is also a huge potential to utilize silvopastoral system in rainfed areas to solve problems like global warming/climate change (through increased carbon sequestration) and in biodiversity conservation. The value-added products from silvopastoral system have abundant scope to improve the livelihood of farmers in the dry regions.

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