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Impact of tree age on biomass growth and carbon accumulation capacity of Agroforestry system

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ABSTRACT

The biomass and carbon storage was assessed during 2017-2019 in a well-established agroforestry experiment on *Dalbergia sissoo* and *Emblica officinalis* based agroforestry system at the experimental field of Krishi Vigyan Kendra, Indira Gandhi National Tribal University, Amarkantak, Madhya Pradesh. The study was conducted ina 4 year old tree vegetation based agroforestry system.Result revealed that the biomass was increased from 6.3%, 8.6%, 16%, 7.7% and 8.6%, respectively in treatments viz; T1, T2, T3, T4 and T5 as tree age increased from 3 years to 4 years. However, highest biomass was observed in treatment T1 (24.48 Mg ha^{-1} yr^{-1}). The trend of carbon sequestration potential (CSP) of land used system to show the percent change was highest in T3 (16%) and lowest was observed in T1 (6.3%), respectively. Meanwhile, highest CSP of the system was observed in pure *Dalbergia sissoo* (T1) base treatment (44.8Mg ha^{-1} yr^{-1}).

***Key word:** Agroforestry, CSP, Carbon storageand Tree age*

Introduction

The importance of various types of land use systems in stabilising atmospheric CO_2 concentrations, reducing CO_2 emissions, and enhancing the carbon sink of forestry and agroforestry systems, is gaining popularity. Forestry has long been recognised as a way to cut CO_2 emissions and improves carbon sinks. Forests (or trees) play an important part in carbon cycles (Thakur *et al.*, 2021a,b) and forests are also a significant carbon sink (Bijalwan *et al.*, 2020; Kumar *et al.* 2021; Rawat *et al.*, 2022). Increased carbon storage capacity of terrestrial vegetation can be achieved through land-use strategies such as afforestation, reforestation, and natural forest regeneration, as well as silvicultural systems and agroforestry (Brown, 1996; Candell *et al*,. 2008; Kumar *et al.*, 2017a,b,c). Given the amount of land currently under cultivation, the number of people who rely on land for their livelihoods, and the need to integrate food production with environmental services, agroforestry systems are critical (Verma *et al.*, 2017; Bijalwan *et al.*, 2020). The growth pattern of elderly trees is particularly important in terms of carbon build-up (Kumar *et al.*, 2017; Bijalwan *et al.*, 2019; Thakur *et al.*, 2021c). Traditional growth and yield research in managed single-species, even-aged forest stands have led to the belief that as trees get older, their height, diameter, and volume grow less, resulting in a sigmoid growth curve (Weiskittel *et al.*, 2011). Variations in the supply rate of necessary resources (light, nutrients, water), shifting balance between photosynthesis and respiration, increased hydraulic resistance, decreasing nutrient availability, or genetic alterations with meristem age are all factors that contribute to declining tree growth over time (Ryan *et al,*. 1997, Woodruff *et al,*. 2011). Delzon *et al*., (2004) found a decrease in above-ground yearly biomass increment per unit leaf area as a function of height. Recent studies have highlighted the importance of old trees for carbon accumulation by highlighting sustained or continually rising mass growth rates with increasing tree size (Stephenson *et al,*. 2014). The following are some of the causes for continued tree growth with age: (i) the metabolic scaling theory (MST), which states that mass production increases with tree size (Price *et al.*, 2012), (ii) the struggle for space (Pretzsch *et al,*. 2009), (iii) the increase in total leaf area of a tree and good light environment feedbacks with tree growth (Stephenson *et al,*. 2014, Bloor *et al,*. 2003 and Rüger*et al.,* 2011), or (iv) Adaptive reiteration (AR) is a process in which freshly formed leaves reduce the ratio of respiration to photosynthesis, renew apical meristems, and enhance hydraulic conductivity (Ishii *et al,*. 2007). Studies on biomass growth increases in huge trees were thoroughly reviewed in a recent study (Sheil *et al.,* 2017). The physiological bases of huge, apparently elderly trees' development patterns are poorly understood. Moving from lower biomass land uses [e.g. grasslands, crop fallows, etc.] to tree-based systems like forests, plantation forests, and agroforestry can assist achieve net improvements in carbon storages (Roshetko *et al.,* 2007; Bijalwan *et al.,* 2017). Agroforestry offers a one-of-a-kind chance to integrate climate change adaptation and mitigation goals. Although agroforestry systems are not specifically designed for carbon sequestration, a growing body of evidence suggests that they can play a significant role in storing carbon in above ground biomass (Niles *et al.*, 2002; Verchot *et al.*, 2007; Thakur *et al.*, 2014 and 2019), in soil and in below ground biomass (Nair *et al.*, 2009; Thakur *et al.* 2017, 2019). The present study reveals the impact of age on biomass and carbon stock of an Agroforestry system.

Materials and Methods

Study area

The assessment of biomass and carbon storage was done during 2017-2019 in a well-established Agroforestry experiment on *Dalbergia sissoo* and *Emblica officinalis* based Agroforestry system at experimental field of IGNTU, KVK Research Farm and analysis work has been completed in the Department of Environmental Science, IGNTU, Amarkantak, Madhya Pradesh. Study area enjoys a somewhat subtropical climate with hot dry summer and cool dry winter. Temperature extremes vary between minimum temperatures of 2.4 ^{0}C in December-January months to maximum temperature of 42 ^{0}C in May–June months. Based on 20 years mean meteorological data, the average annual rainfall of the locality is 1350 mm, which mostly received between mid-June to end of September with an occasional winter shower during December and January months. The mean monthly minimum temperature varies between 5.3 to 6.1 in December and January, and maximum temperature varies between 40 to 42 °C during May and June, respectively. December is the coldest month of the year with minimum temperature being 2.5 °C. Generally relative humidity remains very low during summer (20 to 23%), moderate (60 to 75%) during winter and it attains high value (80 to 95%) during rainy season.

Details of experiment

The study was carried out in Randomized Complete Block Design (RCBD) with five treatments and four replications. One-year old Plants were planted with plant-plant distance of 4.5 meter and Row to Row distance of 5 meters. Sixteen plants were planted under each treatment in June 2016. Each plot was of 360 m^2. A bare strip of 2-meter-wide was maintained between each replication and treatment. Soybean crop variety NRC-86 and wheat crop variety JW3173 was grown as under storey crop in all treatments during kharif- rabi season from 2017-2019. The treatments comprised, T_1: 100% *Dalbergia sissoo L.*, T_2: 75% *Emblica officinalis Gaertn.*+ 25% *Dalbergia sissoo L.*, T_3: 25% *Emblica officinalis Gaertn*. + 75% *Dalbergia sissoo L.*, T_4: 50% *Emblica officinalis Gaertn*. + 50% *Dalbergia sissoo L.*, and T_5: 100% *Emblica officinalis Gaertn*.

Growth and biomass estimation

Growth of individual tree [Diameter at Breast Height (DBH) at 1.37 m and Collar Diameter (CD) at 15 cm from ground level in case of *Emblica officinalis* (Aonla)]. The methodologies developed by IPCC (1996) were used for estimation of biomass. The biomass was divided in to two subheads i.e. above ground and below ground. In crops, the biomass production was measured manually by harvesting the above ground biomass (Grain and straw) by cutting at the ground level and below ground biomass (Root) by excavation method. Three randomly quadrates (1m x 1m) were laid out and harvested in each plot. Dry biomass is determined by drying the freshly harvested crops in hot air oven at 65 ^{0}C.

Above ground biomass

The tree height, diameter and basal area of tree were recorded during both the years to calculate volume of a tree. The above ground biomass of tree was calculated by non-destructive method suggested by Chundawat *et al.* (1993). The volume of a tree multiplied with the specific gravity of wood of each tree component, result above ground biomass of tree components.

Below ground biomass

The below ground biomass of trees was calculated by multiplying above ground biomass with a factor of 0.25 using the guidelines of IPCC (1996).

Carbon content and carbon storage estimation in Agroforestry system

The ash method was used to determine the carbon content of plant biomass. In a pre-weighed crucible, oven dried samples of 5 g for each portion of the tree and crops were taken. The crucibles were placed in the muffle furnace for 2.30 hours at 4000C. Inside the desiccators, the crucibles were gently cooled. After cooling the crucible with ash was weighed and percentage of organic carbon was calculated as formula given by Allen *et al.,* (1986). To determine carbon dioxide sequestration potential by crops and trees, the biomass carbon stock was multiplied with a factor of 3.67 for all species.

Results and Discussion

During the first year of experimentation (2017-18), the above ground biomass production was significantly highest under 100 *sissoo* (T_1; 18.40) than other treatment. During second year (2018-19), the above ground biomass production was increase and highest under 100 *sissoo* (T_1; 19.59). The above ground biomass production under various land use systems is influenced by a variety of factors, including tree and crop selection, growth habits, site quality, soil on which trees are grown, tree age, management practices, frequent intercultural operations, moisture conservation, and their interaction with below ground crops. The results were confirmed with finding of Abbas *et al.,* (2011); Rizvi *et al.,* (2012) and Mangalassery *et al.,* (2014). In the present study, the highest above ground biomass production may be due to growth habit of crop and complementary interaction between *Dalbergia sissoo* and crop for sharing of the resources. During the first year of experimentation (2017-18), the below ground biomass production was significantly highest under 100 sissoo (T1; 4.60) than other treatments. During second year tree age was increases which result increment in below ground biomass. Results on the biomass production of various land use systems are depicted in Table 1 and Fig 1. In the present study, the maximum below ground root biomass under *Dalbergia sissoo* + crop agrisilviculture system may be due to genetic makeup of crop and *Dalbergia sissoo* to gain the higher root biomass (Bijalwan *et al.,* 2010). Chauhan *et al.,* (2009); Thakur and Thakur (2014)reported the same findings.

During the first year of experimentation (2017-18), the total CSP was found significantly maximum under 100 *sissoo* (T_1; 42.10) than other treatment. Sharma *et al.,* (2016) reported that short rotation tree species have less carbon sink potential because, relatively low storage time of the wood products. During the second year, carbon sink under 100 *sissoo* (T_1; 44.81) show enhancement of 6.5 % compare to first

Table 1. Mean annual biomass production (tree and agriculture crops) under different land use systems

Land use systems	Biomass Production (Mg ha^{-1} yr^{-1})								
	Above ground			Below ground			Total		
	2017-18	2018-19	Mean	2017-18	2018-19	Mean	2017-18	2018-19	Mean
100% D. sissoo (T1)	18.40	19.59	19.00	4.60	4.90	4.75	23.01	24.48	23.74
75% *E. officinalis* + 25% *D. sissoo* (T2)	17.27	18.76	18.02	4.32	4.69	4.50	21.59	23.45	22.52
25% *E. officinalis* + 75% *D. sissoo* (T3)	15.42	17.91	16.67	3.86	4.48	4.17	19.28	22.39	20.83
50% *E. officinalis* + 50% *D. sissoo* (T4)	16.20	17.46	16.83	4.05	4.37	4.21	20.26	21.83	21.04
100% *E. officinalis* (T5)	17.07	18.55	17.81	4.27	4.64	4.45	21.34	23.18	22.26
SEm±	0.51	0.66	0.14	0.13	0.16	0.03	0.63	0.82	0.17
CD at 5% (P= 0.05)	1.51	1.97	0.4	0.38	0.5	0.1	1.88	2.46	0.5

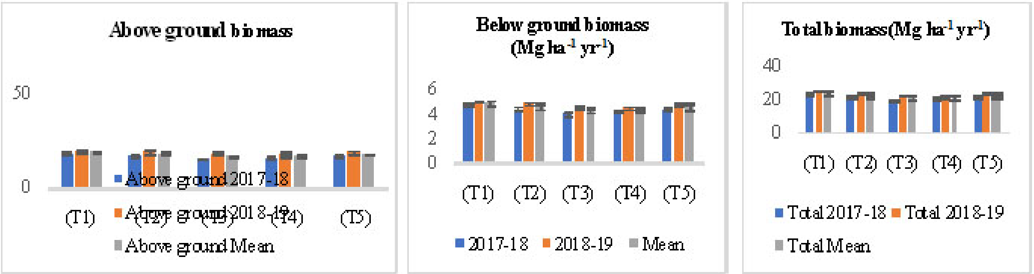

Fig 1. Above ground, below ground and Total biomass Production under various land use systems over the years

Table 2. Annual CO_2 sequestration potential (Mg ha^{-1} yr^{-1}) under different land use systems during the years (2017-18 and 2018-19)

Land use systems	CO_2 sequestration potential (Mg ha^{-1} yr^{-1})								
	Below ground			Above ground			Total		
	2017-18	2018-19	Mean	2017-18	2018-19	Mean	2017-18	2018-19	Mean
00% *D. sissoo (T1)*	33.68	35.84	34.76	8.42	8.96	8.69	42.10	44.81	43.45
75% E. officinalis + 25% D. sissoo (T2)	31.60	34.33	32.97	7.90	8.58	8.24	39.50	42.92	41.21
25% E. officinalis + 75% D. sissoo (T3)	28.22	32.77	30.50	7.05	8.19	7.62	35.27	40.97	38.12
50% E. officinalis + 50% D. sissoo (T4)	29.65	31.96	30.81	7.41	7.99	7.70	37.07	39.95	38.51
100% E. officinalis (T5)	31.24	33.94	32.59	7.81	8.48	8.15	39.05	42.42	40.74
SEm±	0.92	1.21	0.25	0.23	0.3	0.06	1.16	1.5	0.31
CD at 5% (P= 0.05)	2.76	3.60	0.73	0.7	0.9	0.2	3.45	4.5	0.91

years. The result shown in Table 2 & Fig. 1 represent that during the second year the age of tree component increased hence, biomass production also increased which result the increment of carbon sequestration.

The total CO_2 sequestration potential of plants is proportional to the biomass production of the various plant components. Greatest CO_2 sequestration potential in *Dalbergia sissoo* + Crop agrisilviculture may due to more biomass and more carbon stock was observed as compared to other agrisilviculture and conventional cropping land use systems.

Because of the increased growth increment, uniform accounting carbon storage at different ages at the same location leads to varying biomass potential. Konôpka *et al.* (2010) reported that, as trees grow, age-related changes in tree shape and form alter the distribution of biomass among tree components. The biomass production was highest in *Dalbergia sissoo* + Crop agrisilviculture compare to *Emblica offacinalis* + Crop agrisilviculture system. *Dalbergia sissoo* has a high biomass production capacity based on age when compared to other tree species, and it may be used as a multipurpose tree species in rainfed areas to meet the demand for fuel and feed in Central India.

Conclusion

It was shown that biomass and carbon storage are

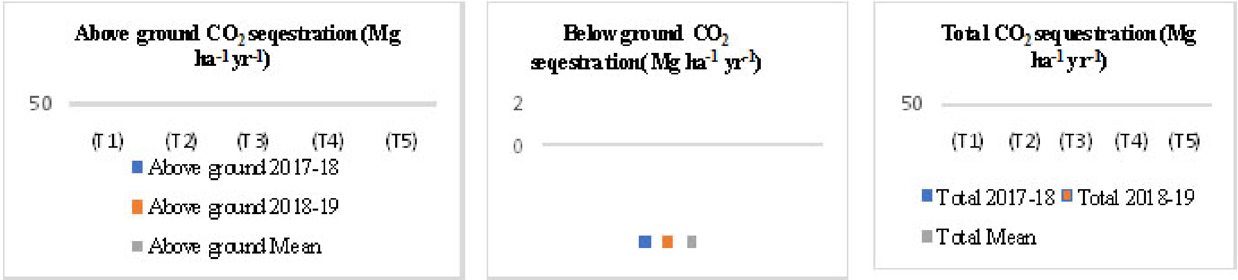

Fig 2. Above ground, below ground and Total CO_2 sequestration potential of land use systems over the years

highly dependent on the agroforestry system in situ, whose form and function are heavily influenced by environmental and socioeconomic factors. The mean annual increment, which varies with location, age, density, tree species, agronomic management practices and plantation, as well as the quality of planting material, are other factors impacting carbon storage in agroforestry systems. During both years of experimentation, planting *Dalbergia sissoo* with crop under the agrisilviculture system of Agroforestry was found to be significantly superior for morphological growth parameters such as cylindrical volume and stand biomass as compared to other combinations of *Emblica officinalis* with agricultural crop. With increasing tree age, all growth indices rose.

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