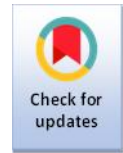




Assessment of carbon sequestration rate in *eucalyptus*-based irrigated forest plantation Bahawalpur



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Abstract

Climate change has attracted significant attention in recent times as more carbon has been emitted into the environment due to anthropogenic activities. Irrigated forest plantations play a significant role in carbon sequestration. The current study aims to determine the species diversity, richness, and CO₂ sequestration in the upper and understory trees of Zakheera Irrigated Forest Plantation, Bahawalpur, Pakistan. The total carbon reserve ha⁻¹ for the available tree species was calculated using the sampling plot method. The study area, having an area of 1504 (609 ha) acres, contained the sampling plots. *Eucalyptus camaldulensis* was found to be the dominant species (60%), followed by *Dalbergia sissoo* (15%), *Vachellia nilotica* (10%), and other mixed species contributed a small portion of the study area species (15%). The study's findings showed that the carbon stores in the tree biomass directly corresponded to tree species and the age of trees. *Dalbergia sissoo* and *Eucalyptus camaldulensis* have a maximum stem biomass of 160.08 Mgha⁻¹, as noted in *E. camaldulensis*. The average tress stem biomass of *Eucalyptus camaldulensis* was observed at 168.23, having a range of 102.89 ± 160.19 Mgha⁻¹. Similarly, the lowest tree stem biomass of 20.70 Mgha⁻¹ was noted in *Vachellia nilotica*, whereas it contained an average tree stem biomass of 20.70 with a range of 20.70 ± 30.50 Mgha⁻¹. The average stem biomass of *Dalbergia sissoo* was noted at 90.70, with a range of 130.90 ± 35.85 Mgha⁻¹. The average stem biomass of the complete plantation was 90.75, with a range of 160.80 ± 30.50 Mgha⁻¹, while the average tree biomass was 140.50, with a range of 245.30 ± 40.70 Mgha⁻¹. The carbon sequestering reserves in the Province of Punjab may be greatly increased by conducting scientific studies and proper forest management operations on the existing 31,223 ha of vacant land.

1. Introduction

A long-term alteration in weather trends is referred to as climate change, lasting from decades to millions of years (Lal and Niwas, 2023). It is happening at an unprecedented rate and if we continue as we are, it will have a profound impact on life on Earth that will be very difficult to reverse. Anthropogenic activities like the use of “fossil fuels and deforestation” have increased during the last century and significantly altered the chemical composition of the atmosphere (Abrahms *et al.*, 2023). These changes have negative consequences for the planet's weather patterns, natural systems, and the well-being of humans and the economy (Abrahms *et al.*, 2023). The Earth's atmosphere consists of three main gases, with nitrogen being the most abundant at 78.09%, followed by oxygen at 20.95%, and argon at 0.93% (Subramani and Applications, 2012). However, it is the less common trace gases that have the greatest influence on Earth's climate (Tkemaladze and Makhashvili, 2016). These trace gases comprise carbon dioxide, methane, carbon monoxide, chlorofluorocarbons, nitrogen oxides, and ozone. Additionally, vapor plays a substantial role in shaping the Earth's climate (Subramanian *et al.*, 2023). Humans have been contributing to the rise in carbon

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dioxide levels in the air by human-based activities such as burning fossil fuels, land use change patterns, and engaging in forestry-related practices (Raihan *et al.*, 2022). These processes are leading to global warming and climate change. According to Upadhyay *et al.* (2005), these phenomena are already occurring. The discharge of carbon into the atmosphere is considered a significant factor in global warming, and it is a major concern addressed in the Kyoto Protocol (Oberthür and Ott, 1999). The majority of CO₂ emissions, over 80%, come from transportation and industrial sources worldwide (Quadrelli and Peterson, 2007). The remaining 20% is primarily attributed to deforestation and the burning of biomass (Sovacool and Brown, 2010).

Before industries were established, the average concentration of CO₂ in the atmosphere was 280 parts per million (ppm) (Monastersky, 2013). With the growth of industries, it increased to 364 mol/mol in 1994 (Samrane *et al.*, 2023). Currently, the rate of concentration increase is approximately 1.5 mol/mol/year (Zhang *et al.*, 2023b). Additionally, the rate at which CO₂ accumulates in the atmosphere is about 3.3 Gt C yr⁻¹ higher than the rate at which it is lost to natural sinks (Huang *et al.*, 2023). As a result, the concentration of CO₂ in the atmosphere is steadily rising and has reached 367 parts per million (ppm) (Zhang *et al.*, 2023a). This is 31% higher than the preindustrial level and is increasing exponentially at a rate of approximately 0.5% per year (Wu *et al.*, 2023). Due to the significant amount of carbon dioxide released from burning fossil fuels, it is considered the most important greenhouse gas (Wu *et al.*, 2023). It is estimated that carbon dioxide emissions from fossil fuels alone will be 6 Gt C per year (Uddin *et al.*, 2023). Efforts to address the greenhouse gas issue have traditionally focused on reducing the use of fossil fuels to minimize the production of carbon dioxide, known as "CO₂ reduction" (Page *et al.*, 2022). Forest ecosystems play a crucial role in the context of climate change as they act as both sources and sinks of CO₂, which is the most abundant greenhouse gas (Chavula *et al.*, 2022; Feng *et al.*, 2022). Apart from the carbon stored in the Earth's crust and sediments, approximately two-thirds of all terrestrial carbon is sequestered in terrestrial ecosystems (Schahczenski *et al.*). This carbon is found in undergrowth plants, standing trees, leaves, forest debris, and forest soils (Mahankale, 2023).

Eucalyptus is a tree species that can capture and store carbon dioxide from the atmosphere at a faster rate than other similar trees (Kumar and Kumar, 2023). Several authors have studied the carbon sequestration capabilities of Eucalyptus, and their findings are summarized here to enhance understanding (Morales *et al.*, 2023). One study conducted in the Punjab state by Dogra (2011) examined the contribution of Eucalyptus trees located outside of forests to wood production and environmental improvement. It was found that these trees can sequester carbon at a rate of 236.8 kg per tree, with a diameter at breast height (DBH) of 30 cm and a height of 24 m. Another study in Pakistan estimated the rate of carbon flux in planted forests and observed that forests with short-rotation tree species, which shed leaves regularly, have a higher capacity for carbon sequestration through litter decomposition. Mixed forests, consisting of exotic/native tree species, were found to be more productive in carbon sequestration compared to pure forest system (Sobola and Modelling, 2023). Pakistan is a subtropical country with 4.55 mha of forest cover, accounting for 4.5% of the whole geographical area (Sa'adi *et al.*, 2023). Irrigated forest plantations contain 0.2% forest cover. These artificial forests were developed from subtropical thorn forests. The forest resources of Pakistan were assessed using different forest inventories. It is important to note that the calculation of carbon reserves in Pakistani irrigated plantations has not yet been completed. The goals of this study were to quantify carbon stocks in biomass at Zakheera Irrigated Forest Plantation.

2. Materials and Methods

2.1 Study area

Bahawalpur is a famous city of Province Punjab, Pakistan. It is known as the 11th one of the most populated cities in Pakistan and the 6th most populated city in Province Punjab. The territory of Bahawalpur is located along with Multan and it is the capital district of the "Bahawalpur Division" and a significant cultural and economic hub in the South region of Punjab Province. Bahawalpur was established in 1748, subsequently, served as main city of the "historic of Bahawalpur", which was governed by Nawab of Bahawalpur till 1955. The Nawabs of Bahawalpur have left behind an amusing architectural heritage, which is now renowned for memorials from that period. Bahawalpur is located on the outskirts of famous Cholistan and serves as the entry point to the neighboring "Lal Suhanra National Park".

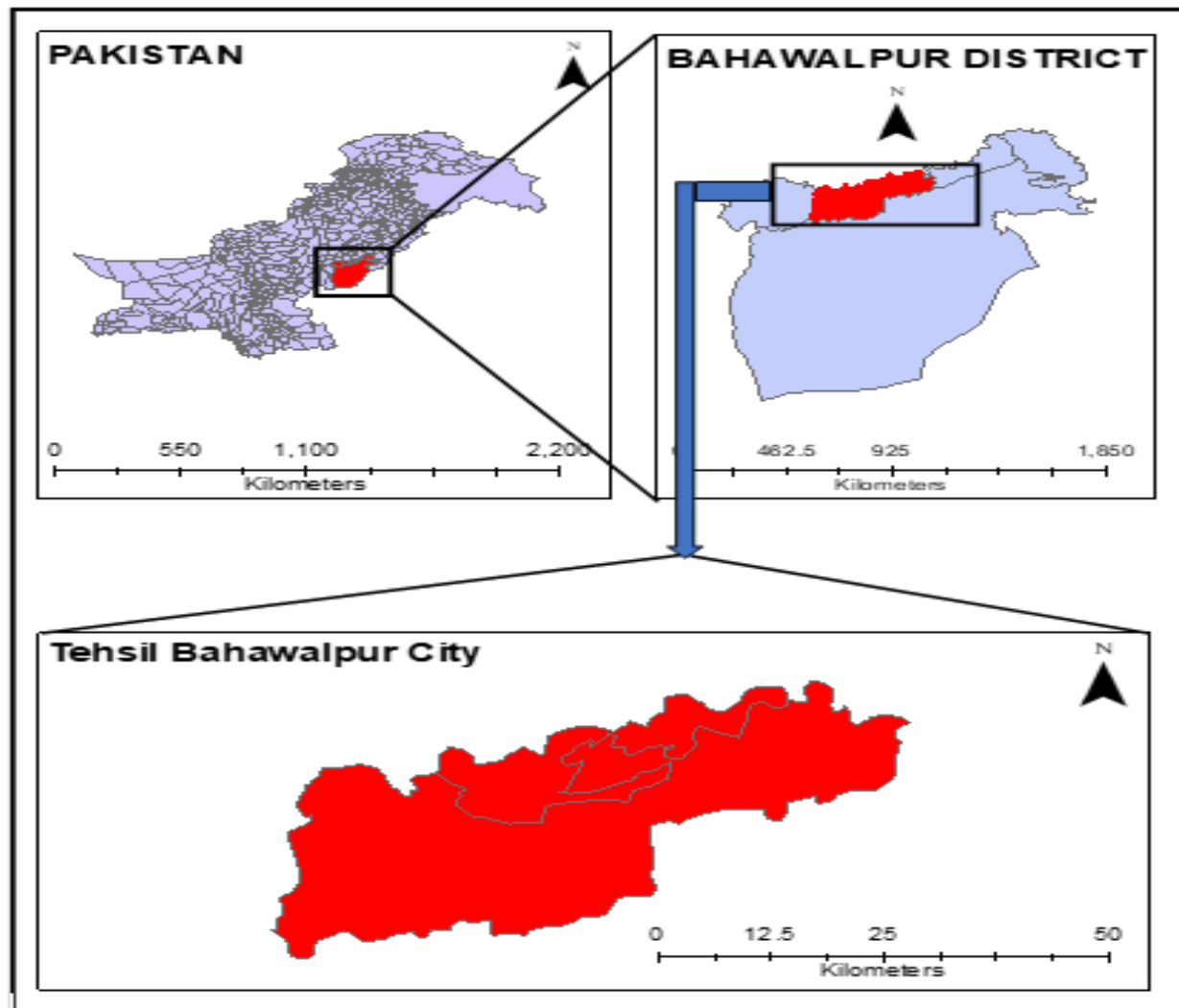


Figure: 3.1. Study Area Map District Bahawalpur

Specifically, the study area is located in the western area of the Tehsil City of district Bahawalpur. Locally, it is known as Zakheera (Forest) situated in the semi-urban area of Bahawalpur near the Railway Line. It is a small irrigated plantation governed by the Punjab Forest Department. The most abundant tree species in this area is *Eucalyptus*. *Dalbergia sissoo* and *Vachellia nilotica* are also the common tree species grown in this irrigated plantation. The study area is shown in Figure 3.2.

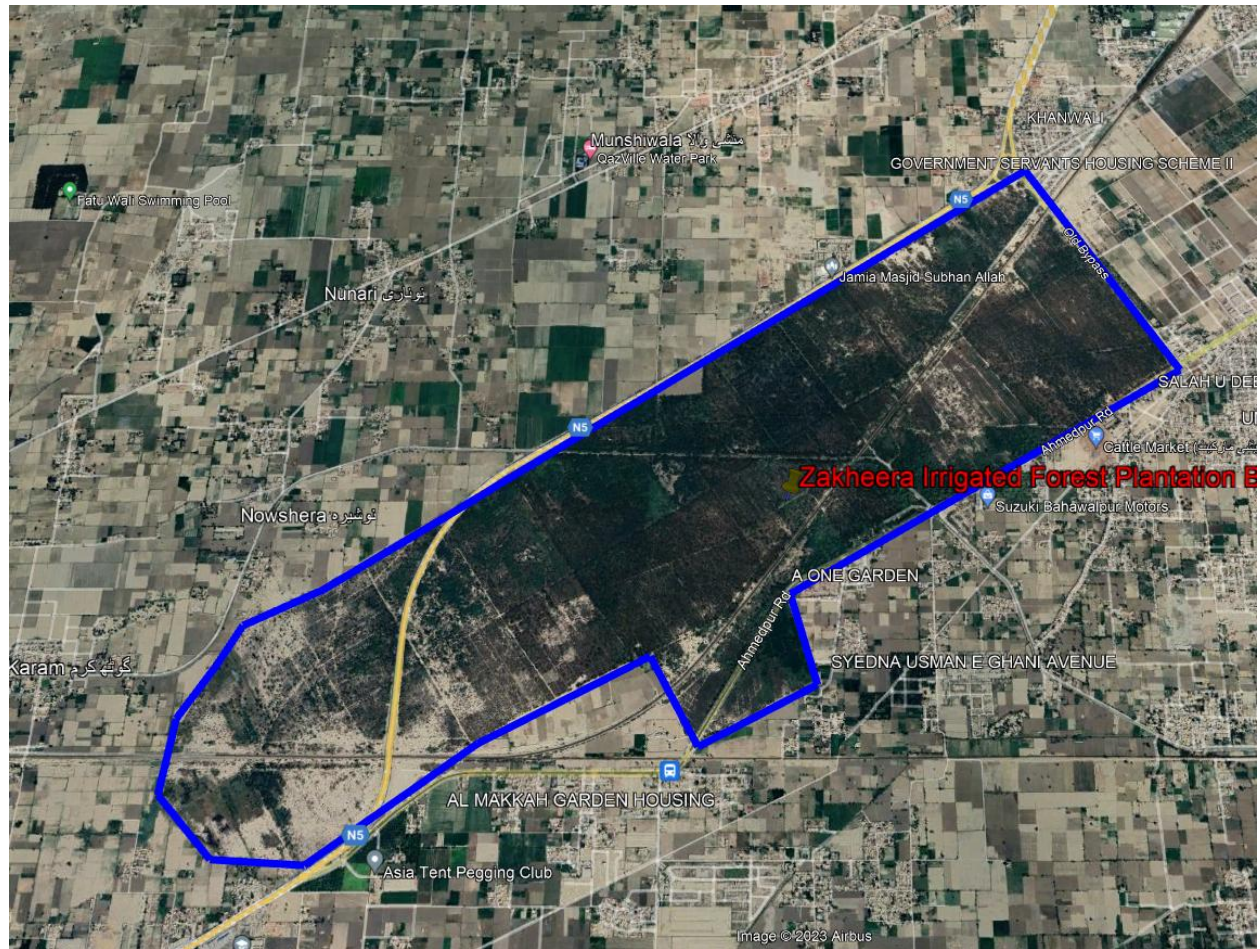


Figure 3.2: Zakheera Irrigated Forest Plantation Bahawalpur

2.2 Methodology

2.2.1 Measurements

Basic forest biometrics tools were used to measure the height, DBH and age of trees to calculate the rate of carbon sequestration in this plantation. Using a random sampling technique, a total of 15 plots of 0.405 hectares area were selected for measuring the following forest inventories.

1. Tree species distribution in the study area
2. No. of trees present in each plot of the study area
3. Height of trees
4. Girth/DBH of trees
5. Tree density
6. Growing Stock

The girth of tree species was taken by tailor tap. Tailor tape was wrapped around the tree at DBH to measure the girth. The Height of tree species was measured using a standard scale of 10 feet length.

2.2.2 Carbon Status and Potential of Carbon Sequestration

The following steps were used for measuring or calculating of C sequestration rate and its potential from the collected data (Afzal and Aqeela, 2003).

1. Determining the (green) weights.
2. Determining the dry weights of selected tree species

3. Determining the carbon weight in selected tree species
4. Determining the CO₂ weight sequestering in selected tree species
5. Determining the CO₂ weight in the forest tree species/year

2.2.3 Determining the (fresh) weight

The following algorithms were used to measure/calculate the above/belowground green weights of the trees.

1. W = Aboveground weights of the tree species
2. D = Diameter
3. H = Height
4. **Tree species having diameter ($D < 11$)**
5. “W = 0.25D²H”
6. **Tree species having diameter ($D \geq 11$)**
7. “W = 0.15D²H”

Depending upon the specific tree kinds, the factors of constant (0.25) may vary, on the other hand “variables D² and H may be increased up to “exponents” slightly above 1 or less than 1. Nevertheless, these allometric equations can be considered as a representation of the average equations for all species. The weight of plant roots is considered almost 20 percent of the total above-ground weights of the tree species. Consequently, to estimate the whole weight of the plant/tree, the weight above the ground should be multiplied by 120%.

2.2.4 Determining the dry-mass of tree species

The information is derived from a publication by the “University of Nebraska”. The research includes table data that provides the mean weight for 1 cord of tree wood from various types of trees in temperate regions. Considering all the tree species listed in the table, it is found that the mean tree consists of 72.5 percent dry mass and 27.5 percent moisture content. To calculate the dry mass of any tree species, the mass of the tree is multiplied by 72.5%.

2.2.5 Determining the C weight in t tree species

It is known that the C contents in a tree make up about 50 percent of its total mass. Therefore, to calculate the quantity or weight of C in the tree species, the dry mass of the tree species is multiplied by 50 percent.

2.2.6 Determining the weight of CO₂ sequestered in tree species

1. “CO₂ consists of a single carbon molecule and two oxygen molecules”.
2. “The atomic mass of carbon is 12.001115”.
3. “The atomic mass of oxygen is 15.9994”.
4. “The mass of CO₂ is calculated as C + 2 * O, resulting in 43.999915”.
5. “The ratio of CO₂ to carbon is 43.999915 divided by 12.001115, which equals 3.6663”.
6. . The weight of C in the tree was “multiplied by 3.6663”.

2.2.7 Determining CO₂ sequestering in forest species/ per annum

CO₂ consists of a single carbon molecule and two oxygen molecules. To measure the quantity of C dioxide in the tree was divided by its weight by its age.

3. Results

3.1 Occurrence/Frequency of tree species/Growing Stock planted in Zakheera Irrigated Forest Plantations Bahawalpur

The most abundant tree species (growing stock) that were planted in the study area during the period of last five years were *Eucalyptus camaldulensis*, *Dalbergia sissoo*, *Vachellia nilotica* and other mixed species in Zakheera Irrigated Forest Plantations Bahawalpur. In the sampling plots, *Eucalyptus camaldulensis* was found dominant species (60%) followed by *Dalbergia sissoo* (15%), *Vachellia nilotica* (10%) and other mixed contributed a small portion in the study area species (15%). Similarly, shrubby vegetations were also found in the study area in a small proportion. The species and age-wise distribution of abundant and all other species as well as the frequency of tree species are shown in Table (4.1). Species-wise tree density/growing stock was also calculated in the study area i.e., Zakheera Irrigated Forest Plantations Bahawalpur and clearly shown in (Table 4.2). It was noted that the most of area of Zakheera Irrigated Forest Plantations Bahawalpur is dominated by *E. camaldulensis*.

Similarly, age wise classes, basal area (m^2), average diameters (cm ha^{-1}), average height (m ha^{-1}), mean stem density of tree species (ha^{-1}) and average volume (m^3) *Eucalyptus camaldulensis*, *Dalbergia sissoo*, *Vachellia nilotica* and other mixed species in Zakheera Irrigated Forest Plantations Bahawalpur is also presented in (Table 4.3). It was noted that trees with fast growing ability gained more stem diameter, tree height and tree volume. This trend was noted in *E. camaldulensis* as it is known as fast growing tree and also found as the dominant tree species in the study area. Maximum tree mean height was noted in *E. camaldulensis* which was around 24 meters and minimum height of this tree was around 14 meters of 4-year age plants. Tree inventory data such as height, diameter, age, volume and basal area are known as important factors in measuring carbon stocks of trees.

The current findings indicated that *E. camaldulensis* having age classes of 0-10 to 26 to 30 years attained mean diameter (24.3 cm), mean height (23.7 meters), mean basal area (15.36 m^2), average stem/shoot density (385 ha^{-1}) and average volume as ($140.9 \text{ m}^3 \text{ ha}^{-1}$). The results indicated that *Dalbergia sissoo* having age class of 0-10 to 26 to 30 years attained mean diameter (45.8 cm), average height (26 meters), mean basal area (15 m^2), average stem density (90 ha^{-1}) and average volume as ($155 \text{ m}^3 \text{ ha}^{-1}$). Similarly, the results indicated that *Vachellia nilotica* having age class of 0-10 to 26 to 30 years attained mean diameter (27.8 cm), mean height (22.1 m), mean basal area (21.98 m^2), average stem/shoot density (385 ha^{-1}) and average volume as ($160 \text{ m}^3 \text{ ha}^{-1}$). Similarly, the results indicated that other tree species having age class of 0-10 to 26 to 30 years attained mean diameter (35.9 cm), mean height (25.2 m), mean basal area (25.97 m^2), average stem/shoot density (390 ha^{-1}) and average volumes as ($165 \text{ m}^3 \text{ ha}^{-1}$). It was noted that the tree age has a strong relationship with the tree diameter (DBH), tree height, Carbon stock, and rate of CO_2 sequestration. Similarly, the stem/shoot volumes of trees are also directly related to tree diameters, consequently, it has a positive association. On the other hand, the tree stem density is related to the stem diameters, thus it showed a negative association. To know relationships among tree diameter (DBH), tree height, carbon stock and rate of CO_2 sequestration, various regression models/data relationships were prepared in MS Excel as shown in Figure 4.1 and Figure 4.2.

3.2 Determination of biomasses, current status of carbon stocks and CO_2 sequestered by upper story trees planted in Zakheera Irrigated Forest Plantations Bahawalpur

Zakheera Irrigated Forest Plantations Bahawalpur area of 609 ha has different compartments on both sides of the railway line. Data from each sample plot was collected and all the trees present in each plot were counted. Their girth, height and age, stem/shoot weight (Mg ha^{-1}) of all selected tree species and carbon storage were measured by the methods that were presented in the materials and method sections (Table 4). The total numbers of tree species from each sampling plot were counted and then the mean number of trees in each hectare was calculated. The amount of carbon sequestered in trees and each sampling plot showed differences slightly from each other due to species distribution. It was also noted that if the average number of trees/ha was greater than the quantity of carbon sequestered by the tree species was also found greater. Moreover, the carbon storage capacity in forest plantations differs across tree species and geographical locations. Further, the amount of carbon in any forest system depends on the structure and function of different components within the systems. To determine this first of all the maximum number of trees grown at a single plot of each sampling plot was calculated by using the statistical tools. Then the average was taken of the maximum number of trees grown at one ha.

The maximum stem biomass of $160.08 \text{ Mg ha}^{-1}$ is noted in *E. camaldulensis*. average tree stem/shoot biomass of *E. camaldulensis* is observed as 168.23 having a range of $102.89 \pm 160.19 \text{ Mg ha}^{-1}$. Similarly, the lowermost tree stem/shoot biomass of 20.70 Mg ha^{-1} is found in *Vachellia nilotica*, whereas it contained an average tree stem biomass of 20.70 having a range of $20.70 \pm 30.50 \text{ Mg ha}^{-1}$. The average stem/shoot biomass of *D. sissoo* is 90.70 having a range of $130.90 \pm 35.85 \text{ Mg ha}^{-1}$. The mean/ average stem/shoot biomass of mixed tree species is found 85.25 having a range of $130.20 \pm 35.80 \text{ Mg ha}^{-1}$. For all tree species, the connections between stem/shoot volume and the basal area, as well as stem/shoot biomass and basal area, were multinomial/quadratic polynomial. The mean/average stem/shoot biomass of the whole area was 90.75 having a range of $160.80 \pm 30.50 \text{ Mg ha}^{-1}$, whereas the average tree species biomass was noted at 140.50 with a range of $245.30 \pm 40.70 \text{ Mg ha}^{-1}$. The average C reserve in upper story trees is 60.19 Mg ha^{-1} with a range of $115.59 \pm 20.90 \text{ Mg ha}^{-1}$.

3.3 Determination of biomasses, current status of carbon stocks and CO₂ sequestered by understory trees planted in Zakheera Irrigated Forest Plantations Bahawalpur

The extreme bio-mass of 7.80 Mgha⁻¹ is noted in shrubby vegetation and understory tree species whereas pastures showed the lowest overall biomass of 1.50 Mgha⁻¹. Bushes and understory trees possess an average biomass range from 4.20 ± 2.40 Mgha⁻¹, whereas grasslands stored average biomass from 3.20 ± 1.41 Mgha⁻¹. Overall, the calculated series of understory tree biomass was noted as 5.62 ± 3.3 Mgha⁻¹ and the entire C reserve ranged as 3.50 ± 1.90 Mgha⁻¹. The extreme understory tree C reserve of 3.80 Mgha⁻¹ is noted in mixed tree species; whereas the least understory tree C reserve of 1.60 Mgha⁻¹ is observed in *E. cammaldulensis*. The average of C reserve in *D. sissoo*, *E. cammaldulensis*, *Vachellia* based vegetations and mixed tree species were noted as 2.80, 1.90, 3.50 and 3.20 Mgha⁻¹, respectively (Table 4). The biomass of trees is the main indicator of calculating the carbon storage capacity of the trees as the biomass increase, the weight of the carbon also increases. Furthermore, the lower age trees have the more capacity of storing carbon due to high eight gaining capacity as compared to the trees which attained the rotational age. Therefore, it is recommended that old trees should be replaced with the new vegetations in order to maximize the rate of carbon sequestration in the forest ecosystems. Zakheera Forest plantation also has some older trees which should be replaced with new vegetation of higher growing patterns to increase the rate of carbon sequestration by this plantation.

Table 4.1; Tree ages and tree species distribution in Zakheera Irrigated Forest Plantations

	<i>E. camaldulensis</i>	<i>D. sissoo</i>	<i>Vachellia nilotica</i>	<i>Morus alba, Neem, Siris, and Sohanjana</i>
0-10	130	15	110	172
11-15	650	100	210	123
16-20	850	75	125	126
21-25	300	90	203	236
26-30	285	70	163	120
>30	200	65	114	96
Total				

Table 4.2: Density-wise stock position of Zakheera Irrigated Forest Plantations

	<i>Tree Species</i>	<i>Planted area ha⁻¹</i>	<i>Density class-wise area ha⁻¹</i>			
			0-25%	26-50%	51-75%	76-100%
0-10	<i>E. camaldulensis</i>	873	218.25	218.25	218.25	218.25
11-15	<i>D. sissoo</i>	326	81.5	81.5	81.5	81.5
16-20	<i>Vachellia nilotica</i>	65	16.25	16.25	16.25	16.25
21-25	<i>Morus alba, Neem, Siris, and Sohanjana</i>	225	56.25	56.25	56.25	56.25
	<i>Grand Total</i>	1489	372.25	372.25	372.25	372.25

Table 4.3: Various age wise average tree diameter, average tree height, tree basal area, mean stem density and average tree volume of *Eucalyptus camaldulensis*

Age in Years	Net planted area (ha)	Average diameter (cm)	Average height (m)	Basal area (m ²)	Average density (ha ⁻¹)	Average volume (m ³ ha ⁻¹)
0-10	130	15	15.6	14.540	950	91.170
11-15	650	26.9	24.8	20.185	415	140.090
16-20	850	28.4	22.2	20.250	375	145.270
21-25	300	25.7	22.6	19.490	310	140.220
26-30	285	26.5	21.2	20.800	425	140.350
>30	200	24.3	23.7	15.360	385	140.990

Table 4.4: Various age0wise average tree diameter, average tree height, tree basal area, mean stem density and average tree volume of *Dalbergia sissoo*

Age in Years	Net planted area (ha)	Average diameter (cm)	Average height (m)	Basal area (m ²)	Average density (ha ⁻¹)	Average volume (m ³ ha ⁻¹)
0-10	15	10.3	10.3	9.7	840	40
11-15	100	18.2	15.9	10.8	415	85
16-20	75	26.2	19.9	13.7	230	110
21-25	90	34.9	22.9	12.2	150	130
26-30	70	40.3	24.9	14.9	118	140
>30	65	45.8	26	15	90	155

Table 4.5: Various age wise average tree diameter, average tree height, tree basal area, mean stem density and average tree volume of *Vachellia nilotica*

Age in Years	Net planted area (ha)	Average diameter (cm)	Average height (m)	Basal area (m ²)	Average density (ha ⁻¹)	Average volume (m ³ ha ⁻¹)
0-10	110	10.1	8.13	13.500	2555	52.23
11-15	210	18.2	14.40	16.930	810	120.01
16-20	125	23.0	16.55	17.280	385	145.07
21-25	203	27.1	16.08	16.285	270	160.17
26-30	163	39.2	19.60	20.522	190	220.5
>30	114	27.8	22.1	21.985	385	160.7

Age in Years	Net planted area (ha)	Average diameter (cm)	Average height (m)	Basal area (m ²)	Average density (ha ⁻¹)	Average volume (m ³ ha ⁻¹)
0-10	172	15.2	10.15	20.550	3050	55.23
11-15	123	20.3	20.45	20.485	890	125.01
16-20	126	24.1	25.60	25.390	400	150.08
21-25	236	30.2	25.10	20.390	295	165.17
26-30	120	45.5	22.65	25.600	200	225.6
>30	96	35.9	25.2	25.978	390	165.7

Table 4.6: Various age0wise average tree diameter, average tree height, tree basal area, mean stem density and average tree volume of others mix tree species

Table 4.7: Tree age-wise tree bio-mass and C reserve of *Eucalyptus camaldulensis*

Age of tree	Tree stem bio-mass (Mgha ⁻¹)	Tree bio-mass (Mgha ⁻¹)	Upper-story tree C (Mgha ⁻¹)	Under-story C (Mgha ⁻¹)
0-10	102.89	160.98	81.98	1.84
11-15	160.16	250.91	125.96	1.77
16-20	161.77	256.62	128.81	1.72
21-25	160.19	250.34	125.17	2.15
26-30	160.08	245.98	123.50	1.95
>30	160.19	252.52	126.76	1.55

Table 4.8: Tree age-wise tree bio-mass and C reserve of *Dalbergia sissoo*

Age of tree	Tree stem bio-mass (Mgha ⁻¹)	Tree bio-mass (Mgha ⁻¹)	Upper-story tree C (Mgha ⁻¹)	Under-story C (Mgha ⁻¹)
0-10	32.95	55.77	26.40	0.90
11-15	64.51	105.17	53.10	2.25
16-20	86.98	137.73	69.35	2.90
21-25	105.40	165.78	82.37	2.56
26-30	120.21	180.41	90.21	3.37
>30	125.84	196.34	98.66	3.72

Table 4.9: Tree age-wise tree bio-mass and C reserve of *Vachellia nilotica*

Age of tree	Tree stem bio-mass (Mgha ⁻¹)	Tree bio-mass (Mgha ⁻¹)	Upper-story tree C (Mgha ⁻¹)	Under-story C (Mgha ⁻¹)
0-10	20.70	30.70	15.90	15.20
11-15	25.90	35.40	20.70	15.8
16-20	24.90	40.15	20.08	15.50
21-25	25.50	38.25	20.70	20.95
26-30	30.20	45.07	25.05	20.50
>30	30.50	40.70	20.90	20.60

Table 4.10: Tree age-wise tree bio-mass and C reserve of other mixed tree species

Age of tree	Tree stem bio-mass (Mgha ⁻¹)	Tree bio-mass (Mgha ⁻¹)	Upper-story tree C (Mgha ⁻¹)	Under-story C (Mgha ⁻¹)
0-10	35.80	50.90	30.45	2.90
11-15	75.45	120.60	58.80	2.80
16-20	90.45	140.45	70.80	3.80
21-25	95.35	150.90	75.98	3.95
26-30	130.20	210.80	110.90	3.79
>30	90.25	135.80	70.40	3.50

3.4 Co-relationships of tree of age of *Dalbergia sissoo* and *Eucalyptus camaldulensis* with: tree height, tree DBH, tree carbon absorbing and CO₂ sequestration capacity

A positive relationship among age of tree species and other biometric parameters were observed in almost all species as shown in Figure 4.1 and Figure 4.2. Both figures show that with increasing the age of trees all other parameters such a tree height, tree DBH, tree carbon absorbing and CO₂ sequestration capacity were increases positively. However, this trend was higher during the early and medium ages as compared to higher ages.

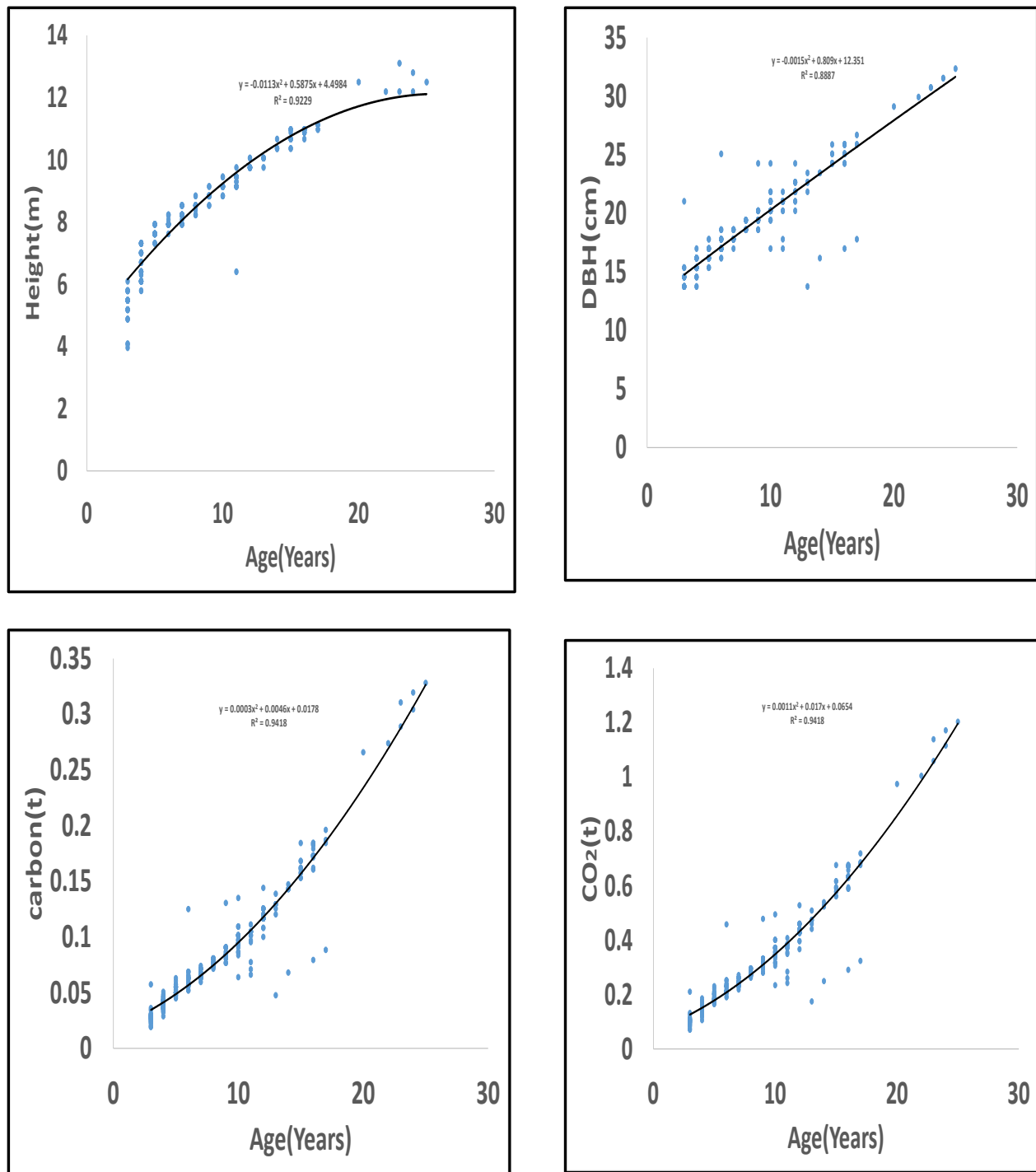


Figure 4.1: Co-relationships of tree of age of *Dalbergia sissoo* with: tree height, tree DBH, tree carbon absorbing and CO₂ sequestration capacity

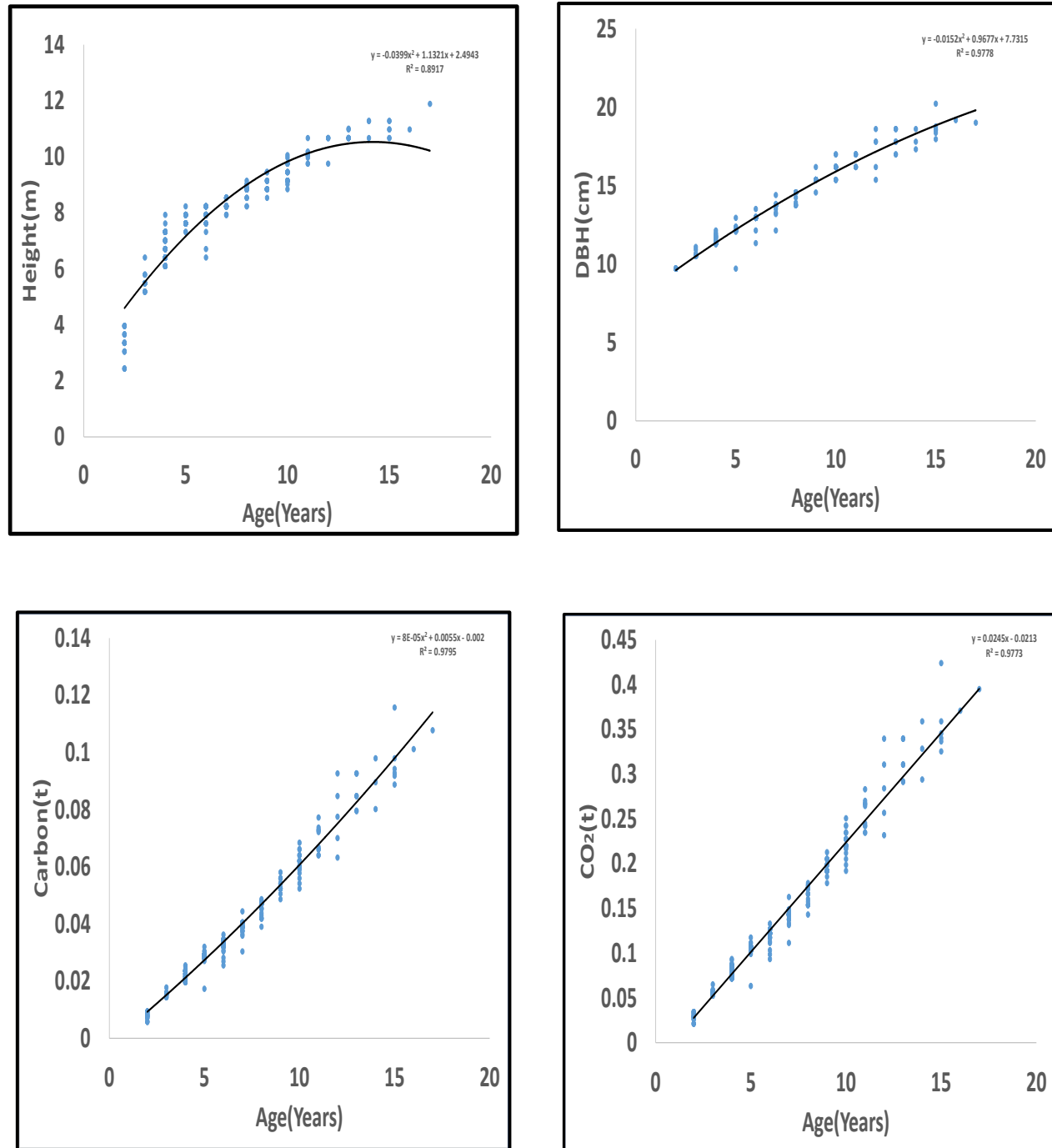


Figure 4.1: Co-relationships of the tree of the age of *Eucalyptus camaldulensis* with tree height, tree DBH, tree carbon absorbing and CO₂ sequestration capacity

4. Discussion

In the current research, the overall biomass carbon reserve change and the demographic contributions of different forest species to the total biomass change in the forest were quantified using “5-year interrupted long-term fields” observations of standing tree species, understory plants as well as soil C. According to our findings, *E. camaldulensis* had the greatest carbon storing capacity which was preceded by mix-species crops, *Dalbargia. sissoo* and *Vachellia nilotica*. Before now, the carbon

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reserve for the “Forndian forests” has been predicted to be between 263 and 11 Mg ha⁻¹. Previous, C stocks were calculated to range from 203 to 16 Mg ha⁻¹ which is far less dense than the Barringtonia floodplain forest research by Baishya *et al.* (2009), Bora *et al.* (2013), Rabha *et al.* (2014) and Borah *et al.* (2015). The reported carbon reserves were 96 Mgha⁻¹ in an agro-forestry system based on *Populus deltoides* in the “Terai region of central Himalaya” (Singh and Lodhiyal, 2009). According to Schmidt-Harsh *et al.* (2012), similarly, the estimated carbon reserve in mango trees (*Mangifera indica*) and coffee based agro-forestry systems were 121 and 73 Mgha⁻¹, correspondingly. According to Masera *et al.* (2003), the carbon-storing capacity of “agro-silvicultural systems” in “Southeast Asia's humid-tropical” ecoregion ranges from 228 to 12 Mgha⁻¹. This disparity must be directly ascribed to the fact that a significant amount of the growing stocks in Zakheera Forest are grown as a pole crop. The results of Ahmad *et al.* (2014) and Zhang *et al.* (2013) indicated that over-aged trees have more tree bio-mass and C-storing capacity than low age trees supported this observation. *E. camaldulensis* has the greatest value of mean bio-mass when it comes to a specific tree species. This is because it grows more quickly than most other tree species (Sheikh, 1993).

The findings of upper-story vegetation, lower-story vegetations as well as carbon present in the soil are the same as the findings of Saeed *et al.* (2016). Assessment of tree, shrub, herb, and grass biomasses has great importance as it provides more accuracy to estimates of forest biomass and C sequestration rates in forests. A technique known as dimension analysis (Whittaker and Feeny, 1971) and regression analysis (Rutherford, 1979) are further approaches to create a link between easily accessible plant parameters and plant bio-mass. The herbaceous and bushes of individual quadrat were selected for a study on forest paper bags that Rana *et al.* (1989) carried out in the lab, and the litter from each quadrat was included (Chhabra *et al.*, 2002). The current findings are consistent with earlier findings that estimated “architectural variables” like tree DBH and tree height, may accurately reflect the forest biomass (Foroughbakhch *et al.*, 2005). In our study, the C reserves for aboveground Bio-mass, which includes upper and lower stories, was estimated to vary from 121.44 to 20 Mgha⁻¹. According to Baishyya *et al.* (2009) and Borahh *et al.* (2015), the calculated AGB of various forest systems in “North-East Indian areas” ranged from 406 to 135 Mgha⁻¹. The reported AGB from India for various planted systems was 307-203 Mgha⁻¹ (Ramachandran *et al.*, 2007; Singh and Lodhiyal, 2009). According to Brown and Lugo (1982), the estimated AGB reserves for humid forests in “Asia and Africa” range from 450-225 Mgha⁻¹. Compared to the bio-mass and C reserves of “Amazonian floodplain forests”, which ranged from 325 to 109 Mgha⁻¹ (Terakunpisut *et al.*, 2007), the estimation of AGB in the current study is noticeably lower. Similarly, the high tree density on the river floodplain is responsible for the Barringtonia forest's high biomass stock. However, variations in growing conditions, site quality, age, structure, and management techniques can also contribute to variations in biomass stock (Goswami *et al.*, 2014). According to Coyle *et al.* (2008), the bio-mass quantity is influenced by a mixture of reserve accessibility, tree types and tree age.

The findings are remarkably similar to that of a different study that measured 85.70 Mg ha⁻¹ and was carried out in 2010 for broad-leaved vegetation in tropical forest plantations (Usuga *et al.*, 2010). The mean value of the similar tree species in the riverine Forests of the of Jehlumm of Punjab, was 331.09 to 9.1 tons ha⁻¹ in a different study (Saeed *et al.*, 2016). This disparity should be directly ascribed to a significant amount of the growing reserve in Zakheera Irrigated Forest Plantation is grown as a pole crop. Ahmad *et al.* (2014) and Zhang *et al.* (2013) observations showing developed trees possess larger tree weight/mass and C stores support this observation. *E. camaldulensis* has the greatest worth of mean weight when it comes to a specific tree/plant species. This is because it grows more quickly than most other tree species (Sheikh, 1993). The study's findings for the upper stories are comparable to those of India, another country located on the same continent. As was previously indicated, the findings of Saeed *et al.* (2016) are identical to the results of upper-story vegetation, lower-story vegetation and C in the soil. Important estimations of the biomass and carbon sequestration of forests can be made by estimating the mass of plants such as trees, shrubs, herbs, or grass. A technique known as dimension analysis (Whittaker and Feeny, 1971) and regression analysis (Rutherford, 1979) are further approaches to create a link among simply obtainable parameters.

In the study conducted for forest paper bags and brought to the lab (Rana *et al.*, 1989), the herbaceous and bushes of each quadrat were picked and the plant materials from separate quadrat were collected (Chhabra *et al.*, 2002). The current findings are consistent with earlier findings that calculated architectural variables, like the diameters and tree height, may accurately reflect the forest biomass (Foroughbakhch *et al.*, 2005). According to Baishyya *et al.* (2009), the estimated aboveground mass for various forests in the North-East Indian area ranged from around 406 to 135 Mgha⁻¹. The reported AGB from India for various planted systems was noted 307 to 203 Mgha⁻¹ by Ramachandran *et al.* (2007) and Singh and Lodhiyal, (2009). According to Brown and Lugo (1982), the aboveground mass and C reserve for the humid forest in Asian and African areas have a range of around 450 to 225 Mgha⁻¹.

Conclusions

Globally, climate change has attracted significant attention in the current times as more carbon has been emitted into the environment due to man-made activities, resulting in damaged ecosystems. According to the current study,

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, Zakheera Irrigated Forest Plantation Bahawalpur has average carbon reserves of 40.30 mgha⁻¹ in the upper story and 1.8 mgha/1 in the understory. Even though irrigated plantations are the only substantial green spaces in southern Punjab, they are primarily relevant in terms of current global atmospheric trends since they are improving the environment. With the right forest management techniques and scientific research, Punjab's potential for increasing its biomass and carbon stock through planting on the 31,223 acres of currently undeveloped land might be significantly improved.

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