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RESEARCH

Trees outside forests as climate change mitigation champions: evaluating their carbon sequestration potential and monetary value in Maharshi Dayanand University, Rohtak (Haryana), India

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Abstract The annual average increase in carbon dioxide (CO_2) concentration is touching new heights every year. Global climate change and warming are twin outcomes of record-breaking CO_2 levels. The trees outside forests (TOF) are the most promising and suitable components in the ecosystem for combating global warming via carbon (C) sequestration. Urban university campuses are the hotspot regions of TOF. We have attempted to quantify the C stock, C sequestration potential, and C credit value of dominant tree species at Maharshi Dayanand University (MDU), Rohtak. Different volumetric and biomass equations were used for biomass computation. We assessed a total of 29,442 trees (top 10) for measuring phytosociological parameters like total tree count, age, height (H), and diameter at breast height (DBH) to quantify the amount of C stored. The total C stock, C sequestration rate, and monetary value were 78.67 (Mg C ha^{-1}), 19.05 (Mg CO_2 ha^{-1} year^{-1}), and 23,101.59 \$ year^{-1}, respectively. *Eucalyptus globulus* is the most dominant tree species on the campus and topped almost all the quantitative characteristics like total tree count (~40 %), age (25 years), density (D) (55.35 trees ha^{-1}), and total C stock (16.06 ± 9.90 Mg C ha^{-1}). Tree basal area (BA), D, diversity, and H positively affected the total C stocks. When the C market becomes operational, these C credits can be traded while generating additional income for the university. The results from this study can also help calculate the total C footprint of the campus.

Keywords Tree biomass · Carbon stock · Carbon sequestration · Carbon credits

Abbreviations

CO_2	Carbon dioxide
TOF	Trees outside forests
MDU	Maharshi Dayanand University
DBH	Diameter at breast height
Mg C ha^{-1}	Megagram carbon per hectare
Mg CO_2 ha^{-1} year^{-1}	Megagram carbon dioxide per hectare
C	Carbon
CDM	Clean Development Mechanism
CER	Certified emission reduction
TOFI	Trees outside forests in India

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NCR	National Capital Region
SOC %	Soil organic carbon %
CBH	Circumference at breast height
H	Height
BA	Basal area
BD	Bulk density
D	Density
TSWD	Tree-specific wood density
BEF	Biomass expansion factor
AGB	Above-ground biomass
BGB	Below-ground biomass
TB	Total biomass
PCA	Principal component analysis
TCS	Total carbon stock
SCS	Soil carbon stock
HCA	Hierarchical cluster analysis
AGCS	Above-ground carbon stock
BGCS	Below-ground carbon stock

Introduction

Global warming, the major cause of climate change, is the most discussed topic in the scientific community, on international platforms, and among governments. Carbon dioxide (CO_2) emissions, mainly due to anthropogenic actions, are further worsening the situation. The ever-increasing population not only increases the rates of CO_2 emissions but will also be responsible for the degradation of ecosystems, fragmentation of urban settlements, and several other adverse effects (Dobbs et al., 2017; Grumbine, 2014; Yang et al., 2020). Globally, 50% of the world's population is living in urban areas, and by the year 2050, this figure will be around 70% (The World Bank, 2022). Cities, particularly in tropical countries like India, Malaysia, and Indonesia, are more prone to experience the devastating consequences of climate change (Somvichian-Clausen, 2020) and are also among the major contributors to greenhouse gases (Pan et al., 2011; Saatchi et al., 2011). The progression of climate change could be slowed down by increasing carbon (C) sinks, particularly in urban spaces. In urban areas, this sink occurs in the form of vegetation, especially trees (Amoatey & Sulaiman, 2020; Salunkhe et al., 2014). These trees in urban settlements which are not part of any recorded forests are generally referred to as trees outside forests (TOF) (FSI, 2021). Through their fast growth rates, the TOF have great potential to absorb CO_2 and effectively combat climate change (Bayat et al., 2012; Liu & Li, 2012). These TOF can also help India achieve its ambitious goal of climate neutrality by the year 2070 (Economic Times, 2023). Though TOF have been defined in the literature, there exists no definition for urban forests. Also, the concept of an urban forest is limited to home gardens, parks, and other green areas (Xie et al., 2019). Due to the substandard planning of green infrastructure in urban areas, many cities face several environmental challenges (Agbelade & Onyekwelu, 2020). The efficiency of trees in mitigating global warming is determined by their capacity to store C. The C concentration in a tree can be computed from the amount of biomass accumulated in the tree. The biomass is mainly present in stem wood, branches, and marginally in leaves and is generally calculated using allometric equations (Byrd et al., 2018; Chandra et al., 2011; Nandal et al., 2023).

Educational institutions, particularly university campuses, can play an important role in the process of C conservation. The universities have been termed "mini-cities" or "small-scale cities" due to the availability of all the facilities inside the campus only (Wibowo et al., 2019). The university campuses are the hub of TOF, and along with greenspaces form an integral part of the campus ecosystem (Arborday, 2022). Recently, universities are incorporating sustainable environmental education as a part of interdisciplinary studies for sensitizing students about C emissions and footprints (Robinson et al., 2018; Savageau, 2013). Also, some of the institutes have established environmental management systems for regular monitoring of the local environment (Varón-Hoyos et al., 2021). The soils on institutional campuses are another ecosystem component that provides many ecosystem services. The C storage and C sequestration are the most essential services provided by soils as they are the 2nd largest reservoir of C after oceans (Zhu et al., 2017). Soils have a higher capacity to store more C than trees as the rates of soil respiration are low (Richter et al., 2020). Besides, C sequestration trees also improve local environmental conditions and provide various socio-economic services for residents (Colding & Barthel, 2017; Liu et al., 2018). This can make a significant contribution towards campus sustainability. The C sequestration by trees and soils not only regulates the environment but can also be used for meeting the finance on campuses through C credits. A C credit generally means a tradable certificate and is part of the emission trading system.

The C credits became popular with the advent of the Clean Development Mechanism (CDM), part of the Kyoto Protocol in 2005. The CDM allows emission-reduction projects in developing countries to earn certified emission reduction (CER) credits, each equivalent to one tonne of CO_2. These CERs can be traded, sold, and used by industrialized countries to meet a part of their emission reduction targets under the Kyoto Protocol. With CO_2 levels roaring up to 416.55 ppm (Daily CO2, 2022), it becomes more important to take immediate steps to address climate change in the hotspots (cities). Considering climate change as a real threat, more and more campuses around the world are working for campus sustainability through green campus initiatives (Tiyarattanachai & Hollmann, 2016). Universities like Shenyang Institute of Technology (SIT) in China, Dalhousie University (USA), and Bogor Agricultural University (Indonesia) (Lavista et al., 2016; Ritchie, 2017; Wang et al., 2021) have previously worked in this direction. Several universities from India like Cotton University, Amity University, Kuvempu University, and Uttar Banga Krishi Viswavidyalaya (Nandal et al., 2019; Narayana et al., 2020; Sharma et al., 2020; Tamang et al., 2021; Yumnam & Dey, 2022) have also calculated the total C stored in campus trees. The SIT campus study provided a detailed account of campus tree structure and function and economic benefits from ecosystem services including C sequestration. Most of the other studies have not focused on the economic dimension of C sequestration by trees and soils. In addition, with the launch of the trees outside forests in India (TOFI) program, it becomes pertinent to evaluate the economic value of the dominant TOF. The study hypothesized that (a) more densely planted tree species have more C stock and (b) the phytosociological characteristics of different tree species considerably affect C sequestration rates. Thus, the study has been undertaken at Maharshi Dayanand University (MDU), Rohtak (Haryana), India, with the following primary research queries: (a) What is the C sequestration potential of trees and soils on the MDU campus? (b) What are the factors that regulate the C stock and C sequestration potential of trees on the campus? (c) What is the monetary value of C credits provided by campus trees?

Material and methods

Study site

The research investigation was undertaken at MDU (Fig. 1), Rohtak (Haryana), India. The study site is located in the country's National Capital Region (NCR). The study site lies in the Haryana state of India, one of the seven states chosen initially for the TOFI program. This program has been launched from the MDU campus itself. The university has also been awarded the cleanest and greenest government university in India in 2018. Climatically, the region lies in the sub-tropical zone. The local temperature varies from 2 to 47 °C. Annually, the region receives rainfall of around 58 cm, mainly from southwest monsoon and western disturbances. The average humidity in the region is around 65%, ranging from 13 to 98% (World Weather Online, 2023). The region is occupied by alluvial soil since the Quaternary age. The soil is mainly constituted of medium-grained sand (Central Ground Water Board, Ministry of Water Resources, RD, & GR Government of India, 2013). The campus encompasses an area of approximately 250 ha. The institution has plantations of herbs, shrubs, and trees. Along with a plant research site, there is also an herbal garden with plantations of different tree species. The campus has around 60 tree species, mainly dominated by families like *Fabaceae* and *Moraceae*. Tree species such as *Eucalyptus globulus* and *Pongamia pinnata* are abundant on the study site (Nandal et al., 2022).

Maps and spatial distribution

The study site map was generated with QGIS version 3.16 software. The spatial distribution of soil organic carbon % (SOC %) on the university campus under different tree species was constructed with the interpolation function of QGIS version 3.16 software by using the inverse weight distance method with a coefficient value of 2.0.

Sampling instruments and tools

We used a measuring tape for circumference at breast height (CBH) measurement and a Haga altimeter for measuring tree height (H). Soil samples were collected using a soil core sampler with a radius of 4.5

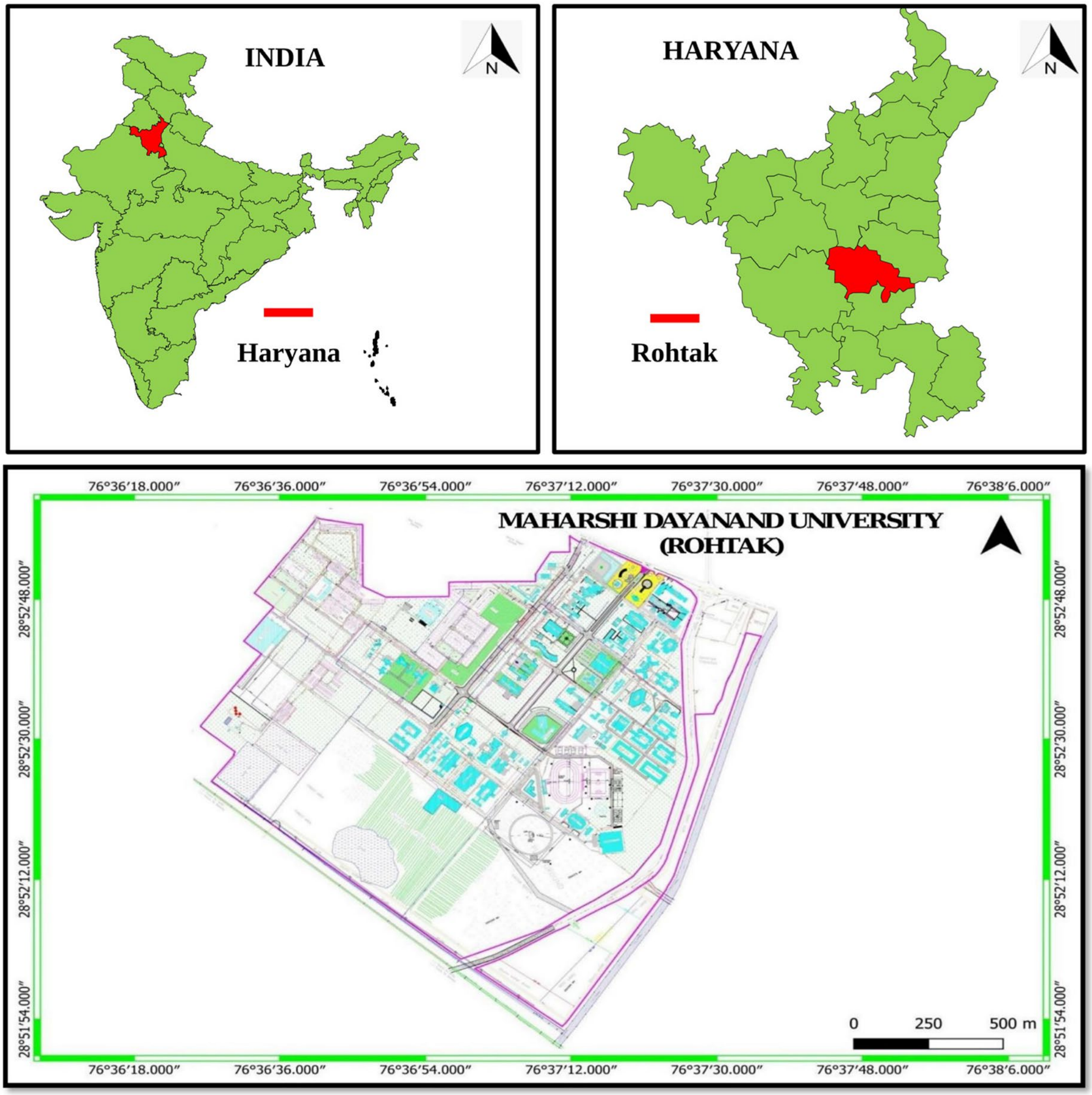


Fig. 1 Map of the study area

cm and 10 cm in H. A 2 mm sieve was used for straining soil, and an oven was used to dry soil samples.

Sampling techniques and processing

The trees were sampled for various quantitative variables like diameter at breast height (DBH), H, and basal area (BA). The tree sampling was carried out from January 2019 to December 2020. Juveniles (DBH < 4–15 cm), as well as adult (DBH > 15 cm) trees (Chaturvedi et al., 2012; Long et al., 2013), were counted. Instead of using a quadrat or plot, we manually counted all the trees on the campus. This was done to capture more precise values of tree structural attributes. Unlike natural forests, the manual and random tree plantations along with several institutional buildings did not allow for the use of the plot method. The top 10 tree species with the highest tree count were considered as dominant tree species. The trees were measured at a vertical distance of 1.37 m from the ground, i.e., breast H. The value of CBH was divided by the value of π (3.14) to get DBH. Trees with CBH~10 cm or greater (corresponding to a DBH of 4 cm) were taken into account for C stock estimation. The DBH was classified into four categories (< 9 cm, 9.1–18 cm, 18.1–27 cm, and > 27 cm). The soil samples were collected in December 2021. Soil samples were collected at four depths from 0 to 10, 10.1 to 20, 20.1 to 30, and 30.1 to 40 cm. At every depth, three sub-samples of the soil were collected and then mixed to make one composite sample. Thus, overall, 40 soil samples were collected (1 sample at each depth under 10 different tree species, accounting for 4 composite samples under a single tree species). The samples were collected at a distance corresponding to half, twice, and thrice of the canopy size of the tree, as depicted in Fig. 2 (Kokkora et al., 2022). The soil samples were sieved through a 2 mm sieve and were oven dried at 65 °C for 24 h. Bulk density (BD) was calculated with a soil core sampler using the fresh weight and oven-dried weight of soil samples at different depths with Eq. (1).

$$\mathrm{BD}\left(\frac{\mathrm{g}}{\mathrm{cm}^3}\right)=\frac{\text{Weight of oven dry soil}}{\text{Volume of soil core sampler}(\mathrm{cm})^3} \tag{1}$$

Tree quantitative parameters:

The tree density (D) and BA were calculated using the following equations:

$$\text{Density}\left(\text{trees ha}^{-1}\right)=\frac{\text{Total tree count of a particular species}}{\text{Total area (hectares)}} \tag{2}$$

$$\text{Basal area}\left(\mathrm{m}^2\mathrm{ha}^{-1}\right)=\frac{(\mathrm{DBH})^2\times\pi\times\text{tree density}}{4} \tag{3}$$

where DBH is in meters (m).

From the tree count, various diversity indices like the species dominance index (Simpson, 1949), species diversity index (Weaver & Shannon, 1963), and species evenness index (Pielou, 1975) were calculated. The species dominance index and species diversity index are employed to determine species dominance and species richness in an ecosystem. On the other hand, the species evenness index is used to detect the degree of commonness or rarity of a species. A value of 1 on the scale indicates complete evenness, and 0 indicates no evenness.

Species dominance index:

$$Ds=\frac{\Sigma n(n-1)}{N(N-1)} \tag{4}$$

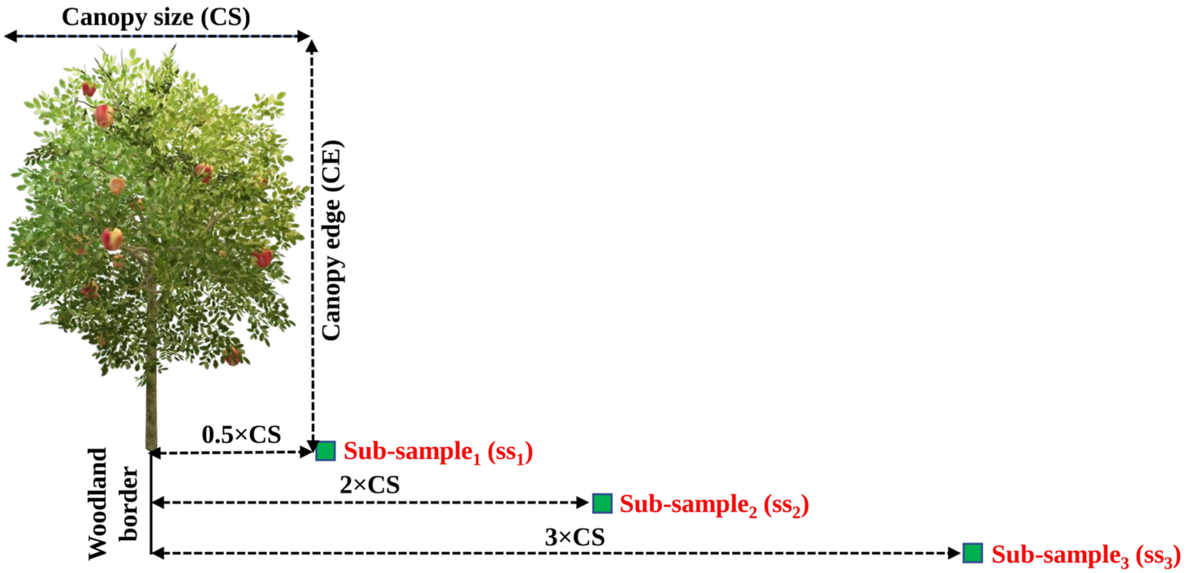


Fig. 2 Soil sample collection method

where Ds is Simpson's dominance index, n is the total number of trees of a particular species, and N is the total number of trees of all species.

Species diversity index:

$$H' = -\sum_{i=1}^{R} \mathrm{p_i} \ln \ \mathrm{p_i} \tag{5}$$

where $H^{'}$ is the Shannon-Weiner diversity index, R is the total number of tree species, and p_i is the proportion of individuals belonging to the ith tree species.

Species evenness index:

$$J' = \frac{H'}{lnS} \tag{6}$$

where $J^{'}$ is Pielou's evenness index, $H^{'}$ is the Shannon-Weiner diversity index, and S is the total number of species.

Biomass and C stock

The tree biomass was calculated by employing direct volumetric and biomass equations. All the volumetric equations were species-specific. Biomass equations on the other hand were species-specific as well as general in nature. The general biomass equation formulated by Chave et al. (2005) was used for *Callistemon lanceolatus*, *Polyalthia longifolia*, *Pongamia pinnata*, and *Terminalia arjuna* and for the rest species-specific equations were used. Already published equations in literature were used for volume and biomass. All the volumetric equations were taken from Volume Equations for Forests of India, Nepal, and Bhutan (1996), while the biomass equation for *Azadirachta indica* was taken from Mohamed et al. (2018). The tree volume obtained from volumetric equations was multiplied by tree-specific wood density (TSWD) (Appendix 1 - List of wood densities for tree species from tropical America, Africa, and Asia., 1997; Tamang et al., 2019). The results obtained were further multiplied by a biomass expansion factor (BEF) of 1.5 (to account for the biomass of other parts of the tree such as leaves, flowers, and fruits) (Brown & Lugo, 1992). In the case of biomass equations, it was assumed that BEF had already been considered while formulating the equations. This biomass obtained was above-ground biomass (AGB). The AGB was multiplied by 0.26 (Cairns et al., 1997; Ravindranath & Ostwald, 2007) to get below-ground biomass (BGB). The total biomass (TB) of the tree was calculated by adding AGB and BGB.

$$Dalbergia\ sissoo, V/DBH^2 = 0.0031/\mathrm{DBH}^2 + 0.000636 \tag{7}$$

$$Eucalyptus\ globulus, V = 0.02894 - 0.89284 \times \mathrm{DBH} + 8.72416\mathrm{DBH}^2 \tag{8}$$

$$Ficus\ \mathrm{spp.}, \sqrt{V} = 0.03629 + 3.95389 \times \mathrm{DBH} - 0.84421\sqrt{\mathrm{DBH}} \tag{9}$$

$$Syzygium\ cumini, V = 0.08481 - 1.81774 \times \mathrm{DBH} + 12.63047 \times \mathrm{DBH}^2 - 6.69555 \times \mathrm{DBH}^3 \tag{10}$$

$$Azadirachta\ indica, AGB = 0.213 \times \mathrm{DBH}^{2.109} \tag{11}$$

$$General\ biomass, AGB = 0.0509 \times \rho \times \mathrm{DBH}^2 \times H \tag{12}$$

where V is the volume of the tree, ρ is the specific wood density, DBH is the diameter at breast height (cm), and H is the tree H (m).

The tree C stock is approximately half of the biomass (Eggleston et al., 2006); thus, TB was multiplied by 0.5 to get the amount of C stored in the tree. The SOC (%) was calculated using the standard protocol of Walkley and Black (1934). All the samples were analyzed in triplicates. The SOC % was converted to SOC Mg ha^{-1} using the formula given in Eq. (13). While processing the data, we used the mean values of BD (Online Resource 1) and SOC. The total carbon stock (TCS) was obtained by adding up the tree and soil carbon stock (SCS).

$$\mathrm{SOC}\left(\mathrm{Mg\ ha^{-1}}\right) = \mathrm{SOC}\ (\%) \times \mathrm{sampling\ depth\ (m)} \times \mathrm{BD}\left(\mathrm{g\ cm^{-3}}\right) \times 10000 \tag{13}$$

C sequestration, C credits, and monetary value

The CO_2 sequestration potential of trees was obtained by multiplying the TCS value by 3.667 (44/12). Then, the obtained value of CO_2 sequestration was divided by the age of the particular tree species to get the CO_2 sequestration potential of trees on a per-year basis. We used the approximate age of trees from the information provided by the university administration, as precise data on the age of trees was lacking. Also, the mean value of the age was used as the planting of trees on the campus is a continuous process.

The value of 1 T of CO_2 sequestered by trees equals one C credit. Therefore, to calculate C credits, we used t CO_2 unit instead of Mg CO_2. The total number of C credits of a tree species was divided by the age of that tree to obtain C credits on a per-year basis. The C credits were converted into monetary value. The average value of one credit was around 3.82 $/$t$ CO_2 equivalent (ClimateTrade, 2022) in 2021. For calculating the value of one C credit in terms of C alone (not CO_2), we multiplied 3.82 by 3.667 (Pache et al., 2020), which turned out to be around 14 $. The value of one dollar was considered equal to 74 (avg. value in 2021) Indian rupees. A brief outline of the protocol followed in the present study is depicted in Fig. 3.

Statistical analysis

The data were subjected to one-way analysis of variance (ANOVA) to look for significant differences in values of various tree variables among different tree species. Correlation coefficient (r) and principal component analysis (PCA) were used to determine the correlation between the various tree variables and tree C stock. The PCA was also used for dimension reduction and to determine the effect of different tree variables on TCS. Based on the quantitative variables, the hierarchical cluster analysis (HCA) was used to combine or cluster the trees of different species. We used Ward's method for clustering the data. All the significance levels were measured at $p < 0.05$. The statistical analysis was performed using Origin Pro and SPSS 25.0 software.

Results

Tree quantitative parameters

We documented 66 tree species on the campus. Among all the documented species, the top ten dominant tree species were selected for C stock estimation. The tree D on the campus was 139.77 trees ha^{-1}. Amidst these, *Eucalyptus globulus*, with a total tree count of 13,932 (39.59%), has the highest tree count on the study site, and *Dalbergia sissoo* has the lowest tree count of 504 trees. The oldest plantations were of *Eucalyptus globulus* (25 years), closely followed by *Callistemon lanceolatus* (23 years), and *Syzygium cumini* plantations were the youngest one (10 years). The DBH (cm) ranged from 4.07 in *Polyalthia longifolia* to 34.39 cm in *Eucalyptus globulus*. Around 35% (maximum contribution) of the trees of *Dalbergia sissoo* were below 9 cm of DBH. In the range of 9–18

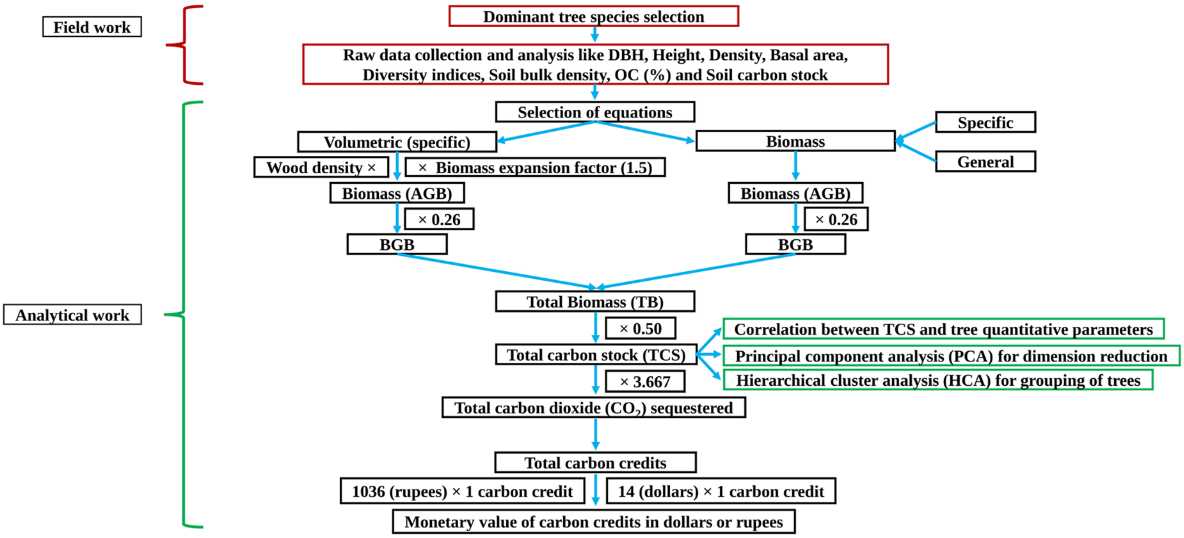


Fig. 3 Research protocol in a nutshell

(cm) DBH, *Ficus benjamina* and *Polyalthia longifolia* were the maximum contributors, with approximately 50–55% of their total trees in this range. Around 40% of the total trees of *Pongamia pinnata* were present in the DBH range of 18.1–27 cm. *Eucalyptus globulus* and *Syzygium cumini* trees dominated the class with DBH greater than 27 cm. Tree species like *Dalbergia sissoo*, *Ficus benjamina*, and *Polyalthia longifolia* were not represented in the DBH class above 27 cm (Fig. 4). The highest mean DBH (cm) was recorded in the case of *Eucalyptus globulus* (21.19 ± 11.46 cm) and the lowest in *Polyalthia longifolia* (10.95 ± 7.63 cm). There was a huge variation in the H (m) among all the measured tree species, i.e., statistically significant at $p < 0.05$. A pattern similar to that of DBH was observed in the case of tree H as well with *Eucalyptus globulus* (14.60 ± 7.13 m) being the tallest and *Polyalthia longifolia* (5.19 ± 1.69 m) being the shortest. *Eucalyptus globulus* with a tree D of 55.35 trees ha^{-1} was the most densely planted tree species, and *Dalbergia sissoo*, on the other hand, was sparsely planted (2.00 trees ha^{-1}). The BA of a tree was expanded to a per-hectare basis by multiplying the BA of a single tree with its D. Maximum BA was reported in *Eucalyptus globulus* (1.926 m^2 ha^{-1}) and minimum in *Dalbergia sissoo* (0.037 m^2 ha^{-1}). Overall, Simpson's dominance index, Shannon's diversity index, and Pielou's evenness index values were 0.184, 2.509, and 0.598, respectively. These values suggest a moderate level of biodiversity on the campus. Relatively, the value of Simpson's dominance index was highest in *Eucalyptus globulus* (0.15679) and lowest in *Dalbergia sissoo* (0.00020). A similar trend was also observed for Shannon's diversity and Pielou's evenness index (Table 1). The bold values in Table 1 are minimums.

Tree biomass and C stock

The biomass on per tree basis, obtained from volumetric and biomass equations, did not show any significant difference. The TB of these 10 tree species was 1999.39 Kg, and the mean was 199.93 Kg. The maximum AGB, BGB, and TB were recorded in *Eucalyptus globulus* (this was on the same lines as the 1st hypothesis of the study), having respective values of 304.65 ± 317.60 (Kg/tree), 79.21 ± 82.58 (Kg/tree), and 383.86 ± 400.18 (Kg/tree). The AGB, BGB, and TB were reported as a minimum in

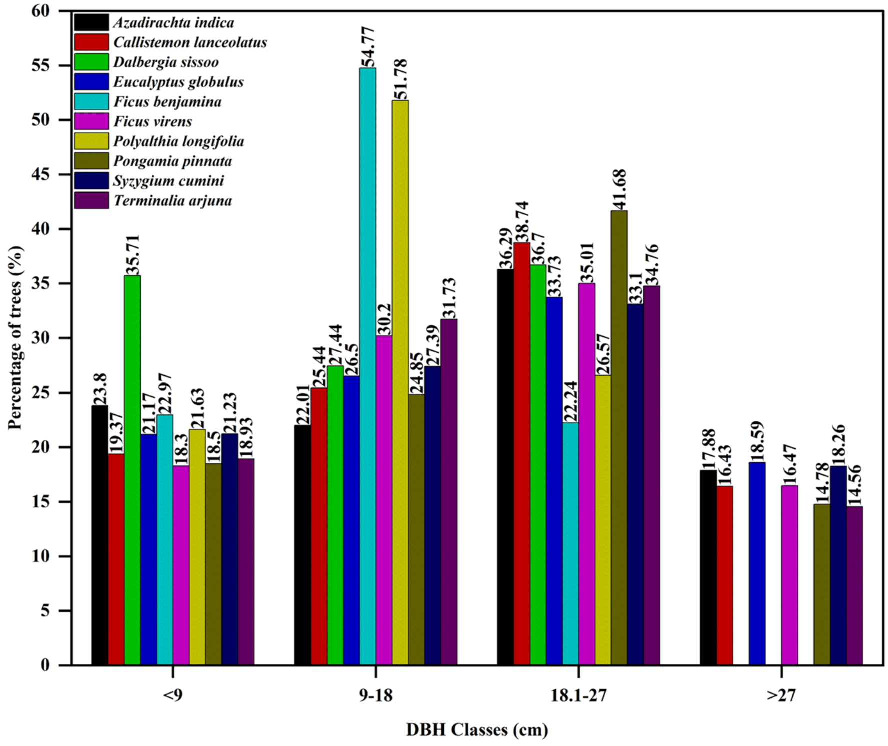


Fig. 4 Percentage distribution of trees in different DBH classes

Table 1 Various quantitative parameters of the dominant tree species

S. no.	Tree species	Age (years)	Total no. of trees	Mean DBH (cm)	H[a] (m)	D (trees ha^{-1})	BA (m^2 ha^{-1})	Simpson's index	Shannon's index	Pielou's index	TSWD (g cm^{-3})
1	*Azadirachta indica A. Juss.*	15	230	20.38 ± 10.87	8.25 ± 2.06	8.46	0.279	0.00366	0.16978	0.04052	0.68
2	*Callistemon lanceolatus D.C.*	23	955	17.84 ± 9.30	8.43 ± 2.48	3.79	0.094	0.00074	0.09789	0.02337	0.83
3	*Dalbergia sissoo Sensu Miq.*	15	**504**	15.54 ± 7.32	7.22 ± 2.01	**2.00**	**0.037**	**0.00020**	**0.06082**	**0.01452**	0.68
4	*Eucalyptus globulus Labill.*	25	13932	21.19 ± 11.46	14.60 ± 7.13	55.35	1.926	0.15679	0.36683	0.08756	0.64
5	*Ficus racemosa L.*	14	2748	15.38 ± 7.07	5.67 ± 1.86	10.92	0.207	0.00610	0.19914	0.04753	0.65
6	*Ficus virens Aiton*	11	2185	17.82 ± 9.51	6.85 ± 2.33	8.68	0.214	0.00386	0.17258	0.04119	0.65
7	*Polyalthia longifolia (Sonn.) Thwaites*	16	1454	**10.95 ± 7.63**	**5.19 ± 1.69**	5.78	0.054	0.00171	0.13167	0.03143	**0.45**
8	*Pongamia pinnata (L.) Pierre*	13	3010	17.57 ± 9.75	5.85 ± 1.86	11.96	0.286	0.00732	0.21034	0.05020	0.73
9	*Syzygium cumini (L.) Skeels*	**10**	876	18.57 ± 9.75	6.84 ± 2.06	3.48	0.093	0.00062	0.09195	0.02195	0.70
10	*Terminalia arjuna (Roxb. ex DC.) Wight & Arn.*	18	1648	19.13 ± 9.79	6.54 ± 1.92	6.55	0.190	0.00219	0.14338	0.03422	0.68

[a] Significant at $p < 0.05$

Polyalthia longifolia with values of 22.75 ± 29.43 (Kg/tree), 5.91 ± 7.65 (Kg/tree), and 28.66 ± 37.08 (Kg/tree), respectively.

The total AGB, BGB, and TB were also recorded in the same order as that of biomass on a per-hectare basis. A total of 31.64 Mg C ha^{-1} (mean 3.16 Mg C ha^{-1}) of biomass was stored in the dominant tree species. *Eucalyptus globulus* was flagged as the highest biomass-accumulating species with 16.86 ± 17.58 (Mg C ha^{-1}), 4.38 ± 4.57 (Mg C ha^{-1}), and 21.24 ± 22.15 (Mg C ha^{-1}) values of AGB, BGB, and TB, respectively (Table 2). *Polyalthia longifolia* has the least amount of biomass, with values corresponding to 0.13 ± 0.17 (Mg C ha^{-1}) of AGB, 0.03 ± 0.04 (Mg C ha^{-1}) of BGB, and 0.17 ± 0.21 (Mg C ha^{-1}) of TB. The amount of biomass stored in trees was significantly different among the different tree species. Except for *Eucalyptus globulus* (8.43 ± 8.79 Mg C ha^{-1}), the above-ground carbon stock (AGCS) levels were quite low and comparable with each other. Similarly, below-ground carbon stock (BGCS) amounts in all the tree species were also very less. Among various tree species, AGCS and BGCS were statistically different. Based on the amount of SOC % in soil samples, 60% of the samples had medium (0.40–0.75%) levels of SOC %. The rest 40% of soil samples under trees, viz., *Callistemon lanceolatus*, *Eucalyptus globulus*, *Polyalthia longifolia*, and *Syzygium cumini*, had low (< 0.40) levels of SOC % (Fig. 5).

The SOC (Mg C ha^{-1}) did not follow a definite path with increasing depth. A maximum value of 13.19 (Mg C ha^{-1}) of SOC was recorded at surface levels, i.e., 0–10 cm depth under *Dalbergia sissoo* (Online Resource 2). The mean peak SOC amount (9.07 ± 2.89 Mg C ha^{-1}) was recorded in *Ficus virens*. The SOC values in the case of *Polyalthia longifolia* 2.46 ± 1.54 (Mg C ha^{-1}) were at the trough. A significant difference was observed among the mean SOC values. These tree species stored a TCS of 78.67 (Mg C ha^{-1}) with a mean value of 7.86 (Mg C ha^{-1}). The maximum TCS amount was stored in *Eucalyptus globulus* (16.06 ± 9.90 Mg C ha^{-1}) plantations. Apart from this, tree species like *Ficus virens* (10.21 ± 2.21 Mg C ha^{-1}) and *Ficus benjamina* (8.03 ± 5.83 Mg C ha^{-1}) had comparable amounts of C stocks. The least amount of TCS was recorded in *Polyalthia longifolia* (2.55 ± 0.81 Mg C ha^{-1}). The TCS values varied significantly among different tree species (Table 2). The bold values in Table 2 are minimal.

C sequestration, C credits, and monetary value

The total and mean values for CO_2 sequestration on a per-year basis were 19.05 (Mg CO_2 ha^{-1} year^{-1}) and 1.90 (Mg CO_2 ha^{-1} year^{-1}), respectively. In terms of the total CO_2 sequestered, the *Eucalyptus globulus* species topped the list with a value of 58.79 ± 36.25 (Mg CO_2 ha^{-1}), followed by *Ficus virens* (37.37 ± 8.09 Mg CO_2 ha^{-1}). The rest of the tree species such as *Ficus benjamina* (29.38 ± 21.34 Mg CO_2 ha^{-1}), *Dalbergia sissoo* (25.98 ± 12.25 Mg CO_2 ha^{-1}), and *Azadirachta indicia* (25.02 ± 0.96 Mg CO_2 ha^{-1}) had equivalent values of CO_2 sequestration. *Callistemon lanceolatus* (13.53 ± 3.74 Mg CO_2 ha^{-1}) and *Polyalthia longifolia* (9.33 ± 2.95 Mg CO_2 ha^{-1}) sequestered the least amount of CO_2. The CO_2 sequestered per year was maximum in *Ficus virens* (3.40 ± 0.74 Mg CO_2 ha^{-1} year^{-1}), while *Eucalyptus globulus* (2.35 ± 1.45 Mg CO_2 ha^{-1} year^{-1}), *Syzygium cumini* (2.16 ± 0.69 Mg CO_2 ha^{-1} year^{-1}), and *Dalbergia sissoo* (2.09 ± 1.52 Mg CO_2 ha^{-1} year^{-1}) had almost similar rates of CO_2 sequestration (Table 3).

The CO_2 sequestration rates were markedly different among different tree species at $p < 0.05$. The trees on the university campus could furnish 1663.58 C credits in 1 year. A massive number of total C credits (approximately 10 times as compared to other species) were provided by the *Eucalyptus globulus* (21552.87). Among other species, *Ficus virens* (2339.92) and *Ficus benjamina* (1792.25) contributed more C credits. A similar trend was observed in yearly C credits contribution where more credits were supplied by *Eucalyptus globulus* (862.11), and the rest of the tree species had a lesser contribution. The lowest values have been highlighted in Table 3. The monetary valuation of the tree species was calculated based on the C credits supplied by trees in 1 year. The total price of these C credits (annually) was around 23,101.59 $ (1,709,518 rupees). The *Eucalyptus globulus* plantations with the highest monetary value could provide 12,069.60 $ (893,151.10 rupees) in a year. *Ficus virens* too had a good monetary value of 2978.07 $ (220,377.53 rupees) (Fig. 6).

Table 2 Biomass and C stock values for soil and different tree species

S. no.	Tree species	AGB (Kg/tree)	BGB (Kg/tree)	TB (Kg/tree)	AGB[a] (Mg C ha^{-1})	BGB[a] (Mg C ha^{-1})	TB[a] (Mg C ha^{-1})	AGCS[a] (Mg C ha^{-1})	BGCS[a] (MG C ha^{-1})	Soil C[a] stock (Mg C ha^{-1})	TCS[a] (Mg C ha^{-1})
1	*Azadirachta indica A. Juss.*	53.38 ± 139.01	39.88 ± 36.14	193.26 ± 175.15	1.30 ± 1.18	0.34 ± 0.31	1.64 ± 1.48	0.65 ± 0.59	0.17 ± 0.15	6.02 ± 0.54	6.84 ± 0.26
2	*Callistemon lanceolatus D.C.*	161.37 ± 167.01	41.96 ± 43.42	203.32 ± 210.43	0.61 ± 0.63	0.16 ± 0.16	0.77 ± 0.80	0.31 ± 0.32	0.08 ± 0.08	3.31 ± 1.35	3.70 ± 1.02
3	*Dalbergia sissoo Sensu Miq.*	183.12 ± 144.75	47.61 ± 37.63	230.74 ± 182.38	0.37 ± 0.29	0.10 ± 0.08	0.46 ± 0.36	0.18 ± 0.14	0.05 ± 0.04	6.87 ± 4.55	7.10 ± 3.35
4	*Eucalyptus globulus Labill.*	304.65 ± 317.60	79.21 ± 82.58	383.86 ± 400.18	16.86 ± 17.58	4.38 ± 4.57	21.24 ± 22.15	8.43 ± 8.79	2.19 ± 2.28	5.44 ± 1.36	16.06 ± 9.90
5	*Ficus racemosa L.*	125.81 ± 127.48	32.71 ± 33.15	158.52 ± 160.63	1.37 ± 1.39	0.36 ± 0.36	1.73 ± 1.75	0.69 ± 0.70	0.18 ± 0.18	7.16 ± 1.44	8.03 ± 5.83
6	*Ficus virens Aiton*	207.81 ± 222.45	54.03 ± 57.84	261.83 ± 280.28	1.80 ± 1.93	0.47 ± 0.50	2.27 ± 2.43	0.90 ± 0.97	0.23 ± 0.25	9.07 ± 2.89	10.21 ± 2.21
7	*Polyalthia longifolia (Sonn.) Thwaites*	**22.75 ± 29.43**	**5.91 ± 7.65**	**28.66 ± 37.08**	**0.13 ± 0.17**	**0.03 ± 0.04**	**0.17 ± 0.21**	**0.07 ± 0.08**	**0.02 ± 0.02**	**2.46 ± 1.54**	**2.55 ± 0.81**
8	*Pongamia pinnata (L.) Pierre*	97.63 ± 108.46	25.38 ± 28.20	123.02 ± 136.66	1.17 ± 1.30	0.30 ± 0.34	1.47 ± 1.63	0.58 ± 0.65	0.15 ± 0.17	5.68 ± 2.72	6.42 ± 2.56
9	*Syzygium cumini (L.) Skeels*	213.87 ± 213.20	55.61 ± 55.43	269.48 ± 268.63	0.74 ± 0.74	0.19 ± 0.19	0.94 ± 0.93	0.37 ± 0.37	0.10 ± 0.10	5.44 ± 2.22	5.90 ± 1.88
10	*Terminalia arjuna (Roxb. ex DC.) Wight & Arn.*	116.43 ± 110.33	30.27 ± 28.69	146.70 ± 139.01	0.76 ± 0.72	0.20 ± 0.19	0.96 ± 0.91	0.38 ± 0.36	0.10 ± 0.09	5.91 ± 2.61	6.39 ± 2.21

[a] Significant at $p < 0.05$

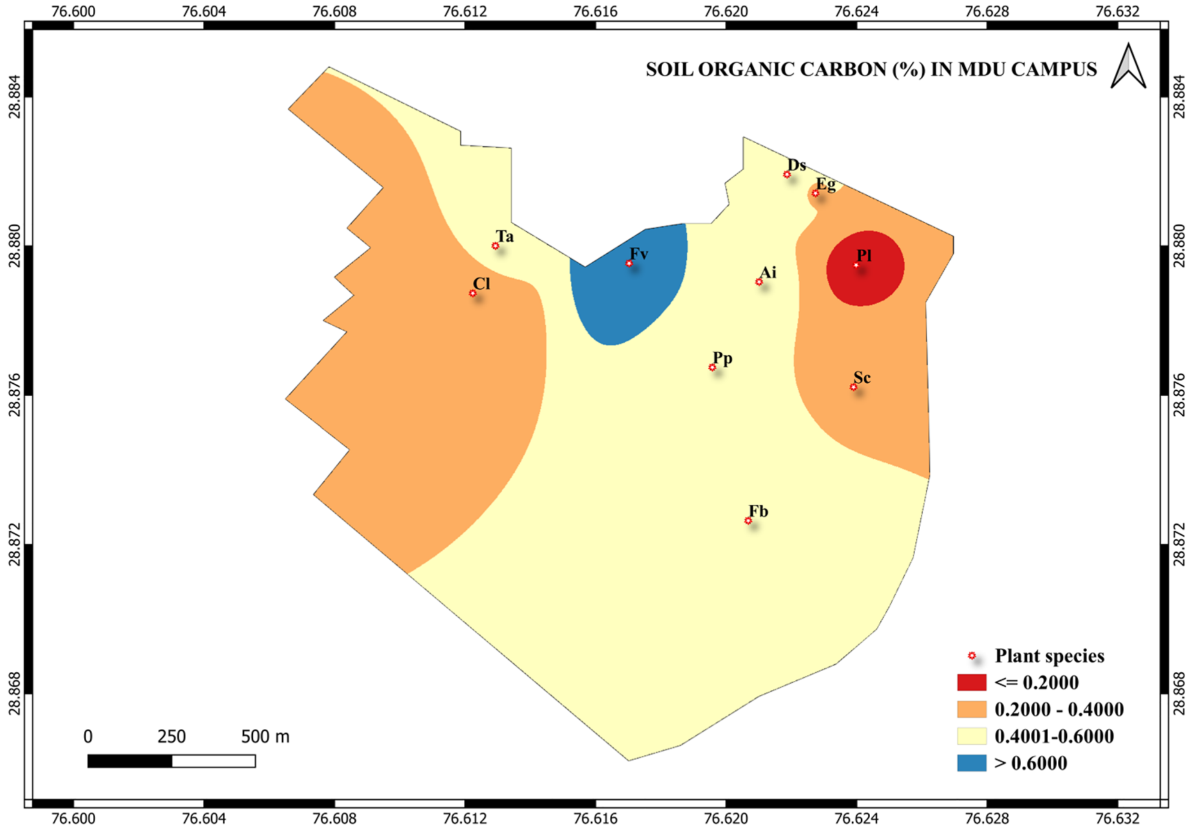


Fig. 5 SOC (%) distribution on the campus

Table 3 C sequestration potential and C credits of different tree species

S. no.	Tree species	CO_2[a] sequestered (Mg CO_2 ha^{-1})	CO_2[a] sequestered (Mg CO_2 ha^{-1} $year^{-1}$)	Total C credits	C credits ($year^{-1}$)
1	*Azadirachta indica A. Juss.*	25.02 ± 0.96	1.67 ± 0.06	1681.57	112.10
2	*Callistemon lanceolatus (Sm.) Sweet*	13.53 ± 3.74	0.59 ± 0.16	795.11	34.57
3	*Dalbergia sissoo D.C.*	25.98 ± 12.25	1.73 ± 0.81	505.12	33.67
4	*Eucalyptus globulus Labill.*	58.79 ± 36.25	2.35 ± 1.45	21552.87	862.11
5	*Ficus benjamina L.*	29.38 ± 21.34	2.09 ± 1.52	1792.25	128.02
6	*Ficus virens Aiton*	37.37 ± 8.09	3.40 ± 0.74	2339.92	212.72
7	*Polyalthia longifolia (Sonn.) Thwaites*	**9.33 ± 2.95**	**0.58 ± 0.18**	**181.01**	**11.31**
8	*Pongamia pinnata (L.) Pierre*	23.48 ± 9.37	1.81 ± 0.72	1513.67	116.44
9	*Syzygium cumini (L.) Skeels*	21.61 ± 6.89	2.16 ± 0.69	972.32	97.23
10	*Terminalia arjuna (Roxb. ex DC.) Wight & Arn.*	23.38 ± 8.10	1.30 ± 0.45	997.20	55.40

[a]Significant at $p < 0.05$

Correlation, PCA, and HCA

The correlation between tree variables was projected in the form of a network (Fig. 7). The thick lines of connection project more interrelationships, and the thin lines demonstrate a lesser association. The color scale depicts the value of the correlation coefficient (*r*) and is represented by lines

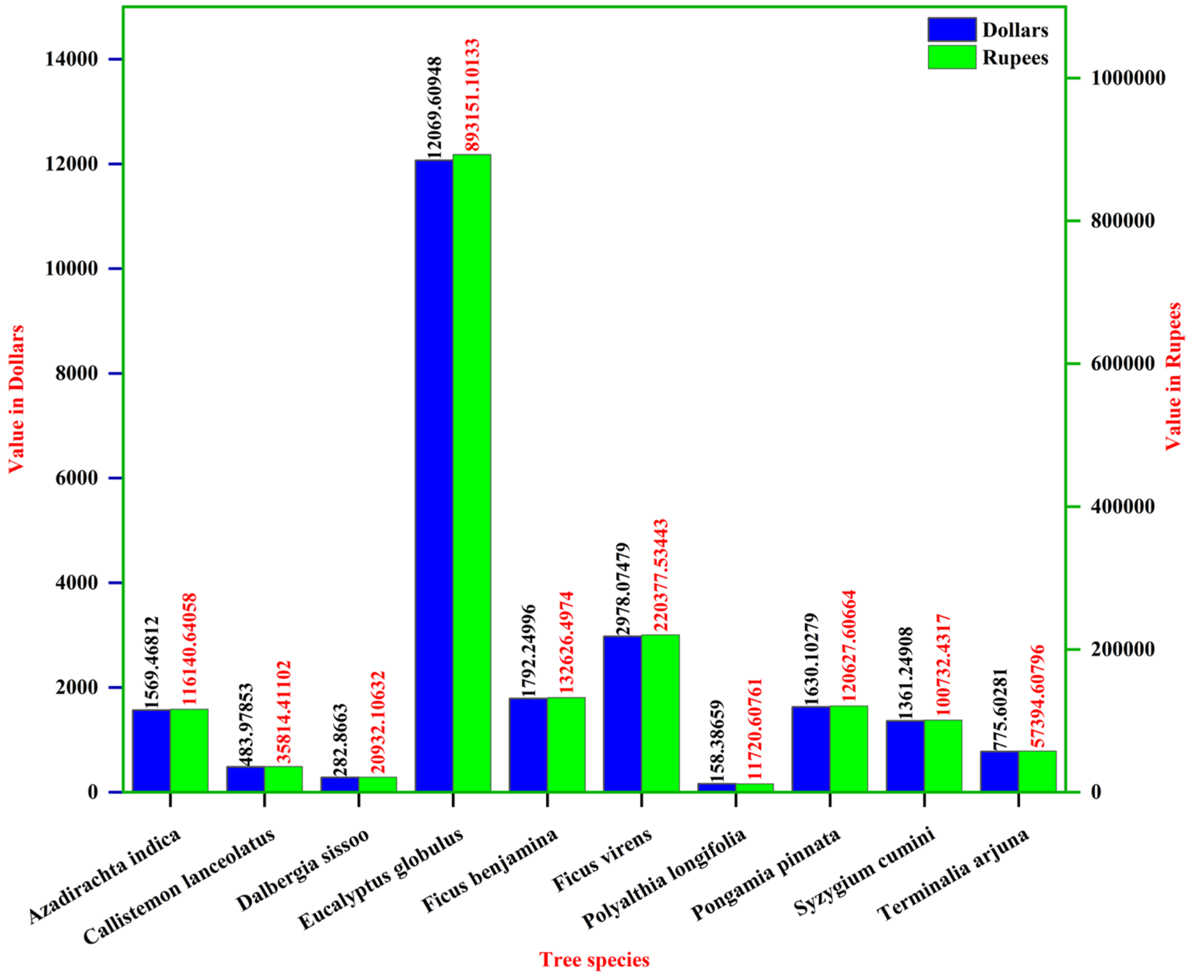


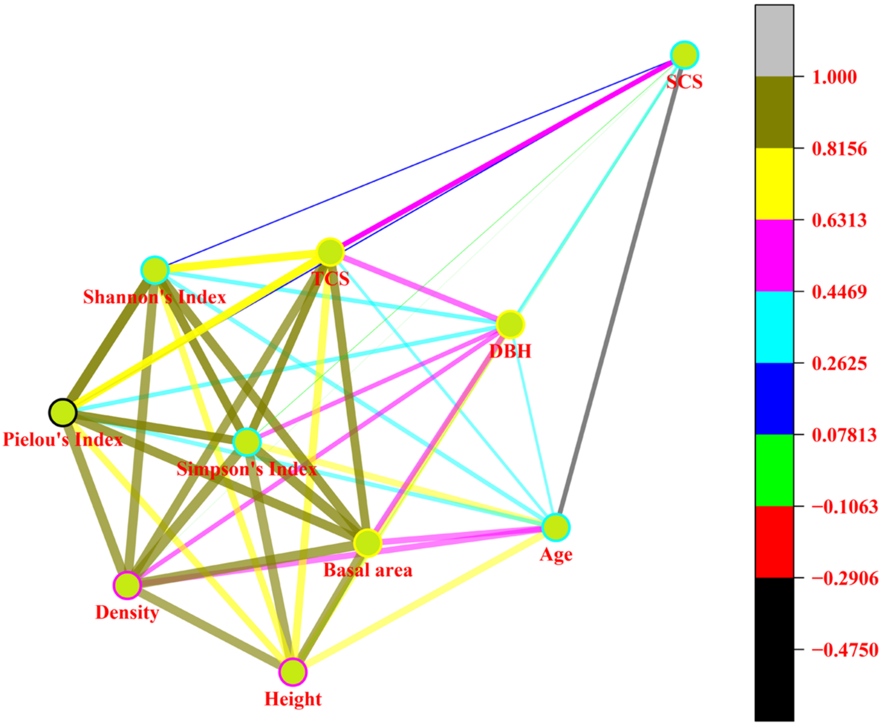
Fig. 6 Monetary value from C credits (annually) by different tree species

connecting various tree variables in Fig. 7. The majority of the tree variables like H, DBH, age, and D were highly and positively associated with each other. Shannon's diversity index and Pielou's evenness index were perfectly complementing each other (r = 1). The tree BA was very closely linked with D and Simpson's dominance index having "r" values of 0.994 and 0.992, respectively. Other than this a strong correlation was also observed between D and Simpson's dominance index (r = 0.998). However, SCS did not show any significant coupling with other variables but feebly had a negative correlation with age, H, and Simpson's dominance index. The "r-value" suggested that TCS was significantly correlated with the BA (r = 0.859) and D (r = 0.853). Also, a strong correlation of TCS with tree dominance (r = 0.834), diversity, and evenness of trees each having an "r" value of 0.804 was observed. Tree H also significantly affected the TCS levels. There was a weak correlation of TCS with DBH, SCS, and age (Online Resource 3).

The tree parameters were dominantly explained in the 1st two principal components (PCs). These both PCs had an eigenvalue greater than 1 and accounted for 86.04% of the variance. Except for SCS, all other tree variables along with TCS were explained in the 1st PC itself. The SCS was present in the 2nd PC (Fig. 8).

The PCA also confirmed that D and BA have more bearing on the TCS as compared to other variables (Online Resource 4). Based on the measured values of tree parameters, two clusters were generated from

Fig. 7 Correlation among different tree variables in the form of a network



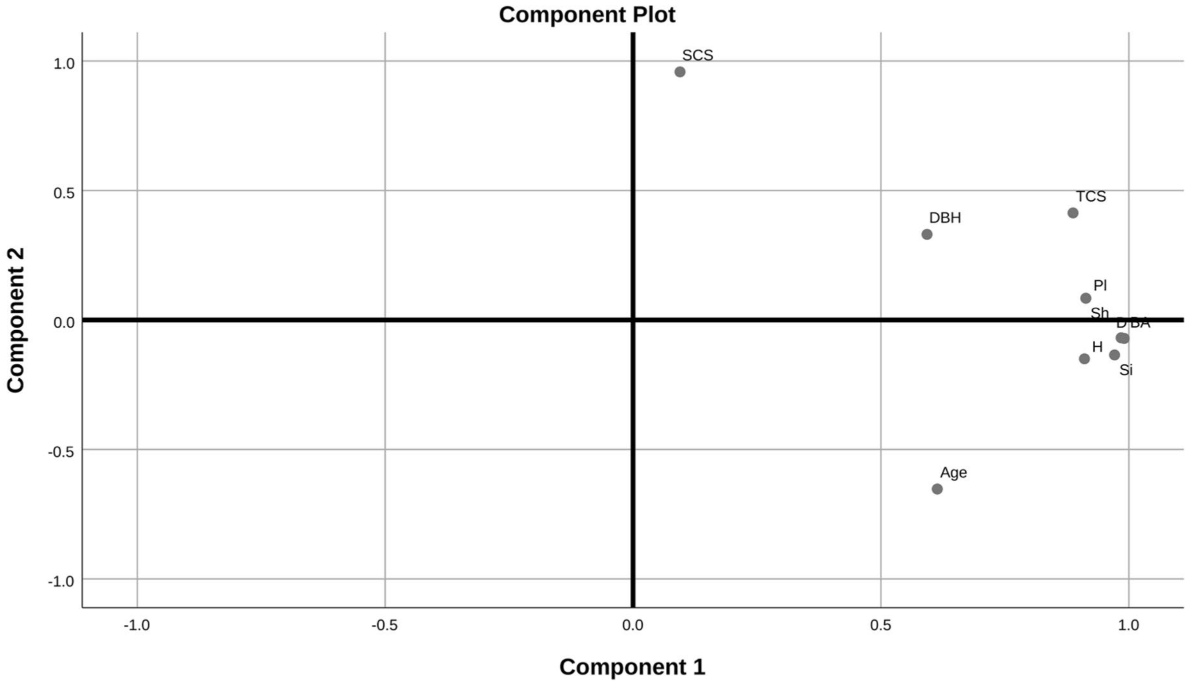


Fig. 8 PCA biplot for various quantitative parameters DBH, H, D, BA, Simpson's dominance index (Si), Shannon's diversity index (Sh), and Pielou's evenness index (Pl), SCS, and TCS

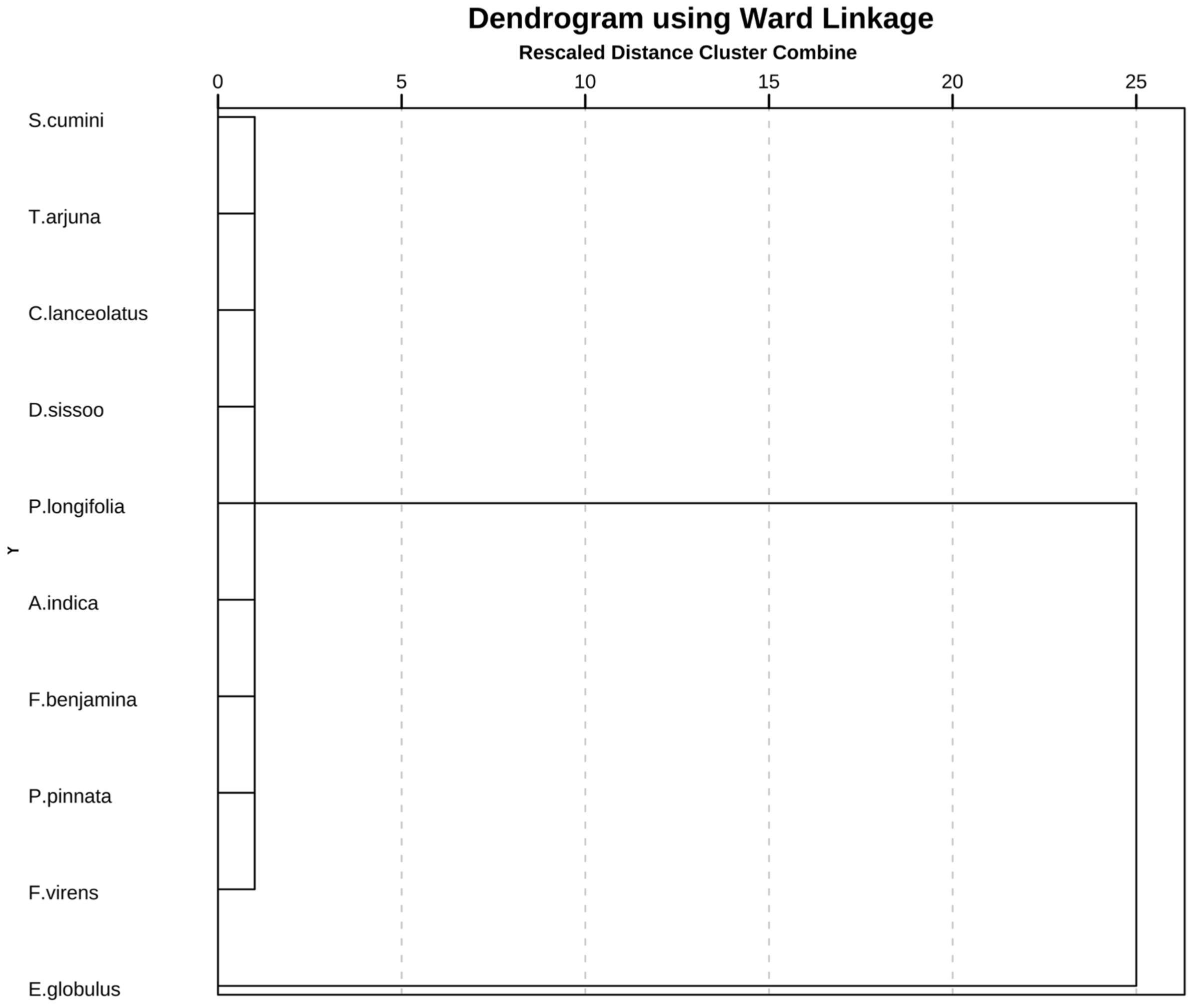


Fig. 9 HCA for various tree species using Ward's method

HCA. All the tree species except *Eucalyptus globulus* (in the 2nd cluster) were combined in the 1st cluster (Fig. 9).

Contribution of different tree species

Eucalyptus globulus was the leading tree species that contributed around 20% to the TCS. *Ficus* species contributed approximately 10–12% towards TCS values. *Callistemon lanceolatus* and *Polyalthia longifolia* contributed less than 5% to the TCS.

The % values of contribution towards monetary value varied widely from 66.66 in *Eucalyptus globulus* to 0.55% in *Polyalthia longifolia*. Apart from this, each tree species contributed less than 10% towards monetary value (Fig. 10).

Discussion

The quantifiable characteristics of a tree-like DBH, H, BA, and diversity largely affect tree ecology. The study demonstrates that every tree species contributes differently to biomass and C stock. The variation in tree variables and the effect of these

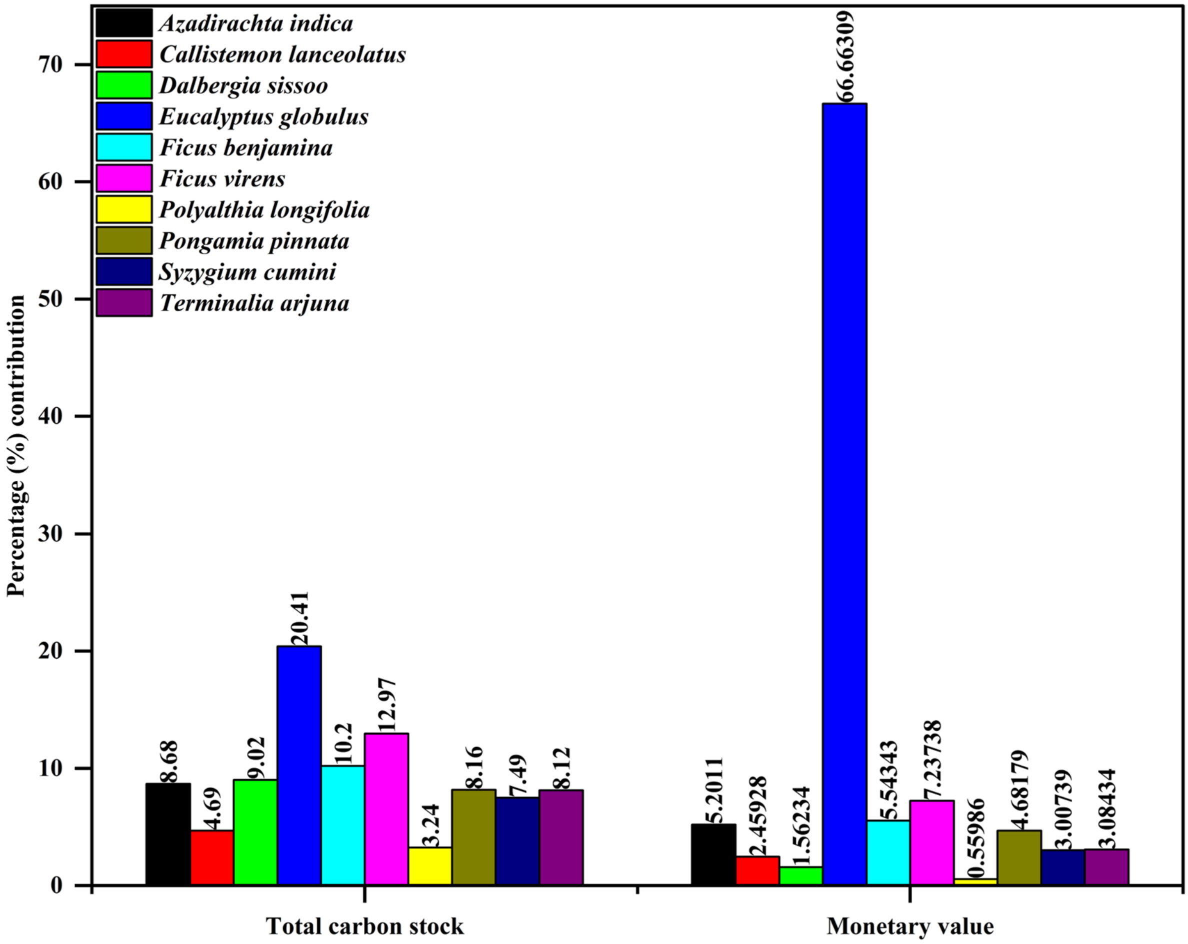


Fig. 10 Percentage (%) contribution of different species towards TCS and monetary value on MDU campus

variables on tree biomass and C stock have been described in the following section.

Phytosociological characteristics of trees

The total number of tree species (66) recorded from the university campus was identical to the tree species documented at Tripura University Campus (Deb et al., 2016), India, and Shenyang Institute of Technology (Wang et al., 2021), China. The tree species were less as compared to the Pondicherry University campus (139 species) (Sundarapandian et al., 2014) and Dalhousie University campus (71 species) (Ritchie, 2017) and quite higher than other campuses (Table 4).

The ten dominant tree species account for 85% of the total tree cover on the campus which is more as compared to SIT (China) where dominant species accounted for 76.5% of the total tree cover. Unlike other institutional campuses where the number of trees of different species was planted in comparable numbers, the MDU campus has huge plantations of *Eucalyptus globulus* (39.59%). The precise data on the age of plantations on the other campuses were not available. The DBH values of trees from other campuses suggested that the plantations on the MDU campus were quite young (Islam, 2013; Yumnam & Dey, 2022). The DBH range (4.07–34.39 cm) in the present study was quite low as compared to trees at Cotton University (up to 142 cm) but was comparable to trees of Tripura University (around 35–40 cm). This indicates that the stems are thinner on the university campus. The H of trees ranged from 3.6 to 23.7 m. The tree H measurement data were not

Table 4 Comparison of results obtained in the present study with other studies

S. no.	University	Country	Total species	D (trees ha^{-1})	C stock (Mg C ha^{-1})	Reference
1	Maharshi Dayanand University	India	66	139.77	78.67	Present study
2	Cotton University	India	47	370	346.14	Yumnam and Dey (2022)
3	Pundibari campus of Uttar Banga Krishi Viswavidyalaya	India	95	–	403.17	Tamang et al. (2021)
4	Amity University	India	45	–	38.14	Sharma et al. (2020)
5	Kuvempu University Campus Forest Area	India	–	–	414.58	Narayana et al. (2020)
6	Dalhousie University's Studley campus	Canada	71	42	411.86	Ritchie (2017)
	Dalhousie University's Carleton campus			35	78.92	
	Dalhousie University's Sexton campus			33	53.52	
7	Bogor Agricultural University, Darmaga campus	Indonesia	–	–	27.36	Lavista et al. (2016)
8	Tripura University Campus	India	66	–	5.36	Deb et al. (2016)
9	Jnana Bharathi Campus, Bangalore University	India	55	–	49.71	Kumar et al. (2015)
10	Pondicherry University campus	India	139	66	8.7	Sundarapandian et al. (2014)
11	Agroforestry & Environmental Science Sher Bangla Agricultural University	Bangladesh	38	1096.88	174.24	Islam (2013)
12	University of Auburn	USA	139	–	41.9	Martin et al. (2012)

recorded by studies conducted in other universities. The H of the trees was quite similar to the trees of the University of Pennsylvania (Bassett, 2015). This huge variation in tree H may be due to differences in plantation timings and other management practices (Amoatey & Sulaiman, 2020). In terms of tree D (139.77 trees ha^{-1}), the MDU campus fared better, except Agroforestry and Environmental Science Sher Bangla Agricultural University which had an exceptionally good D of 1096.88 tree ha^{-1} (Islam, 2013) and Cotton University (370 tree ha^{-1}) (Yumnam & Dey, 2022). The total BA of the dominant tree species was 3.38 m^2 ha^{-1}. This value was very less in comparison with trees at Agroforestry and Environmental Science Sher Bangla Agricultural University which had a BA of 32.48 m^2 ha^{-1}. Contrary to this, the BA in Tripura University (1.95 m^2 ha^{-1}) and Pondicherry University (2.94 m^2 ha^{-1}) (Sundarapandian et al., 2014) was in agreement with our results. This was attributed to the lower DBH values of the trees on the campus. The individual diversity indices were not so significant for comparison and also, we did not find any such study on university campuses that has taken diversity indices into account. Therefore, we compared the total value of these indices with values from natural forests for validation. The tree dominance levels (2.50) and tree evenness (6.209) levels were lower than trees in Eastern Ghats in India with dominance and evenness of 3.87 and 10.75, respectively (Naidu & Kumar, 2016). The individual index values were used to study the relationship between tree diversity and C stock.

Factors affecting biomass and C accumulation in trees

The biomass and C stock in urban forests is mainly accumulated in the form of vegetation, litter, and SCS. We measured the biomass and C stock from two components, i.e., vegetation and soil. The TB (31.64 Mg C ha^{-1}) and C stock (78.67 Mg C ha^{-1}) in the present study were quite high as compared to Tripura University where the biomass storage capacity of the trees was around 11 Mg C ha^{-1} and the C stock was 5.36 Mg C ha^{-1} (Deb et al., 2016). The TCS values of the present study were faintly closer to C stocks at Jnana Bharathi Campus, Bangalore University (Kumar et al., 2015). Despite having smaller DBH, the trees of the MDU campus stored more biomass and C; this was probably due to the large number of trees on campus. The DBH of trees is the main factor that regulates C storage in trees. The tree biomass is determined using stem volume (measured using stem diameter), thus generally, the higher the DBH, the more the biomass and C content (Kumar et al. 2021a; Rizvi et al., 2011). This was true in the case of *Eucalyptus globulus* where the mean DBH and biomass values were highest. In this study, *Azadirachta indica* despite having the 2nd highest DBH (Table 1) had less mean TB (Table 2) as compared to *Syzygium cumini* (269.48 ± 268.63 Kg/tree) and *Ficus virens* (261.83 ± 280.28 Kg/tree). Although DBH has some sort of bearing on the TCS in PCA (Fig. 8), the correlation coefficient proved that there is no direct correlation between TCS and DBH (Fig. 7 and Online Resource 3). This anomaly was also due to a lower % of trees in higher diameter classes (Fig. 4). This reduced the overall DBH of the trees. Apart from DBH, the volumetric and biomass equations also greatly affect the C stocks. As mentioned above, certain tree species with more DBH and H had low C content; this was mainly attributed to the use of different equations for different trees (Manaye et al., 2019). In our study, as compared to DBH, tree H was more correlated with TCS (Fig. 7). *Eucalyptus globulus* species with an overall good tree H stored more C, and *Polyalthia longifolia* with the least H had the least amount of C stock. Various studies have shown a direct and positive relationship between H and TCS (Chauhan et al., 2020). Our results also flag a significant positive correlation between tree H and TCS (Figs. 7 and 8). The age of plantations is also a critical parameter that affects the C storage capacity of trees. A good tree age structure may help reduce the adverse effects of tree mortality from establishment and construction works (Millward & Sabir, 2010). The older stands tend to have more C as compared to the young stands (Martínez-Sánchez et al., 2015; Rana et al., 2020). Even though this was applicable in the case of *Eucalyptus globulus* which has the highest biomass and C accumulation (Table 2) but this hypothesis proved to be wrong in the case of some tree species like *Callistemon lanceolatus* (23 years old) and *Polyalthia longfolia* (16 years old), where TCS was less than 4 Mg C ha^{-1}. This was confirmed with correlation (r) analysis (Fig. 7) and PCA (Fig. 8). The tree D is a key component that affects the overall TCS in the vegetation (Kumar et al. 2021b). *Ficus benjamina* regardless of less TB on a per-tree basis as compared to *Syzygium cumini* had more AGCS and BGCS due to a high tree D. A very high value of tree D of *Eucalyptus globulus* (55.35) helped to store the tree species around 7 times more C than *Polyalthia longifolia* (Table 2). Day et al. (2014) also demonstrated a linear and positive effect of stand D on TCS. Our study also confirmed this, as tree D was the 2nd most (1st being BA) strongly correlated tree variable with TCS (Fig. 7). Besides D, the tree BA is another major phytosociological parameter that controls the amount of C content in trees. While the BA itself is assessed from DBH but here the BA was calculated on a per-hectare basis where tree D came into play. This reduced the effect of DBH on TCS and increased the impact of the BA on TCS. The correlation level between BA and TCS was almost identical as in the case of stand D and TCS (Fig. 7). A similar trend was observed by Amoatey and Sulaiman (2020) and Nowak and Crane (2002) in urban trees of Oman and the USA. The selection effects (dominant species with special traits increase tree biomass) and complementary effects (diversified ecosystems with more species have different niche requirements that promote resource partitioning, which enhances resource utilization efficiency that ultimately increases productivity) are the two aspects of species richness that seems to affect the tree biomass (Cardinale et al., 2007; Kaushal & Baishya, 2021; Loreau & Hector, 2001). Our results also complement these findings, and correlation analysis proves diversity variable as a good predictor of tree biomass and C stock (Fig. 7). Of all the measured biodiversity indices, Simpon's dominance index has a more pronounced effect on TCS (Fig. 7 and Online Resource 3). The majority of the investigations on SCS are limited to surface soils (up to 10 cm) only. The value of SCS in our study ranged from 0.87 Mg C ha^{-1} (30.1–40 cm) under *Polyalthia longifolia* to 13.19 Mg C ha^{-1} (up to 10 cm) under *Dalbergia sissoo* (Online Resource 2). In context with the upper range of SCS, these results were similar to SCS values obtained in the Tezpur University campus (Saha & Handique, 2022), Assam (India), and Pondicherry University (Sundarapandian et al., 2014), India, that had SCS values up to 15.24 Mg C ha^{-1} and 12.56 Mg C ha^{-1}, respectively. The SCS followed a non-uniform pattern with an increase in soil depth. These results were contrary to results obtained by Kurien et al. (2021) and Subashree et al. (2019) in the Western Ghats (India) where there was a uniform decrease in SCS with an increase in soil sampling depth. This anomaly in our study could be linked to a high disturbance in the university campus in the form of routine uprooting and replanting of plants, water availability, and water permeability of the soil and other physical parameters of soil. Besides this tree litterfall, soil erosion and soil transportation also greatly affects the SCS values (de Nijs & Cammeraat, 2020). A comparison of C stocks in different universities is depicted in Table 4. The above-stated different phytosociological parameters affect the tree C stock in different ways, and this also supports the 2nd hypothesis of the study.

C sequestration potential, C credits, and Monetary value of trees

Urban vegetation was generally not considered for C cycle modeling and was considered a source of C emissions (Churkina et al., 2010; Tang et al., 2016). Regardless of the previous views on urban vegetation, our study demonstrated that urban plantations act as a C sink. The CO$_2$-mitigating potential of trees is directly connected with the amount of C stored in them. The trees on the MDU campus sequester 19.05 Mg CO$_2$ ha^{-1} year^{-1}. This rate of CO$_2$ sequestration was quite high as compared to street trees in Beijing (China) where the CO$_2$ sequestration rate was only 0.5 Mg C ha^{-1} year^{-1} (Tang et al., 2016). The values obtained in the present study were closer to the urban trees of Philadelphia which sequestered 13.6 ± 0.2 Mg C ha^{-1} year^{-1}.

The differences in CO$_2$ sequestration rates may be due to mowing, precipitation, and growth rates (Nowak et al., 2013). The C credits were calculated from the CO$_2$ sequestration rates of vegetation. These C credits can be a source of income for people, institutions, and countries (O'Donoghue & Shackleton, 2013). To the best of our knowledge, we could not find any study on university campuses that involved the concept of C credits, though some studies evaluated the monetary value of C stored by vegetation using other methods. The total value of these C credits (452,634.6 \$ and 23,101.59 \$ year^{-1}) was quite high as compared to SIT campus, Fushun (China), where the monetary value for CO$_2$ reduction was 128,360 \$ (total) and 15,785 \$ (annual). This huge difference was probably linked to the use of different methods, i.e., i-Tree eco application for C stock calculation (on SIT campus). Furthermore, the differences could also arise due to the use of the different monetary values of 1 C credit. On the other hand, the economic value of Retezat National Park in Romania (170,607 \$ year^{-1}) (Pache et al., 2020) was quite high compared to the MDU campus. This was attributed to very high rates of CO$_2$ sequestration.

It is worthwhile, to note that in the present study, *Eucalyptus globulus* outcompeted other tree species in almost all the quantifiable parameters. This is due to several factors like a very high growth rate, very long H, and branching pattern initiating from a greater vertical distance, thus making it less vulnerable to pruning. Though, *Dalbergia sissoo* is also a fast-growing tree species and could contribute more to reducing CO$_2$ with more efficiency on the campus. Since *Dalbergia sissoo* could not make it into the top 3 species with the highest contribution towards C stock, this indicates poor management practices. A similar study reported the same trend due to lower DBH values (Deve & Parthiban, 2014). *Azadirachta indica* is known to store huge amounts of C (Times of India, 2016), but in this study, it occupied the 5th spot in terms of C storage capacity. A couple of factors like the location of this species along the walking paths (more anthropogenic disturbance) and less soil C stock may have reduced the magnitude of C stocks. The other younger plantations of *Syzygium cumini* and *Ficus virens* have greater potential to sequester more C and provide more ecosystem services on the campus.

Although tree D on the campus is moderate, this is mainly contributed by *Eucalyptus globulus* plantations. Increasing the D of other tree species with higher C-capturing capacity such as *Azadirachta indica* and *Dalbergia sissoo* may enhance the overall capacity of campus trees to sequester C. In addition to this, management practices like extending the rotation period of stands (reduces soil disturbance), preferring native trees for plantation (apart from C sequestration, native trees also provide numerous ecosystem services), cutting dead trees into pieces (rather than letting them decay) for sustainable use, and harvesting during the winter season (instead of rainy season) may aid in amplifying C stocks on campus.

Limitations of the study

We did not estimate the C stock values for shrubs and herbs. This is one of the limitations of the present study. This was done because around 90% of the biomass is stored in trees (Singh et al., 2011). Furthermore, regular pruning and trimming of grasses and shrubs lead to enormous loss of biomass. We planted litter traps under these tree species in January 2020 for the collection of litterfall on a monthly basis. Yet, we could only collect the litterfall for January and February 2020. This was because of the implementation of a nationwide lockdown due to COVID-19. So, this is also one of the two limitations of this study.

Conclusions and recommendations

Our study assessed the C stocks, C sequestration rates, and monetary worth of the top 10 dominant tree species on the MDU campus. The campus is overly dependent on *Eucalyptus globulus* species which may cause tree management issues. All the trees on the campus are still young (< 25 years) and have lower DBH and BA. Tree D (139.77 ha^{-1}) on the campus is moderately high, and tree diversity lies in the lower to moderate range of the diversity spectrum. A total of 78.67 Mg C ha^{-1} C is stored in trees on the MDU campus. Trees like *Eucalyptus globulus* with a larger diameter and BA stored around 20% of the total tree C on the campus. Tree BA, D, and diversity positively influenced the tree C stocks. The top 10 tree species sequestered 19.05 Mg CO_2 ha^{-1} $year^{-1}$ and have 32,331.04 C credits from inception. These trees also supply 1663.58 C credits annually. Based on the value of these C credits, campus trees sequestered CO_2 that has a net worth of 452,634.60 $ in the international market. Additionally, the campus can earn 23,101.59 $ annually by selling the C credits. To maintain or enhance the rates of CO_2 sequestration, a tree database can be maintained on the campus. This database should primarily address tree mortality as trees are planted in huge numbers but are not looked after. This can be achieved with proper tree management practices that are species-specific. From our analysis, we suggest that these management practices can radically enhance the C stocks in *Dalbergia sissoo*. Furthermore, the results from this study will help this green and clean campus in better management of trees and take a step ahead in its mission of environmental sustainability. Additionally, the onsite composting of the plant litter will have dual benefits in the form of reduced methane emissions and a clean campus. This will also help the university campus to manage some of its finances and take part in C trading in the near future. The results obtained herein could also help educational institutions particularly in the Global South (low- and middle-income countries of the world) for preliminary modeling of C sequestration rates and C neutrality pathways.

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Author contribution Abhishek Nandal: conceptualization, investigation, data curation, and written original draft. Surender Singh Yadav: conceptualization, supervision, validation, and review and editing. Arun Jyoti Nath: conceptualization and review and editing.

Data availability Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Declarations

Ethical approval All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors and are aware that with minor exceptions; no changes can be made to authorship once the paper is submitted.

Conflicts of interest The authors declare no competing interests.

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