



RESEARCH ARTICLE

Carbon stock and sequestration analysis of high-density plantation in Neyveli, Tamil Nadu

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Abstract

Akira Miyawaki developed a unique reforestation method (the Miyawaki method) in Japan during the 1980s, aimed at restoring native ecosystems, conserving natural habitats, improving disaster resilience and reducing CO₂ emissions. This study evaluates the growth performance of tree species planted using the Miyawaki technique at New Thermal Power Station II, Neyveli Lignite Corporation India Limited (NLCIL), Neyveli, where afforestation was completed in 2022. Using a high-density planting strategy, 50 tree species were planted, including timber-species, fruit-bearing trees and ornamental species. Biometric parameters such as plant height and basal diameter were recorded, along with biochemical traits including crude protein, crude fiber and crude fat. Carbon biomass was calculated for each tree and CO₂ sequestration by individual trees was measured to assess their carbon capture potential. The tree species *Albizia lebbbeck* (14.03 kg tree⁻¹), *Diospyros ebenum* (13.25 kg tree⁻¹), *Terminalia arjuna* (12.73 kg tree⁻¹) and *Pithecellobium dulce* (10.97 kg tree⁻¹) exhibited higher CO₂ equivalents than other species. The Miyawaki plantation alter the local microclimate, with a moderate cooling effect observed during winter, reducing air temperatures to 31.25 °C compared to 32.54 °C in the open area. Relative humidity increased to 59.13 % within the plantation compared to 48.79 % in the open area. The plantation also led to marginal increase in soil organic carbon content. Miyawaki plantations demonstrated positive effects on microclimatic regulation and ecosystem functioning. The findings of this study help identify tree species with superior performance under Miyawaki planting conditions, providing useful guidance for future afforestation programs in areas with comparable climatic and ecological settings.

Keywords: biochemical attributes; carbon sequestration; carbon stock; ecosystems; microclimate; Miyawaki plantation

Introduction

Desertification poses significant risks and natural environments are rapidly impacted by urbanization and industrialization across the globe, leading to varied climatic changes (1). Innovative initiatives are essential to safeguard our surroundings and multiple preservation efforts should be implemented in our ecosystems. To revive native ecosystems, researchers have pursued theoretical and applied measures over the last two decades (2). Ecological function recovery, targeted ecosystem expansion and biodiversity restoration gains will feature in boosted sustainability tied to natural regeneration (3). Typically, trees as key ecosystem service elements deliver numerous benefits categorized as ecological roles, structural duties, climate regulation, economic gains, regeneration and cultural merits (4). At the ecosystem scale, restoration means “a deliberate action that starts or hastens an ecosystem’s recovery in

terms of its health, integrity and sustainability” (5). To gain afforestation advantages such as affordability and climate control, such projects must gain worldwide adoption. Cities globally see rising tree and shrub planting drives to meet demands for timber, firewood and wasteland recovery. Urban forest creation yields vast social and ecological perks, such as carbon retention, native wildlife habitats, stormwater control, local cooling and assorted social, wellness and visual upsides.

The Miyawaki approach, initiated by Professor Akira Miyawaki and first used in Japan, offers a hopeful strategy for forest renewal with native plants (6). This technique entails sowing transitional and early species together, forming advanced ecosystems with native greenery, multilayer woods and natural communities. It has proven capacity to build forests ten times quicker and thirty times thicker than conventional ways (7). Several

countries, including Japan, South America, the Far East and Malaysia, have adopted the Miyawaki method to restore degraded areas and urban settings, resulting in rapid urban forest development.

Urban forests deliver countless gains, such as temperature lowering, better air purity, carbon absorption, boosted welfare and higher property worths, making them attractive to urban planners and developers. Informed decisions on tree species selection, afforestation techniques and post-planting management can be achieved by evaluating diverse forest sites. Preventing afforestation failures requires a full review of site factors prior to starting afforestation work. This research selected New Thermal Power Station II (NNTPS II), Neyveli Lignite Corporation India Limited (NLCIL), Neyveli India, as its afforestation site using the Miyawaki method (8). It emphasizes the critical role of species diversity in mitigating monoculture-associated risks in urban environments. By placing these outcomes in higher learning settings, the effort yields useful lessons for scholarly talks and hands-on city green oversight.

This approach addresses a significant gap in understanding high-density plantation dynamics (9). Dense plantation in NLCIL, Neyveli, produced diverse ecological outcomes (10). They markedly boost carbon capture, uplift air purity and aid urban heat relief. The thick cover aids diverse kinds, raising biodiversity in city surrounds (11). The investigation examines the carbon sequestration and biochemical responses of trees in harsh settings. The work covers assessments of biometric features and carbon sequestration (12). This work highlights afforestation adoption as a versatile fix with deep ecological and community effects. In Bilaspur, India researchers used systematic sampling across 30 plots to gauge CO₂ in roadside trees (13, 14). High biomass and CO₂ stocks appeared in *Delonix regia*, along with extensive roadside boundary plantations of *Tamarindus indica*, *Ficus religiosa*, *Albizia lebbek* and *F. benghalensis*. In India, roadside plantation growth proves tough, as vast tree numbers go in yearly, yet survival dips from intense biotic stresses. To soak up huge city CO₂ volumes, offset heating, curb climate shifts and suit roadside planting, these species got endorsed (15). The present investigation was undertaken to assess the growth performance of selected plant species in Miyawaki sites at NLCIL, Neyveli.

Materials and Methods

Study area

Miyawaki's afforestation has been taken up in New thermal power station, Neyveli Lignite Corporation India Limited, Neyveli, India



Fig. 1. Miyawaki plantation in NLCIL, Neyveli, Tamil Nadu.

situated at a geographical position of approximately 11.60°N 79.48° E. with an altitude of approximately 87 meters above sea level (16). Neyveli experiences a tropical climate of low to moderate intensity with hot summers and mild winters. The region contains red soil, which is arable. The research area encompassed 2624 m² designated for Miyawaki afforestation, making it a substantial and relevant site for assessing the performance of various tree species under the Miyawaki afforestation technique (17). The spacing adopted for planting was 0.6 m x 0.6 m. A total of 4992 saplings were planted, categorized into large, medium and small varieties (Fig. 1). Before planting the saplings, the land was prepared by loading it with cattle manure, vermicompost and biofertilizers. This likely helped enrich the soil and provide nutrients for the plants.

Phyto-sociological studies were conducted by applying the quadrat Method (18). To analyze the plant community, a quadrat is as a sampling unit. It is a fixed-size region with a variety of shapes such as square, rectangle and circular. Biometric observations were recorded at four different seasons in five quadrats of size 5 × 5 m. Five individuals for each species were taken for observation from the initial to the final stage of the study such as 2 individuals in each quadrat (19). The following tree species plantation were done, namely *Terminalia arjuna*, *Bauhinia variegata*, *Cassia fistula*, *Spathodia companuleta*, *Pithecellobium dulce*, *Justicia adhatoda*, *Vitex negundo*, *Carica papaya*, *Psidium guajava*, *Albizia lebbek*, *Azadirachta indica*, *Syzigium cumuni*, *Prunus dulcis*, *Thespesia populnea*, *Nyctanthes arbor-tristis*, *Calophyllum inophyllum*, *Hibiscus rosa-sinensis*, *Delonix regia*, *Tamarindus indica*, *Millingtonia hortensis*, *Gmelina arborea*, *Pterocarpus marsupium*, *Couroupita guianensis*, *Switenia macrophylla*, *Pongamia pinnata*, *Simaruba glauca*, *Diospyrus ebenum*, *Bassia longifolia*, *Nerium oleander*, *Mangifera indica*, *Phyllanthus emblica*, *Polyalthia longifolia*, *Artocarpus heterophyllus* and *Ficus religiosa*.

Relative humidity

Relative humidity (%) was measured in the field using a whirling psychrometer. Seasonal observations were conducted, with one week per season studied. During each week, observations were recorded every hour from 6:00 AM to 6:00 PM.

Soil temperature

Soil temperature (°C) was measured using a digital soil thermometer (Model KUSAM MECO - 936) with a probe inserted at the surface and at a depth of 15 cm to record surface and subsurface soil temperatures, respectively. Seasonal monitoring was undertaken, with one week for each season assessed. Data were collected every hour between 6:00 AM and 6:00 PM throughout the week.



Air Temperature

Lynx Thermo hygograph was used for recording the air temperature.

Biochemical analysis

Biochemical attributes

The biochemical characteristics like the crude protein, crude fat and crude fiber were analyzed from these 12 tree species by following standard procedures.

Crude protein

The crude protein of the sample was analyzed by the method prescribed by Kjeldahl (20). The nitrogen content was calculated from which the crude protein content is also calculated.

Crude protein content (%) in the given plant sample = Total nitrogen value \times 6.25

Crude fat

The method given by AOAC is used for the estimation of crude fat in the sample (21).

Crude fiber

The crude fiber content of the sample was determined using the procedure (22).

Soil Analysis

The soil samples were collected from these plantations during initial period and after one year. Organic carbon was determined following the procedures and available nitrogen using method (23, 24). Available phosphorous was estimated and available potassium was recorded (25, 26).

Biometric Traits

The biometric parameters such as height and basal diameter were measured for all the thirty-four plant species. The plants were maintained in the field and observations on plant height (cm) and basal diameter (cm) were taken from 6 months after planting at periodic intervals in all the seedlings inside the quadrats.

Methodology for the carbon stock Assessment

Non-destructive method was followed and the carbon sequestration potential of the total number of enumerated trees was calculated using specific annual biomass increment, area under tree cover, default average above ground biomass growth factor and estimation of tree volume.

The following formula was used to estimate the tree's volume

$$V = \pi r^2 h$$

Where, (V = volume, r^2 = radius, h = height) in cubic meter (cm^3).

Calculation of above ground biomass (AGB)

$$\text{AGB (kg tree}^{-1}\text{)} = \text{volume of tree (m}^3\text{)} \times \text{wood density (kg m}^{-3}\text{)} \quad (27)$$

Note: if the wood density is unavailable, the computation is done using the standard average value of 0.6 gm cm^{-3} .

Calculation of below ground biomass (BGB)

The total biomass of living roots, excluding fine roots with a diameter of less than 2 mm, is referred to as below ground biomass. As the root: shoot ratio was provided, the below ground biomass was estimated by multiplying the above ground biomass by 0.26 factors (28).

$$\text{BGB (kg tree}^{-1}\text{)} \text{ or (ton tree}^{-1}\text{)} = \text{AGB (kg tree}^{-1}\text{)} \text{ or (ton tree}^{-1}\text{)} \times 0.26$$

Where, 0.26 = root to shoot ratio,

Total biomass

The total biomass is the addition of the above and below ground biomass recorded as described by (29).

$$\text{Total Biomass (kg tree}^{-1}\text{)} = \text{AGB} + \text{BGB}$$

Total carbon

$$\text{TC} = \text{TB}/2 \text{ or } \text{TB} \times 50\%$$

Determination of the weight of carbon dioxide sequestered in the tree carbon dioxide is formulated by three molecules which include one molecule of carbon and two molecules of oxygen. The atomic weight of carbon is 12 and of oxygen is 16. The weight of carbon dioxide is 44. $\text{CO}_2 = 1\text{C} + 2\text{O} = 1(12) + 2(16) = 44$. The ratio of CO_2 to carbon is $44/12 = 3.667$. The net O_2 release (t ha^{-1}) = net carbon sequestered (t ha^{-1}) $\times 32/12$ (30).

Statistical analysis

The results were statistically scrutinized by following the method to evaluate the influence of Miyawaki method of afforestation over the trees (31). The critical difference was carried out at 5% probability.

Results and Discussion

Micro-climate moderation

Air temperature

Air temperature was measured within the Miyawaki plantation and in an adjoining open natural tree stand using a thermometer. The measurements were taken hourly for one week during the rainy, winter and summer seasons and the hourly air temperatures were averaged for each season. During the rainy season, the maximum air temperature was observed in the open area (32.54°C), while the minimum was observed in the Miyawaki plantation (31.25°C). Temperature plays a major role in growth of trees and vegetation influences the air temperature to a greater extent. Microclimate edge influence has been demonstrated to differ with season and aspect (32). In the open stand the minimum temperature is 32.25°C and maximum temperature stands at 32.65°C . A similar trend was observed during the winter season, inside the Miyawaki plantation showing comparable patterns. Diurnal changes in air temperature during the rainy, winter and summer seasons showed that peak temperatures occurred between 12:00 PM and 02:00 PM irrespective of species composition. The edge effects seemingly diminish when the forest interior and exterior temperature and humidity levels became nearly uniform (33).

Relative humidity

The relative humidity (RH) of the Miyawaki plantation and an adjacent open natural tree stand was monitored using a spinning psychrometer. Measurements were made hourly for a week throughout each of the rainy, winter and summer seasons and the results were averaged of each season. During the rainy season, the Miyawaki plantation had the highest RH (59.13%), while the open area had the lowest (48.79%). Similarly, the maximum RH was 61.10% and the minimum was 51.24% , whereas in the open stand the maximum was 51.69% and the minimum was 48.79% . Soil temperature showed no substantial variation. Plantations may also moderate near-dawn low temperatures observed at abrupt margins (33).

During winter and summer, RH remained higher in the

Miyawaki plantation than in the open area. Across all seasons, RH was highest at 6:00 AM and lowest between 12:00 noon and 2:00 PM, with a slight increase after 3:00 PM. Seasonal analysis indicated that RH in the plantation peaked at 59.13 % at 6.00 AM and declined to a minimum of 48.79 % at 12.00 PM. Similarly, the maximum RH of open stand is recorded in winter season at 72.7 % and the minimum RH was 36.2 %, whereas in the Miyawaki plantation the maximum RH is 90.7 % and the minimum declined to 34.2 %. In summer season the open stand recorded the maximum RH at 69.7 % and a minimum of 35.9 %. In comparison, in the Miyawaki plantation recorded a maximum RH of 80.2 % and a minimum of 34.2 %.

Soil temperature

Soil temperature was monitored in the Miyawaki plantation and an adjacent open natural tree stand using a soil thermometer, with hourly recordings averaged over a week in each of the rainy, winter and summer seasons. In the rainy season, the open area had the highest soil temperature (27.20 °C), while the Miyawaki plantation had the lowest (26.48 °C). The microclimate within *Acacia* spp. plantations showed that these plantations experienced reduced air temperature, relative humidity and soil temperature during the summer season. Across all seasons, soil temperature peaked at 6:00 AM and was lowest at 1:00 PM, with a slight rise after 5:00 PM. The Miyawaki plantation consistently showed the lowest temperature during the rainy and winter seasons between the two plantations studied. By comparing the inside and outside canopy of *Prosopis cineraria*, it was found that the outside canopy has a higher soil temperature of 5 to 8 °C than the inside canopy (34). A well-developed canopy protects the soil microflora from high-temperature variation and drought stress. Temperature decrease and RH were affected by the canopy density, canopy spread, tree height and solar radiation (35).

Biochemical parameters

The biochemical parameters, such as crude protein, crude fat and crude fiber were estimated in leaf samples of tree species found in the Miyawaki plantation at NLCIL, Neyveli and the values (on dry weight basis) were shown. The tree species with crude protein content of 15 % and above were *Albizia lebbbeck*, *Bauhinia purpurea*, *Pongamia pinnata* and *Simarouba glauca*. Plant development includes cell wall development. As the plant matures crude fiber, cell wall compounds increase and crude protein decreases (36).

Crude protein level decreases with the season and maturity of the leaves. This is attributed to the dilution effect, such as at a specific growth stage, the nutrient inflow rate into the leaves may be lower than the dry matter produced (37). The average crude protein levels were higher in spring (13.33 %) and the maximum (18.73 %) recorded in *Robinia pseudoacacia* and minimum (11.52 %) in *Populus deltoides*, followed by summer (10.87 %). In our study, the highest crude protein content was observed in *Albizia lebbbeck* (26.69 %), followed by *Simarouba glauca* (20.36 %). Similar results were observed in other tree legume in various studies (38). The results were consistent with those, who documented elevated crude protein in *Melia azedarach*, *Morus alba* and *Sorgum bicolor* (39).

The previous research also reported high crude protein contents in *Morus alba* (15.31-30.91 %) on dry matter basis. Similar findings were also reported a high crude protein content of 18 to 25 % on dry matter in *Morus alba* (41). The highest crude fat content was observed in *Cassia siamea* (9.0 %), followed by *Pongamia pinnata* (5.60 %). The tree species with crude fibre content of 20 % and above were *Simarouba glauca*, *Bauhinia purpurea*, *Albizia lebbbeck*, *Pongamia pinnata*, *Ficus religiosa* and *Cassia siamea*. The tree species with crude fiber content of 20 % and above are *Simarouba glauca*, *Bauhinia purpurea*, *Albizia lebbbeck*, *Pongamia pinnata*, *Ficus bengalensis*, *Dalbergia latifolia*, *Terminalia catappa*, *Magnolia champaca*, *Senna siamea* and *Ficus religiosa* (Fig. 2). Several studies have indicated that cell wall formation is linked to plant growth and as the plant matures, the wall constituents and crude fibre increase while protoplasm components such as crude protein declined. Comparable research has also revealed the seasons exhibited highly significant variation in ether extract among the tree species evaluated (42).

Soil characteristics

Soil samples were collected at a depth of 15 cm from the Miyawaki plantation and analyzed for several parameters including pH, electrical conductivity, bulk density, particle density and porosity. Samples were collected once a year from each block and analyzed.

Physicochemical properties of soil

Soil samples were obtained from the Miyawaki plantation site in NLCIL, Neyveli and tested for pH, EC, organic carbon and available nutrients. The organic carbon level was 0.28 % in dense plantation

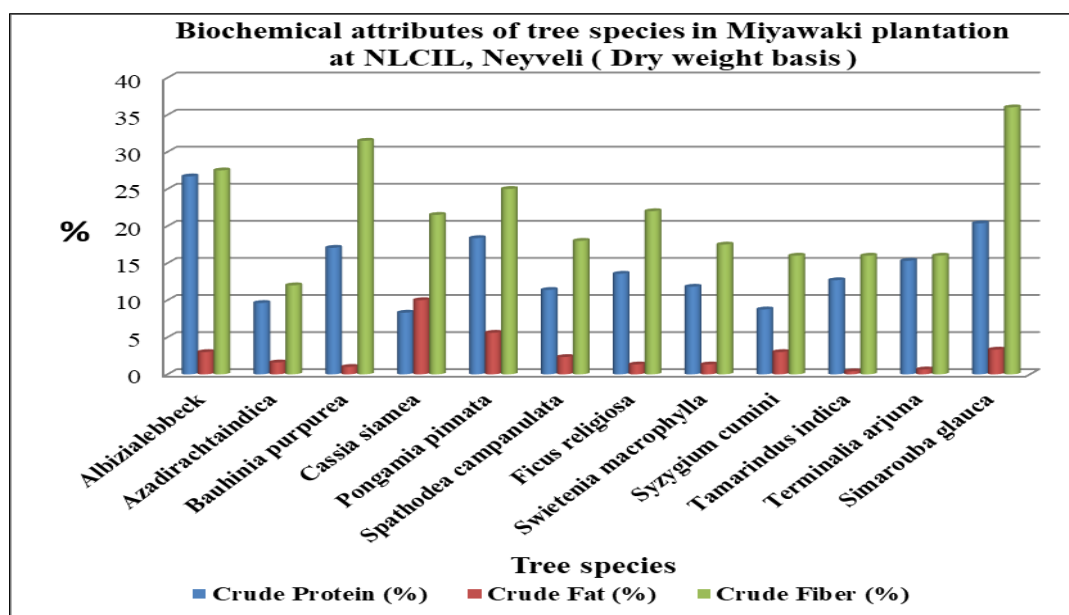


Fig. 2. Biochemical attributes of tree species in Miyawaki plantation at NLCIL, Neyveli (dry weight basis).

area, while available nitrogen, available phosphorous and available potassium were 102.5 kg ha⁻¹, 27.5 kg ha⁻¹ and 225.0 kg ha⁻¹, respectively (Table 1). The nitrogen status was low when compared to other two nutrients. The organic carbon content of the soil increased significantly over a period of 12 months in the Miyawaki plantation.

Biometric observations

In Miyawaki plantations, the highest basal diameter was observed in *Terminalia arjuna*, *Diospyrus ebenum*, *Carica papaya*, *Spathodea companulata*, *Albizia lebbbeck*, *Ficus religiosa*, *Bauhinia variegata* and *Thespesia populnea*. *Terminalia arjuna*, *Gmelina arborea*, *Diospyrus ebenum*, *Ficus religiosa* and *Phyllanthus emblica* showed good height growth, while *Polyalthia longifolia* showed the lowest height in the Miyawaki plantations. Woodlot assessment showed that *A. decurrens* trees reached a height of 11.51 m and 5.92 cm diameter within 5.5 years (43). The basal area and volume increment of *A. decurrens* woodlot were 45.95 m²ha⁻¹ and 262.15 m³ha⁻¹ for 5.5 years respectively. Moreover, findings on *Acacia crassicaarpa* indicated superior growth performance in height and root collar diameter, while *L. pallid* exhibited improved water utilisation (44).

Observations on basal diameter (mm) of tree species in

certain cases indicated a more efficient utilisation of site resources by various species in mixed stands, resulting in higher yields compared to pure stands, as interspecific competition is less intense than intraspecific competition (45). The seasonal effect on height of tree species was also observed and upper canopy trees in mixed stands are expected to attain the same height as in pure stands, with height remaining unaffected by stand density except under extremely wide or narrow spacing (46). In the annual increment concern, the basal diameter was observed higher in *Diospyrus ebenum* (4.40 cm) and minimum in *Switenia macrophylla* (1.10 cm). Similarly, in the annual height increment the maximum was recorded in the trees *Terminalia arjuna* (1.80 m), *Gmelina arborea* (1.65 m) and the minimum in *Calophyllum inophyllum* (0.35 m). Similar findings were obtained in a study on *Acacia mangium*, where mean heights of 5.0 m in 3 years and 6.0 m in 5 years were observed in Indonesia and *Bambusa vulgaris* var. *vulgaris* also exhibited good height of 2.25 m and basal diameter of 1.72 cm in Sivagangai, Tamil Nadu (47). *Gmelina arborea*, *Pithacelobium dulce*, *Albizia lebbbeck*, *Vitex negundo* and *Diospyrus ebenum* performed well in high density plantation in NLCIL, Neyveli and *Mangifera indica*, *Polyalthia longifolia*, *Bassia langifolia*, *Nerium oleander* and *Calophyllum inophyllum* grown very slowly (Table 2).

Table 1. Physicochemical characteristics of soil under Miyawaki plantation

pH	EC (dsm ⁻¹)	Organic carbon (%)	Available nitrogen (kg ha ⁻¹)	Available phosphorous (kg ha ⁻¹)	Available potassium (kg ha ⁻¹)
7.9	0.11	0.28	102.5	27.5	225.0

Table 2. Biometric parameters of tree species in the Miyawaki plantation at NLCIL, Neyveli

S.No.	Tree species	Height (m)			Basal diameter (cm)		
		Initial	Final	Increment	Initial	Final	Increment
1	<i>Terminalia arjuna</i>	3.38	5.18	1.80	16.00	18.60	2.60
2	<i>Bauhinia variegata</i>	3.52	5.04	0.52	9.00	12.50	3.50
3	<i>Cassia fistula</i>	3.63	4.73	1.10	9.00	11.70	2.70
4	<i>Spathodia companuleta</i>	3.50	4.30	0.80	13.00	14.30	1.30
5	<i>Pithacelobium dulce</i>	3.95	5.26	1.31	16.00	18.40	2.40
6	<i>Justicia adhatoda</i>	2.00	2.62	0.62	5.50	6.40	1.10
7	<i>Vitex negundo</i>	4.40	5.50	1.10	11.00	12.80	1.80
8	<i>Carica papaya</i>	3.27	4.18	0.91	21.00	23.90	2.90
9	<i>Psidium guajava</i>	2.45	3.16	0.71	5.00	7.50	2.50
10	<i>Albizia lebbbeck</i>	5.00	6.20	1.20	16.00	19.30	3.30
11	<i>Azadirachta indica</i>	2.75	3.63	0.88	8.00	11.50	3.50
12	<i>Syzygium cumuni</i>	2.60	3.31	0.71	6.50	8.20	1.70
13	<i>Prunus dulcis</i>	2.60	3.12	0.52	6.50	7.80	1.30
14	<i>Thespesia populnea</i>	3.70	4.61	0.91	9.50	12.50	3.00
15	<i>Nyctanthes arbor-tristis</i>	2.20	2.66	0.46	4.00	5.30	1.30
16	<i>Calophyllum inophyllum</i>	1.75	2.10	0.35	3.00	4.20	1.20
17	<i>Hibiscus rosa-sinensis</i>	2.33	3.08	0.75	3.00	3.90	0.90
18	<i>Delonix regia</i>	2.50	3.32	0.82	6.50	8.30	1.80
19	<i>Tamarindus indica</i>	2.70	3.49	0.79	8.00	9.60	1.60
20	<i>Millingtonia hortensis</i>	3.60	4.51	0.91	7.50	8.90	1.40
21	<i>Gmelina arborea</i>	4.00	5.65	1.65	7.50	9.50	2.00
22	<i>Pterocarpus marsupium</i>	2.50	3.59	1.09	7.50	9.10	1.60
23	<i>Couroupita guianensis</i>	2.00	2.75	0.75	5.50	6.80	1.30
24	<i>Switenia macrophylla</i>	2.25	3.15	0.90	6.00	7.10	1.10
25	<i>Pongamia pinnata</i>	2.45	3.26	0.81	7.50	8.80	1.30
26	<i>Simaruba glauca</i>	2.15	3.25	1.10	6.00	7.90	1.90
27	<i>Diospyrus ebenum</i>	3.50	4.92	1.42	15.00	19.40	4.40
28	<i>Bassia longifolia</i>	1.50	2.32	0.82	4.00	5.80	1.80
29	<i>Nerium oleander</i>	1.10	1.65	0.55	5.00	6.30	1.30
30	<i>Mangifera indica</i>	0.85	1.75	0.90	7.00	8.40	1.40
31	<i>Phyllanthus emblica</i>	2.80	3.99	1.19	5.00	6.80	1.80
32	<i>Polyalthia longifolia</i>	0.55	1.05	0.60	8.00	9.80	1.80
33	<i>Artocarpus heterophyllus</i>	2.75	3.50	0.75	5.00	6.90	1.90
34	<i>Ficus religiosa</i>	4.00	5.23	1.25	9.00	12.50	3.50
	SEd.	0.05	0.09	-	0.18	0.25	-
	CD	0.10	0.17	-	0.36	0.49	-

Total biomass, carbon storage, carbon dioxide equivalent and oxygen emission of the Miyawaki Plantations

In this study, among these 34 selected species, *Terminalia arjuna* (6.94 kg tree⁻¹), *Pithecellobium dulce* (5.99 kg tree⁻¹), *Carica papaya* (6.94 kg tree⁻¹), *Albizia lebbbeck* (7.65 kg tree⁻¹) and *Diospyrus ebenum* (7.23 kg tree⁻¹) were the top tree species in terms of highest total biomass (Table 3; Fig.3). *Albizia lebbbeck* (7.65 kg tree⁻¹) recorded the highest total biomass in the study area and the lowest biomass was observed in *Calophyllum inophyllum* (0.13 kg tree⁻¹) and *Hibiscus rosa-sinensis* (0.13 kg plant⁻¹).

The carbon stock of selected 34 tree species ranged from 0.06 to 3.83 kg tree⁻¹ (Table 3). Among these species, the highest carbon stock was recorded in *Albizia lebbbeck* (3.83 kg tree⁻¹), followed by *Diospyrus ebenum* (3.61 kg tree⁻¹), *Carica papaya* (3.47 kg tree⁻¹), *Terminalia arjuna* (3.47 kg tree⁻¹). The lowest carbon stock was observed in *Calophyllum inophyllum* (0.06 kg tree⁻¹) and *Hibiscus rosa-sinensis* (0.06 plant⁻¹).

The carbon dioxide equivalent (CO₂e) of the selected 34 tree species ranged from 0.23 to 14.03 kg tree⁻¹ (Table 3). Among these selected 34 tree species, the highest CO₂e was recorded in *Albizia lebbbeck* (14.03 kg tree⁻¹) and lowest was observed in *Calophyllum inophyllum* (0.23 kg tree⁻¹) and *Hibiscus rosa-sinensis* (0.23 kg plant⁻¹). Among these selected 34 tree species, the maximum oxygen release

was recorded in *Albizia lebbbeck* (10.20 kg tree⁻¹) and lowest in *Calophyllum inophyllum* (0.17 kg tree⁻¹) and *Hibiscus rosa-sinensis* (0.17 plant⁻¹).

During productive season, CO₂ from the atmosphere is taken up by vegetation and stored as plant biomass (41). The variation in biomass and carbon accumulation may be attributed to differences in wood specific gravity and growth dynamics between fast and slow growing species. Wood specific gravity shows considerable variation among tropical forest tree species, being strongly associated with differences in diameter growth rates. The CO₂ eq. and oxygen release (O₂ release) of *Swietenia macrophylla*, which ranged from 125.5 to 1004.5 Mg ha⁻¹ (mean 436.3 Mg ha⁻¹) and 91.25 to 730.26 Mg ha⁻¹ (mean 317.2 Mg ha⁻¹), respectively. *Eucalyptus camaldulensis* data from 45 sample plots (100 m² each) representing different age classes (2, 5, 7, 8, 11, 13 and 21 years). The aboveground, belowground and total biomass and carbon differed significantly across stand ages ($p < 0.05$), with the highest aboveground (302.6 ± 10.9 Mg C ha⁻¹), belowground (49.4 ± 1.6 Mg C ha⁻¹) and total carbon (352 ± 12.5 Mg C ha⁻¹) recorded at the age of 21 years. The previous studies examined the above-ground biomass production on per hectare basis, reporting the highest biomass for *Acacia* (326, 184 and 141 Mg ha⁻¹ at 8.8, 7 and 5 years, respectively). *Paraserianthes* achieved the second highest biomass (183 Mg ha⁻¹ at 8.8 years), whereas *Leucaena* recorded the lowest biomass.

Table 3. Carbon sequestration and oxygen release potential of tree species in the Miyawaki plantation at NLCIL, Neyveli

Tree species	Height (m)	Diameter (m)	Volume (kg m ⁻³)	Wood density (kg m ⁻³)	Above ground biomass (kg tree ⁻¹)	Below ground biomass (kg tree ⁻¹)	Total biomass (kg tree ⁻¹)	Carbon stock (kg tree ⁻¹)	CO ₂ (eq.) (kg tree ⁻¹)	Oxygen release (kg tree ⁻¹)
<i>Terminalia arjuna</i>	3.38	0.16	0.007	800	5.51	1.43	6.94	3.47	12.73	9.26
<i>Bauhinia variegata</i>	3.52	0.09	0.002	720	1.63	0.43	2.06	1.03	3.78	2.75
<i>Cassia fistula</i>	3.63	0.09	0.002	829	1.94	0.51	2.45	1.22	4.48	3.26
<i>Spathodia companuleta</i>	3.50	0.13	0.005	330	1.55	0.40	1.96	0.98	3.59	2.61
<i>Pithecellobium dulce</i>	3.95	0.16	0.008	590	4.75	1.24	5.99	2.99	10.97	7.98
<i>Justicia adhatoda</i>	2.00	0.06	0.000	600	0.29	0.08	0.36	0.18	0.67	0.49
<i>Vitex negundo</i>	4.40	0.11	0.004	670	2.84	0.74	3.58	1.79	6.56	4.77
<i>Carica papaya</i>	3.27	0.21	0.011	480	5.51	1.43	6.94	3.47	12.73	9.26
<i>Psidium guajava</i>	2.45	0.05	0.000	671	0.33	0.09	0.41	0.21	0.76	0.55
<i>Albizia lebbbeck</i>	5.00	0.16	0.010	596	6.07	1.58	7.65	3.83	14.03	10.20
<i>Azadirachta indica</i>	2.75	0.08	0.001	727	1.02	0.27	1.28	0.64	2.35	1.71
<i>Syzygium cumuni</i>	2.60	0.07	0.001	701	0.61	0.16	0.77	0.39	1.42	1.03
<i>Prunus dulcis</i>	2.60	0.07	0.001	600	0.53	0.14	0.66	0.33	1.21	0.88
<i>Thespesia populnea</i>	3.70	0.10	0.003	639	1.70	0.44	2.14	1.07	3.92	2.85
<i>Nyctanthes arbor-tristis</i>	2.20	0.04	0.000	940	0.26	0.07	0.33	0.17	0.61	0.44
<i>Calophyllum inophyllum</i>	1.75	0.03	0.000	800	0.10	0.03	0.13	0.06	0.23	0.17
<i>Hibiscus rosa-sinensis</i>	2.33	0.03	0.000	600	0.10	0.03	0.13	0.06	0.23	0.17
<i>Delonix regia</i>	2.50	0.07	0.001	600	0.51	0.13	0.64	0.32	1.17	0.85
<i>Tamarindus indica</i>	2.70	0.08	0.001	990	1.36	0.35	1.72	0.86	3.15	2.29
<i>Millingtonia hortensis</i>	3.60	0.08	0.002	600	0.97	0.25	1.22	0.61	2.24	1.63
<i>Gmelina arborea</i>	4.00	0.08	0.002	640	1.15	0.30	1.45	0.72	2.65	1.93
<i>Pterocarpus marsupium</i>	2.50	0.08	0.001	880	0.99	0.26	1.24	0.62	2.28	1.66
<i>Couropita guianensis</i>	2.00	0.06	0.000	440	0.21	0.06	0.27	0.13	0.49	0.36
<i>Swietenia macrophylla</i>	2.25	0.06	0.001	850	0.55	0.14	0.69	0.35	1.27	0.92
<i>Pongamia pinnata</i>	2.45	0.08	0.001	600	0.66	0.17	0.83	0.42	1.52	1.11
<i>Simaruba glauca</i>	2.15	0.06	0.001	380	0.23	0.06	0.30	0.15	0.54	0.39
<i>Diospyrus ebenum</i>	3.50	0.15	0.006	915	5.74	1.49	7.23	3.61	13.25	9.64
<i>Bassia longifolia</i>	1.50	0.04	0.000	625	0.12	0.03	0.15	0.08	0.28	0.20
<i>Nerium oleander</i>	1.10	0.05	0.000	600	0.13	0.03	0.17	0.08	0.30	0.22
<i>Mangifera indica</i>	0.85	0.07	0.000	597	0.20	0.05	0.25	0.13	0.46	0.33
<i>Phyllanthus emblica</i>	2.80	0.05	0.001	728	0.41	0.11	0.51	0.26	0.94	0.68
<i>Polyalthia longifolia</i>	0.55	0.08	0.000	563	0.16	0.04	0.20	0.10	0.36	0.27
<i>Artocarpus heterophyllum</i>	2.75	0.05	0.001	700	0.38	0.10	0.48	0.24	0.89	0.64
<i>Ficus religiosa</i>	4.00	0.09	0.003	443	1.14	0.30	1.44	0.72	2.64	1.92
SE Mean	0.83	0.05	0.008	-	4.22	1.10	5.32	2.70	9.95	7.19
SED	1.18	0.07	0.011	-	5.97	1.56	7.60	3.81	14.07	10.17
CD 0.05	2.35	0.14	0.022	-	11.95	3.12	15.04	7.62	28.14	20.33

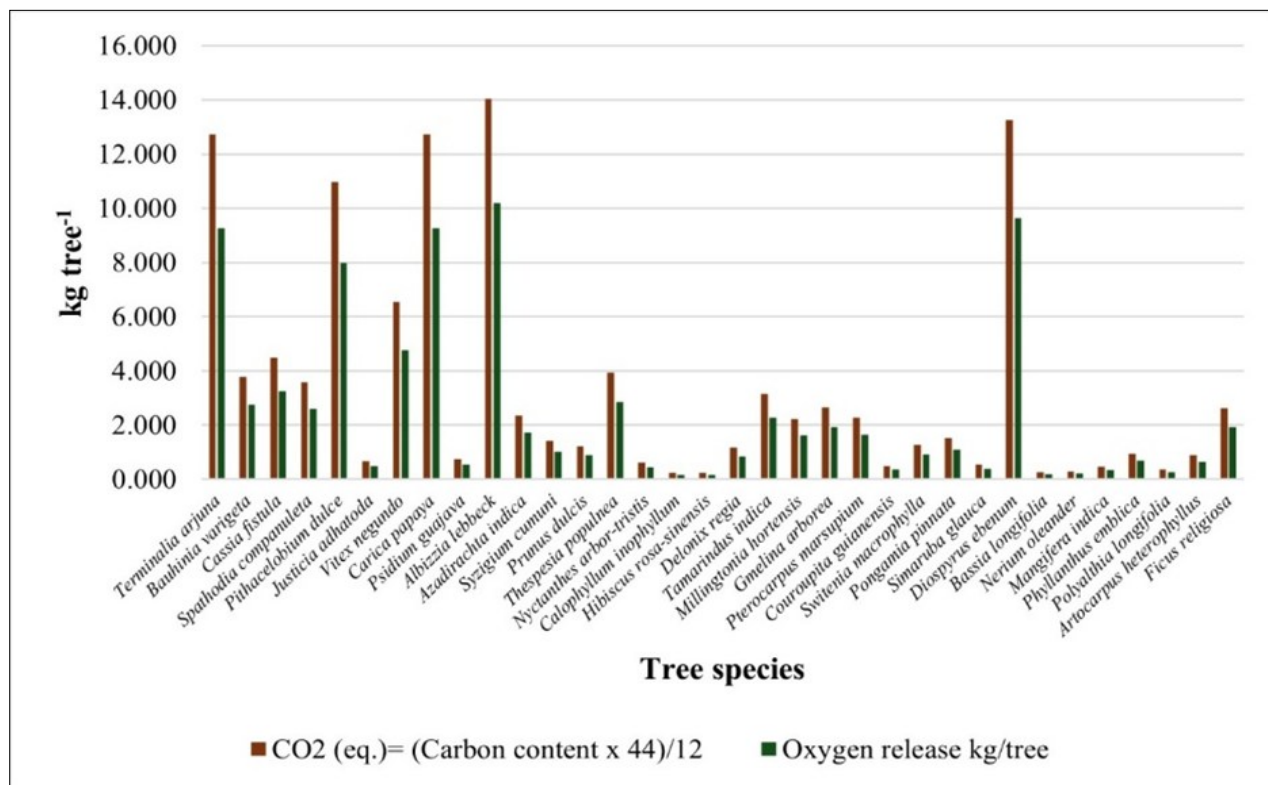


Fig. 3. Carbon dioxide sequestration and oxygen release by tree species in the NLCIL, Neyveli plantation.

Correlation between diameter at breast height (DBH), volume and carbon dioxide equivalent in the Miyawaki plantations

The correlations observed in this study, demonstrate the influences of tree growth on carbon sequestration and oxygen production in the Miyawaki plantations at NLCIL, Neyveli (Fig. 4, 5). Among the growth parameters measured, DBH, tree age and height play a significant role in determining a tree's ecological contribution. The analysis revealed strong positive relationships between DBH and stem volume, as well as between DBH and CO₂ eq. A very strong correlation was observed between DBH and volume ($R^2 = 0.9221$),

indicating that as trees increase in diameter, their biomass increases substantially. Similarly, DBH showed a strong positive relationship with carbon sequestration ($R^2 = 0.864$), demonstrating that trees with larger diameters store more carbon. Biologically, this relationship is expected, as thicker stems reflect greater wood formation and biomass accumulation over time. These findings confirm that DBH is a reliable and practical indicator for estimating biomass, carbon storage and oxygen production in the Miyawaki plantations, making it useful for evaluating plantation performance and carbon accounting efforts.

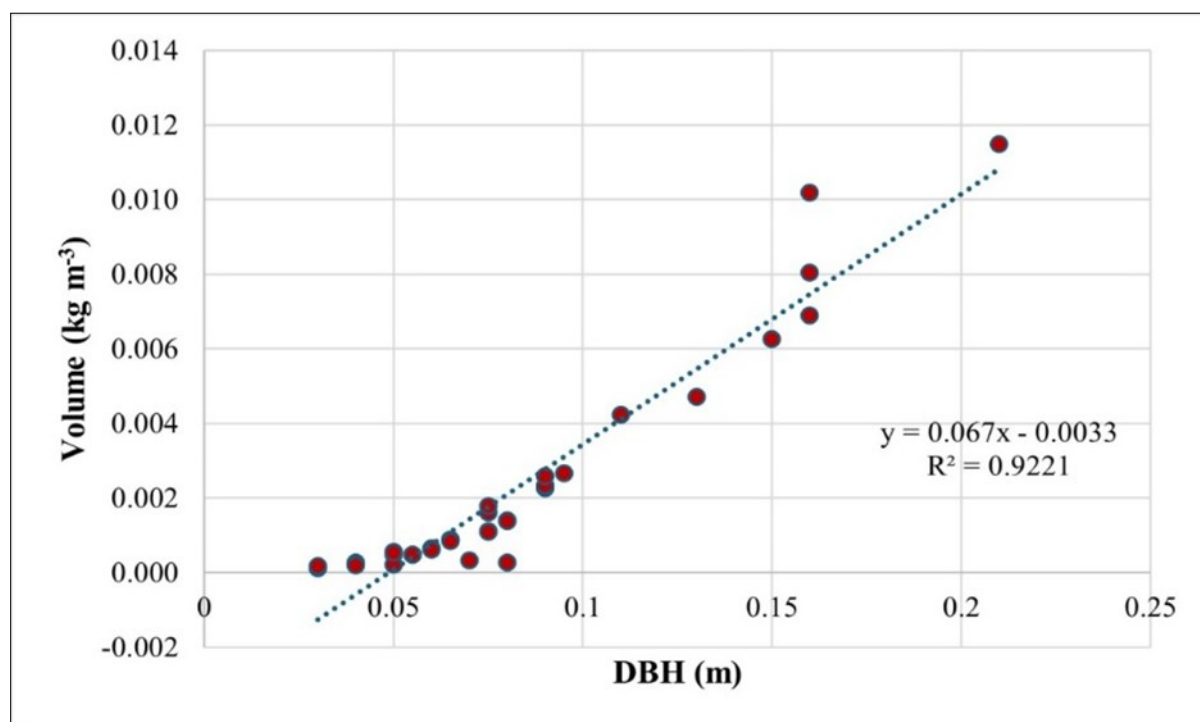


Fig. 4. Correlation coefficient (R^2 value) between DBH and volume (kg m^{-3}) of selected tree species in Miyawaki plantations in NLCIL, Neyveli.

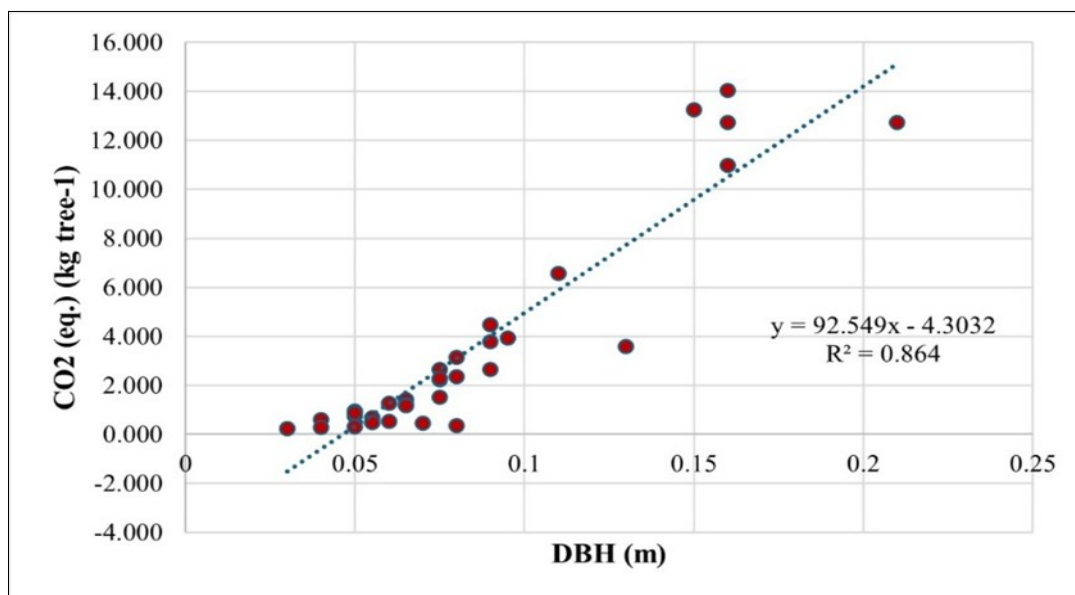


Fig. 5. Correlation coefficient (R^2 value) between DBH and carbon stock of selected tree species in Miyawaki plantations in NLCIL, Neyveli.

Conclusion

The Miyawaki approach has emerged as an effective way to restore degraded tropical and semi-arid areas by encouraging fast forest development and improving local biodiversity. Forest ecosystems play a vital role in reducing climate change impacts by absorbing large amounts of atmospheric carbon dioxide each year, which underlines the growing importance of small-scale afforestation initiatives. Alongside these efforts, sustainable forest management practices such as limiting logging activities, preventing deforestation and controlling poaching remain critical for long-term environmental protection. In urban environments, green spaces strongly influence ecological stability, climate regulation and overall human well-being. Tree planting and the conservation of diverse plant species are therefore key components of landscape restoration. In the present study, tree species were assessed using growth measurements, productivity indicators and carbon biomass estimates. Among the thirty-four species evaluated, *Albizia lebbek*, *Diospyros ebenum* and *Terminalia arjuna* demonstrated the highest growth rates and carbon sequestration capacity. Other species, including *Gmelina arborea*, *Pithecellobium dulce*, *Vitex negundo* and *Diospyros ebenum*, also showed strong performance across several parameters. Miyawaki forests further contribute to reducing urban heat island effects by increasing canopy cover, lowering surface temperatures and improving air quality. By addressing issues such as reduced vegetation cover, heat-absorbing surfaces, air pollution and limited airflow, these dense plantations provide multiple environmental benefits. The results highlight the importance of careful species selection to maximize carbon storage and ecological performance. Prioritizing well-adapted native species and integrating Miyawaki forests into urban planning can strengthen climate mitigation efforts. Regular monitoring of biomass and carbon sequestration is recommended to support sustainable and evidence-based afforestation practices.

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Authors' contributions

SMP worked on conceptualization. SMP, GAS, GG and GP did the formal analysis. Original draft was written by SMP and GSG. GP, KM, GG, KK, BBK and KN contributed to writing, reviewing and editing of the manuscript. All authors read and approved the file version of manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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