Journal of Agrometeorology
(A publication of Association of Agrometeorologists)
ISSN : 0972-1665 (print), 2583-2980 (online)
Vol. No. 28 (2) : 177-184 (June - 2026)
https://doi.org/10.54386/jam.v28i2.3403
https://journal.agrimetassociation.org/index.php/jam

Research paper

Structural Attributes of Urban Trees Controlling Carbon Dioxide Sequestration: An Applied Study in Al-Umma Park – Baghdad

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ABSTRACT

With the dramatically increasing global urbanization, cities have evolved as a leading Greenhouse gases (GHG) emissions contributor. In this regard, urban parks are important carbon sinks as trees absorb Carbon Dioxide (CO_2) from the atmosphere through photosynthesis that helps in achieving climate sustainability. The current study aimed to evaluate the sequestered CO_2 by urban trees in a park in Baghdad called Al- Umma Park. The estimate was based on field measurements of each tree for six dominant species of 236 individual: *Acacia spp.*, *Ficus religiosa*, *Ficus benghalensis, Albizia lebbeck*, *Phoenix dactylifera*, and *Syzygium cumini*. CO_2 sequestration were estimated using allometric equations. Results showed that *Phoenix dactylifera* had the highest average annual CO_2 sequestration (38.39 ± 9.87 kg/year per tree). While *Ficus benghalensis* obtained the least (1.225 ± 0.065 kg/year per tree). The total annual sequestration for all trees was 4047.2 kg/year. Multiple linear regression analysis demonstrated that tree structural attributes strongly explain variations in annual CO_2 sequestration ($R^2 = 0.97$, $p < 0.001$). Tree diameter emerged as the primary predictor of sequestration potential, while tree height contributed a secondary but significant effect. Overall, results highlight the relevance of urban parks to improving carbon balance locally and contribute to urban sustainability.

Keywords: Climate resilient, Tree biomass, Urban park, Sustainable urban planning, CO_2 Sequestration

The world is undergoing fast and historic urbanization, with almost 70% of the global population expected to live in cities by 2050 (Esperon-Rodriguez *et al.,* 2022; Anonymous, 2019). Now cities house more than half of the global population and are responsible for about 70% of greenhouse gas (GHG) emissions. This fact makes urban areas important nodes in overcoming climate challenges (Wang *et al.,* 2021). Carbon dioxide (CO_2) is the main gas causing global warming, with atmospheric levels having risen from 280 ppm to more than 418 ppm now (IPCC, 2014). Warming, if unabated is projected to further increase global average temperatures by 2.4–4.2°C (Sharma *et al.,* 2024). Urban trees and vegetation play an important role in mitigation of these challenges due to the fact they sequester CO_2 from atmosphere and store carbon as the biomass components: stem, branch, root etc (Wang *et al.,* 2024; Khalbas & Kadhum, 2024). Urban green spaces including public parks, university campuses and treelined streets offer a range of ecosystem services (air purification, temperature regulation and noise abatement), which contribute to the greater resilience and sustainability of cities (Sharma *et al.,* 2024). Among its components, urban parks are particularly good long-term carbon sinks (Shadman *et al.,* 2022).

Several studies have emphasized the significance of estimating CO_2 sequestration potential in urban parks. Shadman *et al.,* (2022) studied one 0.7 ha urban park and estimated its life-cycle carbon sequestration potential which turned out to be quite high, at 660.8 tCO_2e in total. More recently, Kim *et al.,* (2024) surveys and modeling to report a carbon pool of 15.30 tC ha^{-1}, on average ha^{-1} in a 5.74 ha urban park. In contrast, Wang *et al.,* (2021) evaluated the spatial pattern of C sequestration efficiency at tree level in 28 urban areas in Beijing based on an individual tree survey. Zhao *et al.,* (2024) conducted more empirical tests against carbon sequestration capacities in different -structured plant communities, with varied structural characteristics, identifying the primary contributing elements. In general, these studies highlight the reliability and

Article info - DOI: https://doi.org/10.54386/jam.v28i2.3403
Received: 28 February 2025 ; Accepted: 29 May 2026 ; Published online : 04 June 2026

precision of field-based carbon sequestration assessment techniques despite their large data needs (Wang *et al.,* 2024).

Studies indicate a knowledge gap in assessing CO_2 in urban parks, with most research focusing on European and North American cities and limited evidence from rapidly growing urban cities. Therefore, this study aims to estimate and compare the CO_2 sequestration potential of dominant species in Al-Umma park based on field measurements such as diameter and height, with the goal of providing a scientific basis for green space management and promoting low-carbon urban sustainability.

MATERIALS AND METHODS

Study area

Al-Umma Park is one of the oldest and most prominent green spaces in Baghdad. It was first opened in 1937 as a public park and rehabilitated and landscaped in 2022 with the planting of six new tree species and a reorganization of its landscape. Located in the heart of Baghdad at coordinate 33.3186°N, 44.3939°E, the park straddles major streets such as Al-Saadoun Street and is close to Tahrir Square, making it an important cultural, commercial, and traffic hub which is shown in Fig. 1. Its central location and daily exposure to heavy traffic emissions make it an ideal location for assessing the CO_2 sequestration potential of urban trees within a dense urban environment. The Park spans 24830 m² and features 236 trees from six different species: *Acacia spp.*, *Ficus benghalensis*, *Syzygium cumini*, *Albizia lebbeck*, *Ficus religiosa*, and *Phoenix dactylifera*.

The city experiences a subtropical, semi-arid climate, having hot and dry summers and cold winters. Annual rainfall average about 140 mm, from December to February; there is no rain in summer (Mohsen & Abdulkareem, 2023). With normally clear sky, that permits the highest amount of solar radiation reaching to earth surface during the day (Al-Samarrai & Al-Jiboori, 2022).

Data and methodology

Accurate field measurements of trees planted in the urban park were used to estimate tree CO_2 sequestration ability. These measurements included diameter at breast height (DBH) using a measuring tape and tree height using a laser device. Additional information including tree species, tree numbers, and ages was obtained from Baghdad Mayoralty /Al-Rusafa Central Municipality/ Agriculture Department. The physical connection between tree volume and wood density serves as the foundation for the calculation used to determine a tree's dry weight. Because tree density data might vary even within the same species, applying various formulas for each tree species does not always result in more accurate CO_2 estimates. As a result, the method utilized is based on average wood density values from species (De Villiers *et al.,* 2014). Using these non-destructive field measurements, above-ground biomass and annual CO_2 sequestration were estimated following the procedure described by County, B. (2012), which involved five steps:

1. The total above-ground weight of the tree in pounds (W) was estimated using the measured diameter of the trunk in inches (D) and the measured height of the tree in feet (H) using one of the two formulas:

   For trees with D < 11

   $$W=0.25D^2 H \quad (1)$$

   For trees with D >= 11

   $$W=0.15D^2 H \quad (2)$$

   With an average of 72.5% dry matter and 27.5% moisture content, the dry weight of the tree was determined by (De Villiers *et al.,* 2014),

   $$Dry\ weight = W \times 0.725 \quad (3)$$

2. Determined the tree's carbon weight (content of carbon). The average carbon content of a tree is approximately 50% of its overall volume (Mohsen & Abdulkareem, 2025).

   $$Carbon\ weight = Dry\ weight \times 0.50 \quad (4)$$

3. Determined the amount of CO_2 sequestered by trees. CO_2 is made up of one atom of carbon and two atoms of oxygen. The atomic weight of carbon is 12.001115. The atomic weight of oxygen is 15.9994.

- CO_2 has a molecular weight of 43.999915, calculated as 1*C+2*O.
- The CO_2 to C ratio is 43.999915/12.001115 = 3.6663.

  So the weight of CO_2 sequestered in the tree (De Villiers *et al.,* 2014) is calculated as;

$$CO_2\ sequestered = Carbon\ weight \times 3.6663 \quad (5)$$

4. The annual amount of sequestration is the total CO_2 sequestration divided by the tree's age.

$$Annual\ CO_2 = Total\ CO_2\ sequestered/\ Tree\ age \quad (6)$$

For consistency with the International System of Units (SI), the resulting weight values were converted from pounds to kg and field measurements (diameter and height) to cm.

Data analysis

Then SigmaPlot 12.5 software was used to calculate descriptive statistics (average and standard deviation), calculate Pearson's correlation coefficient (r) to assess the linear relationship between DBH, height, and CO_2 sequestration and create graphical representations of the analyzed variables. Furthermore, multiple linear regression analysis was applied using SigmaPlot to determine the combined effect of diameter and height in explaining the variance in CO_2 sequestration and to estimate the predictive power of the studied physical variables. The work steps are shown below in the flowchart at Fig. 2.

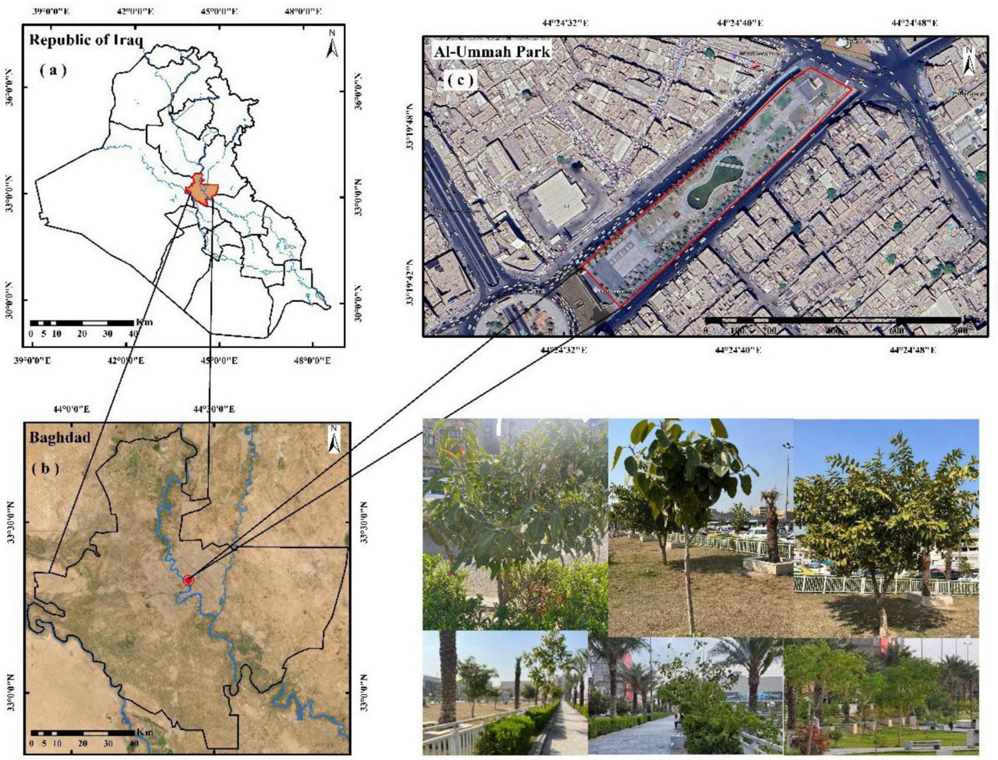

Fig. 1: Location of Al-Umma Park in central Baghdad, Iraq, showing its position, boundaries, and field photographs of selected tree species. The map was prepared using ArcGIS based on Google Earth Pro imagery (20 September 2025)

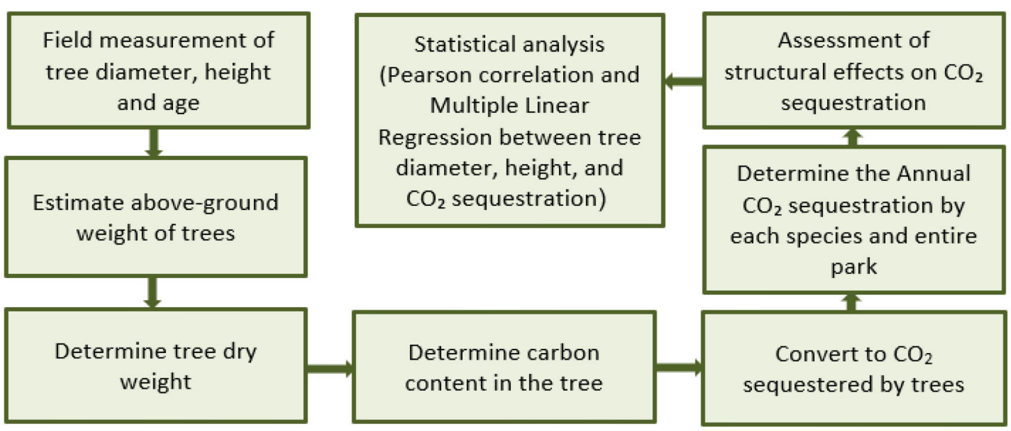

Fig. 2: The research methodology

RESULTS AND DISCUSSIONS

The relative distribution of tree species in the studied park is presented in Fig. 3. *Phoenix dactylifera* recorded the highest proportion 39.4%, whereas *Acacia spp.* had the lowest 6.78%. The remaining species ranged between 8.05% and 19.92%, with *Ficus religiosa* being the most dominant among them.

Potential for CO_2 sequestration by tree species

In an effort to understand the effectiveness of urban trees planted in the park in mitigating CO_2 emissions at this site, a comprehensive analysis was conducted of the trees' ability to sequester CO_2. This analysis aimed to calculate the annual sequestration of CO_2 and identify the most efficient plant species in this role, based on their physical characteristics, such as diameter, height, and adaptability to local climate conditions. To achieve this, a complete field survey of the trees was conducted, including measuring the DBH, total height of each tree, and data on age from the Baghdad municipality. As shown in Table 1, the six studied species showed clear variation in their physical characteristics and CO_2 sequestration ability. *Ficus benghalensis* recorded the lowest sequestration value, with a mean of 1.23 ± 0.07 kg/year per tree and a total of 30.6 kg/year from 25 individuals. This can be explained by its small diameter (4.9 ± 0.09 cm) compared to other species, despite reaching a height of 226 ± 5 cm, indicating that height alone does not reflect sequestration ability.

Table 1: Descriptive statistics of the physical attributes of trees and annual CO_2 sequestration values by species`

Species	Tree Count	Age (year)	(Height (cm	Diameter (cm)	CO_2 Sequestered (kg/year)	Total CO_2 Sequestered (kg/year)
		Mean ± Std Dev	Mean ± Std Dev	Mean ± Std Dev	Mean ± Std Dev	
Acacia spp.	16	0.25 ± 3.9	198 ± 22.868	6.2 ± 0.75	1.729 ±0.468	27.6
Ficus benghalensis	25	4 ± 0	226 ± 5	4.9 ± 0.097	1.225 ± 0.065	30.6
Syzygium cumini	36	4.08 ± 0.368	190 ± 28.221	7.14 ± 2.845	2.239 ± 1.868	80.6
Albizia lebbeck	19	3.421 ± 0.507	299.47 ± 59.299	7.34 ± 1.402	4.504 ± 1.756	85.5
Ficus religiosa	47	3.19 ± 0.471	217.9 ± 51.548	9.65 ± 2.746	5.369 ± 4.061	252.3
Phoenix dactylifera	93	8.323 ± 1.055	323.18 ± 55.246	42.077 ± 4.675	38.394 ± 9.868	3570.6
Total	236					4047.2

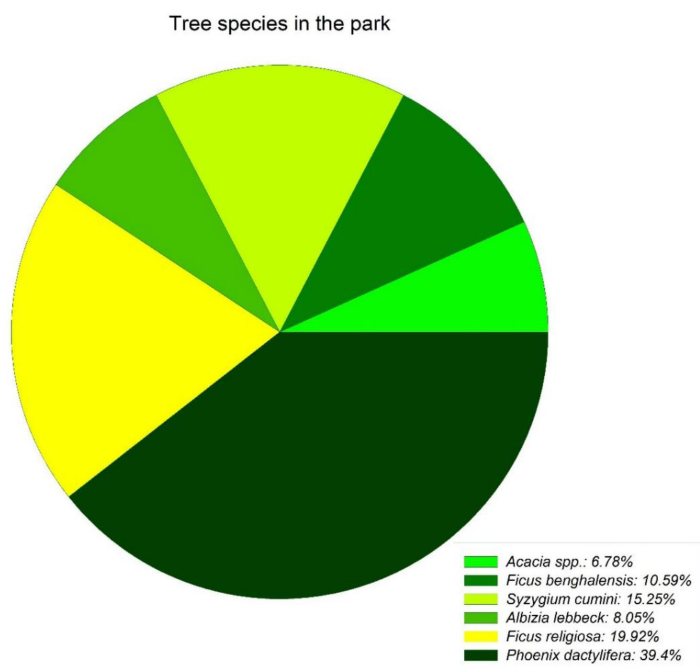

Fig. 3: percentage of the park's tree species

Similarly, *Acacia spp.* showed a low sequestration of 1.73 ± 0.47 kg/year per tree, with a total of 27.6 kg/year from 16 trees, mainly due to its limited diameter (6.2 ± 0.75 cm) and relatively lower height (198 ± 22.87 cm), which constrain its ability to sequester CO_2.

In contrast, *Syzygium cumini* exhibited a relative improvement in sequestration, with a mean of 2.24 ± 1.87 kg/year per tree and a total of 80.6 kg/year. This is associated with its moderate diameter (7.14 ± 2.85 cm), despite having a comparable height, indicating that diameter plays a more influential role.

Albizia lebbeck showed higher performance, with a mean sequestration of 4.5 ± 1.76 kg/year per tree and a total of 85.5 kg/year from 19 individuals, due to its relatively larger diameter (7.34 ± 1.4 cm) and greater height (299.47 ± 59.29 cm), reflecting more vigorous growth and greater sequestration ability.

Ficus religiosa recorded even higher values (5.37 ± 4.06 kg/year per tree), with a total of 252.3 kg/year from 47 trees. This can be explained by its considerably larger diameter (9.65 ± 2.75 cm) compared with the other species, despite similar ages.

In contrast, *Phoenix dactylifera* represented a clearly dominant species, recording the highest sequestration with (38.39 ± 9.87 kg/yearper tree) and a total of 3570.6 kg/year from 93 trees. This superiority is attributed to its very large diameter (42.08 ± 4.68 cm), in addition to its greater height and older age, which together result in significantly higher biomass accumulation and, consequently, higher ability to sequester CO_2. Structurally, *Phoenix dactylifera* differ from broadleaf species as they are monocotyledonous and do not accumulate diameter in the same way. Finally, the total annual sequestration for all species studied in the park was 4047.2 kg/year, and the cumulated sequestration over their current life time was about 31978 kg CO_2.

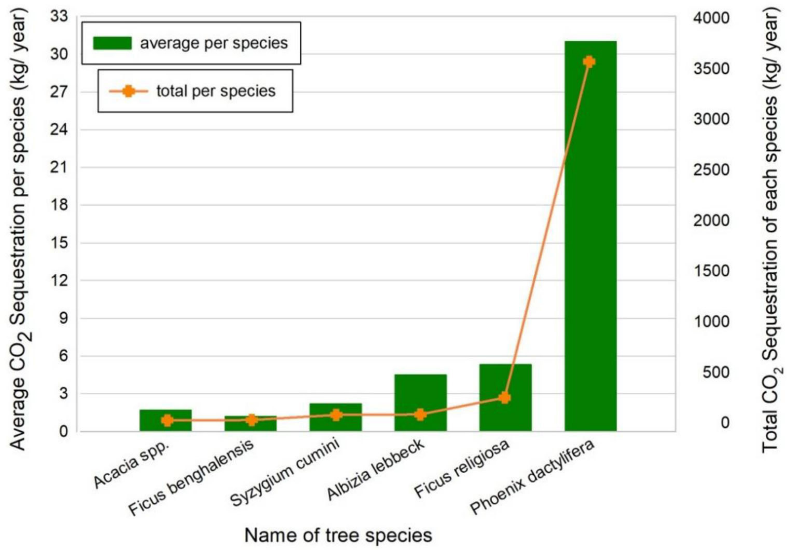

Fig. 4: Average of annual CO_2 sequestration per tree species (green columns) compared to the total sequestration (orange line)

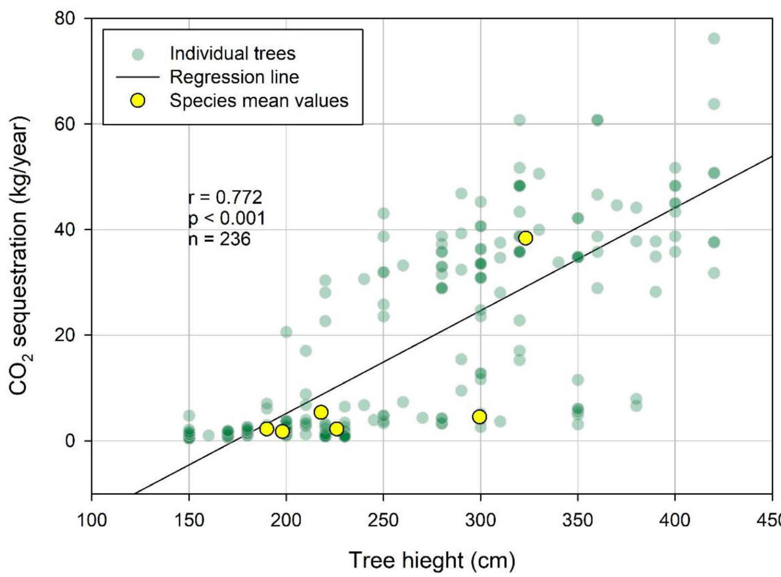

Fig. 5: The relationship between tree height (cm) and annual CO_2 sequestration (kg/year). Green dots represent individual tree measurements, while yellow dots represent the average values for each species and the trend of the relationship is displayed by the regression line.

In general, CO_2 sequestration varied among the studied species as show in Fig. 4. *Phoenix dactylifera* showed the highest values in both mean and total sequestration, reflecting its physical characteristics and number of individuals. Despite the similarity in age among most species, each species exhibited distinct structural characteristics that influenced its sequestration ability. It was followed by *Albizia lebbeck* and *Ficus religiosa*, while *Acacia spp.*, *Ficus benghalensis*, and *Syzygium cumini* recorded lower values due to their less developed physical characteristics. These findings may support urban planning by guiding the selection of species with greater sequestration efficiency and improving planting strategies in densely populated urban areas. Other studies have also examined CO_2 sequestration calculations in similar semi-arid environments. For example, a study in Doha showed that public parks had the highest carbon sequestration capacity, with an annual sequestration rate of 108.4 tons/year (Habib & Al-Ghamdi, 2021). A previous study in Baghdad also demonstrated that limited tree cover in traffic areas leads to a significant reduction in emissions offsetting, with trees sequestering 3198.8 kg/year compared to annual traffic emissions of 11970241.66 kg/year (Mohsen & Abdulkareem, 2025). These results support the importance of selecting tree species with larger structural characteristics, particularly diameter, to improve sequestration efficiency in urban parks.

The studied tree species exhibit varying degrees of adaptability to hot and dry urban conditions, depending on their physiological and structural characteristics. *Acacia* species (*Acacia spp.*) are well-adapted to arid and semi-arid environments through their diverse water use strategies and tolerance to water stress (Uni *et al.,* 2023). *Ficus* species, such as *Ficus benghalensis* and Ficus religiosa, possess the ability to cope with abiotic stresses like drought, heat, and oxidative stress through morphological, physiological,

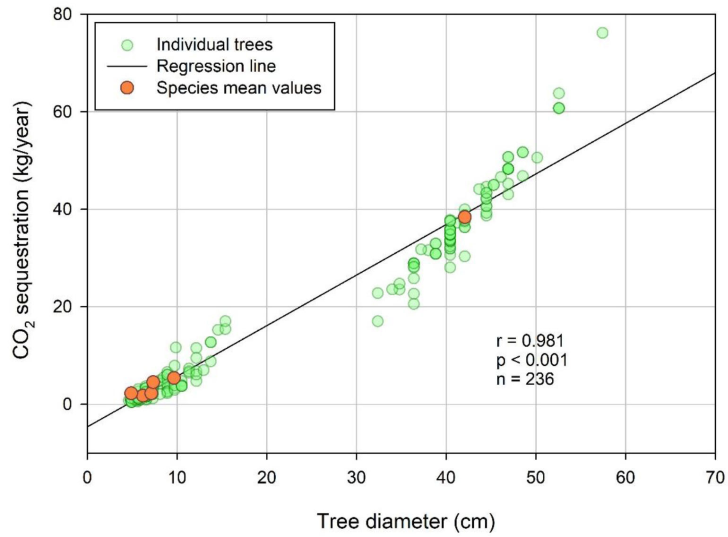

Fig. 6: The relationship between diameter (cm) and annual CO_2 sequestration (kg/year). Green dots represent individual tree measurements, while orange dots represent the average values for each species and the regression line reflects the general trend.

and metabolic adaptations (Yuan *et al.,* 2024). *Syzygium cumini* demonstrates adaptive responses to mild and moderate water stress, such as improved water use efficiency and reduced transpiration; however, severe stress limits its physiological activity, necessitating appropriate irrigation management (Chowdhury *et al.,* 2025). *Albizia lebbeck* is well-suited to hot and semi-arid urban environments due to its tolerance to heat and air pollution (Seyyednejad *et al.,* 2009). While the *Phoenix dactylifera* is among the species most adapted to Iraqi climatic conditions due to its high tolerance to heat, drought, and salinity, these characteristics support its selection for urban afforestation programs in Baghdad, taking into account its varying water requirements and ability to withstand environmental stress (Yaish & Kumar, 2015).

Effect of physical attributes of trees on CO_2 Sequestration

The relationship between the physical Characteristics of trees and CO_2 sequestration in Al-Umma Park was analyzed using individual data from 236 trees. Fig. 5 illustrates the relationship between height and CO_2 sequestration, showing a general positive trend indicating increased sequestration with increasing height. The correlation coefficient ($r = 0.772$, $p < 0.001$) demonstrates a strong relationship, with height explaining approximately 59.6% of the variance in sequestration. However, the scatter plots show significant dispersion in the values, particularly at high heights, where sequestration values vary within the same height range.

In contrast, Fig. 6 shows a clearer and more consistent relationship between diameter and CO_2 sequestration, where the data points cluster closer to the regression line with less dispersion compared to the height relationship. The correlation coefficient ($r = 0.981$, $p < 0.001$) reflects a very strong relationship, with height explaining approximately 96.2% confirms that diameter is the most influential factor in explaining the variance in carbon sequestration at this case.

The multiple linear regression test was applied, which showed high explanatory power ($R^2 = 0.97$, $p < 0.001$), meaning the test explains approximately 97% of the variance in CO_2 sequestration. The relationship was expressed by the Equation:

The test coefficients indicate that both variables contribute significantly to explaining the sequestration, with the effect of diameter remaining more pronounced than that of height. The results also show a diameter is the most reliable physical characteristic for estimating CO_2 sequestration, while height contributes secondarily to explaining the variance, although it is statistically significant. Since diameter and height are included in the biomass estimation equations used to calculate CO_2 sequestration, the high value of the coefficient of determination in the multiple regression test may partially reflect the computational nature of the relationship between the variables, as well as the true structural relationship between tree size and biomass accumulation.

These results are also consistent with the work of Nowak (1994) suggesting that larger tree diameters correspond to higher long-term carbon sequestration potential, and must be considered for biomass estimates. And Mildrexler *et al.,* (2020) found that only 3% of all trees are large (DBH > 50 cm), they do store approximately 42% of all the carbon above ground which says there is a definite effect of bigger diameter giving more capacity to store carbon. So prioritizing diameter in urban CO_2 assessments can lead to more accurate estimations of sequestration and help sustainable urban planning target species that are able to sequester more CO_2. These findings are particularly important in the Iraqi context, where quantitative studies on CO_2 sequestration in urban parks remain very limited, thus filling a clear research gap in the environmental literature at the Iraqi level. Its results can also serve as a preliminary guide for selecting tree species in public parks and densely populated urban areas, supporting emissions mitigation plans and promoting long-term urban sustainability and carbon neutrality.

CONCLUSIONS

Results of this study give a comprehensive assessment of the CO_2 sequestration of urban trees in Al-Umma Park – Baghdad, focusing on the role of physical characteristics and species differences in determining CO_2 sequestration potential.

1. The greatest average sequestration was achieved by *Phonix dactylifera* with 38.39 ± 9.87 kg/year per tree, which could be due to the biomass and age of these trees. In contrast, smaller and younger species such as *Ficus benghalensis* and *Acacia spp.* exhibited the minimum average sequestration as 1.225 ± 0.065 and 1.729 ±0.468 kg/year per tree, respectively.

2. The estimated total annual sequestration for all species studied was 4047.2 kg/year. Compared to that, cumulated sequestration over their current life time was about 31978 kg CO_2 stressed the relevance of the total contribution from the park trees to an improvement of the local carbon balance.

3. CO_2 sequestration was primarily controlled by tree diameter (r = 0.981), while height showed a secondary contribution (r = 0.772), with structural variables explaining 97% of sequestration variability (R^2 = 0.97).

Future studies are recommended to develop species-specific allometric equations for dominant urban tree species in Baghdad under local environmental conditions. Such equations may improve biomass and CO_2 sequestration estimation accuracy and support urban tree management by local municipalities. This research creates a useful reference dataset for future evaluation of urban trees and CO_2 sequestration potential in Baghdad. Results can be used to inform evidence-based urban and environmental planning in the city in pursuit of sustainable urban greening, the city´s carbon-neutral goals and climate resilience.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to the Baghdad Mayoralty /Al-Rusafa Central Municipality/ Agriculture Department, for their cooperation, provision of part of the required data, accompaniment during fieldwork, and facilitation of access to the study area. Their support contributed significantly to the successful completion of this research.

Author's certificate: The manuscript or its part is not under consideration for publication elsewhere and the same has been approved by all co-authors.

Conflict of Interests: The authors declare that there is no conflict of interest regarding the publication of this article.

Funding: No funding agency was involved.

Data Availability: Data to be provided on request.

Authors contribution: **Al-Zahraa A. Mohsen**: conducted the field measurements, performed the data analysis, contributed to the interpretation of results, and drafted the manuscript; **Asraa Khtan**: Abdulkareem supervised the research, contributed to the interpretation of results, and revised the manuscript critically. Both authors read and approved the final version of the manuscript.

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