Impact of increasing CO2 levels on *Mangifera indica* growth and carbon sequestration potential at different nitrogen addition levels

ABSTRACT

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| The rapid increase in atmospheric CO2 concentrations, coupled with nitrogen enrichment in soils, necessitates a thorough examination of their effects on plant growth and carbon sequestration potential. This study carried out during 2018 to 2019 in the department of Environmental Sciences, Bharathiar University, investigates the influence of escalating CO2 levels on the growth metrics shoot length (SL), leaf length (LL), leaf width (LW), and carbon sequestration capabilities of *Mangifera indica* L. under varying nitrogen addition levels. We studied five CO2 conditions separately one after the other, including ambient (408 ppm) and elevated levels (450, 500, 550, and 600 ppm), using an OSC S-1000 L plant growth chamber, while nitrogen was supplied as potassium nitrate at rates of 0, 3, 6, 12, and 24 g N/m². Notably, plant carbon content peaked at 50.96 ± 0.092% (mean ± S.D.) at the highest nitrogen level under 600 ppm CO2. One-way ANOVA revealed significant variations (p < 0.0001) in carbon content across all CO2 conditions and nitrogen levels. Regression analysis demonstrated a positive correlation (p < 0.05) between CO2 conditions and plant growth parameters, including SL, LL, LW, and carbon content across all nitrogen levels. We conclude that both elevated CO2 and nitrogen addition significantly enhance the growth and carbon sequestration potential of *Mangifera indica*, highlighting the importance of strategic nutrient management in optimizing forest productivity under climate change**.** |

*Keywords: Agroforestry, Climate change, Carbon sequestration, Mangifera indica, Nitrogen enrichment*

1. INTRODUCTION

The anthropogenic increase in atmospheric CO2 concentrations has reached significant levels, measuring 430.27 ppm as of June 2025 (CO2.earth, 2025), compared to pre-industrial levels of 280 ppm (Chen et al., 2024). Projections indicate that CO2 concentrations may rise further, reaching between 538 and 670 ppm by the end of the century (IPCC, 2013). This rapid increase, primarily driven by fossil fuel consumption, exacerbates global warming and climate change, posing substantial threats to ecosystems worldwide (Wolf et al., 2025). As a greenhouse gas, CO2 is a major contributor to these environmental challenges, prompting the IPCC’s Sixth Assessment Report to emphasize the urgent need to limit global warming to 1.5 °C above pre-industrial levels (Warren et al., 2022).

Plants serve as natural carbon sinks, utilizing through photosynthesis, utilizing atmospheric CO2 to produce biomass. Forest ecosystems account for over 50% of the terrestrial carbon sink, and improving forest management practices can significantly enhance this capacity. However, since 1990, the area of primary forest has declined by 81 million hectares, though the rate of loss more than halved from 2010 to 2020 compared to the previous decade (FAO, 2020). Global forest cover loss significantly impacts environmental and climatic systems by disrupting the carbon cycle, increasing atmospheric CO2, and accelerating climate change (Roba et al., 2025).

In response, afforestation and reforestation have emerged as key strategies for managing carbon levels in degraded forest areas. Agroforestry systems, which combine high tree density with diverse plant species, are recognized under the Kyoto Protocol as effective carbon sequestration strategies. These systems not only sequester carbon but also offer additional benefits such as food security, enhanced farm income, restored biodiversity, soil conservation, and maintained watershed hydrology (Kassa et al., 2022).

Nitrogen is critical for ecosystem functioning, influencing plant productivity, carbon sequestration, and climate regulation (Kicklighter et al., 2019). It is an essential component of proteins and chlorophyll, driving key physiological processes such as photosynthesis, nutrient absorption, and root development (Pragasan and Ganesh, 2022). Modern agriculture relies heavily on nitrogen fertilizers to boost productivity, leading to elevated nitrogen deposition in soils. However, nitrogen deficiency can limit plant growth under eCO2 conditions (Li et al., 2020), potentially reducing the capacity of plants to sequester carbon effectively.

*Mangifera indica* (mango) plays a significant role in carbon sequestration across various agroforestry systems due to its long lifespan, large biomass, and extensive root system (Adhikari et al., 2020; Mishra et al., 2020; Chavan et al., 2023; Trivedi et al., 2025). Integrating *Mangifera indica* into agroforestry systems not only supports climate change mitigation through carbon capture but also provides socio-economic benefits such as fruit yield, shade, and improved soil fertility, making it a valuable component of sustainable land use strategies (Dagar et al., 2020; Gochera and Worku, 2022).

Despite extensive research on CO2 and nitrogen dynamics, a significant knowledge gap remains in understanding how different nitrogen levels interact with rising CO2 concentrations to affect plant growth and carbon sequestration potential. This gap is particularly relevant for agroforestry species like *Mangifera indica*, a widely cultivated tropical tree known for its ecological and economic importance (Kumar, 2017). The present study addresses this gap by examining the effects of rising CO2 concentrations on the growth and carbon sequestration potential of *Mangifera indica* under varying nitrogen addition levels. This research aims to provide insights into how nitrogen availability modulates the carbon-sequestering capacity of this key agroforestry species, offering practical applications for improving carbon management strategies in agroforestry systems.

2. materials and methods

**2.1 Plant selection and seed germination**

*Mangifera indica* L. (Anacardiaceae) was selected for this study due to its ecological importance and commercial value as an agroforestry species. Seeds were obtained from the Tamil Nadu Agricultural University, Coimbatore. For each of the five separate experiments, seeds were germinated freshly before the start of the respective experiment. Germination was carried out in seedling trays under controlled environmental conditions to ensure uniform emergence and early seedling development. After three weeks of growth, 25 healthy and uniform seedlings were selected based on vigor and morphological consistency. These selected seedlings were then transplanted into individual pots containing 1000 g of well-prepared soil. This process was repeated for each experiment to maintain consistency and ensure that all plants started under comparable developmental stages, tailored specifically to the CO₂ and nitrogen treatments being applied in each experimental run.

**2.2 Experimental design and CO₂ treatments**

The experiment aimed to evaluate the growth responses and carbon sequestration potential of *Mangifera indica* under varying atmospheric CO₂ concentrations and nitrogen levels. Due to equipment constraints allowing only one CO₂ level to be maintained at a time, five separate experiments were conducted sequentially, each under a different CO₂ concentration. The CO₂ levels tested were ambient CO₂ (408 ppm), and elevated CO₂ (eCO₂: 450 ppm, 500 ppm, 550 ppm, and 600 ppm) conditions.

Each experiment lasted for 98 days and was conducted using a plant growth chamber (model: OSC S-1000 L) at the Environmental Ecology Laboratory, Department of Environmental Sciences, Bharathiar University during 2018 to 2019. The CO₂ concentrations were selected based on projected atmospheric levels reported by the Intergovernmental Panel on Climate Change (IPCC) and previous studies demonstrating plant responses to elevated CO₂ (Luo et al., 1999). Each of the five experiments followed an identical protocol, differing only in the CO₂ concentration set in the chamber.

**2.3 Growth chamber conditions**

The growth chamber was programmed to maintain a photoperiod of 16 hours light and 8 hours dark to simulate natural day-night cycles conducive to photosynthesis in *Mangifera indica*. The chamber temperature was maintained at 25 ± 3.1 °C to closely resemble ambient conditions favorable for plant growth. These consistent environmental conditions minimized variability and ensured that observed differences in plant response were due to CO₂ and nitrogen treatments rather than external factors.

**2.4 Nitrogen application**

To assess the interactive effects of nitrogen availability and CO₂ enrichment on plant growth, nitrogen was applied in the form of potassium nitrate at five concentrations: 0, 3, 6, 12, and 24 g N/m². These levels were selected based on previous studies (Pragasan and Ganesh, 2022), which highlighted the significant role of nitrogen in modulating plant physiological responses under elevated CO₂ conditions.

**2.5 Watering regimen**

Soil moisture was maintained consistently within the optimal range of 30-35% throughout the experimental period. Watering was done at regular intervals, with close monitoring to avoid both drought stress and waterlogging. This ensured uniform soil conditions across treatments, supporting healthy plant development and enhancing the accuracy of the growth response data.

**2.6 Growth measurements**

Growth performance was evaluated biweekly over the 98-day experimental period by recording the following morphological parameters, shoot length (SL), leaf length (LL), and leaf width (LW). These measurements provided insights into the growth dynamics of *Mangifera indica* under different CO₂ and nitrogen conditions. At the end of each experiment, plants were carefully harvested for final analyses, ensuring comprehensive data collection for growth and carbon assimilation assessments.

**2.7 Carbon content analysis**

The carbon content of the harvested *Mangifera indica* plants was determined using the loss on ignition technique, a widely accepted method for evaluating organic carbon levels in plant material (Alamgir and Al-Amin, 2007). This technique involves heating the samples to a high temperature to combust organic matter, allowing for the quantification of carbon that has been sequestered by the plants. By assessing carbon content under varying CO2 conditions, this analysis provides critical insights into the carbon sequestration potential of *Mangifera indica*, helping to elucidate its role in mitigating climate change through enhanced carbon storage capabilities.

**2.8 Statistical analysis**

ANOVA was employed to evaluate the significance of variations in growth parameters (SL, LL, LW) and carbon content of *Mangifera indica* among the experimental conditions. Regression analysis was performed to elucidate the influence of CO2 levels on growth and carbon sequestration potential.

3. results and discussion

**3.1 Growth response at 408 ppm ambient condition**

Figures 1–5 present the growth of *Mangifera indica* in terms of SL, LL, and LW under ambient CO2 (408 ppm) and elevated CO2 (eCO2) levels (450, 500, 550, 600 ppm) with varied nitrogen additions (0, 3, 6, 12, 24 g N/m²). Under ambient CO2, the average SL values ranged between 30.18 ± 0.65 cm and 31.76 ± 0.55 cm across nitrogen levels, indicating limited variation in shoot growth. However, the LL showed a significant response, ranging from 11.48 ± 0.44 cm to 12.66 ± 0.21 cm, suggesting that leaf growth is more sensitive to nitrogen input. LW remained fairly consistent, with values between 2.44 ± 0.15 cm and 2.66 ± 0.15 cm. The one-way ANOVA indicated a significant effect of nitrogen levels on LL (F(4,20) = 15.761, p < 0.0001), while no significant differences were observed for SL (F(4,20) = 1.932, p > 0.05) or LW (F(4,20) = 1.262, p > 0.05). This suggests that nitrogen primarily influences LL under ambient CO2 conditions, with minimal impact on SL and LW. The observed variation in LL could be indicative of nitrogen’s role in enhancing photosynthetic efficiency, as increased leaf surface area allows for greater light capture and carbon fixation (Reich et al., 1998). These results are in line with other studies showing that nitrogen availability plays a critical role in improving plant growth parameters under ambient CO2 levels (Padhan et al., 2020). In terms of forest management, this indicates that nitrogen amendments may need to be carefully managed to optimize leaf development without over-application, which may not significantly enhance other growth traits like SL or LW.

**Fig. 1.** Growth performance of Mangifera indica under ambient CO2 level (408 ppm).

**3.2 Growth response at 450 ppm eCO2 condition**

At 450 ppm eCO2 conditions, the mean (± S.D.) values of SL were 32.22±0.54 cm, 32.14±0.63 cm, 32.38±0.77 cm, 31.94±1.53 cm, and 33.18±0.62 cm for the nitrogen addition levels of 0, 3, 6, 12, and 24 g N/m² (Fig. 2). The mean (± S.D.) values of LL were 11.90±0.16 cm, 12.52±0.30 cm, 12.52±0.24 cm, 12.64±0.24 cm, and 12.80±0.16 cm, while LW values were 2.46±0.15 cm, 2.74±0.15 cm, 2.68±0.13 cm, 2.76±0.11 cm, and 2.78±0.22 cm. One-way ANOVA revealed significant variations in LL (F(4,20) = 11.370, p < 0.0001) and LW (F(4,20) = 3.472, p < 0.05) across the five nitrogen addition levels; however, no significant differences were observed for SL (F(4,20) = 1.428, p > 0.05). This indicates that eCO2 enhances leaf growth responsiveness to nitrogen fertilization, suggesting that *Mangifera indica* can optimize leaf morphology under elevated CO2 to improve light and carbon capture. The lack of significant variation in SL may imply that shoot growth is less responsive to nitrogen inputs compared to leaf growth, possibly due to other limiting factors such as light availability or root development. These findings underscore the importance of tailored nitrogen applications in eCO2 environments to maximize leaf growth and enhance carbon sequestration potential (Li et al., 2023). However, careful monitoring is essential to avoid excessive nitrogen input, which may not yield proportional benefits in shoot growth, thereby emphasizing the need for integrated nutrient management strategies in agroforestry practices.

**Fig. 2.** Growth performance of Mangifera indica at 450 ppm elevated CO2 level.

**3.3 Growth response at 500 ppm eCO2 condition**

At 500 ppm eCO2 conditions, the mean (± S.D.) values of SL were 32.76±0.68 cm, 33.08±1.57 cm, 32.16±0.57 cm, 32.66±0.75 cm, and 34.50±0.48 cm for the nitrogen addition levels of 0, 3, 6, 12, and 24 g N/m² (Fig. 3). The mean (± S.D.) values of LL were 12.66±0.29 cm, 12.68±0.11 cm, 12.62±0.18 cm, 12.72±0.16 cm, and 12.74±0.17 cm, while LW values were 2.62±0.15 cm, 2.74±0.15 cm, 2.76±0.13 cm, 2.56±0.11 cm, and 2.74±0.15 cm. One-way ANOVA revealed significant variation in SL (F(4,20) = 4.817, p < 0.01) across the nitrogen addition levels, whereas no significant differences were observed for LL (F(4,20) = 0.313, p > 0.05) and LW (F(4,20) = 1.989, p > 0.05). This suggests that nitrogen significantly influences SL at this eCO2 level, indicating a positive response to higher nitrogen levels, likely due to improved nutrient uptake and photosynthetic capacity. The lack of significant variation in LL and width indicates that these parameters may reach a saturation point or are limited by other factors, such as inherent genetic traits of *Mangifera indica* or environmental conditions beyond nitrogen availability. These results align with previous studies that demonstrate how elevated CO2 can enhance growth traits in response to nitrogen fertilization (Liu et al., 2021). Understanding the specific impacts of nitrogen on shoot growth under elevated CO2 is critical for effective forest management, as it highlights the potential for nitrogen management strategies to optimize growth in tropical species. However, it also raises questions about the long-term sustainability of such practices, particularly in relation to nutrient runoff and ecosystem health, necessitating a balanced approach to nutrient application.

**Fig. 3.** Growth performance of Mangifera indica at 500 ppm elevated CO2 level.

**3.4 Growth response at 550 ppm eCO2 condition**

At 550 ppm eCO2 conditions, the mean (± S.D.) values of SL were 34.82±0.45 cm, 33.52±0.40 cm, 34.46±0.54 cm, 32.34±0.74 cm, and 34.20±1.19 cm for the nitrogen addition levels of 0, 3, 6, 12, and 24 g N/m² (Fig. 4). The mean (± S.D.) values of LL were 12.54±0.23 cm, 12.66±0.21 cm, 12.72±0.18 cm, 12.62±0.15 cm, and 12.78±0.26 cm, while the values for LW were 2.62±0.13 cm, 2.74±0.15 cm, 2.74±0.11 cm, 2.78±0.15 cm, and 2.78±0.13 cm. One-way ANOVA indicated significant variation in SL (F(4,20) = 9.154, p < 0.001) across the nitrogen addition levels, whereas no significant differences were found for LL (F(4,20) = 0.977, p > 0.05) or LW (F(4,20) = 1.174, p > 0.05). The significant increase in SL at this eCO2 level suggests that higher nitrogen availability positively impacts growth, corroborating previous findings on nitrogen's enhancement of growth responses to increased CO2 (Norby et al., 2010; Langley and Megonigal, 2010). The consistent LL and LW, despite varying nitrogen levels, may indicate that these parameters are less responsive to nitrogen under conditions of elevated CO2, potentially due to the physiological limits of *Mangifera indica* or compensatory growth mechanisms (Zhao, 2024). These results underscore the importance of optimizing nitrogen inputs to enhance shoot growth in tropical species under elevated CO2 scenarios. However, the limited response of leaf dimensions highlights the need for a holistic approach to nutrient management, ensuring that tree health and growth do not rely solely on nitrogen fertilization but also consider other environmental factors and nutrient balances.

**Fig. 4.** Growth performance of Mangifera indica at 550 ppm elevated CO2 level.

**3.5 Growth response at 600 ppm eCO2 condition**

At 600 ppm eCO2 conditions, the mean (± S.D.) values of SL were 34.08±1.33 cm, 33.20±1.18 cm, 34.86±1.12 cm, 34.86±0.89 cm, and 35.44±0.61 cm for the nitrogen addition levels of 0, 3, 6, 12, and 24 g N/m² (Fig. 5). The mean (± S.D.) values of LL were 12.52±0.23 cm, 12.46±0.17 cm, 12.58±0.19 cm, 12.86±0.22 cm, and 12.88±0.22 cm, while the values for LW were 2.68±0.16 cm, 2.68±0.15 cm, 2.78±0.08 cm, 2.66±0.15 cm, and 2.82±0.18 cm. One-way ANOVA revealed significant variation in SL (F(4,20) = 3.372, p < 0.05) and LL (F(4,20) = 4.552, p < 0.01) across the nitrogen addition levels, while no significant differences were found for LW (F(4,20) = 1.144, p > 0.05). The enhanced shoot and LL observed at 600 ppm eCO2 suggest that higher nitrogen levels can stimulate growth under conditions of increased atmospheric CO2. This finding supports earlier research indicating that elevated CO2 enhances the responsiveness of plant growth to nitrogen availability (Ma et al., 2018). The significant increase in LL, in particular, indicates that nitrogen not only facilitates overall growth but may also play a critical role in optimizing leaf morphology for better photosynthetic efficiency under high CO2 conditions. Moreover, the increased SL and LL could contribute to enhanced carbon sequestration potential, which is vital in the context of climate change mitigation. In terms of forest management, these results imply that nitrogen fertilization strategies can be effectively employed to enhance the growth of *Mangifera indica* in environments experiencing rising CO2 levels (Ma et al., 2018). However, the lack of significant variation in LW suggests that other factors may be influencing leaf expansion. This observation emphasizes the need for a holistic approach to nutrient management, considering not just nitrogen but also other essential nutrients and environmental conditions. This warrants further investigation to ensure comprehensive nutrient management and maximize growth potential in tropical forestry systems.

**Fig. 5.** Growth performance of *Mangifera indica* at 600 ppm elevated CO2 level.

**3.5 Carbon content analysis under varying CO2 and nitrogen conditions**

The determined carbon content (%) of *Mangifera indica* under five different CO2 environmental conditions with varying nitrogen addition levels is illustrated in Fig. 6. Notably, the carbon content was highest under ambient CO2 conditions (408 ppm), with a mean (± S.D.) value of 48.76 ± 0.053 % at a nitrogen addition level of 12 g N/m². For elevated CO2 (eCO2) conditions, carbon content reached its maximum at 24 g N/m², showing mean values of 49.46 ± 0.053 % at 450 ppm, 50.18 ± 0.053 % at 500 ppm, 50.42 ± 0.072 % at 550 ppm, and 50.96 ± 0.092 % at 600 ppm, respectively. One-way ANOVA demonstrated significant variations in carbon content across the different CO2 conditions at all nitrogen addition levels: 0 g N/m² (F(4,14) = 953.721, p < 0.0001), 3 g N/m² (F(4,14) = 410.213, p < 0.0001), 6 g N/m² (F(4,14) = 422.776, p < 0.0001), 12 g N/m² (F(4,14) = 164.051, p < 0.0001), and 24 g N/m² (F(4,14) = 592.574, p < 0.0001). These results underscore a clear trend: carbon content increases with both elevated CO2 levels and higher nitrogen addition, indicating a synergistic effect on the carbon sequestration potential of *Mangifera indica*. Regression analysis further revealed a positive correlation (p < 0.05) between carbon content and CO2 environment conditions across all nitrogen addition levels: 0 g N/m² (y = 0.0128x + 41.7, R² = 0.9364), 3 g N/m² (y = 0.0088x + 44.016, R² = 0.7253), 6 g N/m² (y = 0.0069x + 45.416, R² = 0.5583), 12 g N/m² (y = 0.0068x + 45.924, R² = 0.9715), and 24 g N/m² (y = 0.0121x + 43.848, R² = 0.9462). This data strongly supports the notion that CO2 conditions positively influence the carbon sequestration potential of the species across varying nitrogen addition levels.

**Fig. 6.** Influence of increasing CO2 condition on carbon content of *Mangifera indica*.

**3.6 Elevated CO2 and nitrogen increase growth**

In connection with the findings from Figs. 1-5, the growth performance of *Mangifera indica* under different CO2 concentrations indicates that elevated CO2 levels, combined with adequate nitrogen, significantly enhance overall plant growth metrics, including SL, LL, and carbon content. This suggests that effective nitrogen management could maximize the benefits of rising CO2 levels on plant growth. This is consistent with existing literature, which suggests that increased atmospheric CO2 can improve plant growth efficiency when nitrogen is sufficiently available (Lekshmy et al., 2013; Ma et al., 2018). In terms of forest management implications, these findings advocate for the strategic application of nitrogen fertilizers in environments experiencing rising CO2 levels. Such practices could be vital for enhancing the growth and carbon sequestration capabilities of *Mangifera indica*, thereby contributing to improved forest management and carbon mitigation strategies. However, as noted in Figures 1 to 5, it is crucial to monitor other growth parameters to fully understand the multifaceted impacts of nitrogen on leaf morphology and overall plant health, especially in tropical forestry systems where nutrient management plays a key role (Sayer and Banin, 2016).

**3.7 Carbon sequestration under CO2 and nitrogen levels**

Understanding the effects of increasing atmospheric CO2 concentration on plant growth and carbon sequestration potential is critical, as atmospheric CO2 levels are rising at an alarming rate. This experimental study focused on the influence of elevated CO2 conditions on the growth of *Mangifera indica* in terms of SL, LL, LW, and carbon sequestration ability under various nitrogen addition levels. We found that increasing CO2 significantly impacts (p < 0.05) the growth and carbon storage potential of *Mangifera indica* across all nitrogen addition levels. The maximum carbon content was recorded under ambient CO2 conditions (408 ppm) with a mean (± S.D.) value of 48.76 ± 0.053 % at a nitrogen addition level of 12 g N/m². Under elevated CO2 conditions, carbon content peaked at 24 g N/m², with mean values of 49.46 ± 0.053 % at 450 ppm, 50.18 ± 0.053 % at 500 ppm, 50.42 ± 0.072 % at 550 ppm, and 50.96 ± 0.092 % at 600 ppm. In comparison, *Mangifera indica* exhibited significant carbon content growth under elevated CO2, reaching a maximum of 50.96 ± 0.092% at 600 ppm with 24 g N/m² of nitrogen. In contrast, Eucalyptus globulus exhibited a maximum carbon content of 52.37 ± 0.03% under elevated CO2 conditions of 600 ppm at 24 g N/m² (Ganesh and Pragasan, 2024). Similarly, *Azadirachta indica* reached 54.82 ± 0.53% (Ganesh and Pragasan, 2019), while *Syzygium cumini* recorded 53.3 ± 0.09% (Pragasan and Ganesh, 2022). Plants in high CO2 environments enhance photosynthesis, leading to increased growth rates and enhanced carbon uptake (Dusenge et al., 2019). Research indicates that plants exposed to elevated CO2 grow faster than those in ambient conditions (Lee et al., 2020). This acceleration in growth may also improve resilience to environmental stressors, enabling better adaptation to changing climates. To contextualize these findings, it is important to consider the ecological and physiological differences among these species, such as variations in leaf morphology, nutrient uptake efficiency, and overall resource allocation. Such differences could significantly influence their carbon sequestration capabilities and adaptability to high CO2 conditions. Brienen et al. (2020) observed that elevated CO2 responses included increased net photosynthesis, biomass production, and faster growth in younger seedlings compared to older trees.

**3.8 Nitrogen’s role in growth and physiology**

In our study, nitrogen addition improved growth parameters such as SL, LL, and LW of *Mangifera indica*. This finding aligns with Bai et al. (2020), who reported similar improvements in growth characteristics with nitrogen supplementation. Increased leaf nitrogen is crucial for enhancing stomatal conductance, transpiration, photosynthetic rate, and gas exchange (Wang et al. 2012). Further, the carbon sequestration ability of *A. indica* (Ganesh and Pragasan, 2019) and *S. cumini* (Pragasan and Ganesh, 2022) increases with higher nitrogen and CO2 levels. The relative ratio of carbon dioxide to nitrogen significantly shifts with rising CO2 concentration and temperature (Fitter and Hay, 2012). Elevated carbon intake may influence plant nitrogen, causing metabolic changes that affect carbon balance (Terrer et al., 2018). Increased nitrogen availability supports plant growth and the development of terrestrial ecosystems (Liao et al., 2021), a trend also observed in this study. Although nitrogen deposition affects ecosystem services, the mechanisms governing its cycle are not fully understood (Niu et al., 2016). Further research is needed to elucidate these mechanisms and assess their implications for forest health and productivity. Wormer (1965) noted that nitrogen fertilizer application increased stomatal aperture, although the reasons for this were not clearly explained, as factors such as temperature, vapor pressure deficit, and radiation also play roles. Stomata are crucial for plant adaptation to changing environmental conditions, regulating both water loss and CO2 uptake (Damour et al., 2010).

**3.9 Implications for forest management and climate adaptation**

Overall, the increasing CO2 environment positively influences the growth of *Mangifera indica* regarding SL, LL, LW, and carbon sequestration potential. Similar findings have been documented in other studies (Li et al., 2020; Xu et al., 2020). Ward et al. (2013) reported decreased stomatal conductance in elevated CO2 conditions for *Pinus taeda L.* compared to ambient conditions, attributing this response to changes in a hydraulic allometry index defined as sapwood area per unit leaf area per unit canopy height. Several factors, including air temperature, nitrogen, phosphorus, various nutrients, growth time, mycorrhizal symbiosis, and water availability, influence the plant’s response to CO2 (Shi et al., 2021). As environmental changes occur, plants adjust their physiological processes and metabolic pathways, with some species benefiting more than others from rising atmospheric CO2 concentrations (Raza et al., 2019). This underscores the importance of selecting suitable species for reforestation and carbon sequestration in a changing climate. The findings demonstrate that elevated CO2 levels, along with adequate nitrogen, significantly enhance the growth and carbon sequestration potential of *Mangifera indica*, highlighting the need for strategic nutrient management to optimize forest productivity and carbon mitigation.

4. Conclusion

We conclude that the rising CO2 concentrations significantly enhance the growth and carbon sequestration potential of *Mangifera indica* under varying nitrogen addition levels. These findings underscore the dual benefit of *Mangifera indica* plantations: contributing to both the national fruit market and playing a crucial role in climate change mitigation through carbon sequestration. The results suggest that efficient nitrogen use under elevated CO2 is governed by complex physiological and ecological mechanisms. Understanding these interactions is essential for optimizing carbon sequestration, particularly in agroforestry systems. Further, our findings highlight the importance of strategic nutrient management in maximizing the growth and carbon storage potential of this species. Future research should focus on the biochemical pathways and nitrogen transformation processes under elevated CO2 to better grasp how nutrient management can be fine-tuned for maximum carbon storage. The insights from this study provide practical guidance for policymakers, planners, and farmers. By implementing effective nutrient management strategies that align with the unique requirements of *Mangifera indica*, stakeholders can not only enhance crop productivity but also significantly boost carbon sequestration, thereby promoting agricultural resilience and supporting global climate action initiatives.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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