

Review Article

Exploring the Responses of Teak and Eucalyptus to Elevated Carbon Dioxide in a Changing Atmosphere

Abstract : This study investigates the responses of Teak and Eucalyptus trees to elevated CO₂ concentrations in Automated Open Top Chambers (AOTC) at the Institute of Forest Genetics and Tree Breeding (IFGTB), Coimbatore. Through physiological and morphological analyses, it sheds light on how these key tropical species adapt to rising atmospheric CO₂ levels. The findings contribute vital insights for forest management amidst climate change. Previous research on plant responses to elevated CO₂, primarily in agricultural crops, underscores the significance of understanding these dynamics. Growth and morphological responses, particularly in shoot development, indicate significant impacts of elevated CO₂ on plant productivity and biomass accumulation.

Keywords : Open top chamber, carbon di oxide

Introduction:

Forests, comprising diverse ecosystems and housing a plethora of plant species, play a critical role in mitigating climate change by acting as carbon sinks. Among the key contributors to this dynamic, Teak and Eucalyptus, as prominent tropical tree species, have been identified for their potential to sequester carbon dioxide (CO₂) and influence ecosystem dynamics. Understanding how these trees respond to elevated CO₂ levels is imperative for predicting the resilience and adaptability of forest ecosystems in the face of ongoing climate change. The present study, conducted at the Institute of Forest Genetics and Tree Breeding (IFGTB) in Coimbatore, delves into the responses of Teak and Eucalyptus to elevated CO₂ concentrations within Automated Open Top Chambers (AOTC). By examining physiological, morphological, and growth-related parameters, this research contributes to the broader discourse on the impact of rising atmospheric CO₂ on tropical tree species. As we navigate a changing climate, unraveling the intricacies of how these vital tree species interact with elevated CO₂ provides crucial insights for informed forest management and conservation practices.

Responses of plant to elevated CO₂

Garbutt & bazzaz, (1984) studied the plant response to higher CO₂ levels under laboratory conditions, green house or controlled environment. Nakayama & Kimball (1988) used square wall open top chambers with 0.2m diameter. (Hungate *et al.*, 2006) developed an OTC system for CO₂ enrichment of salt marsh vegetation that re circulated a part of input air. (Baker, Allen, & Boote, 1990) studied the responses of plant community to elevated.

The response of plants to the elevated CO₂ has been documented in numerous researches and detailed biochemical to broad physiological studies ((Hungate *et al.*, 2006) and (Long *et al.*, 2004). However, it must be emphasized that most of the findings on physiological and allocation responses to CO₂ were first discovered in agricultural crops. Most of the earlier studies on plant responses to the raising atmospheric CO₂ were done on temperate species using closed chambers and controlled facilities or short term responses. Carbon enrichment studies in special chambers help in understanding the changes at individual level and also at physiological, biochemical and genetic level in tree species.

Growth and morphological responses in elevated CO₂ level

Shoot responses

The plant (shoot) height is to be considered as an important for growth and development. The elevated carbon dioxide leads to increases the plant productivity, depending upon the species growth stage and the responses to that particular environment without association of climate changes. (Kimball, 1992) observed that the productivity of most herbaceous plants by about one-third in response to doubling of CO₂ content.

Under elevated CO₂ levels the growth stimulation ceased after 40 days in *eucalyptus sp.*(Wong, 1997) and the growth rate was also increase in early, which was resulted the greater plant size with an extended period of time. So the elevated CO₂ level, may directly or indirectly affect the global climate, plant productivity and development. It has been observed that, the exposure of plants to the elevated CO₂ level resulted total biomass accumulation with alteration in plant morphological parameters.

(Poorter, 1993) reported that the growth of faster-growing species was more than that of slow growing species to elevated CO₂ and it stimulates to increase the growth rate

10 per cent in all the species. Moreover, the long term increases the in growth rate was occurring in some long lived tree species and it was observed by (Bazzaz, 1993).

Lima *et al.*, (2003) reported on variations in responses to eucalyptus species to carbon enrichment. Warriret *et al.*, (2013) reported that the shoot length had significant influence on elevated CO₂ level in terms of shoot fresh and dry weights. The combined effect of CO₂ and growth period had no significant influence on fresh and dry weights. Under elevated CO₂ level it was increased about 40.27% in shoot fresh weight and 52.91% in shoot dry weight over ambient environmental conditions.

Root responses

The plant response to elevated CO₂ levels, that shows the root dry weight increased in tree species (Rogers, 1992). The plant responses in CO₂ enriched level there will be the alteration in developmental processes including root and shoot architecture (Janssens, *et al.*, 1998) observed in scots pine seedlings for six months in open-top chambers maintained with extra CO₂ increased total root length by 122 per cent and total root dry mass by 135 per cent.

Weihong *et al.*, (2002) reported that atmospheric CO₂ enrichment was typically enhances the growth rates of roots, especially those of fine roots, and CO₂ induced to increase in root production on belowground plant growth and development, lead to increase and enhance the root turnover, although, several researchers have claimed that plants should receive little direct benefit and leads to produced significant increases in root growth (Splittstoesser, 1996), as well as yield itself (Baron and Gorski, 1986), with CO₂ enriched level.

Gleadow *et al.* (1998) observed in *Eucalyptus* seedlings under elevated CO₂ level and it stimulates greater root growth of 33 per cent higher root, shoot ratio. Similarly (Gunderson & Wullschleger, 1994) suggested that the effect on growth, gas exchange and plant water relations in CO₂ enriched studies probably it increase the root shoot ratio or fine-root proliferation.

Leaf level responses

Leaf area is an important components that is closely related to the physiological processes controlling dry matter production, yield and contributes to the formation of assimilates. Chandra and Polisetty (1998) reported that the leaf area was positively

correlated with dry matter accumulation in pea varieties. There was fivefold difference in leaf area among the seed sources of *Acacia nilotica* spp. *Tomentosa*. Elevated CO₂ increases the leaf area index (LAI), through increasing photosynthetic efficiency and lower light compensation point (LCP) of photosynthesis, allowing the leaves to maintain positive carbon balance in elevated CO₂ than atmospheric CO₂. Alternatively, greater carbohydrates supply and improved water use efficiency may lead to larger individual leaves and more rapid canopy development, thereby increasing the LAI. Ceulemans & Mousseau, (1994) observed that the leaf area was increased 8-18 per cent in *populus* clones under CO₂ enrichment. It leads to increase leaf area index, leaf number, branches, thus positively changing canopy structure under optimal conditions (Arp *et al.*, 1998). Open-top chamber experiments usually showed an increase in leaf area of seedlings with CO₂ enrichment (Norby & Cotrufo, 1998).

Tissue *et al.* (1997) reported that the leaf area was increased 41% in *pinus taeda* growing in elevated CO₂ environment for subsequent four growing seasons compared to ambient CO₂.

The tree height, leaf area, number and size, under elevated CO₂ levels influence branching patterns (Veldhoen *et al.*, 2006) investigated under elevated CO₂ levels.

Biomass increment

When the plants are exposed under elevated CO₂ condition the growth performance and biomass was varied over the period of study. In tree species, the increase of height (15 per cent) and biomass (30-45 per cent) was observed by Tupker *et al.* (2003). Further, (Devakumar *et al.*, 1998). observed in two clones of *Hevea brasiliensis* under elevated CO₂ concentration and they found that higher biomass accumulation, leaf level variation and better growth when compared to ambient CO₂ level for 120 days.

Kimball *et al.* (2002) reported that, the root biomass in wheat, ryegrass, and rice under elevated CO₂ level, the average increase of 70, 58 and 34% respectively. 40 per cent root biomass increase was reported. The biomass enhancement in tree species under elevated CO₂ level in experiments of variable exposure duration (Saxe *et al.*, 2014). Elevated CO₂ concentration generally increases the stem biomass. (Norby & Cotrufo, 1998) recorded the increase in stem growth and dry biomass increased and the

rate of growth was different among the studies. (Norby et al., 2005) described these differences to the growth rate or growth potential of different species, effects of environmental interactions. CO₂ enrichment significantly increased the biomass accumulation and the relative ratio of biomass increase to leaf area expansion in *incirsiumarvense* was observed. Bazzaz et al., (1998) observed that, the total plant biomass was higher (31%) in the elevated CO₂ treatment with a mean enhancement of 23% in aboveground and 62% in belowground level. (Dijkstra et al., 2010) were also observed that the significant increase in above ground biomass in *quercus* species, 44% were exposed under elevated CO₂ level the above ground biomass showed 85% increases over ambient environmental conditions.

Rogers et al., (1992) observed significant increases of dry matter accumulation in soybean about 78% at 700 ppm CO₂. Baker et al., 1990 showed that shoot biomass and root biomass increased under increasing CO₂ concentration. The shoot biomass approximately 35 per cent greater for creeping bent grass plants grown under elevated CO₂ the root biomass increased by 37 percent due to elevated CO₂ (Burgess & Huang, 2014). Several authors reported that the dry matter production was increased under elevated CO₂ levels of 55 per cent in *P. Sylvestris* L (Jach & Ceulemans, 1999), 32 per cent reported by (Jackson et al., 2009).

Physiological responses

Stomatal Conductance and transpiration

The stomata in leaves are the channels through which plant can directly interact with atmosphere and the density of the stomata on leaf may be responsive to CO₂ levels. Stomata play a pivotal role in controlling the balance between photosynthetic assimilation and transpiration (Beadle et al., 1981). Increase in atmospheric CO₂ concentration and its doubling of from the present ambient concentration generally results in a reduction in (g_s) stomatal conductance of the order of 40% (Morison, 1993).

The physiological response of teak seedlings were significantly influenced by elevated CO₂ levels as compared to counterparts in the ambient environment. The seedlings imposed to 600 ppm of CO₂, Pn (net photosynthesis) (39.7 and 20.2%) and Ci (intercellular CO₂) (13.4 and 11.1%) significantly increased respectively with or without relative humidity. The range of Pn in tropical seedlings varied between 2.09 and 6.71

$\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$. There was an increased Pn in Teak, Maharukh and Bamboo seedlings to 600 ppm CO_2 (over the chamber control/ambient).

Water Use Efficiency (WUE)

Higher the ratio of WUE, better the ability for carbon assimilation. Morison (1993) confirmed the trend where WUE increased invariably in elevated CO_2 which will lead to reduced (g_s) and directly proportional with transpiration rate. The water molecules lost per molecule of carbon fixed by the plant during photosynthesis, is referred to as water use efficiency (Ellsworth, 1999). An increase in WUE is probably the most common leaf level response to elevated CO_2 although changes in WUE are not necessarily linked with proportional changes in plant growth and photosynthesis (Beerling et al., 1996) despite its potential importance for regulating the water use efficiency in plants (Drake *et al.*, 1997) and (Morison, 1993). So combined with reduced stomatal opening and conductance, transpiration rates, elevated CO_2 concentration also depresses dark respiration rates also leading to increased water use efficiency ((Gunderson & Wullschleger, 1994). Increase in water use efficiency has been found to increase in drought tolerance in many plants, which may allow increased plant distributions ((Tyree & Alexander, 1993); (Huxman, 1998).

(Prior *et al.*, 2011) observed a rise in atmospheric CO_2 will limited direct impact on photosynthesis. However a number of C_4 crop plants expresses a positive response to elevated CO_2 . Further, the reductions in total above-ground biomass were 42% in maize and 36% in sorghum at ambient CO_2 , but only 18% in Maize and 14% in sorghum at double ambient CO_2 environmental conditions. (Grünzweig & Körner, 2001) observed in grasslands, which is exhibited cumulative water use efficiencies 17-28% greater than control CO_2 . The effect of elevated atmospheric CO_2 concentrations on the water use efficiencies of trees is clearly positive, having been documented in numerous single species studies of long leaf pine (Pritchard et al., 2006), Red Oak (Cole *et al.*, 2010).

Tjoelker, (1998) reported that when the seedling of quaking aspen, paper birch, tamarack, black spruce and jack pine were grown under elevated CO_2 levels, the water use efficiencies increased by 40-80%. Similar findings were recorded when the trees were exposed to elevated CO_2 level by 50% (Centritto & Jarvis, 1999), 52-94% (Wayne et al., 1998), 60% (Centritto, 1999), 80% (Leavitt *et al.*, 2003) lead to increase in water

use efficiency in response with increased atmospheric CO₂ concentration . Battipaglia et al., (2013) reported, the elevated CO₂ increased the water use efficiency in many species *Liquidambarstyraciflua* (73%) for *Pinustaeda* (77%) and *Popolussp*(75%).

Farquhar,(1992) defined intrinsic water use efficiency (IWUE) as the ratio of the photosynthetic uptake of CO₂ through leaf stomata to the simultaneous transpirational loss of water vapour through the stomatal opening (Wang, 2001; Ashraf *et al.*, 2002). Water use efficiency can be used as a selection criterion to improve yield in a dry environment (Tardieu, 1997). Intrinsic water use efficiency implies the inherent ability of the plant to assimilate CO₂ (Ares and Fownes, 1999). Edwin Raj, (2014) observed the IWUE, in many of the tropical tree species when the species subjected to 600 ppm CO₂ level it consumed higher amounts of water for transpiration *Ailanthus.sp* (112%) seedling were found to be vulnerable to water loss.

Waterhouse *et al.*, (2004) determined the intrinsic water use efficiency (WUE) response of three species such as *Quercusrobur*, *Fagus sylvatica* and *pinussaylverstris* with increased CO₂ concentration. In that, the IWUE was increases the amount to for *Quercusrobur*,(158%) for *pinussaylverstris*(195%)and for *Fagus sylvatica* (220%). Liu *et al.*,(2011)evaluated in *Sabina przewalskii* and *Piceacrassifolia* trees, the IWUE values showed in long term increases, by 33.6 and 37.4% for *Piceacrassifolia* in the arid and semiarid areas, respectively. These findings help to predict the water use efficiency responses from a variety of tree species exposed to elevated CO₂ environmental conditions and species specific relationship help modeling of elevated CO₂ and climate impacts on forest productivity.

Biochemical responses in elevated CO₂ conditions

Chlorophyll content

Chlorophyll is the most important pigment and sensitive indicator for photosynthetic capacity of trees under various environments. In chlorophyll pigment, Chlorophyll a and b are virtually essential pigments for the conversion of light energy to stored chemical energy. The Chlorophyll content can directly determine photosynthetic rate and primary production. Furthermore, leaf chlorophyll content was closely related to pant stress responses. Sgherriet *al.*, (1998) observed that alfalfa plants grown in Open Top

Chamber (OTC) with enriched atmospheric CO₂ concentration of 600 ppm and greater leaf chlorophyll concentrations was recorded in plants grown at 340 ppm.

Wullschleger,(1994) observed a reduction in chlorophyll and accessory pigments in yellow poplar and white oak seedling were under elevated CO₂ conditions and the reduction in chlorophyll was 27 and 55 per cent, respectively. Centritto & Jarvis, (1999) experimented on spruce saplings with CO₂ enrichment in open-top chamber and observed lower leaf chlorophyll content. Nevertheless, atmospheric CO₂ enrichment does not always results in decreased leaf chlorophyll concentrations. When the plants exposed to elevated CO₂ level in between these two responses sometimes there is no significant effect on leaf chlorophyll concentration. Sicher & Bunce, (1999) reported in twice ambient CO₂ concentrations and elicited that there was no changes in leaf chlorophyll content in potato seedlings. Further, Monje and Bugbee (1998) did not find any changes in leaf chlorophyll content in wheat seedlings even With higher CO₂ of 870 ppm over ambient concentrations, similar results have been reported in woody plants and there is no significant impact on leaf chlorophyll concentrations in *Acer saccharum*(Vertucci, 1989) and *Quercus sp.* These studies demonstrate atmospheric CO₂ enrichment may alter or it may not effect leaf chlorophyll concentrations, and even when leaf chlorophyll concentrations are decreased the reallocation of the nitrogen that is essential for producing chlorophyll, and other photosynthetic components typically occurs without any adverse consequences. Moreover, Faria *et al.*, (1996) observed in tomato plants, the chlorophyll a/b ratio decreased significantly over nine days of exposure to CO₂. Faria *et al.*, (1996) observed that the total chlorophyll content at elevated CO₂ level was decreased significantly on dry weight basis. Edwin Raj *et al.*,(2014) reported that the biochemical parameters of chlorophyll a, b and chlorophyll content is become on excellent indicator with accordance to that the *Eucalyptus* clones and it was it was varying among the clones.

Proteins

Rogers, (1996) observed CO₂ induced reduction in the protein concentration of flour derived from wheat plants. Allard *et al.*, (2003) observed under enriched CO₂ levels the leaves of the individual species exhibited lower nitrogen concentrations, but higher water soluble carbohydrate concentrations. PiconCochard *et al.*, (2004) also observed the

increase in response to elevated CO₂ despite reduction in protein concentration. Moreover, Fuchsman *et al.*, (2010) grew *Lolium multiflorum* and *Bouteloua curtipendula* in open top chambers and maintained doubled CO₂ concentration of 740 ppm for two months and the protein concentration was decreased by 20% over ambient environmental conditions. On contrary, elevated CO₂ enrichment was found to be increased the leaf protein concentration in plants.

Kimball, (2002) observed that, 50% increased the leaf protein concentration under enriched CO₂ levels in Wheat plants. Idso, (1996) conducted number of studies and reported under elevated CO₂ levels, the concentration of proteins either increased, decreased or no effect in various agricultural crops. Jablonski, et al., (2002) observed in rice no reduction in grain of nitrogen and protein concentration in response to atmospheric CO₂ enrichment.

Phenolic components

Under elevated level of CO₂ there is an enhancement in the rate of photosynthetic rate thereby increase in carbon uptake which leads to production of plant secondary carbon compounds and phenolic compounds. Castells *et al.*, (2002) studied two perennial grasses of *Dactylis glomerata* and *Bromus erectus* under elevated CO₂ levels total phenolic concentration was increased 15 and 87% respectively, while there were no significant CO₂ and genotype interaction in these species which correlates with similar findings in *Calamagrostis epigejos* and *Vicia lathyroides* and phenolic concentration increased by 20 and 32% respectively Hoorens *et al.*, (2002). Jablonski *et al.*, (2002) observed that the CO₂ enrichment will increase the fruit phenolic, flavonol and anthocyanin concentration in strawberry when the plants grown under enriched CO₂ conditions.

Wetzel & Tuchman, (2005) grew Cat tails (*Typhalatifolia*) in Open Top Chambers and they found leaves contains 40.6% of total phenolic content in elevated CO₂ levels compared to ambient air. Further, Gebauer, (1998) grew loblolly pine seedling in glasshouses with elevated CO₂ levels which increases above and below ground total phenolic concentrations by 21 and 35% respectively as observed by de Frenne *et al.*, (2010). Peñuelas & Estiarte, (1998) studied in temperate regions the trees have shown leaf phenolic concentrations was raised by 20 - 605 mg g⁻¹ in response to doubling of CO₂

content Koricheva, (1998). Wetzal & Tuchman, (2005) Observed that Aspen seedlings grown in elevated CO₂ contained 63.2% more total phenolic compounds.

Coleman *et al.*, (1993) reported nine species of tropical trees grown in open top chamber in which eight species exhibiting positive leaf phenolic responses and the maximum increases of 119% but Single negative response lead to 27% decline while the mean response of all nine species shows an increase of 48% in phenolic content. These results are compatible to the temperate region trees in which both temperate and tropical trees shows large inter specific variation in the extent of their response to CO₂ with increase in phenolic content was 50%. Kuokkanen, *et al.*, (2003) studied that birch trees in closed top chambers exposed to CO₂ concentration of 700 ppm. Hamilton, (2002) studied in the loblolly pine plantation found no effect of elevated CO₂ on the chemical composition of leaves. Under elevated CO₂ environmental conditions most of the experiments were conducted in agricultural and temperate species in the global scenario. But very few of experiments were conducted in tropical tree species under enriched CO₂ level. Particularly, in Teak and Eucalyptus there have been no such studies carried out till date. So, the present study was initiated could act as milestone to understand the actual responses under elevated CO₂ environmental conditions by using different planting stock materials of Teak and Eucalyptus.

Conclusion:

In conclusion, the comprehensive exploration of Teak and Eucalyptus responses to elevated carbon dioxide (CO₂) levels within Automated Open Top Chambers (AOTC) reveals a nuanced interplay between physiological adaptations and morphological changes. The study's findings contribute valuable insights into the complex dynamics of tropical tree species under changing atmospheric conditions. The observed alterations in shoot, root, and leaf morphology, coupled with variations in biomass increment, highlight the sensitivity of Teak and Eucalyptus to elevated CO₂. These responses are indicative of the trees' adaptive strategies to optimize growth and productivity in an environment with increased carbon dioxide concentrations. Moreover, the physiological responses, such as increased water use efficiency (WUE) and intrinsic water use efficiency (IWUE), underscore the trees' ability to acclimate to elevated CO₂ levels. These responses have broader implications for drought tolerance and ecosystem dynamics, emphasizing the

interconnectedness of plant species with their surrounding environment. Understanding these intricate responses is crucial for predicting the long-term impact of climate change on forest ecosystems. The research conducted at the Institute of Forest Genetics and Tree Breeding (IFGTB) in Coimbatore adds significant depth to the ongoing discourse on climate change impacts, providing a basis for informed decision-making in forestry and conservation practices. As we grapple with the challenges of a changing climate, the knowledge gained from this study contributes to a growing body of research aimed at fostering sustainable forest management. It highlights the need for continued monitoring and research to adapt forestry practices to the evolving conditions brought about by rising atmospheric CO₂ levels. Ultimately, the study encourages a holistic approach to ecosystem management, considering the intricate relationships between tropical tree species and their environment. By advancing our understanding of these dynamics, we can work towards resilient and adaptive strategies that mitigate the impact of climate change on vital components of our ecosystems, ensuring the long-term health and sustainability of our forests.

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