GROWTH RESPONSES OF SWIETENIA MACROPHYLLA SAPLINGS TO ELEVATED LEVELS OF CARBON DIOXIDE

Anjana K. and Harilal C.C.

1Department of Environmental Sciences, University of Calicut, Tenhipalam, Malappuram, Kerala, India.

2Department of Botany, University of Calicut, Tenhipalam, Malappuram, Kerala, India.

Corresponding author: ccharilal22@gmail.com

ABSTRACT

Responses of elevated levels of carbon dioxide on the growth and biochemistry of Swietenia macrophylla saplings has been attempted in the present study. The experiment was carried out in closed rectangular chambers with a dimension of 2×2×3 ft. For experimentation, three sets of plants (initial, control and CO₂ treated) of 3 months old were taken. Plants marked as control and CO₂ treated were retained in closed chambers and to the later one, CO₂ was supplied from an external source till the air inside the chamber attained an ambient CO₂ concentration of 600 – 650 ppm. The experimentation was carried out for 7 days, with an assessment of the growth and biochemical parameters on the first and seventh day. The growth parameters assessed include plant height, leaf area, root/shoot ratio, root and shoot biomass and moisture percentage of root and shoot. Similarly the biochemical parameters studied include pigments, proteins, amino acids, phenol, sugar, reducing sugar, non-reducing sugar and starch.

Consolidation of results revealed that though the plants in the treatment chamber are supplied with a CO₂ concentration ranging from 600 – 650 ppm, due to specific growth conditions and metabolic status, the plants were eventually exposed to a CO₂ concentration ranging from 436 – 1076 ppm with a mean value of 727.14 ppm. Due to high CO₂ influx, the microclimatic conditions associated with the plants within the chamber have changed, evidenced by high temperature and humidity. Though the growth of plants continued in the control set, such an initiation has not been evident in CO₂ treated set. The changes in pigments are indicative of the photosynthetic efficiency of plants subjected to elevated levels of CO₂. Other biochemical components associated with the plants are indicative of both growth promoting and stressful conditions. However, discolouration and formation of brown patches on the leaf surfaces of CO₂ treated plants are morphological evidences of a stressful condition. Even with morphological and physiological symptoms of stress, the persistence of the plant within the chamber in an extreme CO₂ rich environment are indices of their tolerances to higher levels of CO₂ supply.

Key words: Swietenia macrophylla, growth chamber, CO₂ supply, Growth and Biochemical analysis

INTRODUCTION

Carbon dioxide is estimated to be the major cause for global warming and climate change. Human activities, especially burning of fossil fuels have caused substantial increase in the concentration of carbon dioxide in the atmosphere. Measurements taken globally at various intervals showed that atmospheric CO₂ has increased dramatically over the last 5 decades. It is assumed to have increased from 280 ppm in the beginning of industrial revolution to the present levels of more than 415 ppm (Mauna Loa Observatory, Hawaii), indicating the pronounced human impact. Concentration of CO₂ is still rising at a rate of about 0.5% per year. According to Intergovernmental Panel on Climate Change, CO₂ levels may reach 660 - 790 ppm from 2060-2090 (IPCC, 2007).

Global initiatives for the control and mitigation of CO₂ emissions are many. The Kyoto protocol, so formed, permits the developed countries to reach their target through several mechanisms, including emission reduction, joint implementation, clean development mechanism, etc. COP 7 UNFCCC in 2001 included afforestation and reforestation as an effective way to reduce atmospheric carbon. Carbon sequestration potential of tree species becomes relevant in this respect (Sreejesh, et al., 2013).
Plants contribute a lot in the capture of CO₂ from the atmosphere for the process of photosynthesis. During photosynthesis, plants take in CO₂ and releases oxygen to the atmosphere. The plants retain and use the stored carbon for growth and other metabolic functions (Maiti, 2015). Carbon sequestration also provide associated ecosystem co benefits, such as increase of soil water holding capacity, improved soil quality, nutrient cycling and reduce soil erosion (Patil, 2012). Rate of soil sequestration is higher than that in plants. Here, a portion of the atmospheric CO₂ captured by plant is converted into organic form by photosynthesis and the remaining proportion is translocated through plant root into the soil, where it is stored in organic as well as inorganic form (Nogia, et al., 2016).

The relative performance of plants to varying levels of carbon dioxide varies considerably. This can vary in accordance with the morphology, physiology and genetic makeup of the plant. Also the photosynthetic mechanisms of plants are reported to be different (C3, C4 and CAM). Moreover young plants / plantations can sequester relatively larger quantities of carbon while a mature plantation can act as a reservoir (sreejesh, 2013). Hence without directly studying a plant species and the community in which it lives, it remains difficult to predict whether that species will benefit from elevated CO₂.

Carbon management in plantations will probably be the most important agenda of the first half of the 21st century in India, in the context of global climate change mitigation (Pichode, 2017). In this perspective, it is meaningful to assess the CO₂ assimilation efficiencies of individual plants, especially tree species. The present study has been carried out to assess the CO₂ assimilation efficiency of *Swietenia macrophylla* grown under controlled conditions.

**REVIEW OF LITERATURE**

Among various methods of carbon sequestration, phyto-sequestration is performed by several photosynthetic mechanisms such as C₃, C₄ and CAM pathways of plants, cyanobacteria and microalgae. Plants act as a sink for CO₂ by fixing it through photosynthesis and storing excess carbon as biomass. Plants serve as the most suitable carbon sink for several centuries, if it is retained undisturbed and properly maintained. There are several reports on the effects of plants, especially trees, to elevated levels of carbon dioxide. Some of the recent ones are listed.

Experiments on the response of *Populus tremuloides* to elevated CO₂ and O₂ showed positive response to CO₂ elevation, but elevated O₂ negates expected positive growth effects (Isebands et al., 2001). Studies of Vu et al. (2002) on sweet orange grown under elevated CO₂ revealed higher photosynthetic rate, lower transpiration, lower conductance, higher water use efficiency, down regulation of RuBisCO activity and its concentration and increased starch and sugar concentration.

Melkania et al. (2009) studied carbon sequestration potential of forests and concluded that forests can store much amount of carbon. Long term total carbon storage range from 101 to 156 mg cha⁻¹ with the largest carbon stock in Sal forest followed by *Populus*, *Eucalyptus* and Teak forest in India (Kaul et al., 2010).

According to Yiping et al. (2010), forest have been discussed very specifically in climate change research and discussion, due to the high contribution of forest in increasing carbon stocks by the removal of atmospheric carbon dioxide. They conducted a comparative analysis of carbon sequestration between bamboo plantation and fast growing Chinese Fir and Eucalyptus using biomass and carbon models and found that bamboo plantation sequestered an equal or greater amount of carbon than other two plants.

Typical deciduous tree species, *Gmelina arborea* has higher CO₂ sequestration ability and could potentially become a dominant species with better net primary productivity under future global scenario (Reddy et al., 2010). Chavan and Rasalin (2012) estimated the total sequestered carbon stock of *Mangifera indica* using allometric equation and reported that total above ground and below ground standing biomass of Mangifera are 44.73 ha⁻¹ and 11.63 ha⁻¹, respectively.

Karyati (2013) conducted a study on the ecology and carbon sequestration of different stages of secondary forests in Sabal, Sarwak. Specific allometric equations were used to estimate the above ground biomass and carbon stock and concluded that secondary forests contributed more in the regional, national and local scale climate change mitigation because of their action as carbon source and sink. Pandya et al. (2013) carried out studies on the carbon storage of 25 valuable tree species of Gujarat, India and reported maximum carbon storage in *Tamarindus indica* followed by *Terminalia arjuna* and the lowest carbon storage value estimated in *Emblica officinalis*. Similar studies carried out by Suryawanshi et al. (2014) at Maharashtra university campus reported that *Moringa oleifera* species was found
to be dominant and sequestrated 15.77 tonnes of carbon annually.

Maiti, et al. (2015) determined carbon fixation and accumulation of various native and exotic species in Mexico. They noticed high carbon concentrations in trees and shrubs such as *Eugenia caryophyllata* (51.66%), *Forestiera angustifolia* (49.47%), *Pinus arizonica* (49.32%), *Cinnamomum verum* (49.34%), *Acasia rigidua* (48.23%) and *Rosmarinus officinalis* (47.77%). Mitra (2015) listed out carbon sequestration rates of *Delonix regia*, *Cassia fistula* and *Albizia saman* in Bhubaneswar city and ultimately revealed the potential of these trees in off-setting carbon. Eucalyptus plantations have considerable biomass and carbon sequestration potential during development (Du et al., 2015). Selvaraj et al. (2016) estimated standing biomass, standing carbon and equivalent CO₂ in tree species and were recorded high in *Tectona grandis* followed by *Cocos nucifera*, *Mangifera indica* and *Manikara zapota* in 20 year old trees. Picode and Nikhil (2017) stated that in its life time, a teak tree with a girth of 10-30cm can absorb 3.70 lakh tonnes of CO₂ from the atmosphere and play a vital role in sequestration and climate change mitigation.

It has been reported by Superales et al. (2016) that Mahogany (*Swietenia macrophylla*) saplings potentially captured a total of 34.29 g CO₂ from the atmosphere and carbon was mostly stored in the wood than leaves and bark. However, such studies are pertinent to the normal growth responses of the plant under ideal conditions and not as a result of any controlled treatment using carbon dioxide. The present study is an attempt to assess the growth and physiological changes associated with *Swietenia macrophylla* owing to an extraneous supply of carbon dioxide under controlled condition.

**MATERIALS AND METHODS**

Response of elevated levels of carbon dioxide on the growth and biochemistry of *Swietenia macrophylla* was attempted in the present study. The materials and methods followed in the study are depicted below.

*Swietenia macrophylla*, commonly known as ‘Mahogany’ belongs to the family Meliaceae. For the study, healthy saplings of similar age were obtained from the nursery of Kerala Forest Research Institute (KFRl) and are transferred to pots containing potting mixture (soil: sand: compost in the ratio 3:1:1). They were then made ready for experimentation by giving proper irrigation and care in the poly house of the Department of Botany, University of Calicut.

The experiment was carried out in closed rectangular chambers of size 2×2×3 ft. For experimentation, three sets of plants of 3 months old were taken. First set of plants were taken for the analysis of various growth and biochemical parameters (initial). Similarly another set of plants were retained within the chamber and are treated as control. The third set of plants was taken to the second chamber and was maintained as the CO₂ treated set. The control and treated sets were kept closed with a lid and sealed. To the treatment set, carbon dioxide was supplied from an external source. The experimentation was carried out for 7 days. Every day, at 10 am., CO₂ was supplied, till the ambient concentration of CO₂ within the chamber was between 600 – 650 ppm. Every time, prior to the supply of carbondioxide, the resultant quantity of CO₂ within the chamber was monitored. Monitoring of CO₂ was carried out using an Automated CO₂ Analyzer (NDIR Type Infrared Gas Analysr, Fuji Electric, Japan). The growth chambers (control and treated) were also equipped with a thermo hygrometer for continuous monitoring of temperature and humidity developed within the system.

The growth and biochemical parameters associated with the plants (initial) were assessed on the first day of experimentation. Similar attempts were also carried out on plants retained as control and CO₂ treated on the final day of experimentation (7th day). The growth parameters of plants from initial, control and CO₂ treated sets analyzed include plant height, leaf area, root/shoot ratio, root and shoot biomass and moisture percentage. Similarly the biochemical parameters studied include pigments (Chlorophyll a, b, total chlorophyll and carotenoids) following Shof and Lium, (1976), protein (Lowry et al., 1951), amino acids (Moore and Stein, 1948), phenol (Malick and Singh, 1980), starch (McCready et al., 1950), total sugar (Dubois et al., 1956), reducing sugar (Nelson – Somogyi, 1944) and non-reducing sugar (Loomis and Shull, 1937) and the results are represented in milligram per gram.

**RESULTS AND DISCUSSION**

For assessing the responses of *Swietenia macrophylla* to elevated levels of CO₂, saplings of similar age and uniform size were selected and subjected to experimentation, as stated in materials and methods. The treated set was maintained in an ambient concentration of 600 – 650 ppm of carbondioxide every day, after assessing its initial concentration in the growth chamber. Variation in the concentration of CO₂ noticed daily on the experimental sets are depicted in table 1. Variation in temperature and humidity experienced in the chamber are given in table 2. Similarly variation in
the growth parameters is depicted in table 3 and those of biochemical parameters in table 4.

Upon comparison of the gaseous flux associated with the experimental system, it has been noticed that the control set showed CO₂ concentration ranging from 439 – 550 ppm with a mean value of 482+/-39.99 ppm. The CO₂ flux associated with the treated set was higher, with a value ranging from 436 – 1076 ppm and a mean value of 727.14 +/-227.6 ppm. The level of CO₂ in the control chamber than the ambient concentration of 457.28 +/-10.561 might have been due to respiratory release and resultant accumulation of CO₂. Though the level of CO₂ within the treated chamber was maintained in a state of steadiness till the 4th day, a drastic increase from the fifth day was noticed and is indicative of the specific metabolic status of the plants, resulting in either respiratory release of CO₂ or non-accumulation of supplied CO₂ by the plantlets.

Apart from this, plants with in the chambers were greatly influenced by the microclimatic conditions, represented by temperature and humidity. In the control set, morning temperature at 10 am ranged from 25.2 – 27.4°C and evening temperature at 5 pm from 26.2 – 29.4°C. Similarly, the humidity content at 10 am ranged from 68-74% and at 5pm, it ranged from 59 – 72%. The mean values of morning temperature recorded were 26.33 +/-0.708 and that of evening were 24.06 +/-1.321. Similarly, humidity at morning hours was 70.43 +/-1.902 and that of evening hours was 65.71 +/-4.386.

Likewise, temperature and humidity concerning CO₂ treated set also fluctuated over a wider range. Morning temperature (10 am) ranged from 24.8 – 26.4°C and evening temperature (5 pm) from 25.4 -28.4°C. Similarly, the humidity content at 10 am ranged from 76 – 99% and at 5pm, it consistently recorded a value of 99%. The mean values of morning temperature recorded were 25.73 +/-0.522 and that of evening were 27.24 +/-1.113. Similarly, humidity at morning hours recorded 95.71 +/-8.693 and evening hours recorded 99 +/- 0.

A comparison of the micro climatic conditions prevalent in both control and CO₂ treated sets revealed that, though

### Table 1. Levels of CO₂ (ppm) in the control and CO₂ treated chamber at a pressure of 0.5kg/cm²

<table>
<thead>
<tr>
<th>Day of treatment</th>
<th>Ambient air</th>
<th>Control chamber</th>
<th>Treated chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Day</td>
<td>442 ppm</td>
<td>439</td>
<td>436</td>
</tr>
<tr>
<td>2nd Day</td>
<td>441 ppm</td>
<td>439</td>
<td>632</td>
</tr>
<tr>
<td>3rd Day</td>
<td>442 ppm</td>
<td>508</td>
<td>628</td>
</tr>
<tr>
<td>4th Day</td>
<td>493 ppm</td>
<td>486</td>
<td>632</td>
</tr>
<tr>
<td>5th Day</td>
<td>458 ppm</td>
<td>460</td>
<td>1000</td>
</tr>
<tr>
<td>6th Day</td>
<td>440 ppm</td>
<td>492</td>
<td>1076</td>
</tr>
<tr>
<td>7th Day</td>
<td>485 ppm</td>
<td>550</td>
<td>690</td>
</tr>
<tr>
<td>Range</td>
<td>441 - 493</td>
<td>439-550</td>
<td>436 - 1076</td>
</tr>
<tr>
<td>Mean with standard deviation</td>
<td>457.28 +/- 10.561</td>
<td>482 +/- 39.99</td>
<td>727.14 +/- 227.6</td>
</tr>
</tbody>
</table>

### Table 2. Variation in temperature (°C) and humidity (%) experienced in the control and CO₂ treated set.

<table>
<thead>
<tr>
<th>Day of treatment</th>
<th>Control</th>
<th>(CO₂ treated)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10.00 Am</td>
<td>5.00 Pm</td>
</tr>
<tr>
<td>1st Day</td>
<td>26.0</td>
<td>68</td>
</tr>
<tr>
<td>2nd Day</td>
<td>26.4</td>
<td>70</td>
</tr>
<tr>
<td>3rd Day</td>
<td>26.8</td>
<td>71</td>
</tr>
<tr>
<td>4th Day</td>
<td>26.6</td>
<td>69</td>
</tr>
<tr>
<td>5th Day</td>
<td>27.4</td>
<td>70</td>
</tr>
<tr>
<td>6th Day</td>
<td>25.9</td>
<td>71</td>
</tr>
<tr>
<td>7th Day</td>
<td>25.2</td>
<td>74</td>
</tr>
<tr>
<td>Range</td>
<td>25.2</td>
<td>68</td>
</tr>
<tr>
<td>Mean with standard deviation</td>
<td>26.33 +/- 0.708</td>
<td>70.43 +/- 1.902</td>
</tr>
</tbody>
</table>
the mean values of morning temperature was high in control; evening temperature was high in CO$_2$ treated set. Carbon dioxide is a greenhouse gas and is capable of trapping heat. The higher heat content in the CO$_2$ treated set can be attributed to this reason. Contradictory to temperature, humidity content of CO$_2$ treated set was consistently higher in both morning as well as evening hours. This can be attributed to the higher level of transpiration associated with plants confining to CO$_2$ treated set. Values of humidity concerning CO$_2$ treated chamber can be even higher as the hygrometer used for humidity assessment have limitation in recording humidity values greater than 99%.

As far as growth of plants concerned, mean values of the height of plants in the control before and after experimentation remained the same (44.66 cm). Similar was the case of plants retained in CO$_2$ treated set, where the height of plants before and after experimentation remained the same (47.66 cm). Ainsworth et al (2006) reported an increase in the height of plants by 14% and leaf number by 80% after prolonged exposure of the plant to higher concentration of CO$_2$. However in the present study, no such changes were noted in the plants subjected to CO$_2$ treatment and short experimental duration can be one among the reasons for the same. An increase in number of leaves concerning control was noticed from the initial day (42) to the final day (43). However in the case of CO$_2$ treated set, number of leaves remained constant (36.66) throughout experimentation. Leaf area with regard to the control was noted to be increasing from the initial day (1201.7 cm$^2$) to the final day (1218.4 cm$^2$). With regard to CO$_2$ treated set, leaf area remained the same throughout the period of experimentation (1252.46 cm$^2$). Graham and Nobel (1996) noticed an increase in the total leaf area of Agave desserti under elevated CO$_2$. According to them, plants under elevated CO$_2$ showed increased dry matter accumulation in leaves, stems and roots and had a large leaf area per plant. However in the present study, no characteristic increase in the number and area of leaves were noticed.

An estimation of above and below ground biomass, moisture percentage of root and shoot and root / shoot ratio were worked out. Upon comparing with initial values, both control and CO$_2$ treated set showed higher above and below ground biomass and root / shoot ratio after 7 days of experimentation. However, the moisture percentage of the shoot and root were higher with the initial set. Graham and Nobel (1996) observed that biomass of Acer saccharum increased when grown under elevated CO$_2$ than ambient CO$_2$. Ainsworth et al. (2006) underlined that above ground and below ground biomass increased with exposure to elevated CO$_2$. In the present study, such an enhancement in the growth attributes were not noticed in Swietenia macrophylla, subjected to CO$_2$ treatment than its control, which is indicative of a stressful condition prevalent in the treated set.

Chlorophyll is the most abundant green pigment occurring in the chloroplast of plants, and is specialized for light absorption in photosynthesis. Higher plants contain two types of chlorophylls – chlorophyll a and chlorophyll b. Carotenoids are the accessory pigments in all photosynthetic systems, which gives colour to plant parts and transfer absorbed light energy to chloroplast for photosynthesis. In the present study, comparing various pigment fractions, the presence of chlorophyll-a, chlorophyll-b, carotenoids and total chlorophyll were higher in CO$_2$ treated set than control.

Many studies were carried out to establish the impact of elevated CO$_2$ on the chlorophyll content of plants. In most of the cases, pigments got reduced under elevated CO$_2$. Graham and Nobel (1996) reported depletion in chlorophyll content in Agave desserti and Helianthus

Table 3. Variation in the growth parameters of Swietenia macrophylla under experimental conditions

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Control Initial (Mean)</th>
<th>Control Final (Mean)</th>
<th>CO$_2$ treated Initial (Mean)</th>
<th>CO$_2$ treated Final (Mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (Cm)</td>
<td>44.66</td>
<td>44.66</td>
<td>47.66</td>
<td>47.66</td>
</tr>
<tr>
<td>Number of leaves</td>
<td>42.0</td>
<td>43</td>
<td>36.66</td>
<td>36.66</td>
</tr>
<tr>
<td>Leaf area (cm$^2$)</td>
<td>1201.7</td>
<td>1218.4</td>
<td>1252.46</td>
<td>1252.46</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Initial</th>
<th>Control</th>
<th>CO$_2$ treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below ground biomass (g)</td>
<td>4.055</td>
<td>5.68</td>
<td>4.25</td>
</tr>
<tr>
<td>Above ground biomass (g)</td>
<td>9.34</td>
<td>10.75</td>
<td>10.71</td>
</tr>
<tr>
<td>Moisture percentage of root (%)</td>
<td>66</td>
<td>59</td>
<td>58</td>
</tr>
<tr>
<td>Moisture percentage of shoot (%)</td>
<td>64</td>
<td>62</td>
<td>61</td>
</tr>
<tr>
<td>Root / Shoot ratio</td>
<td>0.32</td>
<td>0.61</td>
<td>0.43</td>
</tr>
</tbody>
</table>
annus. Positive responses are also reported for pigments under higher concentrations of CO₂ by various authors. Carter et al. (2000) observed that elevated CO₂ has no effect on the leaf chlorophyll of Acer saccharum. Vu et al. (2002) observed increase in chlorophyll content in soybean under elevated CO₂. From the present study it is clear that in Swietenia macrophylla, all pigments showed an increasing trend under elevated levels of CO₂. Generally the growth conditions of the plant (nutrient availability) influences the pigment content. Though the results are indicative of the increase in pigment content in Swietenia macrophylla owing to CO₂ treatment, the leaves of plants after 7 days of treatment showed signs of chlorophyll breakdown, evidenced by discolouration and formation of brownish patches.

Upon analysing the biochemical components of the plants under study, the extent of starch, reducing sugar and phenols were higher in CO₂ treated set than control. Plants under elevated CO₂ generally show significant increase in starch content compared to control. Various authors made different remarks on the carbohydrate content of plants under elevated CO₂. However Aggarwal et al. (2003) observed an increase in concentration of total sugar and starch in Wheat under elevated CO₂. Aguera et al. (2006) reported excess carbohydrate content in cucumber under elevated CO₂. Elevated CO₂ had significant effects on the synthesis of phenolics. Similar responses were reported by Coley et al. (2002) in their study on the effects of CO₂ on secondary metabolites of tropical trees and they observed that average phenol content of the leaves were 48% higher under elevated CO₂. They also gave explanation to the increasing phenolic contents on the basis of CNB hypothesis. According them, due to increases in photosynthesis and carbon content under enriched CO₂, the excess carbon will be allocated to carbon based defence compounds, predicts the allocation of excess carbon to phenolics. Ghasemzadeh et al. (2010) reported increase in total phenolic compounds in Wheat and Zingiber officinale grown under elevated levels of CO₂.

In contrary to the above, extent of protein, amino acid, sugar and non-reducing sugar were higher in plants from the control than CO₂ treated set. Number of studies reported the influence of elevated CO₂ on protein content. In Wheat, protein content significantly decreased under elevated CO₂ (Broberg, 2015). Hemantaranjan (2012) reported the depletion in protein concentration of potato due to prolonged exposure with high CO₂ concentration. Faria et al. (1996) observed decrease in the soluble protein and activity of RuBisCO under elevated CO₂.

Amino acids are the building blocks of proteins and it also occurs as free amino acids. Very often in plants, under disease and other stressful condition they exhibit changes in their composition. Hence, their measurements give an idea about the physiological and health status of plants. In the present study, amino acid concentration was slightly higher for the control than those of CO₂ treated plants. Decrease in amino acid concentration can happen during treatments and is assumed to be as a result of the transformation of proteins to structural compounds (Top et al., 2014).

Various studies are attempted on the impact of elevated CO₂ on sugar content. Aggarwal et al. (2003) reported an increase in total soluble sugar and starch content in Wheat under elevated CO₂. Accumulation of carbohydrates causes down regulation of photosynthesis (Vu et al., 2000; Ward et al., 1999). Acclimatization to elevated CO₂ concentrations alters source sink relationships, especially in C3. With the accumulation of excess soluble sugars, feedback inhibition of photosynthesis occurs. On contrary, in Ficus indica, basal starch accumulation results in cladodes and this starch accumulation due to CO₂ enrichment do not down regulate photosynthesis rate. Thus it indicates that starch accumulation is not a limiting factor of photosynthesis (Drennan and Nobel, 2000). Winter et al. (1997) also found that the sugar level was higher in the leaves of Kalonchoe pinnata under elevated CO₂ but its diurnal variation is similar to ambient and elevated condition.
According to Walter et al. (2005) sugar content decreased due to starch accumulation, since it affects sucrose metabolism, thus reduce glucose content. At the same time long term exposure of potato with CO$_2$ did not show marked difference in the level of soluble sugar, but it increased the starch content. Under elevated CO$_2$, reducing sugar content has declined, but it was not significant (Vann and Megonigal, 2002).

Upon consolidation of the results of growth and biochemical parameters of the present study, it can be noticed that though the plants were poised for a treatment under an elevated level of CO$_2$ ranging from 600 – 650, due to specific growth conditions and metabolic status, the plants were exposed to a carbon dioxide concentration ranging from 436 – 1076 ppm with a mean value of 727.14 ppm. Due to high CO$_2$ influx, the micro climatic condition associated with the plants within the chamber has changed with high retention of temperature and humidity. Though the growth of plants continued in the control set, such an initiation has not been evident in CO$_2$ treated set. The changes in pigments are indicative of photosynthetic efficiency in the plants subjected to elevated levels of CO$_2$. Other biochemical components associated with the plants were indicative of both growth promoting and stressful conditions. Discolouration and formation of brown patches on the leaf surfaces of CO$_2$ treated plants are morphological evidences of a stressful condition. Even with morphological and physiological symptoms of stress, the persistence of the plants within the chamber under an extreme CO$_2$ rich environment are indices of their tolerances to higher levels of CO$_2$ supply.

CONCLUSION

From the results of growth and biochemical parameters, it has been noticed that the plants were exposed to a carbon dioxide concentration ranging from 436 – 1076 ppm., with a mean value of 727.14 ppm. Due to high CO$_2$ influx, the micro climatic condition within the chamber have changed with higher temperature and humidity. Though the growth of plants continued in the control set, such an initiation has not been evident in CO$_2$ treated set. The changes in pigments are indicative of photosynthetic efficiency of the plants subjected to elevated levels of CO$_2$. Other biochemical components assessed were indicative of both growth promoting and stressful conditions. Formation of brown patches on the leaf surfaces of CO$_2$ treated plants are morphological evidences of a stressful condition. Even with morphological and physiological symptoms of stress, the persistence of the plants within the chamber under an extreme CO$_2$ rich environment are indices of their tolerance to higher levels of CO$_2$ supply.

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