EFFECT OF ELEVATED CO_2 CONCENTRATION ON GROWTH AND PHYSIOLOGY OF SELECTED TROPICAL TREE SEEDLINGS

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **"Effect of elevated CO_2 concentration on growth and physiology of selected tropical tree seedlings."** is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any University or Society.

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Nayana

and

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INTRODUCTION

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The Earth's atmospheric CO_2 concentration has risen at an accelerating rate since the beginning of the industrial revolution. At present, CO_2 is approximately 38 per cent higher at 372 ppm and by the middle of this century it is predicted to reach 550 ppm and to surpass 700 ppm by the end of the century (IPCC, 2007). The rate of CO_2 concentration increase is estimated to be 1.5 ppm annually. Rapid change in the industrial development, heightened consumption of fossil fuels and deforestation contribute to accumulation of CO_2 in the atmosphere leading to global climatic changes. The elevated atmospheric CO_2 changes the global energy balance and thereby the climate.

As a single tree will absorb approximately one ton of carbon dioxide during its lifetime, the carbon sequestration property of trees could be exploited to balance atmospheric CO_2 concentration (Norby et al., 1999). Hence massive afforestation is evidently the only feasible way to combat global warming and climate change. The schemes entitled Clean Development Mechanism or more commonly carbon trading allows investment in reforestation and other green project such as large scale tree plantations which is a lucrative alternative to mitigate carbon in the atmosphere. In addition to this, converting some of the low productive areas to higher yielding agroforestry systems would sequester 5 to 50 tonnes of carbon per hectare per year. Rehabilitating dry forests in India could double sequestration from 27 to 55 tonnes of carbon yearly for every hectare of dry forest improved. The recently declared National Action Plan on Climate Change (http://www.energymanagertraining.com/NAPCC/main.htm) and Green India Mission are all looking forward to increase the green cover all over India through afforestation activities. It points out the increasing demand of good quality tree seedlings for rehabilitation activities in the near future.

It is predicted that the CO_2 increase will have a significant impact on the growth and eco - physiological response of plants, since the plant growth depends on several environmental factors including atmospheric CO_2 levels. It is already understood that elevated CO_2 can improve biomass and leaf production in different plant species. Higher growth rate and high biomass accumulation in plants is due to the influence of CO_2 on various metabolic activities of plants (Devakumar et al., 1998). Therefore, CO_2 fertilization is widely exploited in the green houses in order to boost up the growth of plants. However, the response of the tree species is species specific and dependent on the growth stages.

A number of innovative techniques have been developed in order to use increased CO_2 in a more useful way in the nursery. Depending upon the need and purpose, one can select the desirable type of CO_2 enrichment system which includes closed systems in controlled environment cabinet, open top chambers, branch bag techniques and Free Air CO_2 Enrichment (FACE) technique. There are advantages and disadvantages associated with these techniques. However, one of the major constraints is high cost involved in exposing seedlings to higher CO_2 concentrations. Hence, one of the most simple ways of creating higher CO_2 concentrations in the nursery is to trap the CO_2 released by respiration of plants and soil microbes (Devakumar et al., 1996).

The state of Kerala is the home of a number of timber yielding trees. A clamour for planting trees like *Tectona grandis* L.F. (teak) and *Pterocarpus marsupium* Roxb (Venga.) in farmlands has been observed in the recent years among the farmers of Kerala. Tree species like *Swietenia macrophylla* King (mahogany) and *Ailanthus triphysa* (Dennst.) Alston. (matti) are also widely being planted in the Kerala homesteads. *Syzygium cumini* (Njaval), an evergreen fruit yielding tree species is also highly preferred for avenue planting. Hence, the demand for good planting stock of these multipurpose trees has been increasing from year to year. For any successful afforestation programme, it is necessary to produce robust and healthy tree seedlings. Lack of availability of healthy tree seedlings usually delays the progress of greening activities. Moreover, as the growth rate of most tree seedlings in the initial phase is slow, they have to remain in the nursery for a longer period.

As increased CO_2 concentration facilitates higher photosynthetic production, this will have synergistic effects on growth and biomass production in the early stages of tree growth. So, CO_2 fertilization is possibly a rapid and economical way for the speedy production of healthy seedling. However, considerable variations in the response of various plant species to elevated CO_2 levels have already been observed. It is the need of the hour to collect more reliable information on the influence of CO_2 fertilization on the growth, development and physiology of more number of tree species of ecological and economic importance.

It is against this backdrop that the current study was undertaken with the following objectives:

1. To understand the responsiveness of five selected tropical tree seedlings to two CO_2 levels

2. To assess the changes in their growth rate, physiology and biomass production under CO_2 enrichment

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The photochemical reduction of CO_2 via photosynthesis is the basis of orgin of all higher life on earth. Thus, a change in the CO_2 availability will most likely influence plant life and consequently the biosphere in multiple ways. We are currently witnessing an increase in atmospheric CO_2 concentration. That is unprecedented in recent geological time. As atmospheric CO_2 is the sole source of carbon for plants, CO_2 enrichment will act as carbon fertilizer, resulting in far reaching consequences for plants both quantitatively and qualitatively. However the impact of higher CO_2 concentration, on vegetation depends on the period of exposure. Hence the short term and long term responses are varying even in the same species. This scenario is an important benchmark for experimental research on the effects of elevated CO_2 concentration on plants.

The enriched CO_2 concentration in a closed artificial condition is known to modify micro- climate. Elevated concentrations of atmospheric carbon dioxide may have a major effect on woody plants (Sionit and Kramer, 1986; Jarvis, 1989; Eamus and Jarvis, 1989), yet most attention to date has focused on agricultural crops and horticultural plants (Ceulemans et al., 1993). It may be because of the practical difficulty of conducting experiments with trees. As global rise in CO_2 concentration influences the forest ecosystem to a large extent, more information on the likely consequences of elevated CO_2 on growth, development and productivity of tree species is the need of the day. The published literature on the influence of elevated CO_2 concentration on the tree species are reviewed here under.

2.1 Influence of elevated CO_2 on growth parameters

Continuous exposure to high CO_2 enhances growth and is often used in greenhouses to increase biomass and yield (Mortensen, 1987; Campagna and Margolis, 1989). Short pulses of elevated CO_2 may also promote growth and carbohydrate reserves, while reducing costs and the risk of acclimation due to long-term high CO_2 exposure. The CO_2 fertilization hypothesis stipulates that rising atmospheric CO_2 has a positive effect on tree growth due to increasing availability of carbon.

2.1.1 Influence of elevated CO_2 on shoot growth

Carbon dioxide environment was a significant source of variation for all growth parameters. Seedlings of Black spruce grown under elevated CO_2, compared to seedlings grown under ambient CO_2, were 20 per cent greater in height (Johnsen and Major, 1998). Experiments showed that high atmospheric CO_2 concentration leads to increases in height in many plants. According to Wang et al. (2003) height growth of tree seedlings at elevated CO_2 increased by 10 - 40 per cent compared to those grown at ambient CO_2. Similarly in another study, Johnsen and Major (1998) revealed that tree seedlings grown under elevated CO_2, compared to seedlings grown under ambient CO_2, were 20 per cent greater in height.

Experiment in nine-month-old seedlings of *Cedrus atlantica* and *Pinus nigra* (var. maritima) revealed that height and diameter growth were 20 per cent (*C. atlantica*) and 10 per cent (*P. nigra*) greater in the enriched treatment than those plants grown at normal CO_2 concentrations(Kaushal et al., 1989). Melgar et al. (2008) compared growth and other physiological characteristics of two cultivars ('Koroneiki' and 'Picual') of Olive (*Olea europea*) trees in response to elevated CO_2 concentration. After three months of treatment, the 9-month-old cuttings of 'Koroneiki' had significantly greater shoot growth, at elevated CO_2 than at ambient CO_2 under normal soil conditions, but this difference disappeared under salt stress. Likewise, *Abies faxoniana* seedlings after one year's exposure to elevated CO_2 concentration (ambient+350 micro mol/mol) under two planting densities (28 or 84 plants/sq.m) were investigated in closed-top chambers. Tree height, stem diameter and cross-sectional area, were enhanced under elevated CO_2 concentration, and reduced under high planting density (Yun-Zhou et al., 2008).

Elevated CO_2 increased the basal area increment of *Pinus taeda* trees by 13-27 per cent. In most years, exposure to elevated CO_2 increased the growth rate but not the duration of the active growth period (Moore et al., 2006). A study was conducted in seedlings of four and seven month old *Garcinia gummi-gutta* under elevated CO_2 and supplemented with nutrients and hormones. A significant increase in plant height, stem diameter, were noticed in both the age groups in all the treatments (Jagadish et al., 2008). It has been noticed that an increase in the growth of vegetative-propagated olive trees (*Olea europea)* underwent CO_2 fertilization during greenhouse production during winter in a Mediterranean climate (Biel et al., 2008). They suggested that use of CO_2 enrichment can facilitate rapid nursery production of olive trees during the winter season under Mediterranean conditions.

Exposure of the hybrid poplar clone 'Primo' (*Populus deltoides* x *Populus nipa*) to doubled carbon dioxide for just 68 days significantly increased stem height by 13 per cent compared with trees grown in ambient CO_2 concentrations. The stem diameter was also significantly increased than normal plants (Gardner et al., 1995). Similarly, some of the mangrove species also responded to doubled CO_2 in a positive way. *Rhizophora mangle* seedlings exhibited significantly increased total stem length, branching activity, higher root:shoot ratios and total leaf area in elevated CO_2 (Farnsworth et al., 1996). Growth responses of Beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) to increased atmospheric CO_2 was analyzed by Egli and Korner (1997). Their conclusion was that stem diameter increment of beech was significantly increased (+ 9 per cent) under increased CO_2 in the calcareous soil, but not in the acidic soil. The opposite was found for spruce stems, which responded positively in the acidic soil but not in the calcareous soil. This proved the role of soil characteristics on growth of plants.

An experiment conducted by Bazzaz et al. (1990) on american beech (*Fagus grandifolia*) paper birch (*Betula papyrifera*), black cherry (*Prunus serotina*), white pine (*Pinus strobes*), red maple (*Acer rubrum*), sugar maple (*Acer saccharum*) and eastern hemlock (*Tsuga canadensis*) showed large differences in the magnitude of growth enhancement by increased levels of CO_2 between species. Additionally, the three shade-tolerant species (i.e. beech, sugar maple and hemlock) exhibited the largest increase in shoot growth with increased CO_2 concentrations. Similarly, the study on the response of elevated atmospheric CO_2 with unlimited water and complete nutrient supply on the fast- and slow-growing *acacia* species was conducted by Atkin et al. (1999). The stimulation of Relative Growth Rate was evident throughout the twelve week growth period in seedlings of ten woody *acacia* species. However, CO_2 enrichment in Douglas-fir seedlings in USA did not show any significant effects on stem diameter, height, and leaf growth compared to normal atmospheric CO_2 condition (Olszyk et al., 1998).

2.1.2 Influence of elevated CO_2 on leaf growth parameters

Seedlings of four birch species (*Betula lenta, B. papyrifera, B. populifolia and B. alleghaniensis*) were examined to evaluate the response of species to global CO_2 change. All leaf growth parameters including number of leaves, length of longest leaf, leaf area, stem length, biomass) in all four species were significantly stimulated by enriched CO_2 conditions, but the magnitude of response was different among species (Rochefort and Bazzaz, 1992). Jagadish et al. (2008) has found out that the leaf area and leaf number increased in seedlings of four and seven months old *Garcinia gummi-gutta*, when exposed to elevated CO_2 concentrations. Increase in leaf area was due to both increase in leaf number and higher leaf expansion rates. A study on the annual carbon-nitrogen-water economy of trees growing at a CO_2 enrichment experiment at Oak Ridge, Tennessee, USA showed an enhanced Leaf Area Index. (McMurtrie et al., 2008).

According to Gardner et al. (1995) hybrid poplar (*Populus euramericana*) trees in elevated CO_2 had more leaves and a greater total leaf area, while the specific leaf area was decreased in elevated CO_2 on four out of five occasions and was significantly lower after sixty eight days, an effect indicating that leaves were either thicker or heavier. Curtis et al. (2000) conducted a study for two and half growing seasons with *Populus tremuloides* grown under experimental atmospheric CO_2 and soil-N-availability treatments. At the final harvest, stem biomass and total leaf area increased significantly due to CO_2 enrichment in high-N but not in low-N soil. This indicates that soil nitrogen availability has an important role in productivity of CO_2 fertilized plant.

Gaudillere and Mousseau (1989) also examined changes in leaf development of CO_2 treated Poplar species and found that leaves showed increases in area, specific weight, number of chloroplasts and numbers of stomata and epidermal cells. Because of the changes in leaf area, whole plant photosynthesis was increased. Likewise, the stomatal distribution and leaf physiology of *Alnus glutinosa* under elevated CO_2 was analyzed by Poole et al. (2000). In general, a doubling of the atmospheric CO_2 concentration enhanced plant growth and significantly increased stomatal index. However, there was no significant change in relative stomatal density.

One of the major plantation conifers in Australia, *Pinus radiata* was used to investigate effects of high CO_2 concentration on growth and wood production. Two half- sib families (F10 and F62) showed 43 and 30 per cent enhancement of leaf area development respectively and appeared to be associated with increased rates of photosynthesis (Conroy et al., 1990). Tjoelker et al. (1998) studied the impact of CO_2 enrichment in boreal ecosystem. They found that all species (*Picea mariana, Pinus banksiana, Larix laricina, Populus tremuloides* and *Betula papyrifera*) exhibited declines in Specific Leaf Area in response to CO_2 enrichment. Leaf stomatal density and index of *Ginkgo biloba* were significantly reduced after 3 years growth at elevated CO_2 (560 ppm), with values comparable to those of cuticles prepared from Triassic and Jurassic fossil Ginkgo leaves. Experiment indicated that reductions in stomatal density and index irreversibly reduced stomatal conductance (Beerling et al., 1998).

2.1.3 Influence of elevated CO_2 on root growth

In order to predict forest responses to elevated CO_2 concentrations, it is important to determine the tree -soil carbon fluxes. Root systems comprise up to half the total tree biomass and below-ground net primary production may exceed 50% of total net primary production (Curtis et al., 1994). Hence, the effects of elevated atmospheric CO_2 concentration on the root system is studied by many scientists, in order to provide further insight to the response of plants to climate change. Findings on the root system structure of *Betula albosinensis* seedlings, grown in an artificial enclosed-top chamber system showed a significant increase in total root length in the 0-10 cm soil layer, root growth angle in the 5-10 cm layer and 10-22 per cent increased root range under elevated CO_2 concentration. The fine root biomass reached the largest increase of 152 per cent directed towards the significant impact of CO_2 enrichment on entire root system (HouYing et al., 2008).

Johnsen and Major (1998) observed 16 per cent increase in root collar diameter in black spruce seedlings when the seedlings underwent carbon loading during nursery culture. Similarly, increased root growth of forest trees under elevated atmospheric CO_2 has been reported in a longleaf pine (*Pinus palustris*) (Pritchard et al., 2001). Pregitzer et al. (2008) conducted an experiment to understand the ecosystem response to elevated atmospheric carbon dioxide and elevated troposphere ozone. The long term exposure increased the fine root turn over in the *Populus tremuloides* forest as the result of increased soil respiration. The production and mortality of fine roots produced by trees growing under CO_2 enrichment are significantly increased. Increased carbon allocation in the belowground biomass has been observed at elevated atmospheric CO_2 concentrations for a number of tree species. As a result of the enhanced carbon allocation to the belowground biomass, carbon could potentially accumulate in the soil. Moreover, the turnover rate of soil carbon pools may also increase in some ecosystems.

The effects of CO_2 enrichment on surviving and rooting of woody plant cuttings and tissue culture were evaluated. Cuttings of flower cherries, *Prunus incisa* and *Prunus jamasakura*, one endangered five needle pine, *Pinus armandii*, nematode resistant clones of *Pinus densiflora* and three nematode resistant clones of *Pinus thubergii* were evaluated both in normal ambient and under 0.1 per cent CO_2 enriched condition. Rooting rate was 8 per cent and 33 per cent for *Prunus incisa* and *Prunus jamasakura* respectively only with CO_2 enriched condition. Higher rooting was observed in cutting of *Pinus armandii* with CO_2 enrichment, while no rooting appeared without CO_2 enrichment treatment. Branches of *Pistacia chinensis* were rooted under carbon dioxide enriched condition. A marked enhanced rooting rate of in vitro cultured shoots of *Pinus thubergii* was observed under CO_2 enriched condition. (Ishii et al., 2008).

Bassirirad et al. (1996) studied the effects of CO_2 enrichment on growth and nitrogen uptake rate of loblolly pine and ponderosa pine seedlings. It was found out that the increased nitrogen uptake on a per plant basis in response to CO_2 enrichment is largely the result of a compensatory increase in root absorbing surfaces. Pritchard et al. (2008) studied fine root dynamics in a loblolly pine under CO_2 enrichment technique. Averaged over all six years of the study, CO_2 enrichment increased average fine root of standing crop (+23 per cent), annual root length production (+25 per cent), and annual root length mortality (+36 per cent) compared with controls. *Betula albosinensis* seedlings showed 10-22 per cent increased root range under elevated CO_2 concentration (HouYing et al., 2008).

Yellow-poplar (*Liriodendron tulipifera*) saplings were grown in open top chambers with ambient or increased CO_2 concentrations for three growing seasons. This was attributed to a change in carbon allocation patterns, with increase in fine root production (Norby et al., 1992). According to Tingey et al. (2000), elevated CO_2 increases root growth and fine (diameter <=2 mm) root growth across a range of species and experimental conditions. However, there is no clear evidence that elevated CO_2 changes the proportion of C allocated to root biomass, measured as either the root:shoot ratio or the fine root:needle ratio. Measurements of the root length of CO_2 enriched hybrid poplar (*Populus euramericana*) trees suggested that root lengths were greater in the CO_2 treatment. There was a significant increase in the number of fine root tips indicating more fine roots or an increase in fine root branching. (Gardner et al., 1995).

It has been suggested that under many nutrient regimes, the partitioning of carbon to roots in elevated CO_2 conditions may be of major significance, because of the importance of below-ground structures in water acquisition and carbon and nutrient cycling (Norby et al., 1994). However, few studies to date have quantified the impact of elevated CO_2 on root growth, development and function (Berntson and Woodward, 1992; Norby et al., 1994).

2.1.4 Influence of elevated CO_2 on biomass production

The long-term responses of trees to elevated CO_2 are especially crucial to determining the productivity of future forest tree crops. Therefore, Kimball and Idso (2005) initiated a long-term CO_2 enrichment experiment on sour orange trees. Sour orange trees (*Citrus aurantium*) have been grown from seedling stage in open-top chambers under elevated CO_2. The ratio of annual biomass increments of the elevated- CO_2 trees to those of the control trees reached a peak of about 3.0 within two years into the experiment.

The enhanced photosynthesis has generally been followed by a similar enhancement of above-ground growth. Growth enhancement for trees exposed to elevated CO_2 has been about 27 per cent (Norby et al., 1999). This biomass increase results from an extra amount of assimilates which are partitioned into different plant structures, leading to distinctive root/shoot balances. The responses are again varying with species, soil fertility and duration of exposure.

McKee and Rooth (2008) pointed out the possibility of accelerated mangrove transition from the seedling to sapling stage and also increase above and belowground production of existing mangrove stands, exposed to CO_2 enrichment particularly in combination with higher soil nitrogen, based on their findings in the study of multi-factorial effects of elevated CO_2, nitrogen enrichment, and competition on a mangrove-salt marsh community. Yun-Zhou et al. (2008) examined the growth of *Abies faxoniana* seedlings after one year's exposure to elevated CO_2 concentration (ambient+350 micro mol/mol) under two planting densities (28 or 84 plants/m^2) in closed-top chambers. They were grown with increased total biomass. Dry matter production was higher in seedlings of four and seven month old *Garcinia gummi-gutta* under elevated CO_2 for all treatments (Jagadish et al., 2008).

Allen and Vu (2009) observed growth difference of CO_2 enriched to ambient CO_2 exposed young sweet orange trees. They have noticed a higher above ground and below ground biomass in CO_2 enriched trees. A study on the aboveground biomass response of a fire-regenerated Florida scrub-oak ecosystem after eleven years exposure to elevated CO_2 caused a 67 per cent increase in aboveground shoot biomass. Growth stimulation was sustained throughout the experiment; although there was significant variability between years. The absolute stimulation of aboveground biomass generally declined over time, reflecting increasing environmental limitations to long-term growth response. The results of this long-term study show that atmospheric CO_2 concentration had a consistent stimulating effect on aboveground biomass production (Seiler et al., 2009).

Growth under increased CO_2 (700 ppm.) increased final seedling dry weights by 20-48 per cent compared with seedling growth under ambient CO_2

(Johnsen, 1993). JianGuo et al. (2007) suggested that direct CO_2 fertilization increase above and belowground biomass based on the evaluation of tree growth responses to atmospheric CO_2 enrichment. Black spruce (*Picea mariana*) seedlings respond positively to increased CO_2 under varied water and nutrient conditions. Long term exposure of Northern forest to elevated CO_2 and elevated ozone induced increases in belowground carbon allocation suggest that the positive effects of elevated CO_2 on belowground net primary productivity (NPP) might not be offset by negative effects of O_3 (Pregitzer et al., 2008).

In a study of the possibility for use of CO_2 enrichment as a cultural practice in the production of containerized tree seedlings, black spruce (*Picea mariana*) seedlings were exposed to either increased (1000 ppm) or ambient (340 ppm.) atmospheric CO_2 levels. Those seedlings had 30 per cent and 14 per cent greater biomass respectively, than control seedlings (Campagna and Margolis, 1989). The responses of yellow-poplar (*Liriodendron tulipifera*) seedlings to elevated levels of atmospheric CO_2 were investigated by Norby and O'Neill (1992). Whole-plant dry weight increased with CO_2 enrichment provided with additional mineral nutrients. Sour orange trees were grown in enriched CO_2 atmosphere showed that the trees have approximately 2-3 times more fine-root biomass in this soil layer than the trees grown in ambient air (Idso and Kimball, 1992). Seedlings of two species of eucalyptus (*Eucalyptus macrorhyncha and E. rossii*) were grown under conditions of high CO_2 and temperature. The growth enhancement, in terms of total dry weight, was 41 per cent and 103 per cent for *E. macrorhyncha* and *E. rossii*, respectively, when grown in elevated CO_2 (Roden and Ball, 1996).

Devakumar et al. (1998) examined a novel approach to obtain increased growth in nursery seedlings of *Hevea brasiliensis* using CO_2 fertilization. The exposure led to a significant increase in total dry matter per plant. The allocation of biomass to roots was greatest in seedlings grown in elevated CO_2 with fertilizers, followed by those grown in ambient air without fertilizers. One-year-old seedlings of *Pinus koraiensis, P. sylvestris* var. sylvestriformis and *Phellodendron amurense* were exposed to CO_2 enrichment. The results showed that an increase in CO_2 concentration enhanced seedling growth (measured as dry weight biomass).Under doubled CO_2 concentration, biomass increased by 38 per cent on average for conifer seedlings and by 60 per cent for broadleaved seedlings (Wang et al., 2000).

Curtis and Wang (1998) concluded that total biomass in woody plants increased significantly at high CO_2 but there were also significant differences among various stress levels. A long-term study of the effects of double the current atmospheric CO_2 concentration on biomass production of scots pine (*Pinus sylvestris*) was carried out by Jach et al. (2000). Trees grown at elevated CO_2 accumulated 55 per cent more dry mass than trees grown in ambient CO_2. All components (stem, branches, buds, needles and roots) showed dry mass increases.

Growth responses of beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) to elevated atmospheric CO_2 and increased wet deposition of nitrogen in combination with two soil types were studied in open-top chambers. Root biomass was significantly increased in the high-nitrogen treated low fertility acidic soil, but not-in the more fertile calcareous soil. These results suggest that soil type co-determines the CO_2 response of young forest trees and that these interactions are species specific (Egli and Korner, 1997).

Both total biomasses and net CO_2 assimilation increased significantly at about twice ambient CO_2, regardless of growth conditions. Biomass responses to elevated CO_2 were strongly affected by environmental stress factors and to a lesser degree by duration of CO_2 exposure. Increased carbon allocation in the belowground biomass has been observed at elevated atmospheric CO_2 concentrations for a number of tree species (Ceulemans and Mousseau, 1994), although the effect of potential increase in carbon in the soil system is still uncertain and its component carbon pools and fluxes between them are not clearly known (Canadell et al., 1996).

The longest study of continuous exposure of forest trees to elevated atmospheric CO_2 has occurred with forest patches of helm oak (*Quercus ilex*) growing for approximately 30 years in the vicinity of two natural CO_2 springs in Italy (Hattenschwiler et al., 1997). From this study, early growth enhancement included an almost doubling of annual growth ring size under elevated CO_2.

However, a diminishing growth enhancement was noted over the study and at ages 25–30, there is no additional stimulation of annual growth rings, and the CO_2 enhanced trees are only marginally larger than controls. Growth enhancement of a 10-year old loblolly pine (*Pinus taeda*) forest by elevated CO_2 resulted in a few years of growth stimulation (DeLucia et al., 1999). However, this was followed by sharply decreased growth after the third year of exposure (Oren et al., 2001), most likely because soil fertility became a limiting factor. During the entire growth phase, from planting to crown closure, trembling aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*) growth enhancement under elevated atmospheric CO_2 has been maintained for four years (Percy et al., 2002).

2.2 Influence of elevated CO_2 on physiological parameters

One of the direct effects of increasing CO_2 level is the altering of eco physiological response of plants, since the growth of plants depends on a number of environmental factors including CO_2 level in the atmosphere. Elevated CO_2 has both direct and indirect effect on physiology of plants. Understanding the effect of changing CO_2 on behavior and responses of plants and vegetation is a key issue independent of all other global CO_2 effect (Luo et al., 1998).

2.2.1 Photosynthesis

Plants can only sense a change in atmospheric concentration through tissues that are exposed to the open air. In trees, photosynthesis is the major physiological process highly influenced by elevated CO_2. When other environmental factors and resources are present in adequate levels, CO_2 can enhance photosynthesis of trees over a wide range of concentrations.

Numerous experiments showed that high atmospheric CO_2 concentration leads to increases in photosynthetic rate and whole-plant growth in many C_3 species, while in C_4 species the increasing effects were much lower (Bowes, 1993; Idso and Idso, 1994; Ghannoum et al., 2000; Griffin et al., 2000; Gunderson et al., 2000; Jach and Ceulemans, 2000; Finzi et al., 2001; Hymus et al., 2001; Watling et al., 2000). Exposure to elevated CO_2 can increase photosynthesis and starch accumulation

(Moore et al., 1999). As per the finding of Li et al. (1999), plants of *Quercus myrtifolia* and *Quercus geminata,* both grown in open-top chambers in their natural habitat showed stimulated photosynthetic rates by 73 per cent and 51 per cent for *Q. geminata* and *Q. myrtifolia*, respectively in elevated CO_2, compared to ambient CO_2.

When plants are exposed to elevated atmospheric CO_2, photosynthesis and the accumulation of plant biomass are often increased in the short-term (Woodward, 1992; Pritchard et al., 1999). Determining the effect of elevated CO_2 on the tolerance of photosynthesis to acute heat stress (AHS) is necessary for predicting plant responses to global warming because photosynthesis is heat sensitive and AHS and atmospheric CO_2 will increase in the future. Wang et al. (2008) grew 11 species that included C_3, C_4, and CAM species at elevated (370 or 700 ppm) CO_2 and at 30^0C. They found out that thermotolerance of net photosynthesis in elevated CO_2 increased in C_3 plants, but decreased in C_4, and CAM species.

Maier et al. (2008) in field-grown loblolly pine exposed to elevated CO_2 concentration noticed an increased light-saturated net photosynthesis per unit leaf area by 43 per cent and 52 per cent in both existing one year old foliage and developing current-year first-flush. Likewise, CO_2 enrichment of two cultivars ('Koroneiki' and 'Picual') of olive (*Olea europaea*) trees showed a significantly higher net CO_2 assimilation rate (Melgar et al., 2008). A study conducted in seedlings of four and seven months old *Garcinia gummi-gutta* under elevated CO_2 showed a concomitant increase in photosynthesizing surface area, indicating higher photosynthesis at elevated CO_2 concentration leading to higher biomass accumulation (Jagadish et al., 2008).

Kimball and Idso (2005) studied the long term exposure of sour orange trees to elevated CO_2. Their findings showed that the enhancement ratio for net photosynthesis in the initial period, indicating some acclimation to the elevated CO_2. To investigate the effects of the predicted increase in atmospheric CO_2 concentrations upon photosynthesis in two soils, Eguchi et al. (2008) grew two year old saplings of three Betulaceae species (*Betula platyphylla* var.*japonica*, *Betula maximowicziana*, and *Alnus hirsute*) for two years in a free air CO_2 enrichment system in northern Japan. These three species are all able to increase the photosynthesis efficiency at high CO_2. However, the rate of photosynthesis depended on the type of the soil in which they grew.

Stirling and Davey (1995) found out a significant increase in photosynthetic efficiency at elevated CO_2 in *Lactuca serriola, Dactylis glomerata, Poa annua, Poa alpina , Helianthemum nummularium, Bellis perennis* and *Plantago lanceolata.* Effects of CO_2 concentration on the photosynthetic and carboxylation efficiencies of *Fagus crenata* and *Quercus crispula* were investigated by NaiShen et al. (1996). They found that the elevated CO_2 concentrations strongly stimulated net photosynthetic rate and the photosynthetic efficiency, for both species.

Radiata pine (*Pinus radiata*) and red beech (*Nothofagus fusca*) were grown for over one year at elevated and ambient CO_2 partial pressure in open-top chambers. The result showed maximum photosynthetic efficiency in red beech but the same was not observed in pine under higher CO_2 (Hogan et al., 1996). Oosten and Besford (1996) presented molecular mechanisms behind photosynthetic efficiency in higher C_3 plants exposed to long-term CO_2. Wang et al. (1996) undertook CO_2 enrichment studies on saplings of scots pine (*Pinus sylvestris*) and the result showed an increase in CO_2 assimilation rate. Kirschbaum (1994) analysed the sensitivity of C_3 photosynthesis to increasing CO_2 concentration. He found that photosynthesis was much more responsive to CO_2 at high than at low temperatures.

Some reports suggest that different species in the same ecosystem may respond differently in photosynthesis or growth to rising atmospheric CO_2. These reports include the temperate deciduous species, sweetgum (*Liquidambar styraciflua*) and loblolly pine (*Pinus taeda*) (Strain and Cure, 1986), and the arid land *Eucalyptus* species (*E. tetrodonta* and *E. miniata*) (Duff et al., 1994). It has been suggested that different responses of photosynthesis to increased CO_2 concentration by different species may result in significant changes in the distribution of species and the composition of plant communities (Korner and Bazzaz, 1996). There have been only a few studies in which the responses of species were compared in their undisturbed natural environment (Bazzaz et al., 1990; Bowes, 1993). Photosynthetic rates have been reported to be enhanced by 60 per cent following exposure of the *Populus euramericana* clone 'Robusta' to 700 ppm CO_2 for several months (Ceulemans et al., 1993) and of *Populus deltoides* to twice ambient concentrations (Regehr et al., 1975). The effects of CO_2 enrichment on photosynthesis in field grown *Pinus radiata* was studied by Griffin et al. (2000). They could find increased photosynthesis in the initial period of growth.

Fernandez et al. (1999) studied photosynthesis in plants of four tropical species growing under elevated CO_2, differing in carbon fixation metabolism: *Alternanthera crucis, Ipomea carnea, Jatropha gossypifolia* and *Talinum triangulare*. During the first weeks under elevated CO_2 in the first stage, plants of all the species had a very marked increase in their maximum net photosynthetic rates of 3.5 times on average. However, carboxylation efficiency decreased in all the species under elevated CO_2 and this was correlated with a decrease in ribulose-1, 5-bisphosphate carboxylase/oxygenase (RuBPCO) content in all the species.

Elevated CO_2 also reduced the light compensation point for net photosynthesis and increased maximum quantum efficiency by reducing photorespiration. Such effects could be of great importance to the growth of tree seedlings in the forest understorey, with possible implications for inter specific competition and forest regeneration (Saxe et al., 1998). Photosynthetic rate is stimulated by 73 per cent and 51 per cent respectively for *Quercus geminata* and *Q. myrtifolia* in elevated CO_2 (Li et al., 1999). Similarly, seedlings of *Garcinia gummi-gutta* showed higher photosynthesis at elevated CO_2 concentration (Jagadish et al., 2008).

However, photosynthetic enhancement may decline with time due to various limiting factors. With time, trees show a decrease in photosynthetic rate. Down regulation is most pronounced in low soil nutrient supplies. The reasons for this decline are not fully understood, though several reasons have been proposed. They include a reduction in carbohydrate sink strength, a limited capacity to sequester carbon in a storage form, changes in nitrogen allocation and a reduction of rubisco concentration (Hymus et al., 2001).

Indeed, after 17 months of growth in elevated CO_2, field grown poplar cuttings showed evidence of physiological down-regulation (Ceulemans and

Mousseu, 1994). In some cases elevated CO_2 only increased tree photosynthesis in parallel with leaf mass, without an increase in the specific photosynthesis (Garcia et al., 1994). Branch bag technique in twenty one year old loblolly pine for two years showed enhanced rate of net photosynthesis of 53- 111 per cent and no apparent down-regulation (Teskey, 1995). In loblolly pine, photosynthesis was stimulated more during summer than winter, and observed some diminishment in photosynthetic enhancement of CO_2 exposure in subsequent years compared with the first summer during forty two months of exposure (Tissue et al., 2001).

2.3 Influence of elevated CO_2 on bio - chemical aspects

2.3.1 Chlorophyll content

Elevated carbon dioxide concentration increased chlorophyll concentration in two cultivars ('Koroneiki' and 'Picual') of olive (*Olea europea*) trees that showed a positive response to CO_2 enrichment (Melgar et al., 2008). Roden and Ball (1996) studied growth and physiology of two eucalyptus species during high temperature stress under ambient and elevated CO_2. Plants grown in elevated CO_2 had an overall increase in chlorophyll content and hence maximum photosynthetic efficiency. However, alpine vegetation responds to elevated CO_2 with negative result. In addition to that, a study carried out by Thron et al. (1997) revealed that chlorophyll pigment contents per leaf was low due to reductions in the proportion of thylakoid membranes.

Ceulmans et al. (1995) examined the effect of doubled CO_2 on ecophysiological response in two poplar clones under open top chambers. They noticed increase chlorophyll content that contributed higher photosynthetic efficiency. An investigation of increased CO_2 on various aspects of the physiology of leaves of adult Mediterranean oak species (*Quercus pubescens* and *Quercus ilex*) grown at naturally enriched CO_2 concentrations in central Italy was conducted by Schwanz and Polle (1998). The foliar contents of chlorophylls were not affected in trees grown under enriched CO_2 in the long run. The results suggested that the down-regulation of photosynthesis might happen during the course of time.

Jach and Ceulemans (1998) conducted open top chambers (OTC) studies in order to examine the impact of increased atmospheric CO_2 on leaf morphology, biochemistry and physiology of three year old scots pine seedlings. Seedlings grown in increased CO_2 for one growing season exhibited a positive response to these conditions showing higher chlorophyll, nitrogen and carbon concentrations.

Griffin et al. (2000) studied the effects of CO_2 enrichment on photosynthesis and leaf biochemistry in current year and one year old needles of the same branch of field-grown *Pinus radiata* trees. None of the biochemical parameters including leaf chlorophyll were affected by growth in elevated CO_2. These results demonstrate that photosynthetic acclimation can develop over time in field-grown trees and may be regulated by source-sink balance, sugar feedback mechanisms and nitrogen allocation.

2.3.2 Soluble protein synthesis

The majority of experiments using elevated CO_2 have found a 15–30 per cent reduction in leaf nitrogen per unit leaf dry mass and an increase in the carbon/nitrogen (C:N) ratio (Korner and Arnone, 1992; Arnone and Körner, 1995; Poorter et al., 1996; Coley, 1998; Curtis and Wang, 1998).

Huttunen et al. (2008) analyzed chemical and morphological changes in the leaves of silver birch seedlings (*Betula pendula*) under higher CO_2 concentration. There was a decreased in the concentrations of the protein content in leaves when compared to normal atmospheric condition. Crous et al. (2008) investigated whether long-term elevated carbon dioxide concentration causes decline in photosynthetic enhancement and leaf nitrogen in *Pinus taeda* growing in a long term free air CO_2 enrichment (FACE) facility. Their findings showed changes in the apparent allocation of nitrogen to photosynthetic components may be an important adjustment in pines exposed to elevated CO_2 on low-fertility sites.

Protein content and activity of ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) were down regulated in wild cherry (*Prunus avium*) under elevated CO_2. The loss of rubisco on an area basis in plants in the elevated CO_2 treatments was compensated for at the canopy level by increased leaf area (Wilkins et al., 1994). However, the foliar contents of protein and chlorophylls were not affected in trees grown at higher CO_2 compared with those in ambient conditions.

Incorporation of 14C-photosynthate into protein during leaf development in young populus plants showed decline in soluble leaf protein content (Dickmann and Gordon, 1975). A study carried out in birch (*Betula pendula*) trees grown in the field to assess the long-term response of photosynthesis to elevated atmospheric CO_2 concentration in open-top chambers for four consecutive growing seasons recorded a 9 per cent reduction in soluble protein and 12 per cent N concentrations (Rey and Jarvis, 1998). Black spruce seedlings grown under ambient CO_2 had a mean foliar nitrogen concentration (3.68 per cent) significantly greater than elevated CO_2 grown seedlings (3.49 per cent) (Johnsen and Major, 1998).

From all information available today, it is clear that elevated concentrations of atmospheric CO_2 may have a major effect on woody plants. An increase in atmospheric CO_2 will shift the activity of ribulose-l, 5 bisphosphate carboxylase and oxygenase (Rubisco) in favour of carboxylation (Bowes, 1991; Stitt, 1991), depress stomatal conductance (Morison, 1987; Ceulemans and Mousseau, 1994; Field et al., 1995) and change the partitioning of assimilates between root and shoot (Farrar and Williams, 1991). Therefore, it is expected that rising atmospheric CO_2 will have a positive effects on plant photosynthesis, growth, efficiency of water and nutrient use (Lemon, 1983 and Long, 1994) although there is, as yet, no consensus of opinion regarding the extent of climate change and of the adaption of trees to changing environments.

MATERIALS AND METHODS

MATERIALS AND METHODS

The present investigation entitled "Effect of elevated CO_2 concentration on growth and physiology of selected tropical tree seedlings." was undertaken during the year 2008-2010 at College of Forestry, Vellanikkara, Trichur District, Kerala, India.

3.1 Climate and weather pattern

Geographically, the area is located 22.25 m above Mean Sea Level at $10^0 32^1$ N latitude and 76^0 10^1 E longitude. The location experiences a humid tropical climate with a mean annual rain fall of 2668.6 mm most of which is received between June to September. The minimum temperature varies from 22.2^0C (January) to 25.1^0 C (April) and maximum from 29.0^0 C (July) to 36.1^0 C (March). The climatic data for the experiment period is given in Appendix I.

The following five tree species which have high market demand in the study locality were chosen for the experiment.

1) Teak (*Tectona grandis* L. f)
2) Mahogany (*Swietenia macrophylla* King.)
3) Njaval (*Syzygium cumini* L.)
4) Matti (*Ailanthus triphysa* (Dennst.) Alston)
5) Venga (*Pterocarpus marsupium* Roxb.)

3.2 Methodology

All the seedlings were raised in the polythene bags containing standard potting mixture (1: 1: 1 mixture of soil, sand and farm yard manure). They were grown in the nursery for two months. All seedlings with uniform growth age characters were selected for the experiment.

3.2.1 Lay out of the experiment

Experimental design: CRD (factorial)

Treatments: 10 (five tree species at two CO_2 levels)

Tree species: factor A

CO_2 concentrations: factor B

Replication: 3

No of seedlings in each replication: 30

3.2.2 Method

Polybag seedlings of the five tree species were exposed to 500 - 550 ppm CO_2 concentration and another similar set of plants were grown under ambient atmospheric CO_2 condition (370-380 ppm) which served as control (Plate 1). The plants were exposed to elevated CO_2 concentrations for eight month and growth rates and physiology were observed.

For obtaining elevated CO_2 concentration, a simple and economic technique to grow polybag seedlings under elevated CO_2 concentrations was used (Devakumar et.al., 1996). Two rectangular trenches of 3 m length, 1.25 m width and 1 m depth, were dug in a place exposed to open sunlight. A dome shaped metal frame was placed over the trench completely enclosing it. The height of the frame was 1m and it had a gable roof. Using high density polythene sheet of 125 μ gauge, a cover was tailored to suit the size of the frame. The polythene sheet cover was 12 inches longer than the frame for ensuring complete coverage (Plate 2). On this sheet a thin layer of soil was laid to keep the chamber in place. During night hours, the CO_2 released by respiration of plants and soil microbes was trapped raising the CO_2 concentration. Polybag seedlings were exposed to elevated CO_2 between 3.30 pm and 8.00 am i.e. the structure was closed from 3.30 pm till next day 8.00 am (Plate 3 and 4). Apart from CO_2, relative humidity and temperature were also increased inside the chamber.

Plate 1. Overview of the experimental plot

Plate 2. The CO_2 trapping trench

Plate 3. View of opened CO_2 trapping trench

Plate 4. Tree seedlings kept in the trench

3.2.2.1 Standardization

The CO_2 concentration, relative humidity and temperature were measured inside the chamber regularly to make a comparison with outside plot. Carbon dioxide concentration and relative humidity were measured using IRGA (LI 6400 portable photosynthesis system) both in closed and open conditions. Carbon dioxide concentration began to increase inside the trench after closing it and reached 550 ppm within two hours. It continued at high level throughout the night and showed a decreasing trend in the sunlight in the morning (Figure 1). The CO_2 concentration in the ambient air was 370-380ppm. Simultaneously, the closed chamber developed a higher relative humidity than the outer environment and reached at saturation level throughout the night till next day morning (Figure 2a). In addition to that, temperature inside the trench and ambient air were measured using maximum-minimum thermometer. Temperature, particularly maximum temperature was also higher inside the trench (Figure 2b). In essence, the seedlings experienced a new microclimate inside the chamber compared to seedlings growing outside plot.

3.3 Observations

3.3.1 Shoot growth parameters

Observations on various shoot growth parameters were taken at an interval of 30 days till the end of the study period.

3.3.1.1 Height

The height of individual seedlings was measured from collar region to terminal bud at monthly interval using a meter scale and expressed in centimeters.

3.3.1.2 Collar diameter

The collar diameter was measured using a digital vernier calliper at monthly interval and expressed in millimeters.

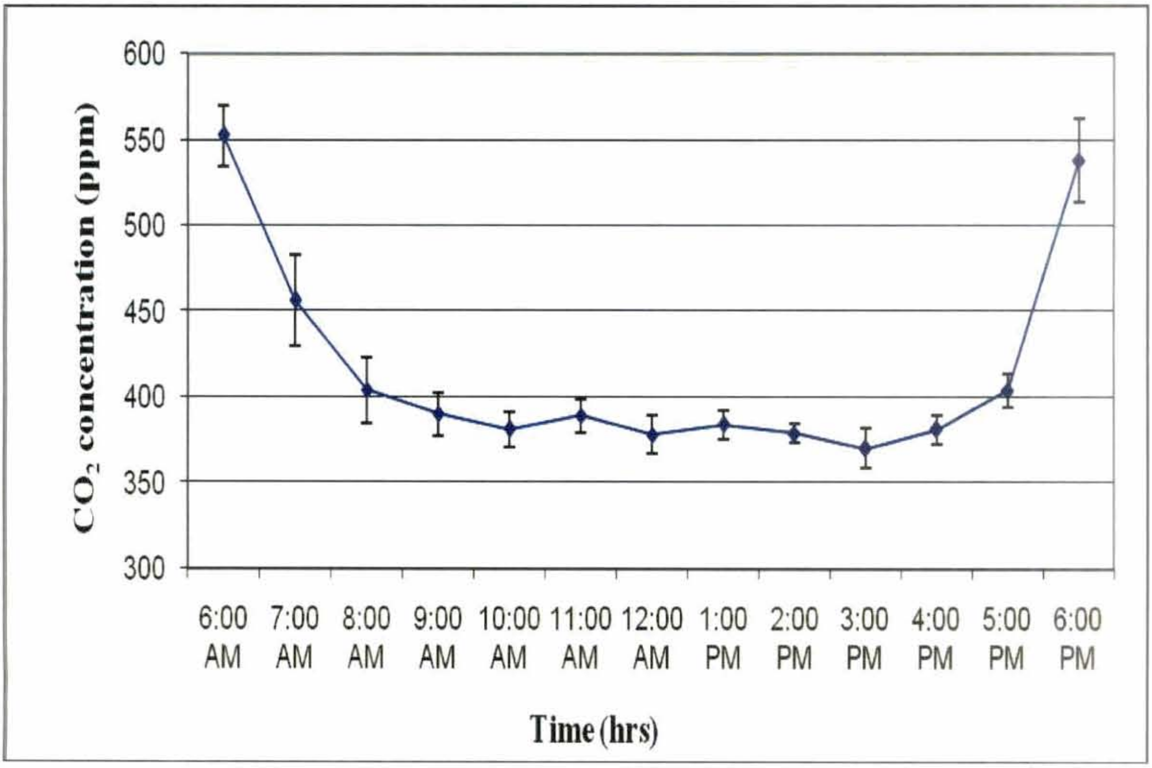

Figure 1. Average carbon dioxide concentration (ppm) inside the chamber

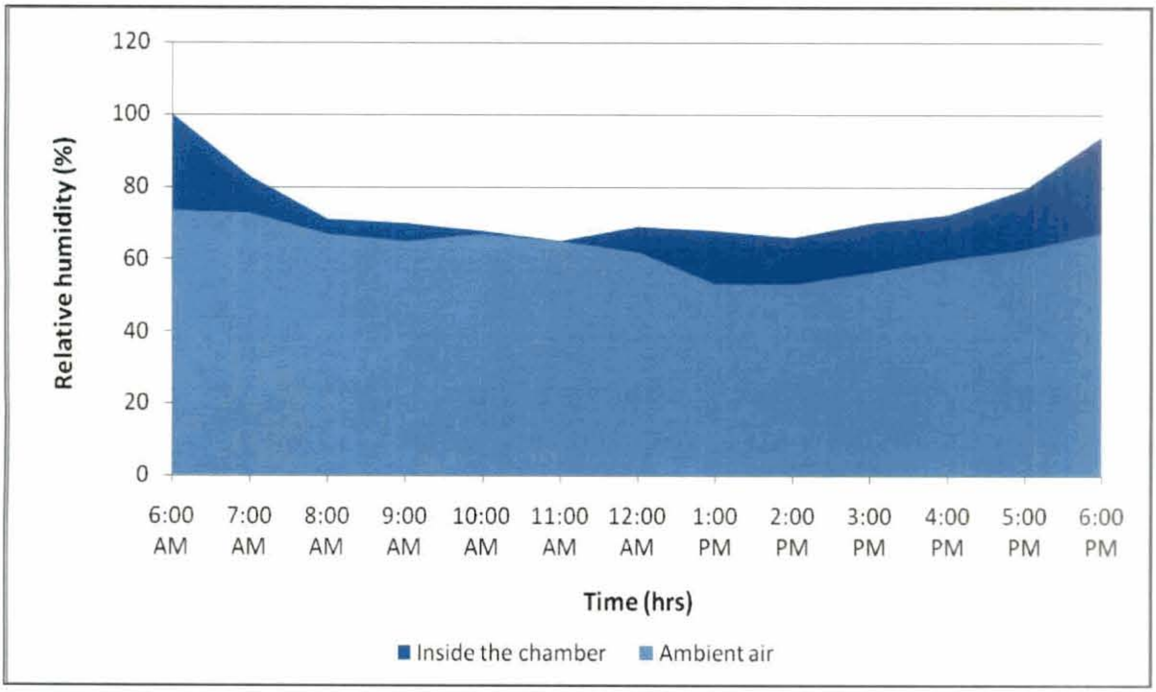

Figure 2 a . Changes in the relative humidity (%) inside the chamber and outside the chamber

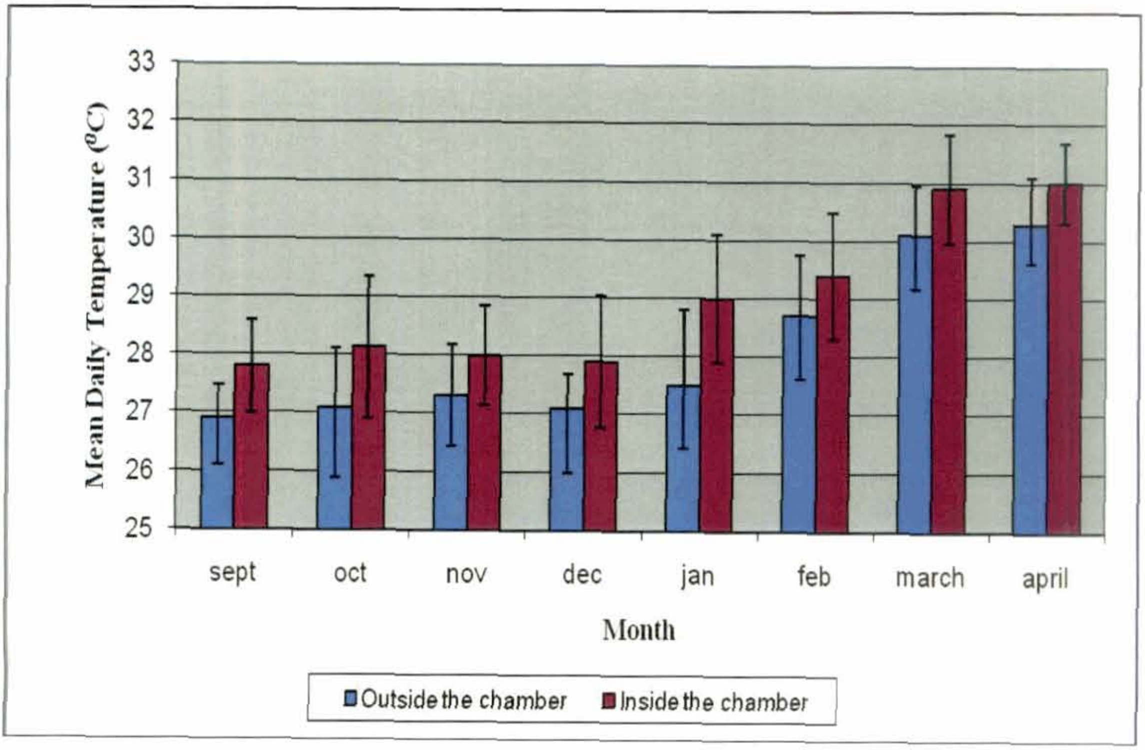

Figure 2b. Changes in the mean daily temperature (^{0}C) inside the chamber and outside the chamber

3.3.1.3 Number of leaves

The number of leaves produced by individual seedlings was counted at monthly intervals.

3.3.2 Root growth parameters

Destructive sampling was done at monthly interval for a period of eight months and the following observations were made.

3.3.2.1 Length of roots

Length of roots was measured from the collar region to the tip of the longest root and expressed in centimeter.

3.3.3 Biomass production

Destructive sampling at the rate of three plants per treatment was done at an interval of 30 days for eight months. Leaves, stem and roots were separated and the dry weight of each seedling was recorded.

3.3.3.1 Fresh weight of shoot and root

The leaves were taken and the fresh weight was calculated. The shoot (includes both stem and leaves) and root portion of seedlings were separated and fresh weight was determined separately using precision balance and expressed in grams.

3.3.3.2 Dry weight of shoot and root

The shoot and root portion of the samples were dried separately in a hot air oven at a temperature of $80^0C \pm 5^0C$ till constant weight was achieved. Dry weights were taken using a precision balance and expressed in grams.

3.3.3.3 Shoot root ratio

Shoot root length ratio was calculated by dividing the average of the shoot length by root length of each plant. Shoot root biomass ratio was calculated by dividing the average of the shoot weight by root weight of each plant.

3.3.3.4 Total dry matter production

Total dry matter production was calculated by summing up of dry weight of shoot and root.

3.3.4 Physiological observations

3.3.4.1 Relative growth rate

The Relative Growth Rate (RGR) of plant total dry matter was estimated out by using the following formula:

$$RGR = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

W_1 and W_2 are dry weights (g) at the beginning and the end of the sampling period, t_1 and t_2 are the dates of sampling respectively, and ln denotes the natural logarithm of the numbers.

3.3.4.2 Net Assimilation Rate (NAR)

NAR is an index of the productive efficiency of plants calculated in relation to total leaf area. NAR is calculated from the formula given below:

$$NAR = (W_2 - W_1)/ (t_2 - t_1) \text{ X } (\text{Log e } LA_2 - \text{Log e } LA_1)/ LA_2 - LA_1)$$

W_1 = Dry weight at time t_1

W_2 = Dry weight at time t_2

LA_1 = Leaf Area at time t_1

LA_2 = Leaf Area at time t_2

3.3.4.3 Leaf area

Individual and total leaf area were measured at periodic interval using leaf area meter (CI - 202) and expressed as cm^2.

3.3.4.4 Specific leaf area (SLA)

Specific leaf area was found out by using the following formula and expressed as cm^2g^{-1}

$$SLA = \frac{\text{Leaf area}}{\text{Leaf dry weight}}$$

3.3.4.5 Leaf area ratio (LAR)

Leaf area ratio was found out by using the following formula and expressed as cm^2g^{-1}

$$LAR = \frac{\text{Leaf area/ plant}}{\text{Whole plant dry weight}}$$

3.3.4.6 Leaf weight ratio (LWR)

Leaf weight ratio was found out by using the following formula and expressed as gg^{-1}

$$LWR = \frac{\text{Dry weight of leaves}}{\text{Plant dry weight}}$$

3.3.4.7 Number of stomata

Leaf samples were collected representing each treatment to find out the stomatal frequency. A thin layer of transparent film forming gum was spread on the under surface of leaf and the membranous layer was peeled off carefully. The number of stomata per field was counted using a binocular microscope and stomata per mm^2 were estimated.

3.3.4.8 Net photosynthesis

Net photosynthesis was measured with a portable Infrared Gas Analyzer (Model LI 6400, LICOR, Nebraska, USA) using a one liter leaf chamber. The measurements were recorded on the data logger supplied with the instrument. The net photosynthesis was calculated using the built in software in the data loggers. The measurements were recorded on a monthly interval and expressed in μ mol m^{-2} s^{-1}.

3.3.5 Biochemical parameters

Biochemical estimations were conducted using fully expanded leaf (mostly second or third leaf from the top) which were sampled during pre-dawn hours (0700 to 0800 hrs 1ST) at the end of every 30 days. Three replicates were used from each treatment for the estimation. In teak, none of the parameters could be estimated due to the interference of phenols in the leaf.

3.3.5.1 Chlorophyll content

Chlorophyll content of the leaf was estimated following the method of Starner and Hardley (1967). Samples were collected from the selected plants, cut into pieces and mixed well; 0.1 g of the sample was weighed into a mortar and ground with a pestle to extract the chlorophyll using 80 per cent acetone. The extract was filtered using Whatsman No.1 filter paper and made up to 25 ml using 80 per cent acetone. The absorbance were read at 663 nm and 645 nm wave length in a spectrophotometer.

Chlorophyll 'a', chlorophyll 'b' and total chlorophyll of each sample were calculated using the following formulae.

Chlorophyll 'a' (mg g^{-1} of tissue)

$$12.7 \text{ (OD at 663 nm)} - 2.69 \text{ (OD at 645 nm)} \times \frac{V}{1000 \times W}$$

Chlorophyll 'b'(mg g^{-1} of tissue)

$$22.9 \text{ (OD at 645 nm)} - 4.68 \text{ (OD at 663 nm)} \times \frac{V}{1000 \times W}$$

Total chlorophyll (mg g^{-1} of tissue)

$$20.2 \text{ (OD at 645 nm)} + 8.02 \text{ (OD at 663 nm)} \times \frac{V}{1000 \times W}$$

Where,

OD Optical density

V Final volume of 80 per cent acetone extract

W Fresh weight of tissue in gram

3.3.5.2 Soluble protein

Foliar soluble protein was estimated by the procedure given by Lowry et al. (1951). Foliar samples were collected fresh from selected plants in each treatment, cut into pieces and mixed well. Extraction was carried out with buffer of pH 7 used for enzyme assay. Five hundred mg of the leaf material was extracted with 10 ml of the buffer. The leaf extract was centrifuged at 5000 rpm for 20 minutes and the supernatant was used for the experiment. The following reagents are used for the experiment:

Alkaline copper reagent

Reagent A: 2% Sodium carbonate in 0.1 N NaOH

Reagent B: 0.5% Copper sulphate ($CuSO_4.5\ H_2O$) in 1 % potassium sodium tartarate

Reagent C: 50 ml of Reagent A and 1 ml of Reagent B were mixed prior to use.

Protein solution

Bovine serum albumin (fraction V) of 50 mg dissolved in distilled water and made up to 50 ml in a standard flask.

From the aliquot 0.1 ml was pipetted into a test tube, made up to 1 ml with distilled water and 5 ml of alkaline copper reagent was added. After 10 minutes, 0.5 ml of Folin phenol reagent was added to the above solution and incubated at room temperature in the dark for 30 minutes. A blue colour developed. The absorbance was measured at 660 nm using a spectrophotometer. The amount of protein was estimated after referring to a standard curve with bovine serum and was expressed in mg g^{-1} of sample.

3.3.6 Statistical analysis

All result was subjected to analysis of variance (ANOVA) using SPSS V 16. Following the ANOVA, Duncan's Multiple Range Test (P=0.05) was used to identify significant differences.

RESULTS

RESULTS

A study on the effects of elevated CO_2 concentration on the growth and physiology of selected tropical tree seedlings was carried out during 2008-10 at the College of Forestry. The results of the different experiments under this study are presented below.

4.1 Shoot growth parameters

The influence of various treatments on the shoot growth parameters of the tree seedlings like height, collar diameter and leaf number recorded at monthly intervals is given hereunder.

4.1.1 Height

The effect of two CO_2 levels on the height of teak (*Tectona grandis*), mahogany (*Swietenia macrophylla*) njaval (*Syzygium cumini*), matti (*Ailanthus triphysa*) and venga (*Pterocarpus marsupium*) seedlings is presented in Table 1 (a and b) and illustrated in Figure 3.

The two levels of CO_2 concentrations had significant impact on height of all the five tree seedlings throughout the study period. The interaction between tree species and two CO_2 concentrations however do not significantly influence the height of seedlings in the first three months.

In the first month, tree seedlings under elevated CO_2 concentration put in more height (33.53 cm) than the seedlings under atmospheric CO_2 (24.80 cm). Both were significantly different. Seedlings of all tree species under elevated CO_2 showed higher shoot growth than that under atmospheric CO_2, but they were not significantly different. In the second month, height under elevated CO_2 (38.58 cm) was significantly different from that under atmospheric CO_2 level (32.15 cm). Similarly in the third month also, seedlings under elevated CO_2 recorded a significant height of 50.51 cm than that under atmospheric CO_2 (35.51 cm).

During the fourth month, height under elevated CO_2 concentration differed significantly (59.95 cm) from that under atmospheric CO_2 level. The interaction effect was also significant. Teak seedlings under elevated CO_2 concentration performed best (65.13 cm). The lowest height was observed in njaval both in elevated CO_2 concentration (47.30 cm) and in atmospheric CO_2 concentration (29.73 cm). Under atmospheric CO_2 concentration, mahogany seedlings showed highest performance (45.97 cm).

In the fifth month, seedlings of venga recorded maximum height (75.67 cm) under enriched CO_2 concentration and mahogany seedlings under atmospheric CO_2 concentration (54.87 cm). The height of njaval seedlings was lowest under both elevated CO_2 (51.00cm) and atmospheric CO_2 concentration (34.47 cm).

In the sixth month, seedlings under CO_2 enriched condition had a height of 77.27 cm while seedlings under normal CO_2 condition had a height of 52.84 cm. The interaction effect was significantly different among the seedlings of five tree species under different CO_2 concentration. The maximum gain in height was observed in teak seedlings under elevated CO_2 (92.33 cm) and lowest growth in njaval seedlings (54.17 cm). Matti seedlings recorded highest height (65.27 cm) and njaval seedlings recorded lowest height of 35.50 cm under atmospheric CO_2 concentration.

In the seventh month, elevated CO_2 recorded highest height (95.64 cm) followed by those under atmospheric CO_2 level (64.71 cm). A significant difference in interaction was observed at this period. Maximum height was observed in the seedlings of venga (118.67 cm) under elevated CO_2 concentration. Njaval seedlings recorded lowest height of 39.47 cm under atmospheric CO_2 concentration.

In the eighth month of the study period, two levels of CO_2 had a significant impact on the height of the tree seedlings. The maximum gain was observed in seedlings of venga (134.00 cm) under enriched CO_2 condition. Njaval seedlings under atmospheric CO_2 concentration recorded the lowest height growth (41.13 cm).

Table 1 (a): Two-way tables on height (cm) of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	34.42	29.40
Mahogany	38.16	30.36
Njaval	29.09	16.67
Matti	33.11	24.17
Venga	32.88	23.40
Mean	33.53^x	24.80^y
$F_{CO2\ levels}$ - 11.39**, SEm+/- =1.70		
$F_{interaction}$ - 0.12 NS, SEm+/- =3.81		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	41.27	33.67
Mahogany	43.87	38.40
Njaval	29.18	24.60
Matti	35.60	31.53
Venga	44.00	32.53
Mean	38.58^x	32.15^y
$F_{CO2\ levels}$ - 23.1**, SEm+/- =0.95		
$F_{interaction}$ - 1.15 NS, SEm+/- =2.12		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	48.40	34.45
Mahogany	55.77	43.51
Njaval	44.87	27.33
Matti	42.20	34.07
Venga	61.33	38.20
Mean	50.51^x	35.51^y
$F_{CO2\ levels}$ - 85.68**, SEm+/- =1.15		
$F_{interaction}$ - 2.443 NS, SEm+/- =2.56		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	65.13^a	36.97^c
Mahogany	64.67^a	45.97^b
Njaval	47.30^b	29.73^d
Matti	59.00^a	44.00^b
Venga	63.67^a	41.83^{bc}
Mean	59.95^x	39.70^y
$F_{CO2\ levels}$ - 253.01**, SEm+/- =0.90		
$F_{interaction}$ - 3.168*, SEm+/- =2.01		

significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 1 (b): Two-way tables on height (cm) of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	72.00^{a}	41.33^{cd}
Mahogany	67.00^{a}	54.87^{b}
Njaval	51.00^{b}	34.47^{d}
Matti	69.33^{a}	51.50^{b}
Venga	75.67^{a}	49.33^{bc}
Mean	67.00^{x}	46.30^{y}
$F_{CO2\ levels}$ - 141.64**, SEm+/- =1.23		
$F_{interaction}$ - 3.802*, SEm+/- =2.75		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	92.33^{a}	50.33^{d}
Mahogany	74.83^{b}	59.33^{cd}
Njaval	54.17^{d}	35.50^{e}
Matti	74.67^{b}	65.27^{c}
Venga	90.33^{a}	53.77^{d}
Mean	77.27^{x}	52.84^{y}
$F_{CO2\ levels}$ - 159.97** , SEm+/- =1.37		
$F_{interaction}$ - 10.66**, SEm+/- =3.05		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	105.00^{b}	62.67^{d}
Mahogany	99.67^{b}	70.00^{cd}
Njaval	61.17^{d}	39.47^{e}
Matti	93.67^{b}	78.57^{c}
Venga	118.67^{a}	72.83^{cd}
Mean	95.64^{x}	64.71^{y}
$F_{CO2\ levels}$ - 128.84**, SEm+/- =1.93		
$F_{interaction}$ - 4.64**, SEm+/- =4.31		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	125.60^{ab}	68.70^{ef}
Mahogany	110.73^{bc}	77.90^{ef}
Njaval	63.83^{f}	41.13^{g}
Matti	103.80^{cd}	85.23^{de}
Venga	134.00^{a}	80.43^{ef}
Mean	107.59^{x}	70.68^{y}
$F_{CO2\ levels}$ - 84.20**, SEm+/- =2.84		
$F_{interaction}$ - 3.81* , SEm+/- =6.36		

significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

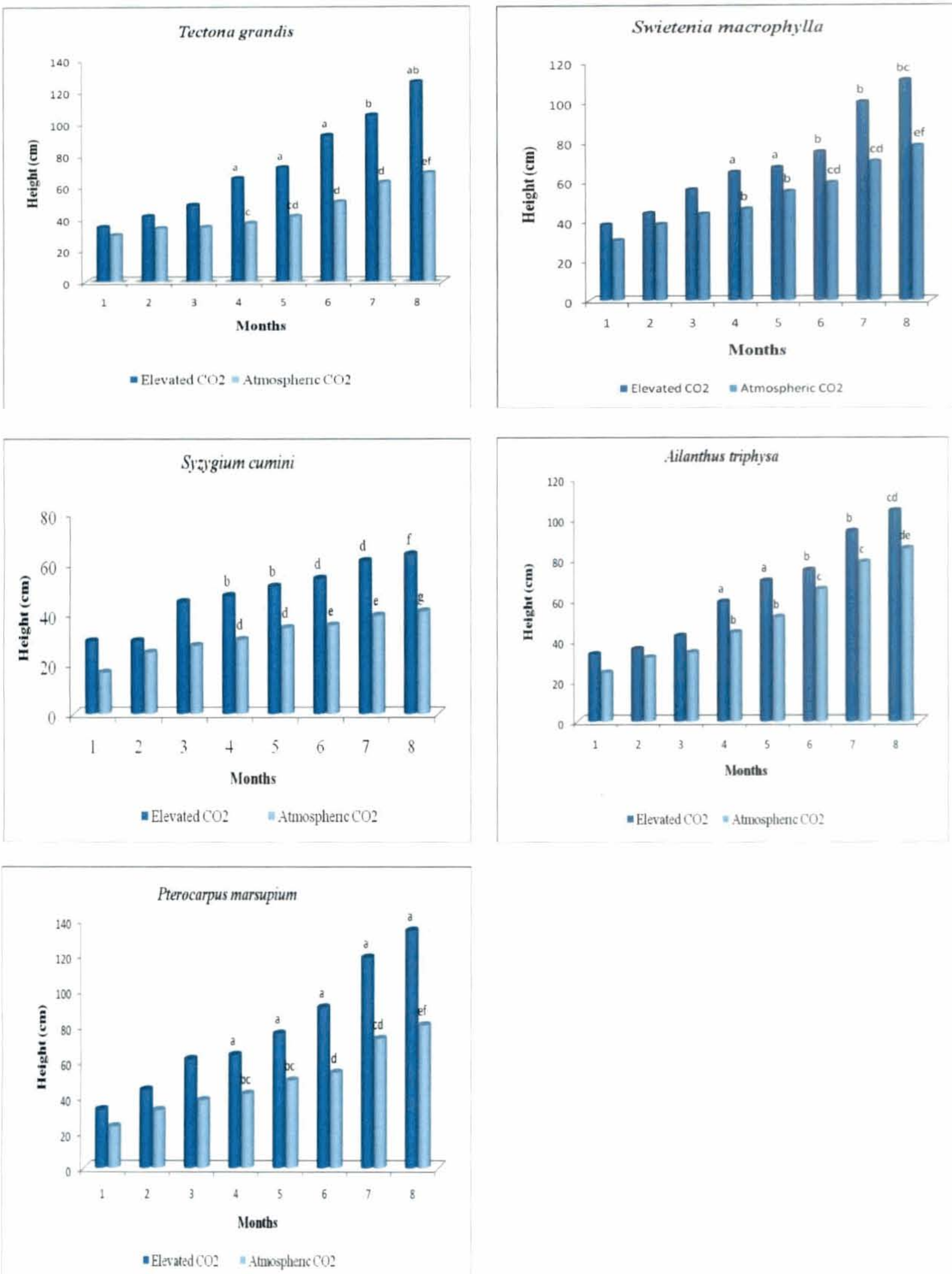

Figure 3. Response of five tree species on height (cm) of seedlings under two CO_2 concentrations

Figures with the similar superscripts or no superscripts do not differ significantly.

4.1.1 Collar diameter

Observations related to the effect of CO_2 concentrations on the collar diameter in seedlings of five tree species is given in Table 2a and 2b and illustrated in Figure 4. From the table it can be observed that the two CO_2 levels influenced the collar diameter of seedlings throughout the study period except in the second month. There was no significant difference with respect to interaction effect.

In the first month, the highest collar diameter was observed in seedlings of mahogany under elevated CO_2 concentration (6.25 mm) while under atmospheric CO_2 concentrations, seedlings of matti recorded a collar diameter of 3.24 mm. However, njaval seedlings under elevated CO_2 concentration recorded only 2.03 mm and in atmospheric CO_2 concentration, collar diameter was 1.08 mm. In the second month the mean collar diameter under elevated CO_2 concentration was 5.48 mm which was significantly different from that at normal atmospheric CO_2 concentration (3.73 mm).

In the third month, the highest collar diameter was observed in seedlings under elevated CO_2 concentration (6.98 mm). Mahogany seedlings recorded maximum collar diameter of 9.52 mm in enriched CO_2 concentration and teak seedlings in atmospheric CO_2 concentration recorded 5.57mm. The seedlings of njaval recorded the minimum growth of 3.81mm and 3.63 mm under elevated CO_2 concentration and atmospheric CO_2 concentration respectively.

During the fourth month, elevated CO_2 concentration gave a significantly different collar diameter (8.51 mm) and there was significant interaction effect on the collar diameter due to different CO_2 concentration. The maximum collar diameter was given by teak seedlings with a recorded mean of 10.90 mm under elevated CO_2 concentration. As far as atmospheric CO_2 concentration is concerned, maximum collar diameter was put forth by venga seedlings with a recorded value of 6.22 mm in the same month.

The collar diameter was found to be the maximum in seedlings grown in elevated CO_2 concentration in the fifth month of the study period and interaction vise there were significant differences in collar diameter.

In the sixth month, the use of different CO_2 concentrations produced significant differences in the collar diameter. Teak seedlings under elevated CO_2 concentration gave a significantly highest collar diameter of 16.73 mm, while njaval seedlings recorded lowest collar diameter of 5.88 mm. seedlings of matti performed best (8.13 mm) under atmospheric CO_2 concentration.

In the seventh month both the CO_2 concentrations produced significantly different collar diameters. Elevated CO_2 concentration also gave a significant mean value of 12.45 mm. Among the different tree species, teak seedlings grown under elevated CO_2 concentration recorded a higher collar diameter of 18.16 mm. Under atmospheric CO_2 concentration, matti seedlings recorded 9.23 mm. On the other hand, under elevated CO_2 concentration lowest growth was recorded for njaval seedlings (6.85 mm) and under atmospheric CO_2 concentration the noted collar diameter was 4.93 mm.

In the last month of the study period, the maximum collar diameter under elevated CO_2 concentration was 13.36 mm. With regards to the interaction effect, teak seedlings performed best (19.8mm) under elevated CO_2 concentration and njaval seedlings performed least under atmospheric CO_2 concentration (5.17mm).

4.1.2 Number of leaves

The data related to the leaf production due to the effect of different concentration of CO_2 in the five tree species seedlings is furnished in Table 3a and 3b and Figure 5. From the table it can be seen that CO_2 concentrations significantly affect leaf production. But the interactions were significant in the first, fourth, fifth and eighth months only.

The CO_2 levels offered no significant effect in leaf production during first month. However, interaction had significant impacts on the leaf production in which

Table 2 (a): Two-way tables on collar diameter (mm) of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	4.92[b]	3.16[d]
Mahogany	6.25[a]	3.14[d]
Njaval	2.03[ef]	1.08[f]
Matti	4.68[bc]	3.24[d]
Venga	3.84[cd]	3.04[de]
Mean	4.34[x]	2.73[y]
$F_{CO2\ level}$ – 54.31**,SEm+/- =0.15		
$F_{interaction}$ – 3.55*, , SEm+/- =0.35		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	6.49	4.21
Mahogany	6.59	4.30
Njaval	3.49	2.52
Matti	5.61	3.93
Venga	5.23	3.71
Mean	5.48[x]	3.73[y]
$F_{CO2\ level}$ - 63.38**, SEm+/- =0.16		
$F_{interaction}$ - 1.27 NS, SEm+/- =0.35		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	8.16[ab]	5.57[cde]
Mahogany	9.52[a]	4.68[ef]
Njaval	3.81[f]	3.63[f]
Matti	6.97[bc]	5.43[de]
Venga	6.42[cd]	5.39[de]
Mean	6.98[x]	4.94[y]
$F_{CO2\ level}$ - 44.75**, SEm+/- =0.22		
$F_{interaction}$ – 6.95**, SEm+/- =0.48		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	10.9[a]	5.68[c]
Mahogany	10.41[a]	5.36[c]
Njaval	4.18[d]	3.74[d]
Matti	8.81[b]	6.00[c]
Venga	8.26[b]	6.22[c]
Mean	8.51[x]	5.40[y]
$F_{CO2\ level}$ – 172.24**, SEm+/- =0.17		
$F_{interaction}$ – 14.76** , SEm+/- =0.37		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 2(b): Two-way tables on collar diameter (mm) of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	14.20^{a}	6.14^{c}
Mahogany	10.67^{b}	5.84^{cd}
Njaval	4.75^{de}	4.04^{e}
Matti	9.81^{b}	6.93^{c}
Venga	10.99^{b}	7.12^{c}
Mean	10.08^{x}	6.01^{y}
$F_{CO2\ level}$ – 254.44**, SEm+/- =0.18		
$F_{interaction}$ – 22.46** SEm+/- =0.40		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	16.73^{a}	7.07^{d}
Mahogany	11.02^{c}	7.03^{d}
Njaval	5.88^{e}	4.59^{f}
Matti	12.23^{b}	8.13^{d}
Venga	11.94^{bc}	7.71^{d}
Mean	11.56^{x}	6.91^{y}
$F_{CO2\ level}$ – 449.12**, SEm+/- =0.16		
$F_{interaction}$ – 38.66**, SEm+/- =0.35		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	18.16^{a}	7.71^{ef}
Mahogany	11.47^{c}	7.83^{ef}
Njaval	6.85^{f}	4.93^{g}
Matti	13.42^{b}	9.23^{d}
Venga	12.33^{bc}	8.46^{de}
Mean	12.45^{x}	7.63^{y}
$F_{CO2\ level}$ –312.71**, SEm+/- =0.04		
$F_{interaction}$ – 28.81**, SEm+/- =0.43		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	19.8^{a}	8.23^{ef}
Mahogany	12.45^{c}	8.73^{e}
Njaval	7.23^{f}	5.17^{g}
Matti	14.00^{b}	10.97^{d}
Venga	13.30^{bc}	9.38^{e}
Mean	13.36^{x}	8.49^{y}
$F_{CO2\ level}$ – 308.07**, SEm+/- =0.04		
$F_{interaction}$ – 38.105**, SEm+/- =0.44		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

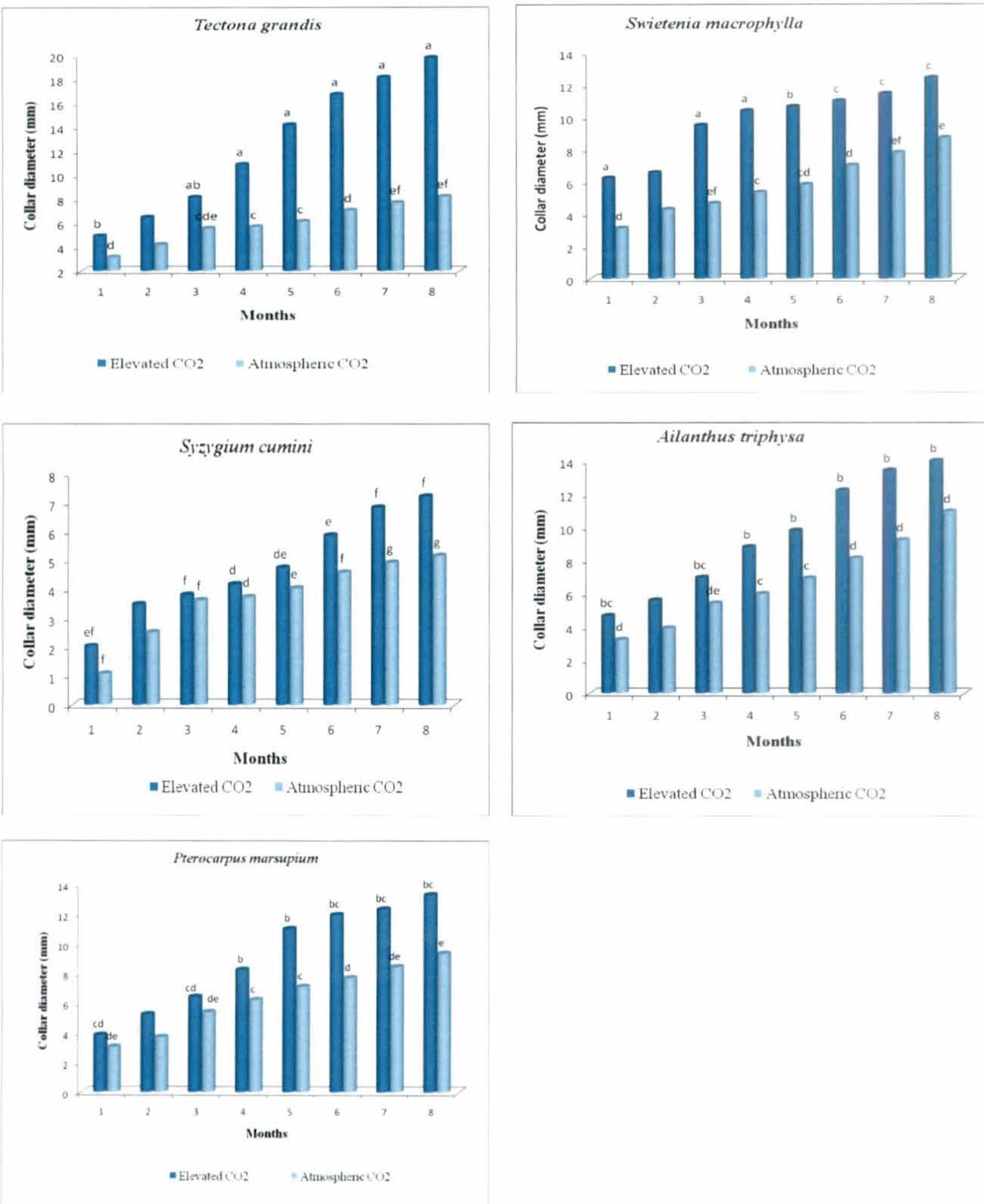

Figure 4. Response of five tree species on collar diameter (mm) of seedlings under two C concentrations

Figures with the similar superscripts or no superscripts do not differ significantly.

seedlings of njaval produced maximum leaves ((18) both in enriched as well as in atmospheric CO_2 concentration. Matti seedlings produced minimum leaves (2.67) at atmospheric CO_2 concentration.

At the second, third and fourth month, the CO_2 levels offered significant effect in leaf production. However, interaction was insignificant. At the fifth month, the highest number of leaves (39.00) was found in njaval seedlings grown under elevated CO_2 concentration with respect to interaction. The minimum number of leaves was produced by matti seedlings grown at atmospheric CO_2 concentration (19.00). In the sixth and seventh month, elevated CO_2 concentration had significant impact on the leaf number which gave mean value of 16.53 and 17.93 respectively.

In the eighth month, the different CO_2 levels treatments produced significantly different leaf number in tree seedlings. The maximum number of leaves was seen in seedlings grown under elevated CO_2 concentration (21.53). In interaction effect, maximum number of leaves was recorded in njaval seedlings grown under elevated CO_2 concentration (52.33) and minimum in teak (11.33). Likewise, under atmospheric CO_2 concentration, njaval seedlings produced maximum leaves (25.33) and matti seedlings produced the minimum (8.00).

4.1 Root growth

The root growth parameter like length of the root as affected by different treatments is presented here. The root growth parameter was found to be influenced by the different CO_2 concentrations.

4.1.1 Length of root

The effect of different CO_2 levels in the development of the root length is given in Table 4a and 4b. From the data it can be concluded that the CO_2 concentrations significantly influenced root growth throughout the study period. In the first month, the longest root observed under elevated CO_2 concentration had a mean value of 15.77 cm and differed significantly from the root length (13.03 cm)

Table 3 (a): Two-way tables on number of leaves of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	7.00^{de}	9.00^{bcd}
Mahogany	5.00^{ef}	10.00^{bcd}
Njaval	18.00^{a}	18.00^{a}
Matti	12.33^{b}	2.67^{f}
Venga	11.00^{bc}	8.33^{cd}
Mean	10.67	9.60
$F_{CO2\ level}$ – 2.59NS, SEm+/- =0.47		
$F_{interaction}$ – 14.08**, SEm+/- =1.04		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	10.00	7.67
Mahogany	7.33	8.00
Njaval	22.00	19.00
Matti	11.33	6.00
Venga	12.67	8.33
Mean	12.67^{x}	9.80^{y}
$F_{CO2\ level}$ - 6.80* SEm+/- =0.80		
$F_{interaction}$ - 0.87NS , SEm+/- =1.79		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	8.33	7.67
Mahogany	11.67	7.33
Njaval	22.33	19.00
Matti	11.00	4.33
Venga	16.67	11.33
Mean	14.00^{x}	9.93^{y}
$F_{CO2\ level}$ - 15.57**, SEm+/- =0.73		
$F_{interaction}$ – 0.97NS, SEm+/- =1.63		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	12.33	6.33
Mahogany	10.67	8.33
Njaval	27.00	16.33
Matti	14.67	5.67
Venga	14.00	9.00
Mean	15.73^{x}	9.13^{y}
$F_{CO2\ level}$ – 27.38** SEm+/- =0.89		
$F_{interaction}$ – 27.38** , SEm+/- =1.99		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 3 (b): Two-way tables on number of leaves of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	12.62^{cde}	8.00^{ef}
Mahogany	17.67^{bc}	9.00^{def}
Njaval	39.00^{a}	19.00^{b}
Matti	13.67^{cd}	6.33^{f}
Venga	11.67^{de}	10.00^{def}
Mean	18.93^{x}	10.47^{y}
$F_{CO2\ level}$ – 66.65**,SEm+/- =0.73		
$F_{interaction}$ – 9.07** SEm+/- =1.64		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	10.33	8.67
Mahogany	15.00	10.67
Njaval	32.67	21.67
Matti	9.67	8.33
Venga	15.00	9.33
Mean	16.53^{x}	11.73^{y}
$F_{CO2\ level}$ – 20.17**, SEm+/- =0.76		
$F_{interaction}$ – 2.68NS, SEm+/- =1.69		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	12.00	8.67
Mahogany	14.33	10.67
Njaval	37.00	26.33
Matti	12.67	8.00
Venga	13.67	9.00
Mean	17.93^{x}	12.53^{y}
$F_{CO2\ level}$ –16.82**,SEm+/- =0.93		
$F_{interaction}$ – 1.04NS, SEm+/- =2.08		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	11.33^{cde}	9.33^{de}
Mahogany	16.00^{c}	11.00^{cde}
Njaval	52.33^{a}	25.33^{b}
Matti	14.67^{cd}	8.00^{e}
Venga	13.33^{cde}	11.33^{cde}
Mean	21.53^{x}	12.99^{y}
$F_{CO2\ level}$ – 56.11**, SEm+/- =0.81		
$F_{interaction}$ – 17.04**, SEm+/- =1.80		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

observed under atmospheric CO_2 concentration. Interaction was significant only in the fourth, sixth and eighth months.

In the fourth month, the different CO_2 concentrations significantly influenced root length. The longest root 31.43 cm was observed in seedlings grown under elevated CO_2 concentration. Among interactions, teak seedlings under elevated CO_2 concentration produced the longest root (35.67 cm) while matti seedlings produced lowest root length (24.83 cm). Similarly, under atmospheric CO_2 concentration longest root was recorded for the matti seedlings (23.67 cm) and shortest for mahogany (18.33 cm).

In the fifth month also seedlings under elevated CO_2 level significantly different (39.13 cm) from those under atmospheric CO_2 level. In the sixth month, interactions were significant and the longest root length was observed in teak seedlings (60.33 cm) under elevated CO_2 concentration. Under atmospheric CO_2 concentration, the shortest root length was recorded for njaval seedlings (25.33 cm).

At the seventh month stage, although interaction did not have a significant influence, the longest root was observed in teak seedlings (68.67 cm). In the eighth month, different CO_2 concentrations significantly influenced root length. Seedlings of teak grown under elevated CO_2 concentration had the longest roots (80.33 cm). However, njaval seedlings grown under atmospheric CO_2 levels recorded lowest root length (30.00 cm).

4.1 Dry matter of seedlings

The influence of different CO_2 concentration on the fresh and dry weights of the shoot and root portions of the seedlings are clearly evident from the data tabulated in Tables 5a and 5b, 6a and 6b, 7a and 7b, 8a and 8b, 9a and 9b, 10a ans 10b and 11a and 11b. The various CO_2 levels significantly influenced dry as well as fresh weights of shoot and root portions.

Table 4 (a): Two-way tables on root length (cm) of seedlings of five tree species of under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	14.00	12.67
Mahogany	15.33	12.50
Njaval	22.67	15.33
Matti	13.17	10.83
Venga	13.67	13.83
Mean	15.77[x]	13.03[y]
$F_{CO2\ level}$ – 6.18**, SEm+/- =0.78		
$F_{interaction}$ – 1.31NS , SEm+/- =1.74		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	15.67	14.67
Mahogany	16.00	13.67
Njaval	25.00	16.50
Matti	16.33	12.67
Venga	18.00	15.33
Mean	18.20[x]	14.57[y]
$F_{CO2\ level}$ - 11.82**, SEm+/- =0.75		
$F_{interaction}$ - 1.49NS, SEm+/- =1.67		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	21.67	18.33
Mahogany	22.33	15.17
Njaval	24.00	17.67
Matti	18.33	16.33
Venga	21.67	17.00
Mean	21.60[x]	16.90[y]
$F_{CO2\ level}$ - 14.74**, SEm+/- =0.87		
$F_{interaction}$ – 0.60NS , SEm+/- =1.94		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	35.67[a]	23.00[cd]
Mahogany	35.00[ab]	18.33[d]
Njaval	28.33[bc]	19.33[d]
Matti	24.83[cd]	23.67[cd]
Venga	33.33[ab]	19.00[d]
Mean	31.43[x]	20.67[y]
$F_{CO2\ level}$ – 59.72**, SEm+/- =0.99		
$F_{interaction}$ – 3.77*, SEm+/- =2.20		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 4 (b): Two-way tables on root length (cm) of seedlings of five tree species of under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	49.67	33.33
Mahogany	38.67	24.50
Njaval	30.67	21.00
Matti	34.33	26.00
Venga	42.33	23.67
Mean	39.13^{x}	25.70^{y}
$F_{CO2\ level}$ – 70.46**, SEm+/- =1.13		
$F_{interaction}$ – 1.49NS, SEm+/- =2.53		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	60.33^{a}	35.67^{c}
Mahogany	44.33^{b}	29.33^{cd}
Njaval	32.33^{cd}	25.33^{d}
Matti	45.00^{b}	31.17^{cd}
Venga	48.67^{b}	28.00^{cd}
Mean	46.13^{x}	29.90^{y}
$F_{CO2\ level}$ – 87.87**, SEm+/- =1.22		
$F_{interaction}$ – 3.06*, SEm+/- =2.74		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	68.67	47.33
Mahogany	55.33	34.00
Njaval	34.33	27.00
Matti	51.33	35.33
Venga	48.67	28.00
Mean	51.67^{x}	34.44^{y}
$F_{CO2\ level}$ –92.88**, SEm+/- =1.92		
$F_{interaction}$ – 2.32NS, SEm+/- =2.67		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	80.33^{a}	57.33^{c}
Mahogany	65.33^{b}	41.33^{d}
Njaval	39.67^{d}	30.00^{e}
Matti	54.67^{c}	42.33^{d}
Venga	53.00^{c}	36.33^{de}
Mean	58.60^{x}	41.46^{y}
$F_{CO2\ level}$ – 124.62**, SEm+/- =1.09		
$F_{interaction}$ – 3.41*, SEm+/- =2.43		

** - significant at 5 %, ** - significant at 1 %, NS – non-significant*

Figures with the similar superscripts or no superscripts do not differ significantly.

4.3.1 Fresh weight of shoot

The influence of various treatments on fresh weight of shoot is given in Table 5 (a and b). Different CO_2 levels significantly influenced the fresh weight of shoot from the second month to the end of the study period. Interactions significantly influenced the fresh weight of shoot from the third month to the eighth month.

In the third month, both the CO_2 levels had significant impact on the fresh weight of shoot (Table 5a). Among interactions, the maximum fresh weight of shoot was observed in seedlings of teak (55.89 g) and mahogany (50.40 g) under enriched CO_2 condition. The lowest fresh weight was, however, recorded in njaval seedlings in elevated CO_2 concentration (18.58 g).

Among interactions, the maximum fresh weight of shoot was found, in teak seedlings (95.62 g) grown under elevated CO_2 concentration in the fourth month (Table 5a).The minimum fresh weight of shoot was obtained in njaval seedlings in both elevated (23.88 g) and in atmospheric CO_2 concentration (23.23 g).

In the fifth month also varying CO_2 levels had significant effects on the fresh weight of shoot. The maximum fresh weight (126.47 g) of shoot was observed in teak seedlings under elevated CO_2 concentration. The minimum value (27.58 g) was recorded in njaval seedlings under atmospheric CO_2 concentration.

In the sixth month, (Table 5b), interaction had a significant impact on the shoot fresh weight. Maximum fresh weight of shoot was observed in teak seedlings under enriched CO_2 concentration (145.59 g). Minimum value was recorded in njaval seedlings (32.81 g) under atmospheric CO_2 concentration.

During the seventh month, the maximum value of fresh weight of shoot was recorded in seedlings of teak grown in elevated CO_2 concentration (167.63 g). Seedlings of njaval under atmospheric CO_2 concentration recorded the lowest fresh weight of shoot (36.28 g) with regard to interaction effect.

At the end of the study period *i.e.* in the eighth month, different CO_2 concentrations had significant impact on the fresh weight of shoot (Table 5b). The maximum fresh weight of shoot was observed in teak seedlings under elevated CO_2 concentration (186.19 g). The lowest fresh weight of shoot (43.55 g) was observed in njaval seedlings under atmospheric CO_2 concentration.

4.3.2 Fresh weight of root

The effect of different treatments on fresh weight of root is furnished in Table 6 (a and b). The varying CO_2 levels had significant influence on the fresh weight of root starting from the second month till the end of the study period. Interaction was significant throughout the study period except in the second and fourth month.

In the third month, the maximum root fresh weight was observed in the teak seedlings grown under elevated CO_2 concentration (25.16 g). The lowest root fresh weight was obtained in njaval seedlings (9.49 g) under elevated CO_2 concentration as the interaction was concerned. They were significantly different under two CO_2 concentrations.

The highest fresh weight of root was observed in seedlings grown under elevated CO_2 concentration (19.23 g) in the fourth month as shown in Table 6 (a). Interaction did not give significant difference in the same month. In the fifth month, the maximum fresh weight of root under varying CO_2 levels was observed in seedlings under elevated CO_2 concentration (22.87g) which was followed by seedlings under atmospheric CO_2 concentration with mean of 15.86 g and they were significantly different from each other (Table 6b). Among the interactions, the highest fresh weight of root was observed in teak seedlings under elevated CO_2 concentration (50.31g). The least value was recorded in njaval seedlings under atmospheric CO_2 concentration level with a recorded mean value of 12.19 g.

When comparison was done in the sixth month, different CO_2 concentrations significantly affected root fresh weight (Table 6 b). The highest root fresh weight was observed in teak seedlings under elevated CO_2 concentration (56.31 g). The

Table 5 (a): Two-way tables on shoot fresh weight (g) of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	20.85	17.30
Mahogany	20.51	19.54
Njaval	15.40	16.42
Matti	19.21	15.23
Venga	19.59	14.41
Mean	19.11	16.58
$F_{CO2\ level}$ – 2.71NS, SEm+/- =0.83		
$F_{interaction}$ – 0.60NS, SEm+/- =1.85		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	23.59	18.90
Mahogany	22.52	21.78
Njaval	17.20	18.50
Matti	21.55	17.77
Venga	22.33	18.58
Mean	21.44^{x}	19.11^{y}
$F_{CO2\ level}$ - 5.21*, SEm+/- =0.72		
$F_{interaction}$ - 1.21NS, SEm+/- =1.62		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	55.89^{a}	25.93^{c}
Mahogany	50.40^{a}	24.18^{c}
Njaval	18.58^{c}	19.80^{c}
Matti	25.62^{c}	23.02^{c}
Venga	36.28^{b}	21.53^{c}
Mean	37.35^{x}	22.89^{y}
$F_{CO2\ level}$ - 104.60**, SEm+/- =0.99		
$F_{interaction}$ – 20.20**, SEm+/- =2.21		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	95.62^{a}	33.51^{cd}
Mahogany	60.97^{b}	30.88^{cd}
Njaval	23.88^{d}	23.23^{d}
Matti	35.12^{cd}	30.46^{cd}
Venga	39.65^{c}	26.09^{cd}
Mean	51.05^{x}	28.83^{y}
$F_{CO2\ level}$ – 71.20**, SEm+/- =1.86		
$F_{interaction}$ – 18.05 **, SEm+/- =4.16		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 5 (b): Two-way tables on shoot fresh weight (g) of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	126.47[a]	41.96[cd]
Mahogany	71.63[b]	36.03[cdef]
Njaval	32.73[def]	27.58[f]
Matti	44.80[c]	38.24[cde]
Venga	46.31[c]	30.92[ef]
Mean	64.39[x]	34.95[y]
$F_{CO2\ level}$ – 207.85 **, SEm+/- =1.44		
$F_{interaction}$ – 52.54**, SEm+/- =3.23		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	145.59[a]	51.86[de]
Mahogany	84.99[b]	43.45[ef]
Njaval	40.98[fg]	32.81[g]
Matti	62.46[c]	47.91[def]
Venga	54.07[cd]	37.86[fg]
Mean	77.62[x]	42.78[y]
$F_{CO2\ level}$ – 303.11**, SEm+/- =1.42		
$F_{interaction}$ – 62.23**, SEm+/- =3.16		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	167.63[a]	63.46[d]
Mahogany	96.72[b]	53.42[de]
Njaval	59.25[d]	36.28[f]
Matti	82.15[c]	63.49[d]
Venga	62.40[d]	45.45[ef]
Mean	93.63[x]	52.42[y]
$F_{CO2\ level}$ –358.33 **, SEm+/- =1.54		
$F_{interaction}$ – 56.96**, SEm+/- =3.44		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	186.19[a]	75.16[cd]
Mahogany	106.00[b]	63.04[de]
Njaval	70.00[cd]	43.55[f]
Matti	120.33[b]	73.24[cd]
Venga	84.67[c]	50.20[ef]
Mean	113.44[x]	61.04[y]
$F_{CO2\ level}$ – 238.39**, SEm+/- =2.39		
$F_{interaction}$ – 19.76 **, SEm+/- =5.37		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

minimum value was observed in njaval seedlings under atmospheric CO_2 concentration (12.84 g) and they were found to be significantly different from each other among interactions.

In the seventh month the different CO_2levels had significant effect on the root fresh weight (table 6b). The maximum weight (68.12 g) was recorded in teak seedlings grown under elevated CO_2 level. The lowest root fresh weight was observed in njaval seedlings under both elevated and atmospheric CO_2 concentrations (14.71 g) as far as interactions were concerned.

Different CO_2 levels showed significant effects on the root fresh weight of the seedlings at the end of the study period (Table 6b). Under elevated CO_2 level the highest root fresh weight recorded was 39.47 g. This was trailed by seedlings under atmospheric CO_2 level (25.18 g). When the interactions were taken in to consideration, the maximum root fresh weight was observed in teak seedlings under elevated CO_2 concentration (94.00 g). The lowest root fresh weight was recorded in njaval seedlings (16.00 g) under atmospheric CO_2 concentration.

4.3.3 Dry weight of shoot

The effects of CO_2 concentrations in tree seedlings during the course of eight months is given in Table 7a and 7b. It can be seen that the different CO_2 concentrations did not show any significant effect on the dry weight of shoot till the second month. But it started to influence the tree seedlings from the third month up to the end of the study period.

In the third month, different CO_2 concentrations provided significantly different results (Table 7a). The highest shoot dry weight was observed in tree seedlings under elevated CO_2 concentration (22.72 g). Interactions between the factors had a significant effect in this month. The maximum shoot dry weight due to interaction was observed in teak seedlings (33.25 g) while njaval seedlings (14.69 g) under elevated CO_2 concentration recorded the lowest.

Table 6 (a): Two-way tables on root fresh weight (g) of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	17.10	11.67
Mahogany	8.29	8.02
Njaval	6.88	8.35
Matti	7.51	7.06
Venga	13.09	9.21
Mean	10.57	8.86
$F_{CO2\ level}$ – 3.95NS , SEm+/- =0.37		
$F_{interaction}$ – 2.18NS , SEm+/- =1.36		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	17.89	14.64
Mahogany	9.07	8.60
Njaval	8.17	8.72
Matti	8.58	8.60
Venga	16.70	13.38
Mean	12.08^x	10.79^y
$F_{CO2\ level}$ - 4.49*, SEm+/- =0.43		
$F_{interaction}$ - 1.85NS , SEm+/- =0.96		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	25.16a	16.16b
Mahogany	11.23cd	9.69d
Njaval	9.49d	9.53d
Matti	11.80cd	9.77d
Venga	18.04b	14.77bc
Mean	15.14^x	11.98^y
$F_{CO2\ level}$ - 18.29**, SEm+/- =0.52		
$F_{interaction}$ – 4.41**, SEm+/- =1.17		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	38.56	16.93
Mahogany	14.03	11.34
Njaval	11.04	10.29
Matti	13.80	11.43
Venga	18.73	17.62
Mean	19.23^x	13.52^y
$F_{CO2\ level}$ – 5.81**, SEm+/- =1.68		
$F_{interaction}$ – 2.84NS, SEm+/- =3.75		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 6 (b): Two-way tables on root fresh weight (g) of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	50.31[a]	21.05[b]
Mahogany	15.20[b]	13.80[b]
Njaval	12.26[b]	12.19[b]
Matti	16.80[b]	13.40[b]
Venga	19.80[b]	18.85[b]
Mean	22.87[x]	15.86[y]
$F_{CO2\ level}$ – 8.59**, SEm+/- =1.69		
$F_{interaction}$ – 5.45**, SEm+/- =3.79		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	56.31[a]	23.54[b]
Mahogany	18.39[b]	15.87[b]
Njaval	13.64[b]	12.84[b]
Matti	20.03[b]	17.25[b]
Venga	27.06$_b$	22.04[b]
Mean	27.09[x]	18.30[y]
$F_{CO2\ level}$ – 11.57**, SEm+/- =1.82		
$F_{interaction}$ – 5.47**, SEm+/- =4.08		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	68.12[a]	28.37[bc]
Mahogany	20.93[bc]	17.75[bc]
Njaval	14.71[c]	14.71[c]
Matti	23.61[bc]	20.83[bc]
Venga	33.15[b]	29.05[bc]
Mean	32.10[x]	22.14[y]
$F_{CO2\ level}$ –8.62**, SEm+/- =2.39		
$F_{interaction}$ – 4.86**, SEm+/- =5.36		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	94.00[a]	36.33[bc]
Mahogany	22.00[de]	19.29[e]
Njaval	16.67[e]	16.00[e]
Matti	26.33[cde]	22.08[de]
Venga	38.33[b]	32.2[bcd]
Mean	39.47[x]	25.18[y]
$F_{CO2\ level}$ – 36.54**, SEm+/- =1.67		
$F_{interaction}$ – 21.38**, SEm+/- =3.73		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

In the fourth month, the different CO_2 levels showed significant effects on the dry weight of shoot (Table 7 a). Interactions had an influence on the shoot dry weight at the same stage of growth. Among the interaction between two factors, the maximum dry weight of shoot was seen in teak seedlings grown under elevated CO_2 concentration (41.41 g). The minimum dry weight of shoot was observed in njaval seedlings under elevated CO_2 concentration (16.49 g).

Varying CO_2 concentrations produced significantly different result in the fifth month (Table 7 b). The maximum shoot dry weight among the different interactions was observed in teak seedlings under elevated CO_2 concentration (60.79 g). On the other hand, under atmospheric CO_2 concentration the lowest shoot dry weight was observed in njaval seedlings (20.05 g).

In the sixth month, both CO_2 levels and interaction showed significant effects on the dry weight of shoot (Table 7b). Seedlings of teak under elevated CO_2 concentration recorded the maximum shoot dry weight (73.84 g). Seedlings of njaval under atmospheric CO_2 concentration recorded the lowest value (23.04 g).

In the seventh month, among the different levels of interactions, the maximum shoot dry weight was observed in teak seedlings under elevated CO_2 concentration (86.28 g). The lowest dry weight of shoot was observed in njaval seedlings under atmospheric CO_2 concentration (25.60 g).

In the last month of study period, different CO_2 concentration produced significantly different shoot dry weight. Under elevated CO_2 concentration teak seedlings recorded highest dry weight of shoot (99.46 g). The lowest value was recorded for njaval seedlings under atmospheric CO_2 concentration (27.23 g).

4.3.4 Dry weight of root

The dry weight of root was found to be significantly influenced by the different levels of CO_2 concentration as evident from Tables 8a and 8b.

Table 7 (a): Two-way tables on shoot dry weight (g) of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	13.12	11.40
Mahogany	13.10	13.12
Njaval	11.16	13.05
Matti	12.82	11.81
Venga	12.58	13.29
Mean	12.56	12.53
$F_{CO2\ level}$ – 0.002NS, SEm+/- =0.33		
$F_{interaction}$ – 1.809NS, SEm+/- =0.74		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	14.84	12.48
Mahogany	16.01	15.02
Njaval	14.31	13.86
Matti	16.12	12.79
Venga	15.58	14.36
Mean	15.37	13.70
$F_{CO2\ level}$ - 10.62NS, SEm+/- =0.36		
$F_{interaction}$ - 1.03NS, SEm+/- =0.81		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	33.25^{a}	15.20^{d}
Mahogany	26.10^{b}	16.43^{cd}
Njaval	14.69^{d}	15.23^{d}
Matti	17.73^{cd}	15.35^{d}
Venga	21.83^{bc}	16.25^{cd}
Mean	22.72^{x}	15.69^{y}
$F_{CO2\ level}$ - 38.32**, SEm+/- =0.80		
$F_{interaction}$ – 8.12**, SEm+/- =1.79		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	41.41^{a}	19.23^{de}
Mahogany	31.31^{b}	19.76^{de}
Njaval	16.49^{e}	17.71^{de}
Matti	23.36^{cd}	21.03^{cde}
Venga	26.90^{bc}	19.62^{de}
Mean	27.89^{x}	19.47^{y}
$F_{CO2\ level}$ – 44.17**, SEm+/- =0.89		
$F_{interaction}$ – 10.28**, SEm+/- =2.00		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 7 (b): Two-way tables on shoot dry weight (g) of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	60.79^{a}	24.45^{de}
Mahogany	36.17^{b}	25.74^{de}
Njaval	20.67^{f}	20.05^{f}
Matti	29.46_{cd}	27.05^{cde}
Venga	31.17^{c}	22.42^{ef}
Mean	35.65^{x}	23.94^{y}
$F_{CO2\ level}$ – 152.75**, SEm+/- =0.67		
$F_{interaction}$ – 46.05**, SEm+/- =1.49		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	73.84^{a}	30.80^{de}
Mahogany	40.32^{b}	29.41^{de}
Njaval	24.61^{e}	23.04^{f}
Matti	37.17^{bc}	34.15^{cd}
Venga	34.20^{cd}	26.81^{ef}
Mean	42.028^{x}	28.84^{y}
$F_{CO2\ level}$ – 186.38 **, SEm+/- =0.68		
$F_{interaction}$ – 62.63 **, SEm+/- =1.53		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	86.28^{a}	34.82^{de}
Mahogany	46.71^{b}	34.28^{de}
Njaval	29.46^{ef}	25.60^{f}
Matti	43.56^{bc}	40.30^{bcd}
Venga	36.90^{cde}	29.20^{ef}
Mean	48.58^{x}	32.84^{y}
$F_{CO2\ level}$ –107.28**, SEm+/- =1.07		
$F_{interaction}$ – 35.67**, SEm+/- =2.40		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	99.46^{a}	40.41^{de}
Mahogany	52.51^{bc}	38.45^{de}
Njaval	34.00^{def}	27.23^{f}
Matti	56.67^{b}	43.65^{cd}
Venga	39.25^{de}	31.93^{ef}
Mean	56.38^{x}	36.33^{y}
$F_{CO2\ level}$ – 82.50**, SEm+/- =1.56		
$F_{interaction}$ – 19.96 **, SEm+/- =3.49		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Different CO_2 levels significantly affected root dry weight from the fourth month till the end of study period with regard to dry weight of root. The interaction also showed significant differences from the fourth month till the end of the study period.

In the fourth month, the exposure of seedlings to different CO_2 concentration showed significant differences in their performances (Table 8 a). Interactions showed significant effect on the dry weight of root. Under elevated CO_2 concentration, the highest dry weight of root was produced by the teak seedlings (18.96 g). Njaval seedlings under elevated CO_2 concentration recorded lowest value (7.34 g).

Root dry weight was significantly different in the fifth month. Among the interaction, under elevated CO_2 concentration the highest root dry weight was recorded in teak seedlings (23.22 g). The njaval seedlings grown under elevated CO_2 concentration produced lowest root drymatter (7.94 g).

In the sixth month, root dry matter production of seedlings under various CO_2 concentrations showed significant differences (Table 8 b). The best performance among different interaction was given by teak where seedlings gave a mean reading of 27.02 g under elevated CO_2 concentration. The least performance was given by njaval seedling under elevated CO_2 concentration (8.80 g).

Two CO_2 levels significantly influenced root dry weight in the seventh month. Interaction also had significant effect in this month on the dry weight of root. Among the interactions, the highest root dry weight was observed in the teak seedlings under elevated CO_2 concentration (30.65 g). The lowest weight was recorded by njaval seedlings (9.72 g) under elevated CO_2 concentration.

The use of different CO_2 concentrations was observed to be significantly influencing the root dry matter production in the eighth month of the study period (Table 8b). among interaction, the best performance was seen in teak seedlings under elevated CO_2 concentration (40.10 g). The seedlings of njaval under elevated CO_2 concentration showed lowest root drymatter (10.21 g).

Table 8 (a): Two-way tables on root dry weight (g) of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	8.73	7.98
Mahogany	6.30	6.13
Njaval	5.77	6.56
Matti	5.63	5.80
Venga	8.03	7.97
Mean	6.89	6.89
$F_{CO2\ level}$ – 0.00NS, SEm+/- =0.36		
$F_{interaction}$ – 0.24NS, SEm+/- =0.79		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	10.06	9.13
Mahogany	6.84	6.80
Njaval	6.69	7.03
Matti	6.65	6.65
Venga	10.37	8.46
Mean	8.12	7.61
$F_{CO2\ level}$ - 1.44NS, SEm+/- =0.29		
$F_{interaction}$ - 0.93NS, SEm+/- =0.67		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	13.00	10.45
Mahogany	7.82	6.10
Njaval	7.07	7.82
Matti	7.50	7.97
Venga	11.16	9.88
Mean	9.31	8.44
$F_{CO2\ level}$ - 3.24NS, SEm+/- =0.34		
$F_{interaction}$ – 1.76NS, SEm+/- =0.76		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	18.96^{a}	11.50^{bc}
Mahogany	8.89^{cde}	7.53^{e}
Njaval	7.34^{e}	8.55^{de}
Matti	10.10^{bcde}	9.06^{cde}
Venga	12.18^{b}	10.52^{cd}
Mean	11.49^{x}	9.43^{y}
$F_{CO2\ level}$ – 14.75**, SEm+/- =0.38		
$F_{interaction}$ – 7.19**, SEm+/- =0.85		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 8 (b): Two-way tables on seedlings root dry weight (g) of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	23.22[a]	14.57[b]
Mahogany	10.65[cde]	9.98[de]
Njaval	7.94[e]	9.25[de]
Matti	12.17[bcd]	10.65[cde]
Venga	13.44[bc]	11.49[cd]
Mean	13.48[x]	11.19[y]
$F_{CO2\ level}$ – 15.89**, SEm+/- =0.41		
$F_{interaction}$ – 8.54**, SEm+/- =0.91		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	27.02[a]	15.97[b]
Mahogany	12.80[bcd]	10.80[de]
Njaval	8.80[e]	9.74[de]
Matti	14.62[bc]	11.98[cde]
Venga	16.27[b]	14.77[bc]
Mean	15.90[x]	12.65[y]
$F_{CO2\ level}$ – 18.89**, SEm+/- =0.53		
$F_{interaction}$ – 7.47**, SEm+/- =1.18		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	30.65[a]	17.80[b]
Mahogany	14.62[bcd]	11.69[d]
Njaval	9.72[d]	10.33[d]
Matti	16.69[bc]	12.84[cd]
Venga	18.42[b]	16.87[bc]
Mean	18.02[x]	13.90[y]
$F_{CO2\ level}$ –18.49**, SEm+/- =0.68		
$F_{interaction}$ – 5.84**, SEm+/- =1.51		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	40.10[a]	20.22[bc]
Mahogany	16.19[bcd]	13.07[cd]
Njaval	10.21[d]	10.55[d]
Matti	18.43[bc]	14.45[bcd]
Venga	21.61[b]	21.39[b]
Mean	21.30[x]	15.94[y]
$F_{CO2\ level}$ – 14.07**, SEm+/- =1.01		
$F_{interaction}$ – 6.75**, SEm+/- =2.26		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

4.3.5 Shoot : root length

The influence of different CO_2 concentrations on five tree seedlings is furnished in Tables 9a and 9b. The seedlings under different CO_2 treatments recorded significant difference only in first three months. Interactions between two factors had no significant impact on the shoot : root length throughout the study period except in the fourth month.

During the fourth month of observations, the maximum shoot : root length was found in seedlings of matti exposed to elevated CO_2 concentration (2.61) followed by seedlings of mahogany exposed to atmospheric CO_2 concentration (2.49) which were significantly different from each other. On the other hand, seedlings of njaval produced lowest ratio (1.51) under elevated CO_2 concentration as far as the interaction was concerned.

4.3.6 Shoot : root biomass

The effects of different CO_2 concentrations on shoot: root biomass can be seen in Tables 10a and 10b. It is evident from the table that different CO_2 concentrations provided significant difference in the third, fourth, fifth and sixth months while interaction between the factors did not give any significant effect on the shoot: root biomass throughout the study period.

The maximum shoot: root biomass due to interaction effect was observed in mahogany seedlings under elevated CO_2 concentration (3.54) in the fifth month. The minimum value of shoot: root biomass was however observed in teak seedlings under atmospheric CO_2 concentration (1.40).

4.3.7 Total drymatter production

The effects of various CO_2 levels in five tree seedlings during the course of eight months is given in Table 11a and 11b and Figure 5. It can be seen that the different CO_2 levels started to give influence on the tree seedlings from the second

Table 9 (a): Two-way tables on shoot root length ratio of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	3.08	2.63
Mahogany	2.88	2.22
Njaval	1.12	1.25
Matti	2.98	2.29
Venga	3.24	2.14
Mean	2.66^{x}	2.11^{y}
$F_{CO2\ level}$ – 6.17*, SEm+/- =0.15		
$F_{interaction}$ – 0.82NS, SEm+/- =0.36		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	3.72	2.40
Mahogany	3.33	2.56
Njaval	1.62	1.38
Matti	3.22	2.42
Venga	3.19	2.14
Mean	3.02^{x}	2.18^{y}
$F_{CO2\ level}$ - 13.13**, SEm+/- =0.16		
$F_{interaction}$ - 0.61NS, SEm+/- =0.37		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	2.89	2.21
Mahogany	2.74	2.53
Njaval	2.13	1.59
Matti	3.33	2.34
Venga	3.21	2.30
Mean	2.86^{x}	2.19^{y}
$F_{CO2\ level}$ - 12.33**, SEm+/- =0.14		
$F_{interaction}$ – 0.57NS, SEm+/- =0.31		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	1.94^{bcde}	1.85^{cde}
Mahogany	2.15^{abcd}	2.49^{ab}
Njaval	1.51^{e}	1.60^{de}
Matti	2.61^{a}	1.80^{cde}
Venga	2.25^{abc}	2.12^{abcd}
Mean	2.09	1.97
$F_{CO2\ level}$ – 1.25NS, SEm+/- =0.08		
$F_{interaction}$ – 3.29*, SEm+/- =0.13		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 9 (b): Two-way tables on shoot root length ratio of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	1.55	1.43
Mahogany	2.14	2.04
Njaval	1.70	1.56
Matti	2.10	1.82
Venga	1.88	1.95
Mean	1.87	1.76
$F_{CO2\ level}$ – 2.11NS, SEm+/- =0.06		
$F_{interaction}$ – 0.56NS, SEm+/- =0.13		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	1.50	1.62
Mahogany	2.00	1.93
Njaval	1.72	1.44
Matti	1.69	1.79
Venga	1.83	2.00
Mean	1.75	1.76
$F_{CO2\ level}$ – 0.015NS, SEm+/- =0.05		
$F_{interaction}$ – 1.23NS, SEm+/- =0.12		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	1.43	1.25
Mahogany	1.69	1.99
Njaval	1.76	1.45
Matti	1.68	1.90
Venga	1.95	1.92
Mean	1.70	1.70
$F_{CO2\ level}$ –0.001NS, SEm+/- =0.07		
$F_{interaction}$ – 1.30NS, SEm+/- =0.15		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	1.42	1.07
Mahogany	1.50	1.71
Njaval	1.62	1.35
Matti	1.77	1.76
Venga	1.96	2.10
Mean	1.65	1.59
$F_{CO2\ level}$ – 0.43NS, SEm+/- =0.06		
$F_{interaction}$ – 1.53NS, SEm+/- =0.14		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 10 (a): Two-way tables on shoot root biomass ratio of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	1.55	1.46
Mahogany	2.14	2.14
Njaval	1.95	1.99
Matti	2.28	2.04
Venga	1.73	1.67
Mean	1.93	1.86
$F_{CO2\ level}$ – 0.31NS, SEm+/- =0.08		
$F_{interaction}$ – 0.16NS, SEm+/- =0.20		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	1.53	1.40
Mahogany	2.35	2.21
Njaval	2.16	1.98
Matti	2.42	1.93
Venga	1.55	1.70
Mean	2.00	1.84
$F_{CO2\ level}$ - 3.03NS, SEm+/- =0.06		
$F_{interaction}$ - 1.27NS, SEm+/- =0.14		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	2.55	1.49
Mahogany	3.35	2.70
Njaval	2.10	1.95
Matti	2.46	1.93
Venga	2.01	1.67
Mean	2.49^x	1.94^y
$F_{CO2\ level}$ - 15.26**, SEm+/- =0.10		
$F_{interaction}$ – 1.22NS, SEm+/- =0.22		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	2.21	1.74
Mahogany	3.54	2.66
Njaval	2.27	2.07
Matti	2.33	2.32
Venga	2.23	1.89
Mean	2.52^x	2.14^y
$F_{CO2\ level}$ – 8.91**, SEm+/- =0.09		
$F_{interaction}$ – 1.34NS, SEm+/- =0.20		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 10 (b): Two-way tables on shoot root biomass ratio of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	2.63	1.70
Mahogany	3.54	2.62
Njaval	2.63	2.17
Matti	2.42	2.55
Venga	2.33	1.97
Mean	2.71^x	2.20^y
$F_{CO2\ level}$ – 10.37**, SEm+/- =0.11		
$F_{interaction}$ – 1.58NS, SEm+/- =0.25		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	2.78	1.96
Mahogany	3.26	2.78
Njaval	2.80	2.37
Matti	2.55	2.87
Venga	2.11	1.83
Mean	2.70^x	2.36^y
$F_{CO2\ level}$ – 5.92*, SEm+/- =0.09		
$F_{interaction}$ – 1.84NS, SEm+/- =0.22		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	2.87	1.96
Mahogany	3.42	3.00
Njaval	3.04	2.49
Matti	2.61	3.15
Venga	2.02	1.75
Mean	2.79	2.47
$F_{CO2\ level}$ –2.92NS, SEm+/- =0.13		
$F_{interaction}$ – 1.60NS, SEm+/- =0.30		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	2.51	1.98
Mahogany	3.49	2.98
Njaval	3.49	2.58
Matti	3.09	3.05
Venga	1.83	1.61
Mean	2.88	2.44
$F_{CO2\ level}$ – 3.98NS, SEm+/- =0.15		
$F_{interaction}$ – 0.38NS, SEm+/- =0.3		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

month up to the end of the study period. Interaction between the factors started to give significant effect in the third month till the eighth months of the study period.

In the second month the different levels of CO_2 showed significant effects on the total dry matter content (Table 11 a). The maximum dry matter was seen in seedlings grown under elevated CO_2 concentration (23.49 g). In the third month, seedlings under elevated CO_2 levels also showed significant differences in their performances (32.03 g). The maximum dry weight due to interaction was observed in teak seedlings under elevated CO_2 concentration (46.25 g). However, the lowest dry weight due to interaction for the same month was observed in mahogany under atmospheric CO_2 concentration (22.86 g).

In the fourth month, the application of various types of CO_2 levels provided significantly different results (Table 11a). The elevated CO_2 concentration recorded maximum dry matter content in seedlings (39.40 g). As far as interaction was considered, teak seedlings under elevated CO_2 concentration recorded the highest dry matter content (60.41 g). Njaval seedlings under elevated CO_2 concentration showed the lowest dry matter content (23.83 g).

Use of varying CO_2 levels gave significant difference in the fifth month (Table 11b). Seedlings under enriched CO_2 concentration performed best with mean value of 49.15 g. The maximum dry matter content among the interactions between tree seedlings and CO_2 levels was observed in teak seedlings under enriched CO_2 concentration (84.07 g). The minimum dry matter content was observed in njaval seedlings under elevated CO_2 concentration (28.61 g).

In the sixth month both the CO_2 levels and the interactions between factors showed significant effects on the dry matter production (Table 11b). Teak seedlings under elevated CO_2 concentration recorded the maximum dry matter (100.87g) among interaction. On the other hand, njaval seedlings under atmospheric CO_2 concentration had the minimum dry weight of seedlings (32.78 g).

In the seventh month interaction between species and CO_2 levels significantly influenced seedlings dry matter (Table 11b). Among the different levels of CO_2, the maximum dry matter was observed in elevated CO_2 concentration (66.60 g). This was followed by atmospheric CO_2 concentration which showed significant differences with mean values of 46.75 g. When interaction was taken into consideration, the maximum value was observed in teak seedlings under elevated CO_2 concentration (139.56 g). The lowest value was given by seedlings of njaval under atmospheric CO_2 (37.78 g).

In the eighth month, the different CO_2 levels showed significant effects on the dry matter content (Table 11 b). Among the interactions, the maximum dry matter was seen in teak seedlings grown under elevated CO_2 concentration (139.56 g). Njaval seedlings under atmospheric CO_2 concentration showed significant differences in their performances with lowest mean value (37.78 g). Hence, the overall performance of the tree seedlings under varying levels of CO_2 concentration was observed to be better under elevated CO_2 concentration (Plate 5, 6, 7, 8 and 9).

4.4 Physiological observations

The effects of different treatments on various parameters like relative growth rate, net assimilation rate, leaf area, specific leaf area, leaf area ratio, leaf weight ratio, number of stomata and rate of photosynthesis are given under this section.

4.4.1 Relative growth rate

Influence of different CO_2 concentrations on the relative growth rate in the selected tree seedlings is shown in Table 12a and 12b. It is clear from the table that the different CO_2 treatment did not significantly affect the relative growth rate of seedlings during the study period except in the first and second month where there was a significant effect. Interactions between factors had no significant effect on the RGR throughout the study period except in the second month.

In the first and second months, elevated CO_2 concentration produced a higher growth rate in all tree seedlings with a recorded mean value of 6.27 mg/day and 9.26 mg/day respectively. In the second month, the maximum RGR was observed in teak seedlings under elevated CO_2 concentration with mean values of 20.33 mg/day.

Table 11 (a): Two-way tables on total dry matter content (g) of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	21.85	19.38
Mahogany	19.40	19.26
Njaval	16.94	19.61
Matti	18.45	17.61
Venga	20.61	21.26
Mean	19.45	19.42
$F_{CO2\ levels}$ - 0.001NS SEm+/- =0.53		
$F_{interaction}$ - 1.27NS , SEm+/- =1.19		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	24.90	21.61
Mahogany	22.84	21.82
Njaval	21.00	20.88
Matti	22.78	19.44
Venga	25.95	22.82
Mean	23.49^{x}	21.31^{y}
$F_{CO2\ levels}$ - 9.26**,SEm+/- =0.51		
$F_{interaction}$ - 0.88NS SEm+/- =1.13		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	46.25^{a}	25.64^{c}
Mahogany	33.92^{b}	22.86^{c}
Njaval	21.76^{c}	23.05^{c}
Matti	25.24^{c}	23.32^{c}
Venga	32.99^{b}	26.13^{c}
Mean	32.03^{x}	24.20^{y}
$F_{CO2\ levels}$ - 35.49**,SEm+/- =0.93		
$F_{interaction}$ - 8.47 **, SEm+/- =2.08		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	60.41^{a}	30.73^{de}
Mahogany	40.19^{b}	27.29^{de}
Njaval	23.83^{e}	26.25^{e}
Matti	33.46^{cd}	30.09^{de}
Venga	39.09^{bc}	30.13^{de}
Mean	39.396^{x}	28.89^{y}
$F_{CO2\ levels}$ - 58.75**,SEm+/- =0.97		
$F_{interaction}$ - 15.84**SEm+/- =2.17		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 11 (b): Two-way tables on total dry matter content (g) of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	84.07^{a}	39.01^{cde}
Mahogany	46.82^{b}	35.72^{de}
Njaval	28.61^{f}	29.30^{f}
Matti	41.63^{bcd}	37.70^{de}
Venga	44.61^{bc}	33.91^{ef}
Mean	49.15^{x}	35.13^{y}
$F_{CO2\ levels}$ - 124.22**,SEm+/- =0.89		
$F_{interaction}$ - 41.06**, SEm+/- =1.99		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	100.87^{a}	46.78^{cde}
Mahogany	53.12^{b}	40.21^{f}
Njaval	33.40^{g}	32.78^{g}
Matti	51.79^{bc}	46.14^{de}
Venga	50.47^{bcd}	41.58^{ef}
Mean	57.85^{x}	41.49^{y}
$F_{CO2\ level}$ – 236.32**,SEm+/- =0.76		
$F_{interaction}$ – 81.09 **, SEm+/- =1.69		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	116.92^{a}	52.62^{bc}
Mahogany	61.33^{b}	45.98^{cd}
Njaval	39.18^{de}	35.93^{e}
Matti	60.25^{b}	53.14^{bc}
Venga	55.32^{bc}	46.08^{cd}
Mean	66.60^{x}	46.75^{y}
$F_{CO2\ level}$ –108.03 **,SEm+/- =1.35		
$F_{interaction}$ – 34.91**, SEm+/- =3.02		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	139.56^{a}	60.63^{cde}
Mahogany	68.69^{b}	51.52^{de}
Njaval	44.21^{f}	37.78^{f}
Matti	75.10^{bcd}	58.09^{de}
Venga	60.87^{bc}	53.32^{ef}
Mean	77.69^{x}	52.27^{y}
$F_{CO2\ level}$ – 70.26**,SEm+/- =2.14		
$F_{interaction}$ – 20.03**, SEm+/- =4.79		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

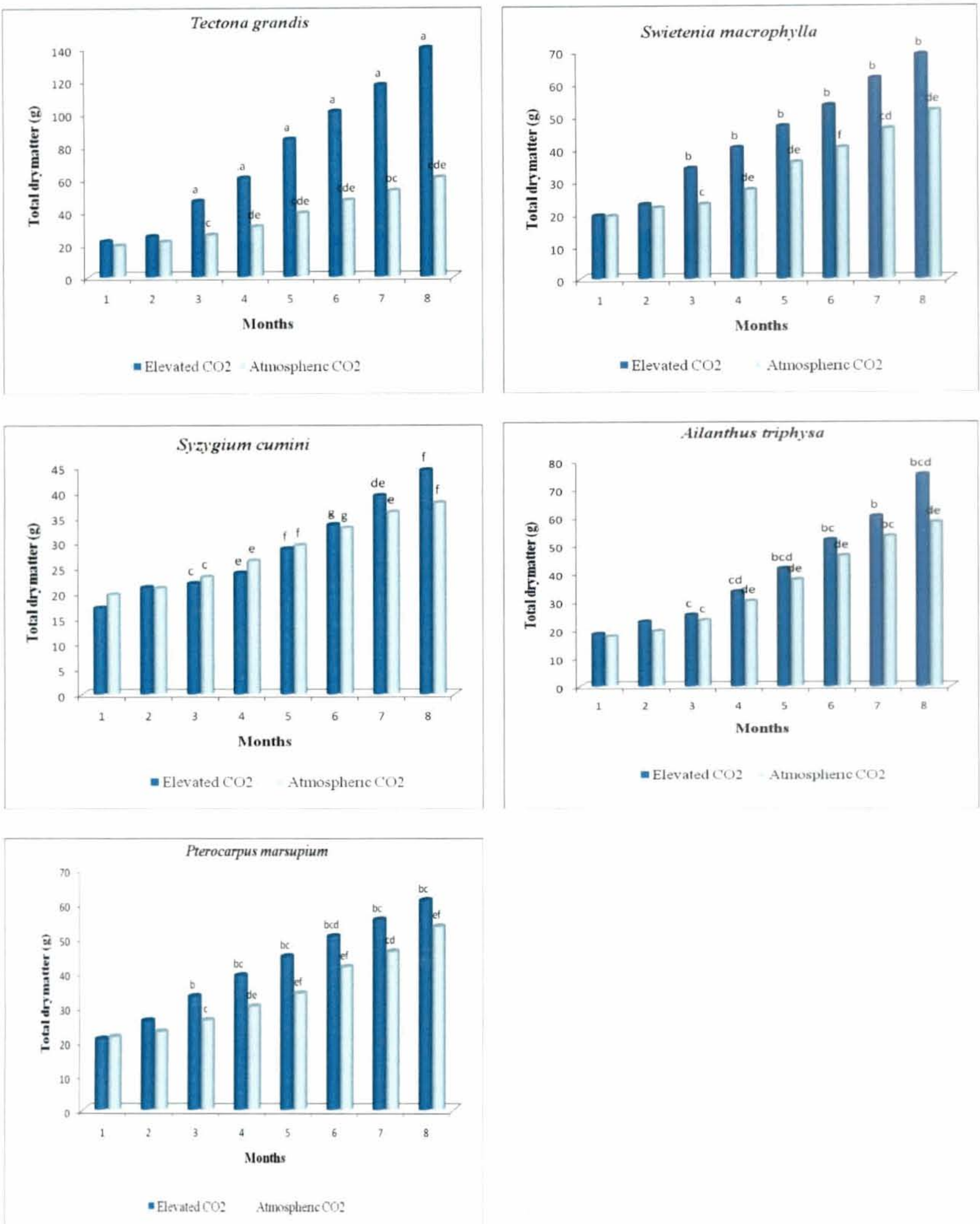

Figure 5. Response of five tree species on total drymatter content (g) of seedlings under two CO_2 concentrations

Figures with the similar superscripts or no superscripts do not differ significantly.

Plate 5. ***Tectona grandis*** **seedlings kept inside the chamber (A) and outside the chamber (B)**

Plate 6. ***Swietenia macrophylla*** **seedlings kept inside the chamber (A) and outside the chamber (B)**

Plate 7. ***Syzygium cumini*** **seedlings kept inside the chamber (A) and outside the chamber (**

Plate 8. ***Ailanthus triphysa*** **seedlings kept inside the chamber (A) and outside the chamber (**

Plate 8. ***Pterocarpus marsupium*** **seedlings kept inside the chamber (A) and outside the chamber (B)**

However, the least performance was given by njaval seedlings under elevated CO_2 concentration (1 mg/day) and it was significantly different from the seedlings of other species when the interactions were taken into consideration.

4.4.1 Net assimilation rate

The influence of different CO_2 concentrations on the NAR of the seedlings of five tree species is furnished in Tables 13a and 13b. The effects of different treatments were not significantly different during the study period except in the second, third and fifth month.

In the second month, the interactions between various treatments were found to be significant. The maximum value of NAR of seedlings was found in teak seedlings under atmospheric CO_2 concentration (0.710 mg/day) with respect to interaction effect. Seedlings of njaval under atmospheric CO_2 concentration had the minimum value (0.104 mg/day). During the third and fifth months, CO_2 concentrations were observed to be significant. The elevated CO_2 concentration recorded maximum NAR in seedlings with a recorded mean value of 0.530 mg/day and 0.370 mg/day respectively. However, interaction was insignificant in this month.

4.4.3 Leaf area

Data tabulated in Table 14(a and b), Figure 6 revealed that different treatments had significant effect on leaf area for the entire period of study. In the first month, tree seedlings under elevated CO_2 concentration had maximum leaf area (378.32 cm^2) which was followed by the seedlings under atmospheric CO_2 (180.06 cm^2). Both were significantly different. Among interactions, matti seedlings under elevated CO_2 showed highest leaf area (474.88 $cm^{2)}$ while that under atmospheric CO_2 produced lowest leaf area (69.89 cm^2) which was significantly different.

In the second month, mahogany seedlings under elevated CO_2 had highest leaf area (780.98 cm^2) which was significantly different when interaction was taken into consideration. Similarly in the third month, teak seedlings under elevated CO_2 recorded leaf area (1517.33 cm^2) which was significantly different from the rest.

Table 12 (a): Two-way tables on relative growth rate (mgd^{-1}) of seedlings of five *tree species under two CO_2 concentrations*

Month 1

Species	CO_2 levels	
	Elevated	*Atmospheric*
Teak	4.33	3.47
Mahogany	5.67	4.67
Njaval	7.00	2.00
Matti	6.67	3.33
Venga	7.67	2.33
Mean	6.27^x	3.16^y
$F_{CO2\ level}$ – 8.55**, SEm+/- =0.74		
$F_{interaction}$ – 0.80 NS, SEm+/- =1.67		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	20.33	5.67
Mahogany	13.33	1.53
Njaval	1.00	3.33
Matti	3.33	6.00
Venga	8.33	4.67
Mean	9.26^x	4.24^y
$F_{CO2\ level}$ - 14.58**, SEm+/- =0.93		
$F_{interaction}$ - 7.33**, SEm+/- =2.08		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	9.13	6.33
Mahogany	5.83	6.00
Njaval	3.33	4.33
Matti	9.33	8.33
Venga	5.67	4.67
Mean	6.66	5.93
$F_{CO2\ level}$ - 0.27 NS, SEm+/- =0.98		
$F_{interaction}$ – 0.21 NS, SEm+/- =2.19		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	11.10	7.67
Mahogany	5.23	9.00
Njaval	6.00	4.00
Matti	7.33	7.33
Venga	4.73	3.67
Mean	6.88	6.33
$F_{CO2\ level}$ – 0.22 NS, SEm+/- =0.81		
$F_{interaction}$ – 1.11 NS , SEm+/- =1.82		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 12 (b): Two-way tables on relative growth rate (mgd^{-1}) of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	.Atmospheric
Teak	6.00	6.33
Mahogany	4.00	4.00
Njaval	5.43	3.77
Matti	7.00	6.67
Venga	4.00	6.67
Mean	5.29	5.49
$F_{CO2\ level}$ – 0.05 NS, SEm+/- =0.65		
$F_{interaction}$ – 0.58 NS, SEm+/- =1.46		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	4.67	4.00
Mahogany	6.17	4.00
Njaval	5.60	3.33
Matti	5.00	4.37
Venga	3.23	3.33
Mean	4.93	3.81
$F_{CO2\ level}$ – 1.84 NS, SEm+/- =0.58		
$F_{interaction}$ – 0.32 NS, SEm+/- =1.31		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	6.00	4.33
Mahogany	4.00	4.00
Njaval	4.00	1.77
Matti	7.00	3.00
Venga	5.00	4.67
Mean	5.2	3.55
$F_{CO2\ level}$ –2.66 NS, SEm+/- =0.71		
$F_{interaction}$ - 0.51 NS , SEm+/- =1.59		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 13 (a): Two-way tables on net assimilation rate (mgd^{-1}) of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	0.311	0.227
Mahogany	0.261	0.217
Njaval	0.326	0.723
Matti	0.501	0.320
Venga	0.285	0.327
Mean	0.34	0.36
$F_{CO2\ level}$ – 0.10 NS, SEm+/- =0.06		
$F_{interaction}$ – 1.41 NS, SEm+/- =0.13		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	0.441^{abc}	0.710^{a}
Mahogany	0.129^{c}	0.479^{abc}
Njaval	0.530^{abc}	0.104^{c}
Matti	0.567^{ab}	0.178^{bc}
Venga	0.368^{abc}	0.325^{abc}
Mean	0.41	0.36
$F_{CO2\ level}$ - 0.34 NS, SEm+/- =0.05		
$F_{interaction}$ - 3.86 *, SEm+/- =0.12		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	0.388	0.304
Mahogany	0.443	0.203
Njaval	0.722	0.249
Matti	0.749	0.401
Venga	0.356	0.220
Mean	0.53^{x}	0.28^{y}
$F_{CO2\ level}$ – 6.33*, SEm+/- =0.07		
$F_{interaction}$ – 0.48 NS, SEm+/- =0.16		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	0.349	0.361
Mahogany	0.362	0.165
Njaval	0.397	0.500
Matti	0.392	0.311
Venga	0.202	0.197
Mean	0.34	0.31
$F_{CO2\ level}$ – 0.34 NS, SEm+/- =0.04		
$F_{interaction}$ – 0.76 NS, SEm+/- =0.09		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 13 (b): Two-way tables on net assimilation rate (mgd^{-1}) of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	0.416	0.211
Mahogany	0.204	0.121
Njaval	0.412	0.408
Matti	0.422	0.302
Venga	0.419	0.171
Mean	0.37^x	0.24^y
$F_{CO2\ level}$ – 6.15*, SEm+/- =0.03		
$F_{interaction}$ – 0.66 NS, SEm+/- =0.08		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	0.250	0.171
Mahogany	0.201	0.141
Njaval	0.290	0.385
Matti	0.261	0.207
Venga	0.197	0.126
Mean	0.24	0.21
$F_{CO2\ level}$ – NS, SEm+/- =0.02		
$F_{interaction}$ – NS, SEm+/- =0.06		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	0.281	0.204
Mahogany	0.147	0.118
Njaval	0.138	0.253
Matti	0.149	0.306
Venga	0.263	0.138
Mean	0.19	0.20
$F_{CO2\ level}$ — 0.02 NS, SEm+/- =0.04		
$F_{interaction}$ - 0.76 NS, SEm+/- =0.09		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

During the fourth month, leaf area of seedlings under elevated CO_2 concentration differed significantly (1142.76 cm^2). Interaction between various treatments had significant impact on leaf development. Teak seedlings under elevated CO_2 concentration had maximum leaf area (2286.67 cm^2). The lowest leaf area was observed in njaval seedlings under atmospheric CO_2 concentration (195.40 cm^2)

In the fifth month, among interactions, teak seedlings under enriched CO_2 concentration recorded maximum leaf area (2428.33 cm^2). njaval seedlings under atmospheric CO_2 concentration recorded lowest leaf area (238.67 cm^2). In the sixth month, seedlings under CO_2 enriched condition had a leaf area of 1468.22 cm^2 followed by 672.24 cm^2 under normal CO_2 condition. The interaction effect was significantly different among the seedlings of five tree species under different CO_2 concentration. The maximum leaf area was observed in teak seedlings under elevated CO_2 (2704.59 cm^2) and lowest leaf area in njaval seedlings (308.33 cm^2).

In the seventh month, elevated CO_2 gave highest leaf area (1828.65 cm^2) followed by the atmospheric CO_2 level (846.10 cm^2). A significant difference in interaction was observed under both CO_2 concentrations. Maximum leaf area was seen in teak seedlings (3599.71 cm^2) under elevated CO_2 concentration. Njaval seedlings showed lowest leaf area (425.33 cm^2) under atmospheric CO_2 concentrations.

In the last month of the study period, the two levels of CO_2 had significant impact on the leaf area. The maximum gain was observed in seedlings of teak (3788.67 cm^2) under enriched CO_2 condition. The lowest leaf area among the five tree species was obtained in seedlings of njaval under atmospheric CO_2 concentration (487.33 cm^2).

4.4.4 Specific leaf area

Data with regard to specific leaf area (SLA) is furnished in Table 15(a and b). Different CO_2 levels showed significant differences in the study period with regard

Table 14 (a): Two-way tables on leaf area (cm^2) of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	384.76^a	195.36^b
Mahogany	437.26^a	348.99^a
Njaval	185.56^b	139.16^b
Matti	474.88^a	69.89^b
Venga	409.15^a	146.88^b
Mean	378.32^x	180.06^y
$F_{CO2\ level}$ – 39.87**, SEm+/- =22.20		
$F_{interaction}$ – 4.16*, SEm+/- =49.65		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	638.11^{ab}	277.73^d
Mahogany	780.98^a	337.44^{cd}
Njaval	236.33^d	178.68^d
Matti	486.88^{bc}	211.68^d
Venga	693.80^a	278.71^d
Mean	567.22^x	256.85^y
$F_{CO2\ level}$ - 78.10**, SEm+/- =24.83		
$F_{interaction}$ - 3.90*, SEm+/- =55.53		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	1517.33^a	326.72^c
Mahogany	829.00^b	457.94^{bc}
Njaval	252.82^c	164.35^c
Matti	532.22^{bc}	301.69^c
Venga	773.67^b	335.69^c
Mean	781.01^x	317.28^y
$F_{CO2\ level}$ - 38.36**, SEm+/- =52.94		
$F_{interaction}$ – 6.54**, SEm+/- =118.38		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	2286.67^a	616.13^{cde}
Mahogany	1172.12^b	569.33^{de}
Njaval	298.42^c	195.40^e
Matti	905.28^{bcd}	399.33^e
Venga	1051.31^{bc}	434.00^e
Mean	1142.76^x	442.84^y
$F_{CO2\ level}$ – 59.99 **, SEm+/- =63.89		
$F_{interaction}$ – 8.28 **, SEm+/- =142.88		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 14 (b): Two-way tables on leaf area (cm^2) of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	2428.33^{a}	626.83^{d}
Mahogany	1583.83^{b}	690.67^{d}
Njaval	344.48^{de}	238.67^{e}
Matti	1061.43^{c}	578.33^{de}
Venga	1115.83^{c}	531.33^{de}
Mean	1306.78^{x}	533.17^{y}
$F_{CO2\ level}$ – 107.19**, SEm+/- =52.84		
$F_{interaction}$ – 14.66 **, SEm+/- =118.15		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	2704.59^{a}	717.87^{d}
Mahogany	1753.73^{b}	845.67^{cd}
Njaval	443.46^{de}	308.33^{e}
Matti	1221.47^{c}	783.67^{d}
Venga	1217.83^{c}	705.67^{d}
Mean	1468.22^{x}	672.24^{y}
$F_{CO2\ level}$ – 100.91**, SEm+/- =56.03		
$F_{interaction}$ – 16.53**, SEm+/- =125.28		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	3599.71^{a}	860.87^{ef}
Mahogany	2128.22^{b}	1082.63^{de}
Njaval	567.93^{fg}	425.33^{g}
Matti	1503.38^{c}	1039.67^{de}
Venga	1344.00^{cd}	822.00^{ef}
Mean	1828.65^{x}	846.10^{y}
$F_{CO2\ level}$ –154.04**, SEm+/- =55.97		
$F_{interaction}$ – 34.11 **, SEm+/- =125.17		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	3788.67^{a}	950.67^{ef}
Mahogany	2055.00^{b}	1415.33^{cd}
Njaval	784.00^{f}	487.33^{g}
Matti	1663.33^{c}	1224.67^{de}
Venga	1383.82^{cd}	996.67^{ef}
Mean	1934.96^{x}	1014.93^{y}
$F_{CO2\ level}$ – 256.73**, SEm+/- =40.60		
$F_{interaction}$ – 70.69**, SEm+/- =90.79		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

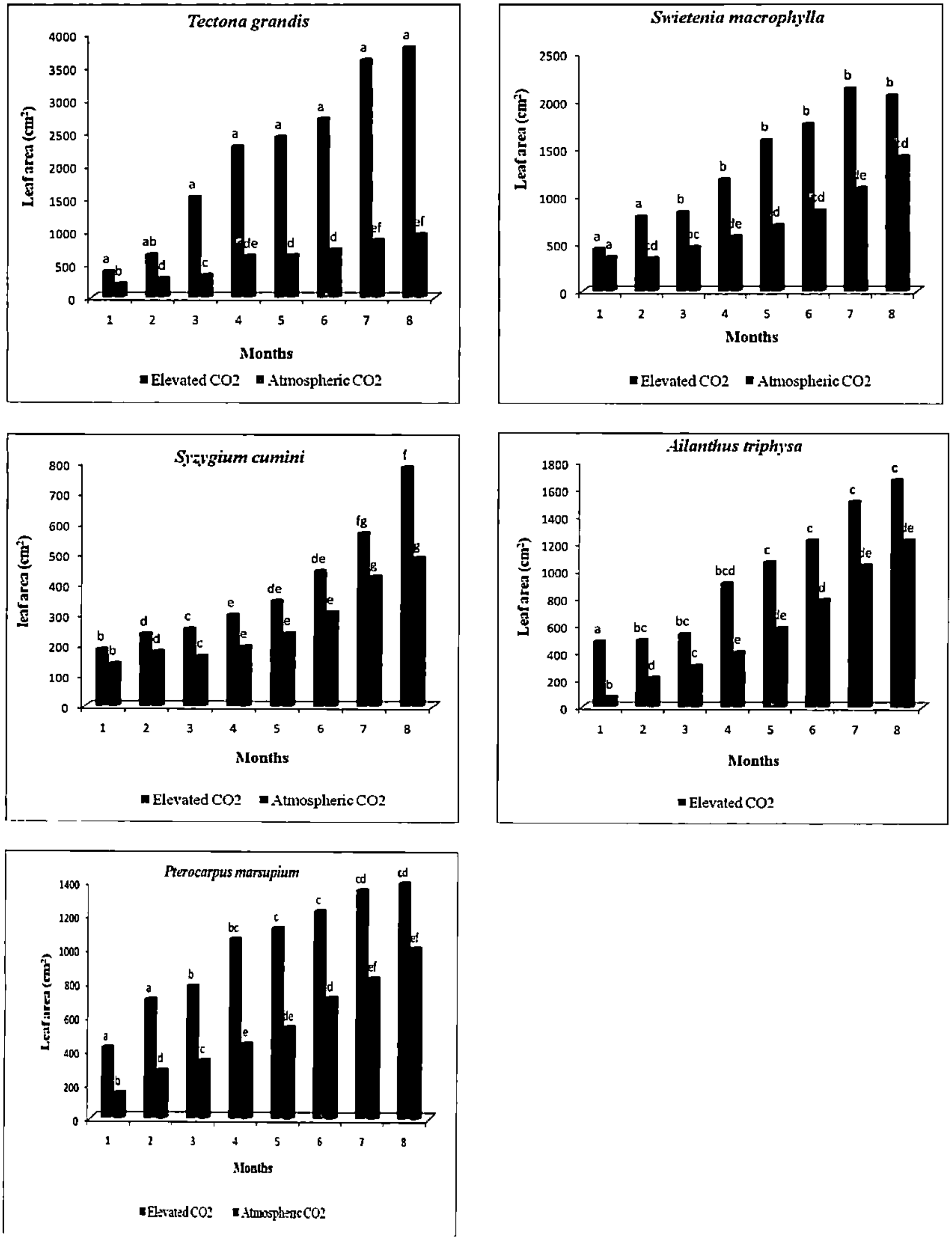

Figure 6. Response of five tree species on leaf area (cm^2) of seedlings under two CO_2 concentrations

Figures with the similar superscripts or no superscripts do not differ significantly.

to specific leaf area. However, the interaction gave significant differences in the first and second month of the study period only.

In the first month, the application of different levels of CO_2 showed significant differences in their performances (Table 15a). The maximum SLA was given by elevated CO_2 concentration (57.30 cm^2g^{-1}). In the same month the interactions showed significant effect on the specific leaf area. The highest SLA was produced by the matti seedlings (71.25 cm^2g^{-1}) under elevated CO_2 concentration. The lowest SLA was also observed in matti seedlings under atmospheric CO_2 concentration (12.60 cm^2g^{-1}).

In the second month, various CO_2 concentrations showed significant differences in the SLA of the seedlings (Table 15 a). The best SLA among different interaction was given by mahogany where seedlings gave a mean reading of 97.32 cm^2g^{-1} under elevated CO_2 concentration. The lowest SLA was observed in njaval seedling under atmospheric CO_2 concentration which showed significant differences with mean values of 26.13 cm^2g^{-1}. The SLA was not significantly different from third month till the end of the study period.

4.4.5 Leaf area ratio

Data furnished in Tables 16a and 16b depict the influence of various treatments on the leaf area ratio in tree seedlings of five species. It is clear from the table that different CO_2 treatment significantly affected the leaf area ratio (LAR) in seedlings throughout the study period. Interactions between factors had no significant effect the study period except in the first month.

In the first month, elevated CO_2 concentration produced the highest LAR in tree seedlings with a recorded mean value of 19.28 cm^2g^{-1}. The interaction effect was significant in this month. The maximum leaf area ratio was observed in matti seedlings under elevated CO_2 concentration (25.37 cm^2g^{-1}). However, the lowest LAR was also given by matti seedlings under atmospheric CO_2 concentration (3.97 cm^2g^{-1}).

Table 15 (a): Two-way tables on specific leaf area (cm^2g^{-1}) of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	58.78^{ab}	35.66^{c}
Mahogany	66.38^{a}	53.12^{b}
Njaval	30.42^{cd}	20.41^{de}
Matti	71.25^{a}	12.60^{e}
Venga	59.68^{ab}	23.08^{de}
Mean	57.30^{x}	28.97^{y}
$F_{CO2\ level}$ – 121.69 **, SEm+/- =1.82		
$F_{interaction}$ – 11.96**, SEm+/- =4.06		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	92.73^{a}	43.98^{bc}
Mahogany	97.32^{a}	52.34^{bc}
Njaval	30.07^{c}	26.13^{c}
Matti	58.00^{b}	37.44^{bc}
Venga	85.33^{a}	40.99^{bc}
Mean	72.69^{x}	40.18^{y}
$F_{CO2\ level}$ – 39.89**, SEm+/- =3.64		
$F_{interaction}$ – 2.86**, SEm+/- =8.14		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	92.52	46.39
Mahogany	55.54	55.30
Njaval	31.49	21.33
Matti	78.91	44.57
Venga	67.67	47.25
Mean	65.23^{x}	42.97^{y}
$F_{CO2\ level}$ – 12.65**, SEm+/- =4.43		
$F_{interaction}$ – 1.72NS, SEm+/- =9.89		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	95.27	62.96
Mahogany	65.68	58.81
Njaval	32.18	19.97
Matti	86.56	35.09
Venga	75.20	46.93
Mean	70.98^{x}	44.75^{y}
$F_{CO2\ level}$ – 15.94**, SEm+/- =4.64		
$F_{interaction}$ – 1.45NS, SEm+/- =10.39		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 15 (b): Two-way tables on specific leaf area (cm^2g^{-1}) of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	67.26	53.12
Mahogany	72.13	55.88
Njaval	31.22	21.48
Matti	78.43	39.51
Venga	71.63	43.91
Mean	64.13 ^{x}	42.78 ^{y}
$F_{CO2\ level}$ – 14.09**,SEm+/- =4.02		
$F_{interaction}$ – 0.87NS, SEm+/- =8.99		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	61.10	50.02
Mahogany	68.64	61.62
Njaval	32.97	23.84
Matti	62.54	38.02
Venga	78.76	49.57
Mean	60.80 ^{x}	44.61 ^{y}
$F_{CO2\ level}$ –8.87 **,SEm+/- =3.84		
$F_{interaction}$ – 0.68NS, SEm+/- =8.59		

Month 7

Species	CO_2 levels	
	Elevated	*Atmospheric*
Teak	66.89	46.34
Mahogany	81.87	56.29
Njaval	33.68	27.93
Matti	62.16	48.19
Venga	84.57	46.87
Mean	65.83 ^{x}	45.12 ^{y}
$F_{CO2\ level}$ – 32.02**,SEm+/- =3.84		
$F_{interaction}$ – 2.17NS, SEm+/- =8.59		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	58.41	44.87
Mahogany	74.15	68.98
Njaval	38.78	31.37
Matti	49.41	52.97
Venga	81.53	55.11
Mean	60.46 ^{x}	50.66 ^{y}
$F_{CO2\ level}$ – 8.75**,SEm+/- =2.34		
$F_{interaction}$ – 2.26NS, SEm+/- =5.24		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 16 (a): Two-way tables on leaf area ratio of (cm^2g^{-1}) of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	17.66^{b}	10.28^{c}
Mahogany	22.30^{ab}	17.82^{b}
Njaval	10.73^{c}	7.10^{c}
Matti	25.37^{a}	3.97^{c}
Venga	20.36^{ab}	6.89^{c}
Mean	19.28^{x}	9.21^{y}
$F_{CO2\ level}$ – 54.33**,SEm+/- =0.97		
$F_{interaction}$ – 5.89**, SEm+/- =2.16		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	25.67	12.97
Mahogany	34.26	15.48
Njaval	11.18	8.68
Matti	21.50	10.89
Venga	26.83	12.53
Mean	23.89^{x}	12.11^{y}
$F_{CO2\ level}$ – 52.43**,SEm+/- =1.15		
$F_{interaction}$ – 2.72NS, SEm+/- =2.57		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	32.66	12.77
Mahogany	24.91	19.78
Njaval	11.71	7.13
Matti	21.37	13.26
Venga	23.45	12.92
Mean	22.82^{x}	13.17^{y}
$F_{CO2\ level}$ – 20.08**,SEm+/- =1.52		
$F_{interaction}$ – 1.66NS, SEm+/- =3.41		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	37.70	20.26
Mahogany	29.45	20.91
Njaval	12.54	7.47
Matti	27.21	13.43
Venga	26.86	14.52
Mean	26.752^{x}	15.32^{y}
$F_{CO2\ level}$ – 24.67**,SEm+/- =1.62		
$F_{interaction}$ – 0.86 NS , SEm+/- =3.64		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 16 (b): Two-way tables on leaf area ratio of (cm^2g^{-1}) of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	29.11	16.01
Mahogany	33.81	19.18
Njaval	12.05	8.14
Matti	25.84	15.35
Venga	25.25	15.79
Mean	25.211^x	14.89^y
$F_{CO2\ level}$ – 32.67**,SEm+/- =1.15		
$F_{interaction}$ – 0.79 NS , SEm+/- =2.57		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	26.85	15.31
Mahogany	33.00	20.86
Njaval	13.29	9.41
Matti	23.61	17.13
Venga	24.19	17.08
Mean	22.19^x	15.96^y
$F_{CO2\ level}$ – 30.74**,SEm+/- =1.05		
$F_{interaction}$ – 1.12 NS , SEm+/- =2.35		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	30.79	16.31
Mahogany	35.35	23.32
Njaval	14.50	11.85
Matti	25.28	20.18
Venga	24.27	17.90
Mean	26.04^x	17.92^y
$F_{CO2\ level}$ – 29.11**,SEm+/- =1.06		
$F_{interaction}$ –2.16 NS, SEm+/- =2.38		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	27.36	15.90
Mahogany	30.41	27.97
Njaval	17.82	12.93
Matti	22.14	21.68
Venga	22.81	19.22
Mean	24.11^x	19.54^y
$F_{CO2\ level}$ – 8.79**,SEm+/- =1.09		
$F_{interaction}$ – 1.48 NS , SEm+/- =2.44		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

4.4.6 Leaf weight ratio

The leaf weight ratio (LWR) was found to be significantly influenced by the different levels of CO_2 concentration as evident from Tables 17 a and 17 b.

Different levels of CO_2 showed significant differences except in the first, sixth, seventh and eighth month till the end of study period. The interaction effect also started to give significant differences from the third month to the seventh month of the study period.

In the third month, the highest LWR was recorded in the seedlings kept under elevated CO_2 concentration with mean values of 0.361. Interactions showed significant difference. The highest leaf weight ratio was produced by the mahogany seedlings (0.458) while lowest LWR for matti seedlings under elevated CO_2 concentration (0.268).

Leaf weight ratio was influenced significantly by different CO_2 levels which showed significant effect in the fourth month. Among the interactions, the highest leaf weight ratio was recorded in matti seedlings under atmospheric CO_2 concentration (0.380). The matti seedlings grown under elevated CO_2 concentration produced minimum LWR with significant differences and mean values of 0.250.

In the fifth month the application of various CO_2 concentrations showed significant differences in the LWR of the seedlings. The best LWR among different interaction was observed in mahogany seedlings under elevated CO_2 concentration (0.475). The lowest LWR was given by teak seedling under atmospheric CO_2 concentration which showed significant differences with mean values of 0.307.

The use of different CO_2 concentrations also proved to be significantly influencing the LWR in the sixth month of the study period (Table 17 b). Among interactions, the best performance was seen in mahogany seedlings under elevated CO_2 concentration (0.481). The seedlings of venga under elevated CO_2 concentration had the lowest mean values of 0.306. They were all significantly different from each other.

Both CO_2 levels showed significantly different impact on the leaf weight ratio of seedlings in the seventh month. Interaction also had significant effect on the LWR in this month. Among the interactions, the best performance was observed in the teak seedlings under elevated CO_2 concentration (0.466). The lowest LWR was for venga seedlings kept under elevated CO_2 concentration which recorded a mean value of 0.288.

4.4.7 Number of stomata

Data tabulated in Table 18 (a and b) and Figure 7 revealed that different CO_2 levels had significant effect on number of stomata for the entire period of study except in the first month. Seedlings under elevated CO_2 recorded lowest number of stomata compared to seedlings under atmospheric CO_2 concentration. Interactions were found to be insignificant in first and second months.

In the third month, teak seedlings kept under atmospheric CO_2 had the highest number of stomata (302.95) which was significantly different from all others when interaction is taken into consideration. On the other hand, njaval seedlings kept under elevated CO_2 recorded lowest stomatal number (167.06) which was significantly different.

During the fourth month, number of stomata of seedlings under elevated CO_2 concentration differed significantly (230.35). Interaction between various treatments had significant impact on stomata development. Teak seedlings under atmospheric CO_2 concentration had the highest number of stomata (324.40). The lowest number was observed in njaval seedlings raised under elevated CO_2 concentration (171.35).

In the fifth month, seedlings of teak recorded maximum number (358.62) under atmospheric CO_2 concentration among interactions. In contrast, njaval seedlings under elevated CO_2 concentration (169.24) recorded the lowest stomatal number. In the sixth month, normal CO_2 condition had a stomatal number of 298.50

Table 17 (a): Two-way tables on leaf weight ratio of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	0.301	0.286
Mahogany	0.334	0.348
Njaval	0.348	0.356
Matti	0.356	0.314
Venga	0.334	0.298
Mean	0.334	0.320
$F_{CO2\ level}$ – 2.21 NS ,SEm+/- =8.16		
$F_{interaction}$ – 0.54 NS , SEm+/- =0.018		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	0.280	0.294
Mahogany	0.352	0.298
Njaval	0.379	0.330
Matti	0.376	0.284
Venga	0.314	0.312
Mean	0.340^{x}	0.303^{y}
$F_{CO2\ level}$ –9.89 **,SEm+/- =8.16		
$F_{interaction}$ – 2.66 NS, SEm+/- =0.018		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	0.359^{bc}	0.276^{cd}
Mahogany	0.458^{a}	0.341^{bcd}
Njaval	0.372^{b}	0.334^{bcd}
Matti	0.268^{d}	0.298^{bcd}
Venga	0.351^{bcd}	0.271^{d}
Mean	0.361^{x}	0.304^{y}
$F_{CO2\ level}$ – 14.98**,SEm+/- =0.012		
$F_{interaction}$ – 2.88*, SEm+/- =0.026		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	0.290^{de}	0.318^{bcd}
Mahogany	0.290^{de}	0.358^{abc}
Njaval	0.326^{abcd}	0.371^{ab}
Matti	0.250^{e}	0.380^{a}
Venga	0.312^{bcd}	0.306^{cde}
Mean	0.294^{x}	0.347^{y}
$F_{CO2\ level}$ –6.87 **,SEm+/- =8.16		
$F_{interaction}$ – 4.85**, SEm+/- =0.018		

** - significant at 5 %, ** - significant at 1 %, NS – non-significant*

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 17 (b): Two-way tables on leaf weight ratio of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	0.434^{ab}	0.307^{e}
Mahogany	0.475^{a}	0.359^{cde}
Njaval	0.392^{bc}	0.382^{bcd}
Matti	0.331^{de}	0.391^{bcd}
Venga	0.347^{cde}	0.358^{cde}
Mean	0.396^{x}	0.359^{y}
$F_{CO2\ level}$ –6.88*,SEm+/- =8.16		
$F_{interaction}$ – 6.88**, SEm+/- =0.018		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	0.441^{ab}	0.322^{cd}
Mahogany	0.481^{a}	0.366^{bcd}
Njaval	0.406^{abc}	0.396^{bc}
Matti	0.381^{bcd}	0.449^{ab}
Venga	0.306^{d}	0.344^{cd}
Mean	0.414	0.375
$F_{CO2\ level}$ –3.56 NS ,SEm+/- =0.012		
$F_{interaction}$ – 6.95**, SEm+/- =0.026		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	0.466^{a}	0.354^{bc}
Mahogany	0.432^{ab}	0.414^{ab}
Njaval	0.432^{ab}	0.424^{ab}
Matti	0.408^{ab}	0.417^{ab}
Venga	0.288^{c}	0.383^{ab}
Mean	0.405	0.398
$F_{CO2\ level}$ – 0.202 NS ,SEm+/- =0.012		
$F_{interaction}$ – 4.88**, SEm+/- =0.026		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	0.469	0.357
Mahogany	0.417	0.408
Njaval	0.461	0.420
Matti	0.451	0.408
Venga	0.278	0.349
Mean	0.415	0.389
$F_{CO2\ level}$ – 1.79 NS ,SEm+/- =0.014		
$F_{interaction}$ – 2.19 NS , SEm+/- =0.032		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

followed by 249.92 under CO_2 enriched condition. The interaction effect was significantly different among the seedlings of five tree species under different CO_2 concentrations. The maximum gain in number of stomata was observed in teak seedlings (374.83) under atmospheric CO_2 concentration and lowest number in njaval seedlings (180.00) under elevated CO_2.

In the seventh month, a significant difference in interaction was observed under both CO_2 concentrations. Maximum stomatal development was seen in the mahogany seedlings (382.54) followed by teak seedlings (381.18) under atmospheric CO_2 concentration. Njaval seedlings showed lowest stomatal count of 190.80 under elevated CO_2 concentration.

In the last month of the study period, the effect of two levels of CO_2 had significant impact on the stomatal count of the tree seedlings. In interactions, the maximum gain was observed in seedlings of mahogany (392.58) under atmospheric CO_2 condition. The least stomatal count among the five tree species was obtained in seedlings of njaval under enriched CO_2 concentration (194.80).

4.4.8 Rate of photosynthesis

The observations related to the rate of photosynthesis of tree seedlings for different CO_2 concentrations is furnished in Tables 19 a and 19 b and Figure 8. The varying CO_2 concentrations showed significant effect on the rate of photosynthesis of the tree seedlings in all months. On the other hand, interactions between factors had significant impacts on the rate of photosynthesis except in the second, fifth and eighth months.

Different CO_2 concentrations provided statistically significant values in the first month (Table 19a) and the best performance was shown by seedlings under elevated CO_2 concentration with a mean value of 25.11 (μ mol m^{-2} s^{-1}). In the same month the interaction was also significant. The highest rate of photosynthesis was recorded in teak seedlings with a significantly different value of 30.90 (μ mol m^{-2} s^{-1}) and lowest rate recorded in the case of njaval seedlings 9.09 (μ mol m^{-2} s^{-1}) under atmospheric CO_2 concentration.

Table 18 (a): Two-way tables on number of stomata (mm^{-2}) of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	248.62	266.71
Mahogany	216.73	222.82
Njaval	162.92	177.22
Matti	185.64	181.72
Venga	199.14	212.22
Mean	202.61	212.14
$F_{CO2\ level}$ – 3.80 NS ,SEm+/- =3.46		
$F_{interaction}$ – 0.63 NS, SEm+/- =7.73		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	278.31	288.85
Mahogany	238.10	261.34
Njaval	166.33	188.74
Matti	186.56	187.85
Venga	208.66	235.38
Mean	215.59^{x}	232.43^{y}
$F_{CO2\ level}$ – 18.05**,SEm+/- =2.80		
$F_{interaction}$ – 1.44 NS, SEm+/- =6.27		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	286.56^{a}	302.95^{a}
Mahogany	224.72^{c}	289.36^{a}
Njaval	167.06^{f}	206.48^{de}
Matti	193.70^{e}	192.50^{e}
Venga	212.32^{cd}	260.21^{b}
Mean	216.88^{x}	250.30^{y}
$F_{CO2\ level}$ – 86.99**,SEm+/- =2.53		
$F_{interaction}$ – 10.54**, SEm+/- =5.67		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	279.95^{bc}	324.40^{a}
Mahogany	262.07^{cd}	298.32^{b}
Njaval	171.35^{g}	235.45^{e}
Matti	192.00^{f}	206.24^{f}
Venga	246.42^{de}	275.53^{c}
Mean	230.35^{x}	267.99^{y}
$F_{CO2\ level}$ – 87.60**,SEm+/- =2.84		
$F_{interaction}$ – 4.23*, SEm+/- =6.36		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 18 (b): Two-way tables on number of stomata (mm^{-2}) of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	296.24[b]	358.62[a]
Mahogany	268.06[cd]	343.64[a]
Njaval	169.24[f]	247.21[d]
Matti	199.25[e]	205.81[e]
Venga	257.57[d]	281.84[bc]
Mean	238.07[x]	287.42[y]
$F_{CO2\ level}$ – 105.68**,SEm+/- =3.39		
$F_{interaction}$ – 8.97**, SEm+/- =7.59		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	314.49[b]	374.83[a]
Mahogany	280.06[cd]	367.31[a]
Njaval	180.00[g]	253.52[e]
Matti	203.55[f]	203.13[f]
Venga	271.50[d]	293.73[c]
Mean	249.92[x]	298.50[y]
$F_{CO2\ level}$ – 232.55**,SEm+/- =2.25		
$F_{interaction}$ – 26.36 **, SEm+/- =5.04		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	310.30[b]	381.18[a]
Mahogany	287.84[c]	382.54[a]
Njaval	190.80[g]	256.52[e]
Matti	204.63[f]	210.57[f]
Venga	275.03[d]	303.15[b]
Mean	253.72[x]	306.79[y]
$F_{CO2\ level}$ – 480.93**,SEm+/- =1.71		
$F_{interaction}$ – 43.14**, SEm+/- =3.83		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	319.98[b]	387.43[a]
Mahogany	290.54[c]	392.58[a]
Njaval	194.80[f]	268.89[d]
Matti	204.14[ef]	215.46[g]
Venga	276.24[cd]	312.20[b]
Mean	257.14[x]	315.32[y]
$F_{CO2\ level}$ – 192.16**,SEm+/- =2.96		
$F_{interaction}$ – 14.06**, SEm+/- =6.64		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

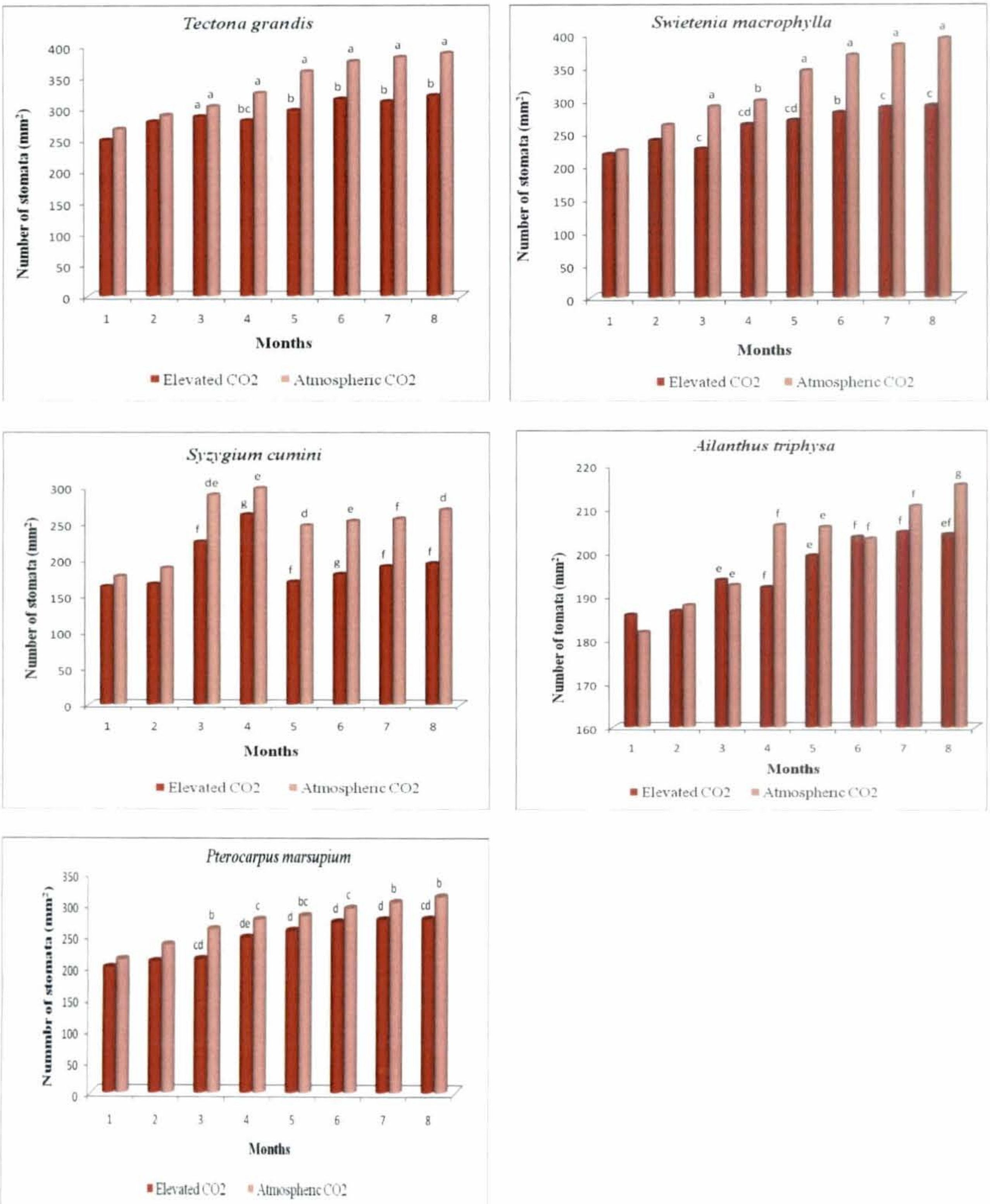

Figure 7. Response of five tree species on number of stomata (mm^2) of seedlings under two CO_2 concentrations

Figures with the similar superscripts or no superscripts do not differ significantly.

In the third month, the varying levels of CO_2 provided significant impacts on the rate of photosynthesis. Among the interactions, the highest rate of photosynthesis was observed in mahogany seedlings under elevated CO_2 concentration with mean values of 30.86 (μ mol m^{-2} s^{-1}). The njaval seedlings grown under atmospheric CO_2 concentration recorded the lowest photosynthesis rate (11.27 μ mol m^{-2} s^{-1}) with significant differences.

In the fourth month, when interactions were taken into consideration, the best performance was recorded by teak seedlings (29.10 μ mol m^{-2} s^{-1}) under elevated CO_2 concentration and the least performance was given by njaval seedling 11.20 (μ mol m^{-2} s^{-1}) under atmospheric CO_2 concentration. They were statistically significant from each other.

At the sixth month stage, different CO_2 concentrations were also observed to be significantly influencing the rate of photosynthesis. Among interactions, teak seedlings under elevated CO_2 concentration performed best when rate of photosynthesis was measured with mean values being 31.70μ mol m^{-2} s^{-1}. The seedlings of njaval under atmospheric CO_2 concentration showed lowest recorded rate of 13.63 μ mol m^{-2} s^{-1}.

Both CO_2 levels showed significantly different impact on the rate of photosynthesis of seedlings in the seventh month. Interaction also had significant effect in this month. Among the interactions, the best performance was observed in the teak seedlings under elevated CO_2 concentration (30.43 μ mol m^{-2} s^{-1}). The least performance was given by njaval seedlings under atmospheric CO_2 concentration (10.20 μ mol m^{-2} s^{-1}).

4.5. Biochemical parameters

4.5.1 Chlorophyll content

The chlorophyll content of leaves was found to be significant at varying CO_2 levels in certain months (Tables 20, 21 and 22). In teak, none of the parameters could be estimated due to the interference of phenols in the leaf.

Table 19 (a): Two-way tables on rate of photosynthesis (μ mol m^{-2} s^{-1}) of seedlings of five tree species under two CO_2 concentions

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	30.90[a]	15.90[d]
Mahogany	25.93[b]	12.45[e]
Njaval	19.57[c]	9.09[f]
Matti	24.93[b]	18.62[cd]
Venga	24.23[b]	12.67[e]
Mean	25.11[x]	13.746[y]
$F_{CO2\ level}$ – 300.78**,SEm+/- =0.46		
$F_{interaction}$ – 5.12 **, SEm+/- =1.04		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	25.73	14.70
Mahogany	28.70	12.55
Njaval	19.40	10.25
Matti	26.69	16.23
Venga	23.27	14.80
Mean	24.76[x]	13.71[y]
$F_{CO2\ level}$ – 252.82**,SEm+/- =0.51		
$F_{interaction}$ – 2.84 NS, SEm+/- =1.14		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	30.23[a]	15.79[e]
Mahogany	30.86[a]	14.13[f]
Njaval	21.07[c]	11.27[g]
Matti	27.33[b]	19.48[d]
Venga	26.10[b]	15.33[ef]
Mean	27.12[x]	15.20[y]
$F_{CO2\ level}$ –1303.13 **,SEm+/- =0.23		
$F_{interaction}$ – 23.77 **, SEm+/- =0.52		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	29.10[a]	16.17[c]
Mahogany	28.26[a]	13.52[cd]
Njaval	21.18[b]	11.20[d]
Matti	26.27[a]	20.09[b]
Venga	25.65[a]	15.90[c]
Mean	26.09[x]	15.38[y]
$F_{CO2\ level}$ – 178.91**,SEm+/- =0.57		
$F_{interaction}$ – 3.36*, SEm+/- =1.27		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 19 (b): Two-way tables on rate of photosynthesis (μ mol m^{-2} s^{-1}) of seedlings of five tree species under two CO_2 concentions

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	29.13	16.22
Mahogany	28.50	15.87
Njaval	23.97	10.04
Matti	26.17	17.54
Venga	27.37	14.53
Mean	27.03^{x}	14.84^{y}
$F_{CO2\ level}$ – 311.57**,SEm+/- =0.49		
$F_{interaction}$ – 1.76 NS, SEm+/- =1.09		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	31.70^{a}	13.94^{e}
Mahogany	27.13^{b}	15.75^{de}
Njaval	22.77^{c}	13.63^{e}
Matti	27.07^{b}	16.54^{d}
Venga	25.97^{b}	15.07^{de}
Mean	26.93^{x}	14.99^{y}
$F_{CO2\ level}$ –675.61 **,SEm+/- =0.32		
$F_{interaction}$ – 10.70**, SEm+/- =0.73		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	30.43^{a}	15.96^{de}
Mahogany	29.63^{a}	14.03^{e}
Njaval	23.21^{c}	10.20^{f}
Matti	29.83^{a}	16.47^{d}
Venga	25.43^{b}	14.83^{de}
Mean	27.71^{x}	14.29^{y}
$F_{CO2\ level}$ –792.33 **,SEm+/- =0.34		
$F_{interaction}$ – 3.08*, SEm+/- =0.75		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Teak	27.47	14.59
Mahogany	29.63	15.03
Njaval	22.80	11.98
Matti	30.47	16.47
Venga	27.27	15.47
Mean	27.53^{x}	14.71^{y}
$F_{CO2\ level}$ – 865.33**,SEm+/- =0.31		
$F_{interaction}$ – 2.54 NS, SEm+/- =0.68		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

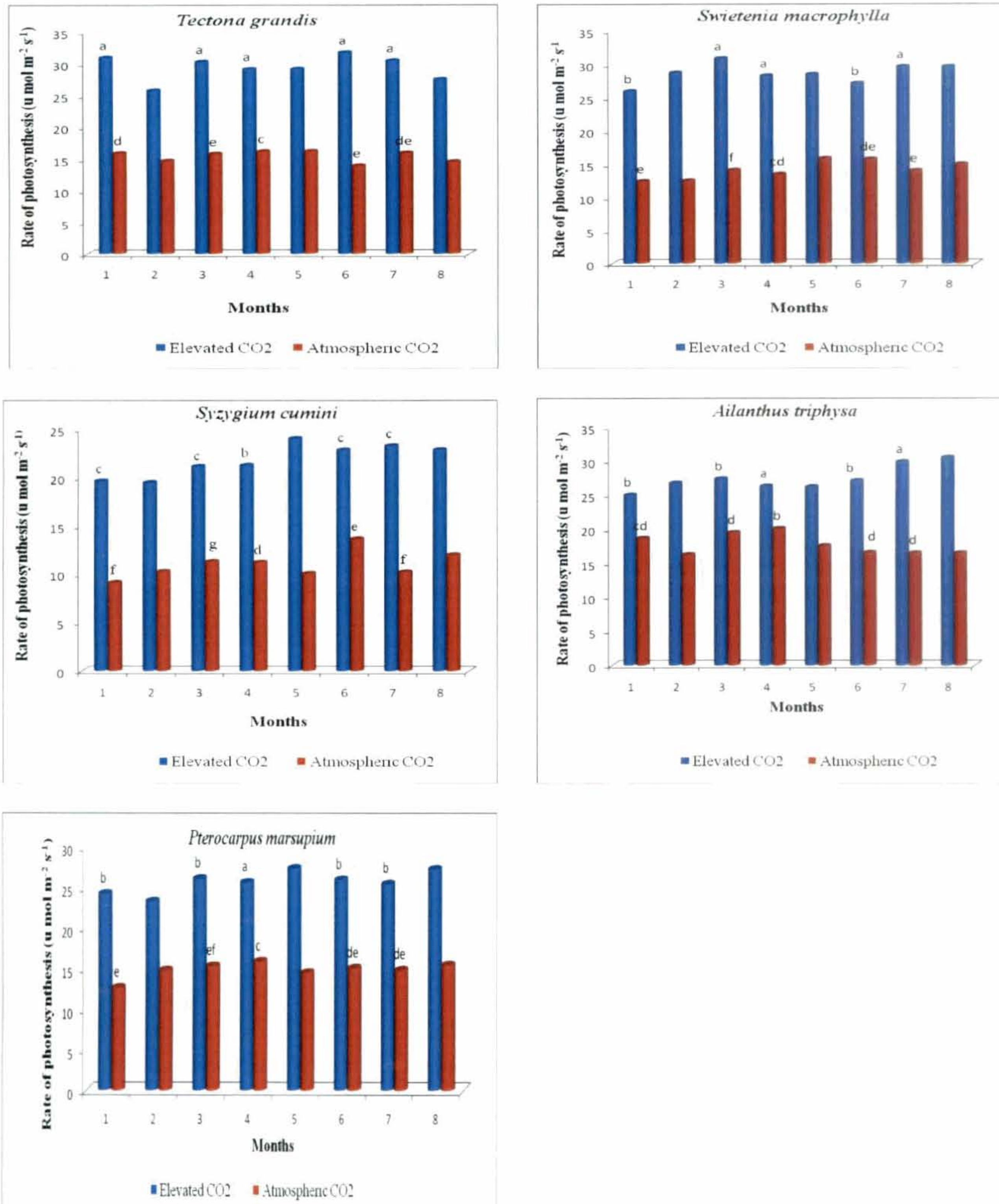

Figure 8. Response of five tree species on rate of photosynthesis (μ mol m^{-2} s^{-1}) of seedlings under two CO_2 concentrations

Figures with the similar superscripts or no superscripts do not differ significantly.

4.5.1.1 Chlorophyll-a

The data related to the chlorophyll-a content of the leaves is furnished in Tables 20 a and 20 b. The influence of different CO_2 concentrations on the chlorophyll-a content could be seen in the tree seedlings starting from the first month till the end of the study period. However, interaction between the factors had significant effect on only in first and fourth month.

In the first month, elevated CO_2 concentration recorded the highest chlorophyll-a content in all tree seedlings (0.775 mg/g). The interaction effect was significant in this month. The maximum chlorophyll-a content due to interaction was noticed in matti seedlings under elevated CO_2 (1.035 mg/g). However, the minimum chlorophyll-a content due to interaction was observed in mahogany seedlings under atmospheric CO_2 concentration (0.197 mg/g).

In the fourth month, when comparison was done for the interaction effect, the best performance was shown by njaval seedlings under elevated CO_2 concentration (1.214 mg/g) and the lowest content was noticed in mahogany seedlings under atmospheric CO_2 concentration (0.609 mg/g).

Thus it can be seen that interaction between five tree seedlings and two CO_2 level did not show significant effect on the chlorophyll-a content in tree seedlings in most of the time during the course of study.

4.5.1.2 Chlorophyll-b

Chlorophyll-b content of tree seedlings was also affected by different CO_2 levels from the first month till the end of the study period. On the other hand, interaction between two factors had no influence during the course of study except in last month. Data related to the influence of these factors are furnished in Tables 21 a and 21 b.

Table 20 (a): Two-way tables on chlorophyll content a (mg g^{-1}) of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	0.745^{c}	0.197^{e}
Njaval	0.581^{d}	0.201^{e}
Matti	1.035^{a}	0.960^{b}
Venga	0.741^{c}	0.225^{e}
Mean	0.775^{x}	$.396^{y}$
$F_{CO2\ level}$ –1632.51 **,SEm+/- =0.009		
$F_{interaction}$ – 131.09 **, SEm+/- =0.018		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	1.049	0.802
Njaval	1.134	0.805
Matti	1.149	0.966
Venga	0.946	0.695
Mean	1.069^{x}	0.817^{y}
$F_{CO2\ level}$ – 47.35**,SEm+/- =0.026		
$F_{interaction}$ – 0.68 NS, SEm+/- =0.050		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	1.047	0.772
Njaval	1.192	0.811
Matti	1.187	1.071
Venga	0.921	0.734
Mean	1.087^{x}	0.847^{y}
$F_{CO2\ level}$ – 46.67**,SEm+/- =0.024		
$F_{interaction}$ – 2.66 NS, SEm+/- =0.048		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	1.068^{ab}	0.609^{d}
Njaval	1.214^{a}	1.007^{b}
Matti	1.209^{a}	1.041^{b}
Venga	1.018^{b}	0.811^{c}
Mean	1.127^{x}	0.867^{y}
$F_{CO2\ level}$ – 53.09**,SEm+/- =0.260		
$F_{interaction}$ – 3.53*, SEm+/- =0.580		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 20 (b): Two-way tables on chlorophyll content a (mg g^{-1}) of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	1.022	0.747
Njaval	1.168	1.016
Matti	1.267	0.985
Venga	1.094	0.849
Mean	1.138^{x}	0.899^{y}
$F_{CO2\ level}$ – 44.43**,SEm+/- =0.026		
$F_{interaction}$ – 0.693 NS, SEm+/- =0.030		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	1.061	0.786
Njaval	1.174	0.887
Matti	1.231	1.062
Venga	1.064	0.947
Mean	1.133^{x}	0.921^{y}
$F_{CO2\ level}$ – 27.104**,SEm+/- =0.029		
$F_{interaction}$ – 1.028 NS, SEm+/- =0.020		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	1.071	0.793
Njaval	1.045	0.893
Matti	1.274	1.113
Venga	1.106	0.883
Mean	1.124^{x}	0.671^{y}
$F_{CO2\ level}$ – 114.44**,SEm+/- =0.0129		
$F_{interaction}$ – 2.31 NS, SEm+/- =0.0258		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	1.143	0.830
Njaval	1.125	0.904
Matti	1.330	1.187
Venga	1.076	0.952
Mean	0.919^{x}	0.968^{y}
$F_{CO2\ level}$ – 33.85**,SEm+/- =0.024		
$F_{interaction}$ – 1.52 NS, SEm+/- =0.048		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

In the last month of the study period, the best performance was given by the venga seedlings under elevated CO_2 concentration (0.688 mg/g) when the interaction was analyzed. The minimum chlorophyll-b content at the end of the study period was found in njaval seedlings under atmospheric CO_2 concentration (0.404 mg/g).

4.5.1.3 Total chlorophyll

The effect of varying CO_2 levels on the total chlorophyll content of the tree seedlings is presented in Tables 22 a and 22 b. Different CO_2 concentrations had significant influence on tree seedlings throughout the study period. However, interactions between two factors showed significant influence only in the first, seventh and eighth months.

In the first month, tree seedlings under elevated CO_2 concentration recorded highest total chlorophyll content (1.60 mg/g). The interaction was also significant in this month. The maximum total chlorophyll content due to interaction was noticed in mahogany seedlings under elevated CO_2 concentration (1.690 mg/g). However, the minimum chlorophyll-a content due to interaction was observed in njaval seedlings under atmospheric CO_2 concentration (1.058 mg/g).

The total chlorophyll content of the tree seedlings was significantly affected due to the varying CO_2 concentrations in the seventh month. When the comparison was done for the interaction, the best performance was shown by matti seedlings under elevated CO_2 concentration (1.853 mg/g) and the lowest content was noticed in mahogany seedlings under atmospheric CO_2 concentration (1.21 mg/g).

In the eighth month of the study period, interactions between the factors had significant impact on the total chlorophyll content. The maximum total chlorophyll content regarding interaction was observed in matti seedlings under elevated CO_2 concentration (1.923 mg/g). However, the minimum value of total chlorophyll content due to interaction for the same month was observed in mahogany seedlings under atmospheric CO_2 concentration (1.329 mg/g).

Table 21 (a): Two-way tables on chlorophyll content b (mg g^{-1}) of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	0.632	0.436
Njaval	0.437	0.324
Matti	0.544	0.398
Venga	0.619	0.496
Mean	0.589^x	0.414^y
$F_{CO2\ level}$ – 36.97**, SEm+/- =0.016		
$F_{interaction}$ – 0.61NS, SEm+/- =0.032		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	0.657	0.311
Njaval	0.443	0.362
Matti	0.548	0.375
Venga	0.632	0.503
Mean	0.57^x	0.388^y
$F_{CO2\ level}$ – 29.62**, SEm+/- =0.024		
$F_{interaction}$ – 2.98 NS, SEm+/- =0.048		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	0.665	0.407
Njaval	0.448	0.358
Matti	0.551	0.405
Venga	0.656	0.506
Mean	0.58^x	0.419^y
$F_{CO2\ level}$ – 57.02**, SEm+/- =0.016		
$F_{interaction}$ – 2.73NS, SEm+/- =0.032		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	0.637	0.451
Njaval	0.455	0.365
Matti	0.556	0.463
Venga	0.628	0.607
Mean	0.569^x	0.472^y
$F_{CO2\ level}$ – 19.62**, SEm+/- =0.016		
$F_{interaction}$ – 2.38NS, SEm+/- =0.032		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 21 (b): Two-way tables on chlorophyll content b (mg g^{-1}) of seedlings five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	0.642	0.488
Njaval	0.452	0.342
Matti	0.563	0.434
Venga	0.606	0.480
Mean	0.566^{x}	0.436^{y}
$F_{CO2\ level}$ – 35.49**,SEm+/- =0.016		
$F_{interaction}$ – 0.17NS, SEm+/- =0.032		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	0.659	0.528
Njaval	0.460	0.368
Matti	0.571	0.438
Venga	0.632	0.484
Mean	0.581^{x}	0.455^{y}
$F_{CO2\ level}$ – 38.45**,SEm+/- =0.013		
$F_{interaction}$ – 0.36 NS, SEm+/- =0.026		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	0.646	0.455
Njaval	0.465	0.403
Matti	0.579	0.441
Venga	0.646	0.487
Mean	0.584^{x}	0.447^{y}
$F_{CO2\ level}$ – 43.75**,SEm+/- =0.016		
$F_{interaction}$ – 1.75 NS, SEm+/- =0.032		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	0.650^{ab}	0.465^{c}
Njaval	0.472^{c}	0.404^{c}
Matti	0.589^{b}	0.465^{c}
Venga	0.688^{a}	0.454^{c}
Mean	0.596^{x}	0.447^{y}
$F_{CO2\ level}$ – 68.33**,SEm+/- =0.013		
$F_{interaction}$ – 3.85*, SEm+/- =0.026		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 22 (a): Two-way tables on total chlorophyll content (mg g^{-1}) of seedlings of five tree species under two CO_2 concentrations

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	1.69^{a}	1.266^{cd}
Njaval	1.655^{a}	1.058^{e}
Matti	1.613^{a}	1.324^{bc}
Venga	1.457^{b}	1.155^{de}
Mean	1.60^{x}	1.20^{y}
$F_{CO2\ level}$ – 128.96**,SEm+/- =0.026		
$F_{interaction}$ – 4.06*, SEm+/- =0.051		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	1.715	1.224
Njaval	1.596	1.167
Matti	1.697	1.341
Venga	1.568	1.198
Mean	1.64^{x}	1.23^{y}
$F_{CO2\ level}$ – 93.72**,SEm+/- =0.03		
$F_{interaction}$ – 0.53NS, SEm+/- =0.06		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	1.725	1.212
Njaval	1.650	1.169
Matti	1.738	1.526
Venga	1.583	1.240
Mean	1.67^{x}	1.29^{y}
$F_{CO2\ level}$ – 66.64**, SEm+/- =0.03		
$F_{interaction}$ – 2.13 NS, SEm+/- =0.07		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	1.721	1.169
Njaval	1.672	1.372
Matti	1.765	1.505
Venga	1.646	1.419
Mean	1.70^{x}	1.37^{y}
$F_{CO2\ level}$ – 58.25**, SEm+/- =0.03		
$F_{interaction}$ – 2.85 NS, SEm+/- =0.06		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 22 (b): Two-way tables on total chlorophyll content (mg g^{-1}) of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	1.710	1.256
Njaval	1.630	1.325
Matti	1.829	1.419
Venga	1.701	1.329
Mean	1.72^{x}	1.33^{y}
$F_{CO2\ level}$ – 148.21**, SEm+/- =0.02		
$F_{interaction}$ – 0.99 NS, SEm+/- =0.04		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	1.731	1.314
Njaval	1.644	1.289
Matti	1.802	1.599
Venga	1.679	1.397
Mean	1.71^{x}	1.39^{y}
$F_{CO2\ level}$ – 57.64**, SEm+/- =0.03		
$F_{interaction}$ – 1.25 NS, SEm+/- =0.06		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	1.734^{b}	1.216^{e}
Njaval	1.520^{c}	1.296^{de}
Matti	1.853^{a}	1.653^{b}
Venga	1.752^{b}	1.371^{d}
Mean	1.71^{x}	1.38^{y}
$F_{CO2\ level}$ – 188.69**, SEm+/- =0.02		
$F_{interaction}$ – 9.45 **, SEm+/- =0.03		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	1.787^{b}	1.329^{d}
Njaval	1.607^{c}	1.358^{d}
Matti	1.923^{a}	1.686^{bc}
Venga	1.765^{b}	1.423^{d}
Mean	1.77^{x}	1.45^{y}
$F_{CO2\ level}$ – 159.03**,SEm+/- =0.02		
$F_{interaction}$ – 4.03*, SEm+/- =0.04		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

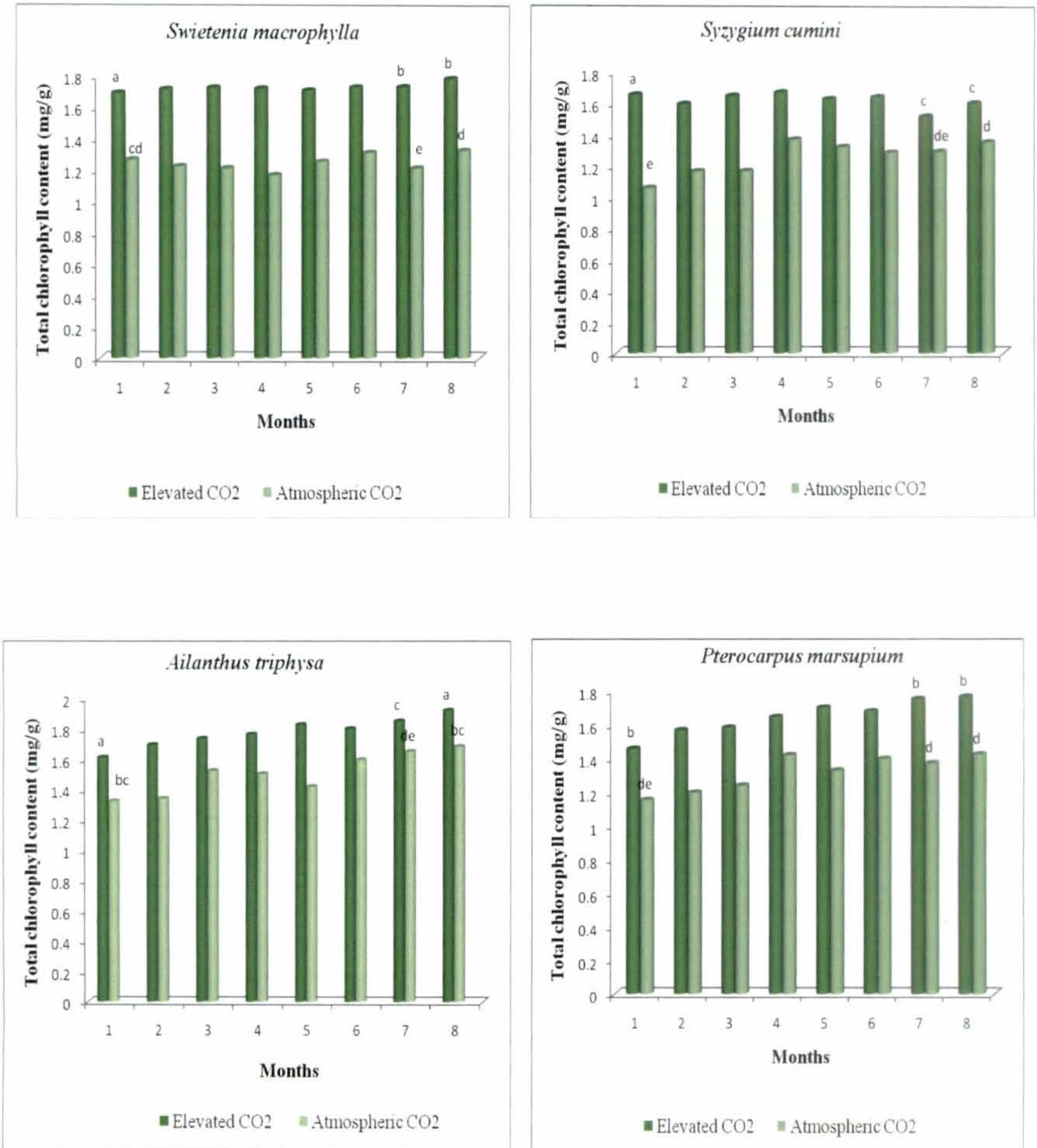

Figure 9. Response of five tree species on total chlorophyll content (mg g^{-1}) of seedlings under two CO_2 concentrations

Figures with the similar superscripts or no superscripts do not differ significantly.

4.5.2 Soluble protein content

The observations related to the soluble protein content of tree seedlings for different CO_2 concentrations is furnished in Tables 23 a and 23 b and Figure 9. The varying CO_2 concentrations showed significant effect on the soluble protein content of the tree seedlings in all months except in the sixth month. On the other hand, interactions between factors had significant impacts on the soluble protein content except in the third, sixth, seventh and eighth months.

Different CO_2 concentrations provided significant difference in the first month (Table 23 a) and the best performance was shown by seedlings under atmospheric CO_2 concentration with a mean value of 7.24 mg/g. In the same month the interactions showed significant effect. The highest soluble protein content was observed in matti seedlings with a significantly different value (8.84 mg/g) while lowest content was recorded in njaval seedlings (5.93 mg/g) both under atmospheric CO_2 concentration.

In the second month, the varying levels of CO_2 provided significant impacts on the soluble protein content. Among the interactions, the highest soluble protein content was observed in venga seedlings under elevated CO_2 concentration (8.19 mg/g). The njaval seedlings grown under elevated CO_2 concentration produced minimum amount of soluble protein (5.42 mg/g) with significant difference.

In the fourth month, when interaction was taken into consideration, the maximum amount of soluble protein was in matti seedlings (10.18 mg/g) under atmospheric CO_2 concentration while the lowest content was in mahogany seedling (6.40 mg/g) under elevated CO_2 concentration.

At the fifth month stage, the use of different CO_2 concentrations also proved to be significantly influencing the soluble protein content. Among interactions, matti seedlings produced maximum amount when soluble protein was measured (11.04 mg/g) under atmospheric CO_2 concentration. The seedlings of njaval under elevated CO_2 concentration recorded the lowest values (4.97 mg/g).

Table 23 (a): Two-way tables on soluble protein content (mg g^{-1}) of seedlings of *five tree species under two CO_2 concentrations*

Month 1

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	6.18^{e}	6.12^{e}
Njaval	6.11^{e}	5.93^{e}
Matti	6.83^{d}	8.84^{a}
Venga	7.33^{c}	8.06^{b}
Mean	6.61^{x}	7.24^{y}
$F_{CO2\ level}$ – 4.68*, SEm+/- =0.20		
$F_{interaction}$ – 3.01*, SEm+/- =0.41		

Month 2

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	5.47^{d}	5.99^{d}
Njaval	5.42^{d}	6.77^{c}
Matti	7.25^{bc}	7.91^{ab}
Venga	8.19^{a}	8.07^{a}
Mean	6.58^{x}	7.19^{y}
$F_{CO2\ level}$ – 14.70**, SEm+/- =0.11		
$F_{interaction}$ – 3.67*, SEm+/- =0.22		

Month 3

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	5.84	7.14
Njaval	5.27	6.32
Matti	7.36	9.42
Venga	6.94	9.09
Mean	6.35^{x}	7.99^{y}
$F_{CO2\ level}$ – 42.06**, SEm+/- =0.18		
$F_{interaction}$ – 1.18 NS, SEm+/- =0.36		

Month 4

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	6.40^{c}	8.12^{b}
Njaval	4.97^{d}	7.12^{c}
Matti	8.99^{b}	10.18^{a}
Venga	8.51^{b}	8.97^{b}
Mean	7.22^{x}	8.59^{y}
$F_{CO2\ level}$ – 45.72**, SEm+/- =0.14		
$F_{interaction}$ – 3.15*, SEm+/- =0.29		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

Table 23 (b): Two-way tables on soluble protein content (mg g^{-1}) of seedlings of five tree species under two CO_2 concentrations

Month 5

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	6.37^{d}	9.13^{bc}
Njaval	4.79^{e}	8.26^{c}
Matti	8.62^{bc}	11.04^{a}
Venga	8.93^{bc}	9.46^{b}
Mean	7.18^{x}	9.47^{y}
$F_{CO2\ level}$ – 85.47**,SEm+/- =0.18		
$F_{interaction}$ – 6.39**, SEm+/- =0.35		

Month 6

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	9.32	9.84
Njaval	6.91	7.35
Matti	10.52	11.64
Venga	9.14	9.98
Mean	8.97	9.70
$F_{CO2\ level}$ – 3.51NS,SEm+/- =0.28		
$F_{interaction}$ – 0.16 NS, SEm+/- =0.55		

Month 7

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	10.52	10.52
Njaval	7.48	8.47
Matti	11.51	12.57
Venga	9.22	10.89
Mean	9.68^{x}	10.61^{y}
$F_{CO2\ level}$ – 9.67**,SEm+/- =0.21		
$F_{interaction}$ – 1.34 NS, SEm+/- =0.42		

Month 8

Species	CO_2 levels	
	Elevated	Atmospheric
Mahogany	10.17	11.01
Njaval	8.17	9.12
Matti	11.68	13.14
Venga	9.88	10.25
Mean	9.98^{x}	10.88^{y}
$F_{CO2\ level}$ – 4.49*,SEm+/- =0.31		
$F_{interaction}$ – 0.28 NS, SEm+/- =0.60		

* - significant at 5 %, ** - significant at 1 %, NS – non-significant

Figures with the similar superscripts or no superscripts do not differ significantly.

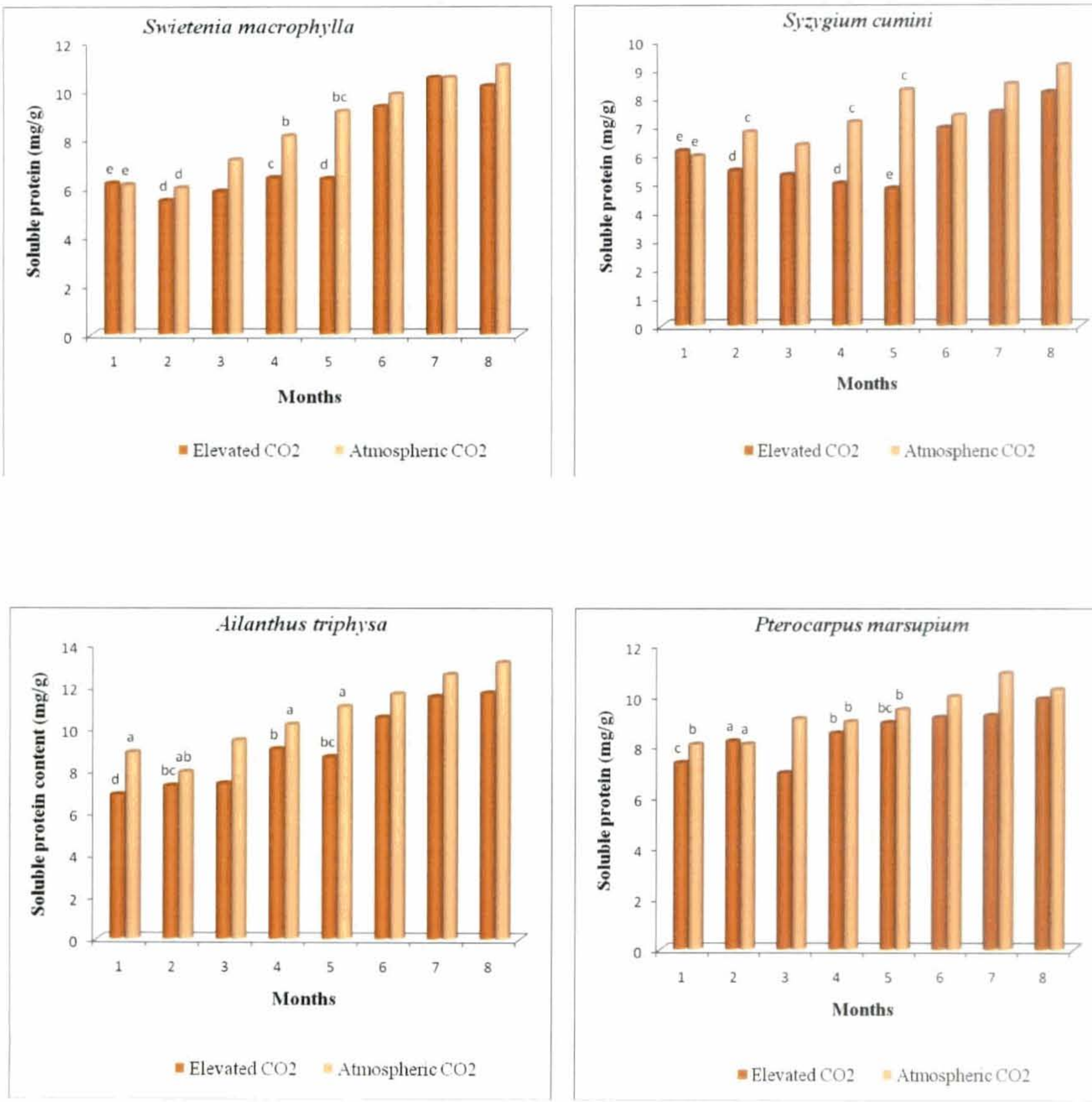

Figure 10. Response of five tree species on soluble protein content (mg g^{-1}) of seedlings und two CO_2 concentrations

Figures with the similar alphabets do not differ significantly

DISCUSSION

DISCUSSION

In plants, a higher level of CO_2 decreases the oxygen inhibition of photosynthesis and increases the net photosynthesis which results in increased growth rates. Plants respond positively to CO_2 enrichment through increased plant height, number of leaves, leaf area, dry weight and lateral branching. Plant quality expressed by growth habit and seed production is also often enhanced by CO_2 enrichment. The rooting of cuttings is also stimulated by high CO_2 levels. So, CO_2 fertilization under a controlled environment can be an important technique to produce healthy and vigorous nursery stock. In forestry programmes, CO_2 enrichment can be exploited for mass production of healthy tree seedling in a shorter time span. Hence, the present study was conducted at College of Forestry, Vellanikkara during the period 2008-2010 with the objective of understanding the growth responsiveness of five selected tropical tree seedlings to two CO_2 levels. The salient findings of the studies are discussed hereunder

5.1 Growth parameters

5.1.1 Height and collar diameter

From the experiment exposing seedlings of five tree species to elevated (500-550 ppm) and atmospheric (370-380 ppm) CO_2 concentrations, it was obvious that seedlings under elevated CO_2 level had greater height throughout the study period (Figure 3). Seedlings of all tree species raised under elevated CO_2 showed significantly higher shoot growth than that under atmospheric CO_2 concentration (Table 1 a and b). The enhanced shoot growth among the seedlings is most likely through the increased uptake of more CO_2. The shoot growth enhancement is a possible outcome of the plants physiological reactions *viz.,* photosynthesis, respiration and carbon allocation. Both carbon assimilation and carbon allocation are significantly higher in seedlings under elevated CO_2 level; these factors increase the height of plants (Johnsen and Major, 1998). Wang et al. (2003) also has proved that height growth of pinus seedlings at elevated CO_2 increased by 10 - 40 per cent compared to those grown at ambient CO_2. Seedlings of *Garcinia gummi-gutta* raised under elevated CO_2 and supplemented with nutrients and hormones also recorded a significant increase in plant height and stem diameter (Jagadish et al., 2008). Similarly, other workers like Norby et al. (1992) and Radoglou and Jarvis (1990), have also reported stimulation of plant height on cuttings and seedlings of woody plants. In the present study, a review of nursery studies (Rajesh, 1996; Adersh, 2001; Girijapushpam, 2004) of all the tree seedlings conducted in the same location also showed an average one third increase in height of seedlings kept under elevated CO_2 concentration

In the present study (Figure 4), an increased CO_2 concentration also contributed to a significant difference in collar diameter among seedlings of all five tree species (Table 2 a and b). Elevated CO_2 concentration produced higher increment in collar diameter of seedlings. It is based on the assumption that high carbon uptake accelerate the assimilation rate and rate of translocation into shoot portion. Hence, collar diameter could be a good correlate of aboveground biomass in our study. Our observation is in line with the findings observed in *Pinus taeda*, where elevated CO_2 increased the basal area by 13-27 per cent (Moore et al., 2006). Likewise, in another study, exposure of the hybrid poplar clone 'Primo' (*Populus deltoides* x *Populus nipa*) to doubled CO_2 significantly increased the stem diameter compared with trees grown in ambient CO_2 concentrations (Gardner et al., 1995).Thus in the present study, collar girth was enhanced better under CO_2 enriched condition probably because of the better carbon assimilation and accumulation strategy achieved by the seedlings.

5.1.2 Leaf production

In the present study, CO_2 concentrations had a significant impact on the leaf production (Table 3 a and b). Leaf number was consistently higher in seedlings under elevated CO_2 concentration (Table 3 a and b). The result of the present study is similar to the findings of Jagadish et al. (2008) who reported that the leaf area and leaf number increased in *Garcinia gummi-gutta* seedlings exposed to elevated CO_2 level. Seedlings of birch species also showed better leaf growth parameters including number of leaves and leaf area at enriched CO_2 conditions (Rochefort and Bazzaz, 1992). Production rate of leaves is linked with extension of the main stem, since plant height is significantly increased in elevated CO_2 condition (Bosac et al., 1995).

In our study also, a higher shoot growth (Table 3 a and b) achieved might have accelerated higher leaf production under enriched CO_2 conditions. This also is an offshoot of better carbon assimilation and carbon allocation under increasd CO_2 level.

5.1.3 Root length

Root length was found to be significantly high under enriched CO_2 condition among seedlings of all the species (Table 4 a and b). Many workers like Hou Ying et al. (2008) and Pritchard et al. (2001, 2008) have reported an increased root length under higher CO_2 levels. Elevated CO_2 could influence root growth through effects on both cell division and expansion (Bosac et al., 1995). Under higher CO_2 levels there is a reduction in the cell wall extensibility (plasticity) which created more cells and hence more cell walls in the segment of roots. Taylor et al. (2001) also found out increased cell wall loosening and extensibility at elevated CO_2 concentration. An increase in root branching was observed in seedlings under elevated CO_2 level (Rogers et al., 2006). It can be concluded that tree seedlings at higher CO_2 condition showed better root elongation because of an increase either in root branching or in cell division or both.

5.2 Biomass production

Above-ground growth is perhaps the most obvious manifestation of the effect of CO_2 on trees. In the present study the shoot and root biomass production was significantly stimulated under higher CO_2 concentrations (Tables 5 a and 5 b, 6 a and 6b, 7 a and 7 b, 8 a and 8b and 11a and 11b). In this experiment, seedlings might have made use of higher CO_2 for carbon assimilation during day time. Through an increased carbon uptake, total growth of seedlings got enhanced under elevated CO_2 concentration. A higher biomass production (Figure 5) could be the result of an enhanced photosynthesis (Figure 8). An increased amount of biomass is partitioned into different plant structures, leading to distinctive root/shoot balances (Norby et al, 1999). In addition, trees exposed to elevated CO_2 need less enzymes, lower quantities of leaf proteins, lose less water (less soil moisture) and need less light(shift in light compensation point of photosynthesis) (Korner, 2000). These factors might also have accelerated the shoot and root drymatter production in the present study. It is possible to increase the biomass production by plants under elevated CO_2 condition (Kimball, 1983; Cure and Acock, 1986; Bazzaz et al., 1990). The experiments with conifers and broadleaf trees at a higher concentration of CO_2 recorded increases in dry matter production within the range 20-120 per cent (Jarvis, 1989). Devakumar et al. (1996) reported a positive response to biomass production among various tropical tree species, though the extent of response varied with species. Nursery seedlings of *Hevea brasiliensis* also showed higher drymatter production under CO_2 fertilization (Devakumar et al., 1998). Similarly, *Abies faxoniana* seedlings under elevated CO_2 concentration showed increased total biomass (Yun Zhou et al., 2008). Seedlings of *Populus tremuloides* and *Betula papyrifera* also showed growth enhancement under elevated CO_2 (Isebrands et al., 2001; Percy et al., 2002). Such an increase in biomass production is largely due to higher photosynthetic rate, lower rate of respiration and photorespiration observed in plants kept under elevated CO_2 concentration. All these factors also might have influenced the shoot and root biomass produced in the present study.

Increased carbon allocation in the belowground biomass has been observed at elevated atmospheric CO_2 concentrations for a number of tree species (Pritchard et al. 2001). In trees the production and mortality of fine roots under CO_2 enrichment were significantly increased (Pregitzer et al., 2008). *Betula albosinensis* seedlings also showed 10-22 per cent increased root production under elevated CO_2 concentration (HouYing et al., 2008). A similar observation was obtained in *Pinus ponderosa* under enriched condition (Tingey et al., 2000). In the present study also, under elevated CO_2 concentration the shoot as well as root biomass production was significantly increased due to higher carbon uptake followed by increased carbon allocation in the below ground biomass. Based on the nursery studies of tree seedlings conducted by Rajesh (1996) and Adersh (2001) in different potting media we can conclude that tree seedlings under elevated CO_2 concentration showed two fold increases in total drymatter at the end of the study period. Hence, CO_2 fertilization can considerably reduce the time and cost of production of tree seedlings in the nursery. However, the shoot: root ratio was statistically not significant during the study period (Table 10 a and b). This non effect could be due to the equal partitioning of drymatter in shoot as well as in root. This is supported by the findings of Saxe et al. (1998) and Stulen and den Hertog (1993).

5.3 Physiological parameters

The two CO_2 levels did not influence any significant changes (Table 12 a and b and Table 13 a and b) in relative growth rate (RGR) and net assimilation rate (NAR) of seedlings. However, CO_2 concentrations had significant influence on other physiological attributes such as leaf area, specific leaf area (SLA), Leaf area ratio (LAR), Leaf weight ratio (LWR) and stomatal number.

The seedlings of all species raised under elevated CO_2 level recorded significantly higher leaf area (Table 14 a and b) (Figure 6). Elevated CO_2 generally promotes an increase in leaf area of most tree species (Norby et al., 1992; Mousseau, 1993). An increase in total leaf area in tree seedlings under CO_2 enrichment resulted due to higher numbers of leaves (Table 3 a and b) and larger individual leaf area. Leaf expansion under CO_2 enrichment was related to changes in the biochemical and biophysical properties of the cell wall. In *Populus* grown under elevated CO_2 concentration, the cell wall extensibility of rapidly growing leaves increased due to an increase in xyloglucan endotransglycosylase activity, a cell wall loosening enzyme, associated with leaf growth rate (Ferris et al. 2001). In addition, an increase in individual leaf area might be the result of an increase in the number of cells (Gaudillere and Mousseau, 1989) or a greater rate of leaf cell expansion through changes of cell wall properties (Taylor et al., 2000). Accelerated rate in both cell production and cell expansion may also contribute to enhance leaf growth in elevated CO_2. Ranasinghe and Taylor (1996) have shown that increased final cell size may be of more importance. Higher leaf area increases plants capacity to take up CO_2 and make more stem and leaf tissue, which further increases their capacity to take up CO_2 and grow. As long as there are no constraints on leaf area production, spectacularly large CO_2 responses can occur (Ceulemans and Mousseau 1994; Norby et al., 1996). In our case too, higher number of leaves and accelerated rate of cell production and cell division could increase leaf area of seedlings under elevated CO_2 concentration.

Specific leaf area (SLA) describes the efficiency with which the leaf captures light relative to the biomass invested in the leaf. It describes whether the leaf is thicker or heavier. Specific leaf area (SLA) was significantly different in two CO_2 levels only in the first two months (Table 15 a and b). In general, elevated CO_2 did not show any significant change in SLA during the study period. This agrees with the findings of Roumet et al. (1996) who did not notice any changes in SLA and leaf thickness in FACE experiments with trees. It might be because of the non-accumulation of TNC (total non-structural carbohydrate) in leaves. On contradictory, there is a large body of literature which reported that SLA decreases in elevated CO_2 (Gardner et al., 1995; Norby et al., 1999). However, in our case more detailed observation is needed to find out the clear cause of the non-effect.

In the present study, leaf weight ratio (LWR) was significantly higher under elevated CO_2 concentration (Table 17 a and b). Leaf weight ratio (LWR) is the ratio of leaf drymatter to total plant drymatter and reflects the allocation of biomass to foliage. This was found to increase significantly in plants grown under elevated CO_2 concentration. Such an increase in LWR is an indication of allocation of higher biomass to photosynthetic surface area. This view point is supported by the findings of Devakumar et al. (1998) in *Hevea brasiliensis* seedlings. In the present study, LWR in seedlings increased with CO_2 enrichment probably due to higher efficiency of the photosynthetic apparatus to use the substrate available for photosynthesis. It could be correlated with the up regulation of the photosynthetic rates (Figure 8) as observed in seedlings that were under elevated CO_2 level.

Elevated CO_2 recorded higher leaf area ratio (LAR) for all seedlings only in the first month (Table 16 a and b). As leaf area ratio (LAR) is the product of the specific leaf area (SLA) and the leaf weight ratio (LWR) *i.e.* LAR was affected similarly as the SLA. Generally in the present study, LAR did not significantly differ in the tree seedlings under elevated CO_2. Previous studies also showed that elevated CO_2 either decreases or had no effect on leaf area ratio (Luo et al., 1998; Norby et al., 1999). LAR reflects the size of photosynthetic surface relative to the plant drymatter. Thus it can be concluded from the present study that seedlings under higher CO_2 level allocated resources to leaf production in proportion to the total plant weight.

The stomata of leaves are the channels through which the plant interacts with the atmosphere directly: gases diffuse inward and outward, water is lost to the air. The stomata open and close in response to various stimuli and physiological states of the plant, including internal vs. external gas concentrations, water stress, heat stress, and pollutants. In the present study too, two CO_2 levels induced significant effect on stomatal number (Figure 7). Reduction in stomatal number/density was observed in seedlings kept under elevated CO_2 concentration. Stomatal number was reported to reduce in plants grown under elevated CO_2 concentration (Woodward and Bazzaz, 1988; Paoletti et al., 1997). Similarly, plants grown under elevated CO_2 concentration were reported to have reduced stomatal conductance and decreased transpiration rate (Medlyn et al., 2001; Woodward, 2002). The density of stomata has been shown in many cases to reflect important changes in atmospheric composition, as well as other kinds of environmental stresses. Hence, it is argued that as the plants under enriched CO_2 concentration did not experience water stress, the lower stomatal density observed in our study might be due to wider and thinner leaves on which the stomata were less densely packed.

5.3.1 Rate of photosynthesis

Rate of photosynthesis was also found to be affected by two CO_2 levels (Table 19 a and b). Photosynthesis rate was always found to be lower in atmospheric CO_2 concentration (Figure 8). Numerous experiments showed that higher atmospheric CO_2 concentration leads to increases in photosynthetic rate and whole-plant growth in many C_3 species, (Idso and Idso, 1994; Ghannoum et al., 2000; Griffin et al., 2000; Gunderson et al., 2000; Jach and Ceulemans, 2000; Watling et al., 2000; Finzi et al., 2001and Hymus et al., 2001). Norby et al. (1999) reported on an average 60% enhancement of photosynthesis for trees exposed to elevated CO_2 concentration. However, the responses vary considerably between species (Naumburg et al., 2001). Seedlings of *Garcinia gummi-gutta* showed higher photosynthesis at elevated CO_2 concentration (Jagadish et al., 2008). Carbon assimilation rate increases with increasing intercellular CO_2 partial pressure. The direct increase in photosynthesis due to CO_2 elevation results from two properties of Rubisco enzyme i.e., the K_m of the enzyme for CO_2 is close to the current atmospheric concentration, so elevated CO_2 increases the velocity of carboxylation and CO_2 competitively inhibits the oxygenation reaction, which produces glycolate leading to photorespiration (Long et al., 2004). In the short term, plants sense and respond directly to rising CO_2 exclusively through direct effects of increased carboxylation by Rubisco and decreased stomatal opening (Long et al., 2004). Hence, in the present study also enriched CO_2 concentration may have provided the positive significant increase on the photosynthetic rate of tree seedlings through higher leaf area and increased activity of Rubisco enzyme.

5.4 Chlorophyll content

In the present study chlorophyll a content was significantly affected by different levels of CO_2 only in the two months (Tables 20 a and 20 b). Chlorophyll b content was significantly higher in the eighth month of study (Tables 21 a and 21 b). Total chlorophyll content also showed significant difference among species towards the end of the study period (Tables 22 a and 22 b and Figure 9). An increase in chlorophyll content could be observed in seedlings kept under elevated CO_2 compared to seedlings grown in atmospheric CO_2 concentration. Enriched CO_2 condition showed an increase in chlorophyll concentration in seedlings of olive trees (Melgar et al., 2008). Roden and Ball (1996) also noticed a positive response in chlorophyll content in eucalyptus species under elevated CO_2 concentration. Higher chlorophyll content results in increased photosynthetic efficiency. It helps the plant to harvest maximum light for photosynthesis. Higher carboxylation efficiency enables higher biomass production which makes the plants more competent in the changing environment. In the present study too, elevated CO_2 concentration has a positive effect on chlorophyll content of the tree seedlings in order to increase the photosynthetic efficiency of the seedlings to utilize the increased CO_2 concentration.

5.6 Soluble protein synthesis

The two CO_2 treatments showed a significant difference in leaf soluble protein content among the seedlings (Figure 10). Under elevated atmospheric CO_2 concentration, there was a reduction in leaf soluble protein content in all species (Table 23 a and b). A similar reduction in leaf soluble protein was observed in birch

(*Betula pendula*) trees grown in elevated atmospheric CO_2 concentration (Rey and Jarvis, 1998). Huttunen et al. (2008) also reported decreased leaf protein content in silver birch seedlings (*Betula pendula*) under higher CO_2 concentration. Plants normally adapt to any stress through response mechanisms including changes in protein content. Reduction in soluble proteins at higher CO_2 concentration reflects the acclimation of plant photosynthetic machinery to more efficient carboxylation by Rubisco (Rey and Jarvis, 1998). In our study too, overall the soluble protein content was consistently, lesser in elevated CO_2 concentration. The seedlings might have reduced soluble protein content in order to affect better carboxylation by Rubisco enzyme. However, more detailed study is required to confirm this conclusion.

In addition to an increase in carbon dioxide concentration, there was also a substantial increase in relative humidity (Figure 2a) and about 0.5 - 1^0C of temperature (Figure 2b) in the CO_2 trapping trenches. Any of these factors could be reasonably expected to influence the response of seedlings to CO_2. Hence, this interaction deserves more pertinent attention in future studies.

The demand for seedlings for reforestation programs will substantially increase from year to year, and nurseries will have to provide large numbers of healthy seedlings in a very short time frame. Moreover, reforestation practitioners are increasingly demanding seedlings better adapted to the environmental conditions where reforestation is going to be carried out. The present study reveals that a higher CO_2 level has a favourable effect on the various growth indices of these economically important tree species. The trench method which was adopted for this study is a viable nursery technique to produce healthy tree seedlings in a shorter time period. The increase in shoot and root biomass and higher photosynthesis rate gained under higher CO_2 level may help to easily produce healthy seedlings that are also better adapted to face stress after transplant.

One of the limitations of the study observed during the period was the less spacing between polybag seedlings kept inside the trenches. So, mutual shading occurred due to the overlapping of leaves which might have negatively influenced seedlings growth

Future line of work

1. Photosynthetic active radiation (PAR) can be measured to find out the light availability inside the chamber

2. Methods can be adopted to apply various shade levels in order to find out the growth and physiology of the different tree seedlings inside the chamber.

3. The role of higher temperature and relative humidity inside the chamber on growth of the seedlings has to be examined in detail for more information.

4. Influence of quality potting mixture under elevated CO_2 need to be studied for rapid production of seedlings for eventual field planting

SUMMARY

SUMMARY

The research programme entitled "Effect of elevated CO_2 concentration on growth and physiology of selected tropical tree seedlings." was carried out during 2008-2010 in the College of Forestry, Vellanikkara. The salient findings from the study are highlighted below.

1. The two levels of CO_2 concentrations had significant impact on height and collar diameter of all the five tree seedlings throughout the study period. Tree seedlings under elevated CO_2 concentration put in more height and collar diameter than the seedlings under atmospheric CO_2. The maximum gain was observed in seedlings of venga (*Pterocarpus marsupium*) under enriched CO_2 condition. Njaval (*Syzygium cumini*) seedlings under atmospheric CO_2 concentration recorded the lowest height. With regards to the collar diameter, teak (*Tectona grandis*) seedlings performed best under elevated CO_2 concentration and njaval (*Syzygium cumini*) seedlings performed least under atmospheric CO_2 concentration.

2. CO_2 treatments induced significant difference on leaf number and leaf area of all the five tree seedlings. Higher leaf production and larger leaf area were recorded in seedlings under elevated CO_2 concentration. Among interaction, maximum number of leaves was recorded in njaval (*Syzygium cumini*) seedlings grown under elevated CO_2 concentration and matti (*Ailanthus triphysa*) seedlings produced the minimum under atmospheric CO_2 concentration. The maximum leaf area was observed in teak (*Tectona grandis*) seedlings under enriched CO_2 condition. The lowest leaf area among the five tree species was obtained in njaval (*Syzygium cumini*) seedlings under atmospheric CO_2 concentration.

3. The CO_2 concentrations significantly affected root length production throughout the study period. The longest root was observed in seedlings grown under elevated CO_2 concentration. Seedlings of teak (*Tectona grandis*) grown under elevated CO_2 concentration had the longest roots

due to interaction. However, njaval (*Syzygium cumini*) seedlings grown under atmospheric CO_2 levels recorded lowest root length.

4. The various CO_2 levels significantly influenced dry as well as fresh weights of shoot and root portions. Interaction had a significant impact on all the parameters. Teak (*Tectona grandis*) seedlings under elevated CO_2 concentration recorded the maximum fresh weight and dry weight of shoot and root. Njaval (*Syzygium cumini*) seedlings under atmospheric CO_2 concentration recorded the lowest fresh weight and dry weight of shoot and root at the end of the study period.

5. The different levels of CO_2 showed significant effects on the total dry matter content. The maximum dry matter was seen in teak (*Tectona grandis*) seedlings grown under elevated CO_2 concentration while njaval (*Syzygium cumini*) seedlings under atmospheric CO_2 concentration showed lowest performances.

6. The different CO_2 treatment did not significantly affect the relative growth rate (RGR) and net assimilation rate (NAR) of seedlings.

7. Tree seedlings under two different CO_2 levels did not show significant differences with respect to specific leaf area (SLA) and the leaf area ratio (LAR). However, both CO_2 levels showed significantly different impact on the leaf weight ratio (LWR) of seedlings. The highest LWR was observed in the teak (*Tectona grandis*) seedlings under elevated CO_2 concentration. The lowest LWR was for venga (*Pterocarpus marsupium*) seedlings kept under elevated CO_2 concentration.

8. CO_2 levels had significant effect on number of stomata in seedlings. Seedlings under elevated CO_2 recorded lowest number of stomata compared to seedlings under atmospheric CO_2 concentration. The maximum gain was observed in mahogany (*Swietenia macrophylla*) seedlings under atmospheric CO_2 condition. The least stomatal count was

obtained in njaval (*Syzygium cumini*) seedlings under enriched CO_2 concentration.

9. The varying CO_2 concentrations showed significant effect on the rate of photosynthesis of the tree seedlings. Matti (*Ailanthus triphysa*) seedlings under elevated CO_2 concentration had the best performance while njaval (*Syzygium cumini*) seedlings under atmospheric CO_2 concentration had the lowest photosynthetic rate at the end of the study period.

10. Chlorophyll a and Chlorophyll b in tree seedlings was not significantly different under two CO_2 concentrations. However, total chlorophyll content showed significant influence. The maximum total chlorophyll content due to interaction was observed in matti (*Ailanthus triphysa*) seedlings under elevated CO_2 concentration while the minimum value was observed in mahogany (*Swietenia macrophylla*) seedlings under atmospheric CO_2 concentration in the last month.

11. The varying CO_2 concentrations showed significant effect on the soluble protein content of the tree seedlings. Seedlings under elevated CO_2 recorded lowest soluble protein content compared to seedlings under atmospheric CO_2 concentration. In interactions, the maximum amount was observed in matti (*Ailanthus triphysa*) seedlings under atmospheric CO_2 condition. The minimum amount was obtained in njaval (*Syzygium cumini*) seedlings under enriched CO_2 concentration.

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APPENDIX

Appendix- I

Weather data of Vellanikkara (2009 July to 2010 April)

Element	Year 2009						Year 2010					
	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Relative humidity (%)	86.5	85.5	81	80	72	62	57	63.5	63	70		
Rain fall(mm)	686.9	454.2	245.6	302.1	104.4	17.8	1.9	3.9	6.6	68.8		
Rainy days	24	21	12	13	5	1	0	0	0	4		
Sunshine hours	3	3.8	5.9	5.9	7	8.5	9	9.3	9.2	8.5		
Maximum temperature (^{0}C)	29.0	29.3	30.5	31.1	31.7	31.7	32.8	34.8	36.1	35.4		
Minimum temperature (^{0}C)	22.9	23.1	23.2	23.0	22.8	22.5	22.2	22.6	23.9	25.1		

EFFECT OF ELEVATED CO_2 CONCENTRATION ON GROWTH AND PHYSIOLOGY OF SELECTED TROPICAL TREE SEEDLINGS

By

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ABSTRACT OF THE THESIS

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ABSTRACT

The present study entitled "Effect of elevated CO_2 concentration on growth and physiology of selected tropical tree seedlings." was carried out in College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur during the period 2008-2010.

There are references that elevated CO_2 typically increases tree seedling growth and has also modified physiological processes. Polybag seedlings of five economically important tree species were exposed to 500-550 ppm CO_2 concentration and another similar set of plants were raised under ambient atmospheric CO_2 condition (370-380 ppm). The growth rates and physiology were observed for eight months. Tree seedlings under elevated CO_2 concentration put in more height and collar diameter than the seedlings under atmospheric CO_2.A higher leaf production and larger leaf area was recorded in seedlings under elevated CO_2 concentration. The different levels of CO_2 also showed significant effects on the total dry matter content. However, interactions between two CO_2 levels and five tree seedlings had no significant impact on the shoot: root ratios throughout the study period.

The different CO_2 treatment did not significantly affect the relative growth rate (RGR), net assimilation rate (NAR), specific leaf area (SLA) and the leaf area ratio (LAR) of seedlings. However, both CO_2 levels showed significantly different impact on the leaf weight ratio (LWR) of seedlings. Seedlings under elevated CO_2 recorded lowest number of stomata compared to seedlings under atmospheric CO_2 concentration. The varying CO_2 concentrations showed significant effect on the rate of photosynthesis of the tree seedlings. Chlorophyll a and Chlorophyll b in tree seedlings was not significantly influenced under different CO_2 concentrations. However, total chlorophyll content showed significant influence. Seedlings under elevated CO_2 recorded lowest soluble protein content compared to seedlings under atmospheric CO_2 concentration. Hence, CO_2 enrichment technique can be used as an economically viable nursery technology for production of more healthy and vigorous planting stock to meet the increasing demand for social forestry /agro forestry programme.