Article

Effect of elevated carbon dioxide concentration on photosynthetic and transpiration rate in Sandal (*Santalum album* L.)

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Abstract

Sandalwood (*Santalum album* L.) belongs to family Santalaceae. It has gained prominence over other tree species, because of high demand for heartwood and essential oil, to fulfill the increasing demand it is needed to achieve fast growth of the seedling in the nursery stage and as well in the planted site. In the present study the response of elevated carbon dioxide concentration on photosynthetic and transpiration rate in sandal was assessed with the following treatments control (ambient condition), elevated CO_2 treatment with FYM (i.e., 3, 6, 9, 12 and 15 kg of FYM) and elevated CO_2 treatment with no FYM. The morphological parameters such as plant height, collar diameter, and number of leaves, leaf area, seedling biomass; physiological parameter such as photosynthetic rate, transpiration rate, and stomatal conductance were recorded at 120 days. Growth parameters found to be higher in the treatment of elevated CO_2 with 15 kg FYM such as seedling height (26.32 cm) and leaf area per plant (247.84 cm^2) compare to the other treatments. Photosynthetic rate (19.66 μ mol. m^{-2} s^{-1}), transpiration rate (3.04 m mol. m^{-2} s^{-1}) and stomatal conductance (0.30 m mol. m^{-2} s^{-1}) was found maximum in 15 kg FYM treatment.

Keywords *Santalum album*; elevated carbon dioxide; photosynthetic rate; transpiration rate.

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1 Introduction

Sandal (*Santalum album* L.) belongs to the family Santalaceae which is economically important and widely distributed genus *Santalum* comprises of 16 species (Ansari et al., 2007). The species is traditionally and commercially popular for its heartwood in which the essential oil is extracted, due to its religious significance and high santalol content is acclaimed as the most economically important of all *Santalum* species (Srinivasan et al., 1992; Jeeva et al., 1998; Mc-Comb and Jones, 1998; Radomiljac et al., 1999). Apart from many customary uses, the scented wood is suited for creating exquisite handicrafts, whereas the oil has well known applications in perfumery and pharmaceutical industries (Srinivasan et al., 1992). *Santalum album* grows in a wide range of temperature, tropical and subtropical regions of India, Sri Lanka and Indonesia (Mc-Comb and Jones, 1998). Sandal is a threatened species indigenous to peninsular India and is naturally distributed over 9600 Km^2 (Srinivasan et al., 1992; Radomiljac et al., 1998), from Kerala in the South to Uttar Pradesh in the North. Naturally it occurs extensively up to 700 m elevation in Southern States of India such as Karnataka, Tamil Nadu and Andhra Pradesh (Kushalapa, 1999). About 90 per cent of sandal is distributed in Karnataka and Tamil Nadu (Jeeva et al., 1998). In Karnataka it is distributed most widely in Coorg and Mysore district. *S. album* is a prized gift of the plant kingdom woven into the culture and heritage of India. It is one of the most valuable trees in the world (Fox, 2000). The tree is a root parasite.

In the wake of global climate change, there is increase in carbon dioxide concentration in the atmosphere (Zhang and Liu, 2012). Currently carbon dioxide concentration is around 350 ppm and it is increasing at the rate of 1.8 ppm per year (IPCC, 2007). The increased carbon dioxide concentration in the atmosphere has influence on ecosystem has inculcated a great deal of research during last two decades. When plants are exposed to elevated carbon dioxide concentration, growth and productivity increases substantially, especially in C_3 species. Hence identifying tree species that respond to elevated carbon dioxide concentration is important to mitigate the raise of important greenhouse gas of the atmosphere. Plant growth and development depends on its genetic traits and the environmental condition in which it grows. The total biomass production of the plant is mainly governed by photosynthesis. One of the major environmental factors that affect the photosynthesis and thus the biomass production is the ambient CO_2 concentration. It is possible to increase the biomass production by CO_2 fertilization (Nataraja, 1991 and Bowes, 1993). Keeping this in view a study was carried out to assess the influence of elevated carbon dioxide concentration on photosynthetic and transpiration rate in sandal.

2 Study Area

The present study was carried out at College of Forestry, Sirsi in Uttara Kannada district located in the hilly zone (Zone-9) of Karnataka state, in the Central Western Ghats, during 2012-13.

3 Material and Methods

3.1 Plant material

Sandal seedlings were grown in polythene bags under elevated carbon dioxide concentration obtained from decomposition of FYM was adopted. 10 polybag seedling of each treatment is exposed to elevated carbon dioxide concentration for a period of 120 days. The plants were watered twice a day to maintain the soil water status at field capacity.

One year old seedlings which were established in the polybags were used for the study. Seedlings were kept inside the trenches for exposing them to elevated carbon dioxide concentration. Rectangular trench of 1.5m length, 1.2m width and 0.5m depth were dug in place well exposed to sun light. A rectangular bamboo frame was placed over the trench completely enclosing it. Height of the frame was 1.6m with a gable roof. Using high density polythene sheet of 125 micron gauge, a cover was tailored to suit the size of the bamboo frame. Length of the polythene cover was 10 inches longer than the frame so, as to allow a free and flat fall on the ground after enclosing the bamboo frame. On this free lying polythene, a thin layer of sand was poured to keep the complete system air tight.

FYM was put in the trenches as per treatments. Seedlings were exposed to elevated carbon dioxide between 4pm and 11am. Before closing the trenches water was sprinkled on the FYM to stimulate soil respiration. Polybag seedlings were also watered before closing the chamber. Control plants were also kept in another trench for maintaining identical growth conditions.

3.2 Measurement of photosynthetic rate, transpiration rate and stomatal conductance

To assess the elevated CO_2 concentration on photosynthesis and transpiration rate in sandal seedlings were carried out by observing morphological parameters such as seedling height, collar diameter, number of leaves and leaf area per plant and physiological parameters such as photosynthetic rates, transpiration rate and stomatal conductance were measured using Portable Photosynthesis System (PPS, model LCpro + photosynthesis system CO_2 gas analyzer, UK) and expressed as m mol. m^{-2} s^{-1} (Nataraja et al., 1998).

3.3 Experimental design

The experiment was laid out in Completely Randomized Design (CRD) following the principles of replication and randomization, due to similarity in variation gradient. There were seven treatments consisting of seedling exposed to ambient conditions (Control), elevated CO_2 with 3, 6, 9, 12 and 15 kg FYM spread uniformly all along the floor. The experimental data was analyzed statistically by adopting CRD design (Kothari, 2012). The level of significance used was P = 0.05. The mean, standard error (S.Em.±) and CD at 5 per cent probability was calculated using M-STAT C program.

4 Results and Discussion

The sandal seedling exposed to elevated carbon dioxide concentration were evaluated by measuring the morphological and physiological character such as photosynthesis rate (A), transpiration rate (E) and stomatal conductance (g_s) where depicted in the Table 1; Fig. 1 & 2.

Table 1 Morphological parameters of sandal seedlings at 120 days after planting.

Treatments	Seedling height (cm)	Collar diameter (mm)	Number of leaves per plant	Leaf area (cm^2) per plant	Root fresh weight (g)	Shoot fresh weight (g)	Root dry weight (g)	Shoot dry weight (g)
T_1 (Control)	23.02	3.07	13.38	181.84	1.50	4.20	0.89	1.25
T_2 (FYM 0 kg)	23.48	3.25	14.34	202.75	2.80	5.23	1.30	2.13
T_3 (FYM 3 kg)	24.13	3.89	14.88	214.25	3.35	4.83	1.68	2.24
T_4 (FYM 6 kg)	24.88	4.13	15.13	220.00	2.75	6.75	1.92	2.10
T_5 (FYM 9 kg)	25.16	4.38	15.68	226.36	5.75	4.83	2.58	4.25
T_6 (FYM 12 kg)	25.71	4.56	16.03	231.16	3.08	7.88	1.45	3.43
T_7 (FYM 15 kg)	26.32	4.71	16.94	247.84	4.30	12.13	1.28	5.53
Mean	24.67	4.00	15.20	217.74	3.36	6.55	1.58	2.99
SEm±	0.71	0.21	0.55	9.75	0.14	0.19	0.14	0.10
C.D (5%)	2.10	0.62	1.61	28.69	0.42	0.55	0.40	0.30

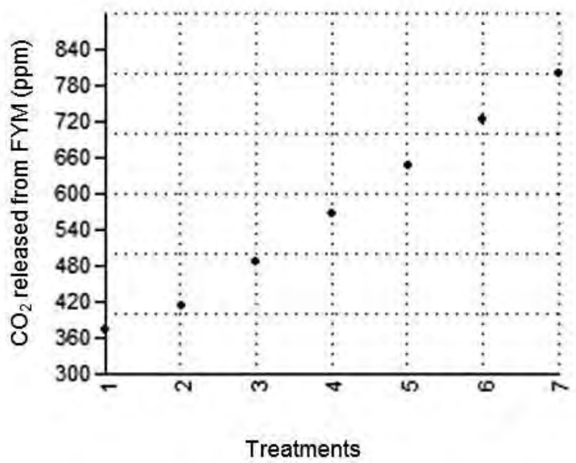

Fig. 1 CO_2 released from FYM (ppm) in different treatments.

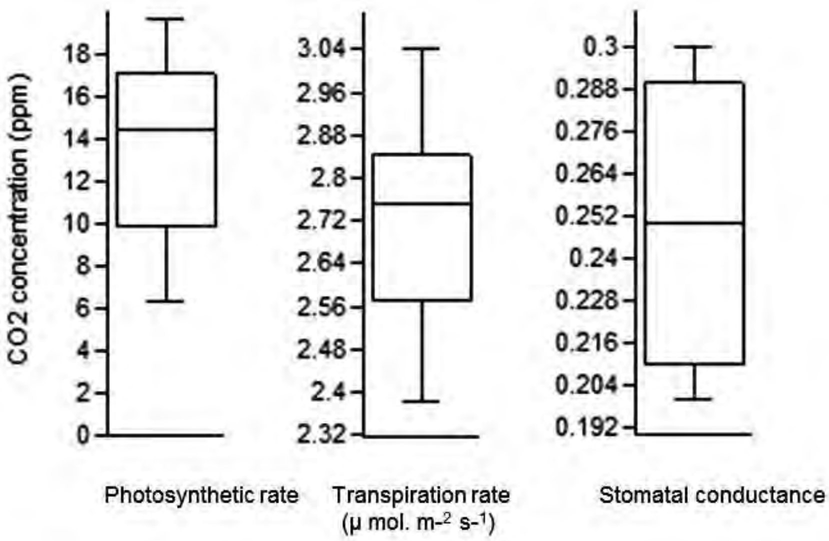

Fig. 2 Physiological response of sandal seedlings for elevated CO_2.

The data pertaining to the morphological traits at 120 days after planting was significantly differed among all the treatment. However, maximum seedling height (26.32 cm), collar diameter (4.71 mm), number of leaves (16.94) and leaf area (247.84 cm^2) was recorded in T_7 (FYM 15 kg) followed by T_6 and T_5 respectively. Whereas, least was recorded in T_1 (control) (Table 1).

Sandal is an C_3 plant, since the first product of carboxylation is a three carbon acid, phosphoglyceric acid this plants show positive response with increased concentration of CO_2 (Benson, 2002; Bassham, 2003) from the evidence of scientific information on the influence of elevated CO_2 among certain trees like *Eucalyptus pauciflora* (Atwell et al., 2002), *Acacia nigrescens* (Possell and Hewitt, 2009), *Betula papyrifera* (Zhang et al., 2008), temperate forest trees (Korner, 2005) and *Havea brasiliensis* (Devakumar et al., 1998), suggested that most of the C_3 trees showed significant positive response to elevated CO_2 atmospheric increase the carboxylation efficiency relative to oxygenation resulting in reduced photorespiration. Increase in seedling height might be due to increased use CO_2 for carbon assimilation.

Similar trend of increase in collar diameter by growing plants under elevated CO_2 was recorded by Guehl et al. (1994), Devakumar et al. (1996), Haittenschwiler and Korner (1997). Similar results with respect to number of leaves and leaf area was observed in deciduous tree seedling (Bucher et al., 1998). This might be because of CO_2 assimilation is increased with rising level of CO_2 concentration and also might be due to higher leaf initiation rate, leaf expansion and individuals leaf area. Leaf elongation rates were more under elevated CO_2 concentration and were associated with higher sucrose phosphate synthesis activity during the early vegetative stage when growing blades were strong carbohydrate sink (Devakumar et al., 1996). Relative humidity is another important weather parameter that determines leaf growth. Elevated CO_2 concentrations, associated with higher temperature and RH might have influenced the leaf expansion rates. RH can reduce the vapour pressure deficits and thus help in maintaining high turgidity of the cells providing congenial conditions for cell division, elongation and expansion.

4.1 Seedling biomass

The seedling biomass was significantly increased when exposed to elevated CO_2 concentration, in treatment T_7 (FYM 15 kg) (6.81g) recorded maximum seedling biomass accumulation compared to other treatments, the lower biomass was recorded in T_1 (control) (2.14 g). This might be due to increase in use of CO_2 for carbon assimilation from FYM. Similar observation was recorded by the increase of biomass production in growing plants under elevated CO_2 (Devakumar et al., 1996; Stitt and Krapp, 1999, Zak et al., 2000).

The general observation from studies on root growth under elevated CO_2 is that root growth is stimulated; Enhanced growth of shoot biomass as well as total plant biomass (Poorter and Perez-Soba, 2001; Gielen and Ceulemans, 2001) has often been observed in plants grown at elevated CO_2, especially in C_3 plants, at least in the short term and shows increased conditions (Sankeshwar et al., 2006).

4.2 Photosynthetic rate, transpiration rate and stomatal conductance

Carbon dioxide release from FYM (ppm) measures at 120 days of exposer to elevated carbon dioxide concentration was presents in the fig.1. The maximum carbon dioxide record in treatment T_7 (FYM 15 kg) (800 ppm) followed by T_6 (FYM 12 kg) (724 ppm) and T_5 (FYM 9 kg) (648 ppm) respectively. Whereas the minimum was in T_1 control (375 ppm).

The present study revealed that at 120 days after planting the seedling showed the maximum photosynthetic rate was significantly increased in treatment T_7 (19.66 μ mol. m-^{2} s-^{1}) followed by T_6 (17.14 μ mol. m-^{2} s-^{1}) and T_5 (15.83 μ mol. m-^{2} s-^{1}) respectively. The minimum was in T_1 (6.31 μ mol. m-^{2} s-^{1}). Similar trend was continued in transpiration rate and stomatal conductance, the maximum transpiration rate were recorded in treatment T_7 (3.04 m mol. m-^{2} s-^{1}) followed by T_6 (2.84m mol. m-^{2} s-^{1}) and T_5 (2.75 m mol. m-^{2} s-^{1}) respectively whereas minimum was in T_1 (2.38m mol. m-^{2} s-^{1}), with respect to stomatal conductance significantly maximum stomatal conductance was recorded in treatment T_7 (0.30 m mol. m-^{2} s-^{1}) followed by T_6 (0.29 m mol. m-^{2} s-^{1}) and T_5 (0.26 m mol. m-^{2} s-^{1}) respectively. Whereas minimum was recorded in T_1 (0.20 m mol. m-^{2} s-^{1}) (Fig. 2). Changes in photosynthetic rates and acclimatory responses in C_3 plants grown under elevated CO_2 concentration could also be attributed to the feedback metabolic control where, in large accumulation of foliar starch and other carbohydrates could inhibit CO_2 assimilation rates, whereas, the plants with potential sinks for carbohydrate translocation and accumulation may not show any down regulation of photosynthetic capacity suggesting that imbalances in source sink could be attributed to the variations in the photosynthetic acclimation in different plants (Long et al., 2004; Vann and Megonigal, 2002). Similar reports state that photosynthetic rate varies among the plants belonging to different taxa and also among the varieties within the same species (Arora and Gupta, 1996). Enhancement in net photosynthesis was found under elevated CO_2 treatment up to 33–46 per cent (Nowak et al., 2004; Ambebe and Dang 2009).

An often observed response to CO_2 enrichment is acclimation of the initial stimulation of photosynthesis and down-regulation of the rubisco activity due to feedback inhibition caused by the accumulation of carbohydrates (Paul and Driscoll, 1997). In C_3 plants, the acclimation of the photosynthetic capacity to elevated CO_2 after long-term exposure is often seen as a decrease in the maximum carboxylation rate of rubisco. However, despite this down-regulation of the photosynthetic capacity, the net carbon uptake can be enhanced by elevated CO_2 (Leakey et al., 2009). This physiological response to CO_2 could be expected, similar studies were conducted in *P. australis* where carbon uptake is saturated at a much higher internal CO_2 concentration than in C_4 plants, for which elevated atmospheric CO_2 has no direct effect on carbon uptake under favorable conditions (Leakey et al., 2009), because higher rubisco activities at elevated CO_2 compared with ambient CO_2 concentration, plants with rubisco-limited photosynthetic capacity (Eller and Brix, 2012).

Availability of water to plant and ability of plant to regulate water potential under climate change condition will help to adapt species (Souza et al., 2004 and Rouhi et al., 2007). The plant physiological character, such as transpiration and its control is also an important factor in changing environmental condition (Camposeo et al., 2011). The result observed that T_7 and T_6 showed good growth performance; similar variation among tropical mountain rain forest trees was observed by Motzer et al. (2005). Earlier studies of Suresh (2011) and Babu (2012), have also confirmed that transpirational behaviour of seedling. Similar report showed that transpiration is one of the major gas exchange related traits associated with plant growth and productivity. In tree species stomatal transpiration contributes more than 90 per cent of total transpiration (Kubiske and Pregitzer, 1997; Centritto et al., 2002).

The stomatal regulation in the form of stomatal conductance is an important factor to control the related physiological character. The stomatal regulation of photosynthetic rate and transpiration rate was well documented by Souza et al. (2004) and Bunce (2005) under changing climate condition. In the present study observation on stomatal conductance behaviour are similar to photosynthetic rate and transpiration rate. Among the treatments high stomatal conductance was recorded in T_6 and T_7, followed by T_4 and T_5 moderate stomatal conductance and poor stomatal conductance was recorded in T_1 and T_2. Similar observations were recorded in *Casuarina equisetifolia* (Balasubramanian and Gurumurthi, 2001), they found that low productivity *C. equisetifolia* clones were shown a higher stomatal conductance and higher productivity and medium stomatal conductance under saline soil condition. The comparison of Eucalyptus clones showed similar result under water logged condition (Balasubramanian et al., 2009). The study result of (Kumar, 2001) and Babu (2012) on comparison of sandal seedling has shown a similar result in stomatal conductance of all treatment.

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