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RESEARCH ARTICLE

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Performance evaluation of different tree species for carbon sequestration under wasteland condition

C.N. HARI PRASATH, A. BALASUBRAMANIAN, M. PRASANTHRAJAN AND S. RADHAKRISHNAN

ABSTRACT : A study was conducted to identify suitable fast growing trees under wasteland condition for carbon sequestration. Accordingly, five fast growing trees namely *Tectona grandis* Linn. , *Gmelina arborea* Roxb., *Dalbergia sissoo* Roxb., *Bambusa vulgaris* var. *vulgaris* and *Swietenia macrophylla* king were selected for field study under wasteland condition. The performance of these trees was assessed with biometrical traits (height, basal diameter) and eco-physiological traits (transpiration, photosynthesis, intercellular CO_2 concentration and stomatal conductance). Among the five species, *Dalbergia sissoo* exhibited highest growth, productivity and also superior in ecophysiological traits suits for carbon sequestration. The tree species, *Bambusa vulgaris* var. *vulgaris* performed well next to *Dalbergia sissoo* interms of biometric, productivity and eco-physiological parameters. The lowest biometric and productivity was observed in *Gmelina arborea*. The tree species, *Dalbergia sissoo* and *Bambusa vulgaris* var. *vulgaris* are highly suitable for afforestation in wastelands to attain carbon sequestration benefits.

KEY WORDS : Tree species, Wasteland, Carbon Sequestration, Eco-physiological traits

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INTRODUCTION

Global climate change has been a focus for many years, in many countries in many fields. The increasing CO_2 concentration in atmosphere was considered as one of the main driving force for global warming. Atmospheric CO_2 levels have risen from 280 ppm to 398.29 ppm from pre-industrial to the present (NOAA, 2015). The mitigation of climate change demands, determined commitment of scientists to develop strategies to effectively manage the issues of the changing climate through carbon sequestration. Two-thirds of terrestrial carbon is sequestered in the standing forests, forest under storey plants, leaf and forest debris and forest soils (Alves *et al.,* 2010).

The eco-physiological behaviour of species within a day reveals a performance of species in its biomass production, which eventually represents the carbon sequestration potential of tree species. Stomata are the points of exit for water vapor from leaves, under conditions of adequate supply of water, stomata opening in the morning with increasing radiant flux and maintain a relatively constant aperture until radiant flux declines in

MEMBERS OF RESEARCH FORUM

Address of the Correspondence : **C.N. HARI PRASATH,** Department of Siliviculture, Forest College and Research Institute (T.N.A.U.), METTUPALAYAM (T.N.) INDIA

Address of the Coopted Authors : A. BALASUBRAMANIAN, M. PRASANTHRAJAN AND S. RADHAKRISHNAN, Department of Siliviculture, Forest College and Research Institute (T.N.A.U.), METTUPALAYAM (T.N.) INDIA

the late afternoon (Gikloo *et al.,* 2012). Transpiration is a process by which water is lost from plants; it is both beneficial and detrimental. It is beneficial as a driving force, moving water and minerals from the soil into the roots and then into the various parts of the plant. Tuba *et al*. (1994) mentioned that reduction in transpiration rate will eventually lead to favourable instantaneous water use efficiency, improved plant water status, higher carbon gain and biomass accumulation and lower seasonal water consumption rate. Both C_3 and C_4 species experience increase in water use efficiency through reduced transpiration and hence it helps in increased growth (Morison, 1985).

The effects of elevated atmospheric CO_2 on tree canopies are manifested by changes in photosynthesis. Studies of both deciduous and evergreen species have shown that elevated CO_2 leads to increased photosynthesis (Ellsworth *et al*., 2004) and decreased stomatal conductance (Calfapietra *et al*., 2005). Previous research on diurnal dynamics on different tree species have revealed afternoon declines in photosynthesis, even under unchanging light conditions (Spunda *et al*., 2005) when some other stress occurs. This afternoon decline is often attributed to stomatal closure and/or photo inhibitory damage (Muraoka *et al*., 2000), subsequent decreases in intercellular CO_2 (Spunda *et al*., 2005). The present study aims to show an eco physiological behaviour of trees in wasteland condition and its influence on carbon sequestration.

EXPERIMENTAL METHODS

Experimental location and climate :

The experimental area, Energy Plantation Projects India Public. Ltd. (EPPI) is located at Nattarasankottai village, Sivagangai district in Tamil Nadu. This location receives an annual average rainfall of 500 – 600 mm and mean annual temperature of 35.2°C (minimum of 30.6°C and maximum of 39°C). The soil type of the experimental location is red sandy clay with the pH and EC of 5.35-5.75 and 0.11dS m^{-1}, respectively.

Materials :

The tree species selected for the investigation of eco-physiological traits are *Tectona grandis* Linn., *Gmelina arborea* Roxb., *Dalbergia sissoo* Roxb., *Bambusa vulgaris* var. *vulgaris* and *Swietenia macrophylla* king with a spacing of 2.5 m x 2.5 m with Randomized Block Design (RBD).

Biometric traits :

The biometric traits namely height, basal diameter and volume were estimated for all the five tree species as per the method described by Chaturvedi and Khana (1982).

Eco-physiological attributes and diurnal variation :

The eco-physiological characters were measured using a portable photosynthesis system (PPS, model LCpro + Photosynthesis system CO_2 gas analyzer, UK) to assess the carbon capturing potential of targeted tree species. The measurements were made on fully matured leaves (5-6 leaves from the bud) at thirty two months after planting. The eco-physiological estimations *viz*., transpiration rate, stomatal conductance, intercellular CO_2 Concentration (CINT) and photosynthetic rate were measured on a sunny day between 10.00 AM to 11.00 AM. The diurnal variations of eco-physiological traits were measured at an hourly interval from 8.00 AM to 5.00 PM for all the tree species.

Statistical analysis :

The data obtained were subjected for statistical analysis to evaluate the possible relationship between the different parameters and analysis of variance employing statistical methods described by Panse and Sukhatme (1985).

EXPERIMENTAL RESULTS AND ANALYSIS

The results obtained from the present investigation as well as relevant discussion have been summarized under the following heads :

Biometric and biomass carbon evaluation of afforested plantation :

In biometric evaluation, the maximum height was observed in *Dalbergia sissoo* with 4.55 m followed by *Bambusa vulgaris* var. *vulgaris* (4.14 m) and the minimum height was recorded in *Gmelina arborea* with a height of 1.64 m in 3 years. Almost similar performance was observed in both basal diameter and volume. The highest basal diameter and volume of 6.82 cm and 14970.82 kg ha^{-1} was noticed in *Dalbergia sissoo* under

dry land condition and the second highest was observed in *Bambusa vulgaris* var. *vulgaris* with 4.09 cm and 9611.58 kg ha^{-1}. Due to the severe edaphic and climatic stress, other species like *Gmelina arborea, Tectona grandis* and *Swietenia macrophylla* resulted a lowest height, basal diameter and volume (Table 1). Goel and Singh (2008) stated that the *Dalbergia sissoo* recorded highest growth height of 5.35 m in 5 years under sodic soil condition and that considered to be a good sign for its suitability for wasteland. In the present study it was observed that *Gmelina arborea* and *Tectona grandis* have recorded lowest height under wasteland condition. However, Kumar (2011) and Babu (2012) revealed that highest diameter increment was observed in the order of *Dalbergia sissoo, Bambusa vulgaris* var. *vulgaris, Swietenia macrophylla, Tectona grandis* and *Gmelina arborea.* Goel and Singh (2008) also concluded that *Dalbergia sissoo* produced an above ground biomass of 13.52 μ ha^{-1} at the age of 5 years with a maximum segmented part of stem wood followed by branch wood and leaf, respectively at Uttar Pradesh in India.

In biomass carbon, the maximum carbon was sequestered in *Dalbergia sissoo* (6593.55 kg ha^{-1}) followed by *Bambusa vulgaris* var. *vulgaris* (4078.87 kg ha^{-1}), *Swietenia macrophylla* (1344.61 kg ha^{-1}) and minimum biomass carbon in *Gmelina arborea* (771.80 kg ha^{-1}).

Eco-physiological traits :

The eco-physiological behaviour like photosynthetic rate (A), transpiration rate (E), stomatal conductance (Gs) and intercellular CO_2 concentration (CiNT) were studied with the planted five tree species. The *Dalbergia sissoo* had a maximum photosynthetic rate (A) of 12.04 μ mol. m^{-2} s^{-1}. Even though *Gmelina arborea* had poor productivity, it showed a photosynthetic rate of 11.02 μ mol. m^{-2} s^{-1}. It is interesting to note that although *Bambusa vulgaris* var. *vulgaris* had a second highest growth and volume, it showed a lowest photosynthetic rate of 6.67 μ mol. m^{-2} s^{-1}, transpiration rate of 2.92 μ mol. m^{-2} s^{-1} and stomatal conductance of 0.09 μ mol. m^{-2} s^{-1} (Table 2). The *Dalbergia sissoo* was proven for its maximum stomatal conductance and transpiration rate of 0.14 μ mol. m^{-2} s^{-1} and 4.79 μ mol. m^{-2} s^{-1}, respectively. In all the eco-physiological parameters, *Tectona grandis* was observed a moderate level of photosynthetic rate, transpiration rate and stomatal conductance with 9.19 μ mol. m^{-2} s^{-1}, 4.12 μ mol. m^{-2} s^{-1} and 0.14 μ mol. m^{-2} s^{-1}, respectively. When Intercellular CO_2 concentration is concern, the maximum of 201.81 ppm was registered in *Tectona grandis* followed by *Bambusa vulgaris* var. *vulgaris* (197.96 ppm), *Gmelina arborea* (192.06 ppm) and minimum CiNT was showed in *Dalbergia sissoo* with 178.08 ppm.

Balasubramanian *et al*. (2009) reported a high photosynthetic and high transpiration rate in Eucalyptus clones under water logged condition. However, the low performing clones show a lower growth, lower photosynthetic and low transpiration rate. Availability of

Table 1 : Biometric evaluation of three year old trees planted at wasteland in Sivagangai

Name of the tree species	Height (m)	Basal diameter (cm)	Volume (kg ha^{-1})	Biomass carbon (kg ha^{-1})
Tectona grandis	2.40	5.15	2608.29	1125.99
Gmelina arborea	1.64	3.04	1799.13	771.80
Dalbergia sissoo	4.55	6.82	14970.82	6593.55
Bambusa vulgaris var. *vulgaris*	4.14	4.09	9611.58	4078.87
Swietenia macrophylla	1.87	3.69	3177.30	1377.61
S.E.±	0.38	0.62	3.38	4.84
C.D. (P=0.05)	0.84	1.35	7.38	10.58

Table 2 : Ecophysiological behaviour of three year old trees planted at wasteland in Sivagangai

Name of the tree species	Photosynthetic active radiation (PAR)	Transpiration rate (E)	Stomatal conductance (Gs)	Photosynthetic rate (A)	Intercellular CO_2 concentration (CiNT)
Tectona grandis	1296.90	4.12	0.14	9.19	201.81
Gmelina arborea	1297.53	4.18	0.12	11.02	192.09
Dalbergia sissoo	1392.86	4.79	0.14	12.04	178.07
Bambusa vulgaris var. *vulgaris*	1371.71	2.92	0.09	6.67	197.96
Swietenia macrophylla	1390.60	2.90	0.13	7.30	180.54
S.E.±		0.05	0.01	0.46	1.48
C.D.(P=0.05)		0.11	0.02	1.00	3.24

water to plant and ability of plant to regulate water potential under climate change condition will help to adapt species (Rouhi *et al.*, 2007 and Souza *et al.*, 2004). The plant physiological character, such as transpiration and its control is also an important factor in changing environmental condition (Campose *et al.*, 2011). Earlier studies of Kumar (2011) and Babu (2012) have also confirmed that transpirational behaviour of *Tectona grandis* and *Gmelina arborea* was lower than that of *Dalbergia sissoo* and *Bambusa vulgaris* var. *vulgaris* during 1st year and 2nd year, respectively.

Diurnal variation of eco-physiological traits in afforested plantation :

Diurnal variation in photosynthesis (*A*) *rate* :

The modulation of photosynthetic efficiency of afforested trees helps to identify growth potential of trees in dry condition of wastelands. The diurnal variation of photosynthesis (A) rate were estimated and computed in Fig 1. Generally there is a strong positive co-relation between high photosynthetic rate and productivity (Barrett *et al*., 2005). The highest photosynthesis rate was observed in *Dalbergia sissoo* at 8.00 AM with 18.82 μ mol. m^{-2} s^{-1} and the same tree had performed a highest photosynthesis rate during 9.00 AM, 10.00 AM, 12.00 Noon, 1.00 PM and 5.00 PM with 18.76 μ mol. m^{-2} s^{-1}, 18.46 μ mol. m^{-2} s^{-1}, 17.30 μ mol. m^{-2} s^{-1}, 17.30 μ mol. m^{-2} s^{-1} and 16.54 μ mol. m^{-2} s^{-1}, respectively.

Even though *Bambusa vulgaris* var. *vulgaris* had performed a second highest in growth as well as volume, it was registered with lowest photosynthesis rate throughout the day. The lowest photosynthesis rate was observed in *Bambusa vulgaris* var. *vulgaris* with 5.84 μ mol. m^{-2} s^{-1} at 4.00 PM. Among the five fast growing trees, sudden mid day depression was recorded in *Tectona grandis* at 1.00 PM with photosynthesis rate of 10.33 μ mol. m^{-2} s^{-1}. It is peculiar to observe that although, *Gmelina arborea* was poorly performed in growth and productivity it was registered with a moderate level of photosynthesis rate than other well performing trees. The diurnal measurement of photosynthesis also showed high photosynthetic rate in Eucalyptus (Bakshi, 1996). It is presumed that the high photosynthetic rate is related to high transpiration and stomatal conductance to maintain high productivity under water logged condition.

Diurnal variation in transpiration (*E*) *rate* :

The transpiration behaviour of all the five species is described in Fig 2. Similar to photosynthetic trait, the transpiration rate in *Bambusa vulgaris* var. *vulgaris* was observed to be lowest throughout the day with a mean transpiration rate (E) of 3.51μ mol. m^{-2} s^{-1}. The maximum transpiration rate was observed in *Tectona grandis* with 10.79 μ mol. m^{-2} s^{-1} at 2.00 PM and it also registered a second maximum of 9.54 μ mol. m^{-2} s^{-1} at 5.00 PM. Both *Dalbergia sissoo* and *Gmelina arborea* is gradually increasing during morning hours and reached its maximum during mid day and started to fall from 2.00 PM. The lowest transpiration rate was recorded in *Bambusa vulgaris* var. *vulgaris* with E of 2.40 μ mol. m^{-2} s^{-1} at 8.00 AM. Likewise, *Bambusa vulgaris* var. *vulgaris* and *Swietenia macrophylla* had a consistent transpiration rate throughout the day with a minimum E of 3.51 μ mol. m^{-2} s^{-1} and 3.81 μ mol. m^{-2} s^{-1}, respectively. The above result was substantial with Kumar (2011) and Babu (2012) that transpirational behaviour of *Tectona grandis* and *Gmelina arborea* was higher than that of *Dalbergia sissoo* and *Bambusa vulgaris* var.

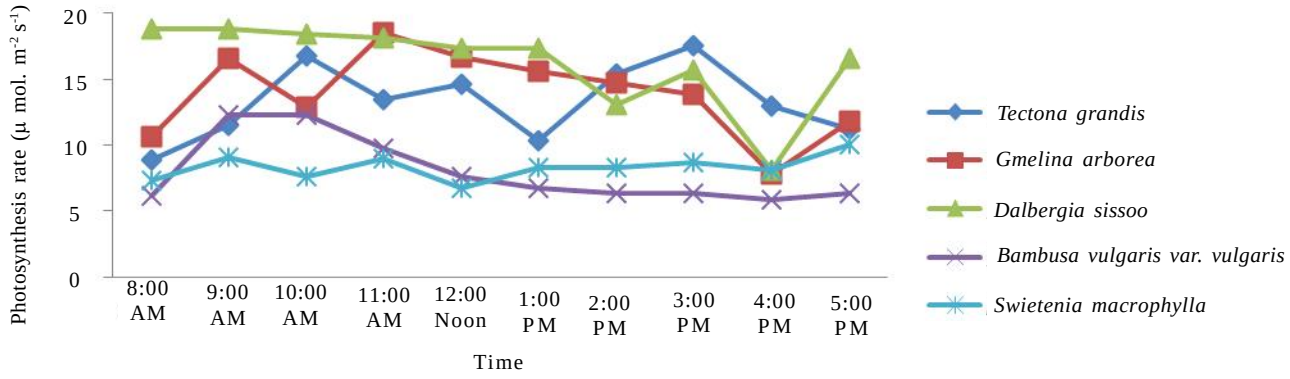

Fig. 1 : Diurnal variation in photosynthesis rate (μ mol. m^{-2} s^{-1}) of three year old trees planted at wastelands of Sivagangai

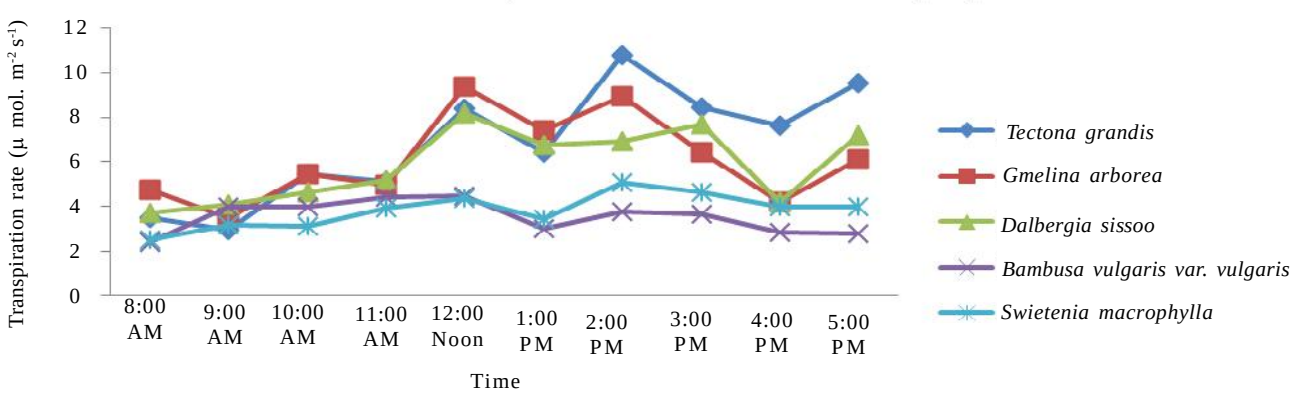

Fig. 2 : Diurnal variation in transpiration rate (E)(« mol. m^{-2} s^{-1}) of three year old trees planted at wastelands of Sivagangai

vulgaris during 1st year and 2nd year, respectively. Kumar (2006) reported that transpiration of poor performing trees will be low with minimum productivity and *vice versa*.

Diurnal variation in stomatal conductance (Gs) :

Stomatal conductance (Gs) is also an important trait for deciding the growth and productivity of trees for carbon sequestration. The performance of afforested trees under dryland condition interms of stomatal conductance is presented in Fig 3. The result revealed that *Tectona grandis* was recorded a maximum stomatal conductance (Gs) value of 0.27 µ mol. m^{-2} s^{-1} at 9.00 AM followed in a orderly increase at 10.00 AM, 11.00 AM, 2.00 PM, 3.00 PM, 4.00 PM and 5.00 PM with stomatal conductance (Gs) of 0.23 µ mol. m^{-2} s^{-1}, 0.22 µ mol. m^{-2} s^{-1}, 0.22 µ mol. m^{-2} s^{-1}, 0.20 µ mol. m^{-2} s^{-1}, 0.19 µ mol. m^{-2} s^{-1} and 0.21 µ mol. m^{-2} s^{-1}, respectively. Similar to the transpiration rate, moderate level of stomatal conductance (Gs) was observed in *Dalbergia sissoo* and *Gmelina arborea* with a mean stomatal conductance of 0.17 µ mol. m^{-2} s^{-1} each. The lowest stomatal conductance (Gs) was recorded in *Bambusa vulgaris* var. *vulgaris* with 0.06 µ mol. m^{-2} s^{-1} at 4.00 PM. The high stomatal conductance implied that stomatal pores were kept open throughout the day by the turgid guard cells by maintaining maximum water potential. This mechanism as influenced by the atmospheric vapour pressure (VPD), the diffusion of CO_2 into the pores was achieved significantly. The above process thereby increased the CiNT in the afforested trees. Pereira *et al.* (1987) found significant correlation between stomatal conductance and VPD. They obtained their correlation which was dependent on the leaf water potential variation and this evidence support the present investigation results.

Diurnal variation in intercellular CO_2 concentration (CiNT) :

Intercellular CO_2 concentration which is also a measure

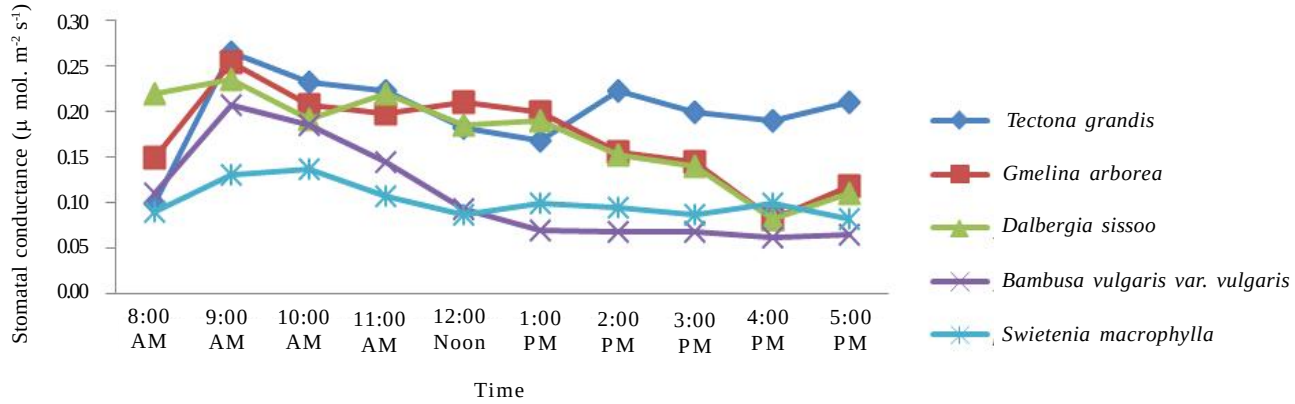

Fig. 3 : Diurnal variation in stomatal conductance (« mol. m^{-2} s^{-1}) of three year old trees planted at wastelands of Sivagangai

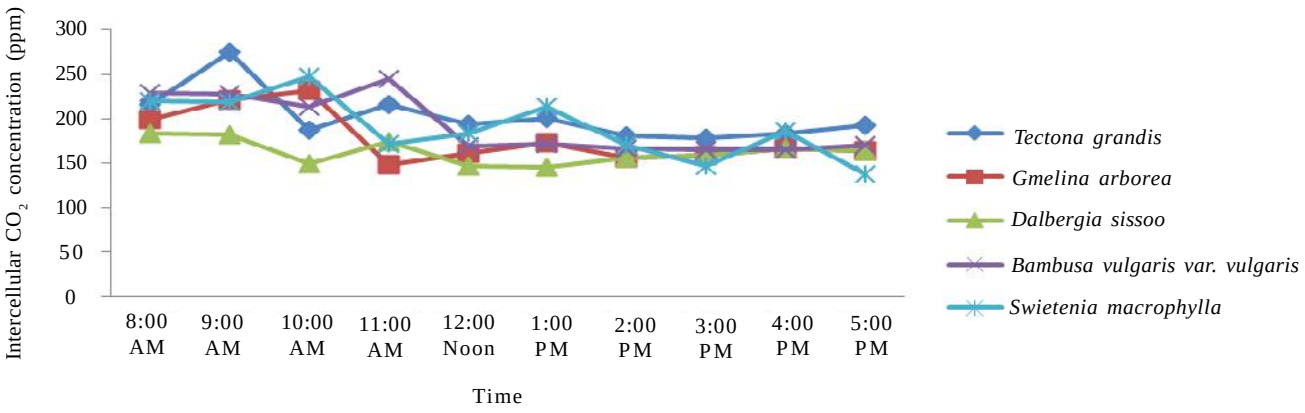

Fig. 4 : Diurnal variation in intercellular CO_2 concentration (ppm) of three year old trees planted at wastelands of Sivagangai

of high productivity and carbon sequestration potential of trees was described in Fig 4. The highest CiNT (275.25 ppm) was observed at 9.00 AM in *Tectona grandis.* It is observed that *Tectona grandis* was maintained a highest CINT values throughout the day. It is also significant that even though, *Dalbergia sissoo* recorded a highest growth and productivity it showed a lowest intercellular CO_2 concentration than other moderately performing trees. Intercellular CO_2 concentration was observed in the mean order values of *Tectona grandis* (202.33 ppm) > *Bambusa vulgaris* var. *vulgaris* (192.10 ppm) > *Swietenia macrophylla* (189.58 ppm) > *Gmelina arborea* (177.78 ppm) > *Dalbergia sissoo* (162.45 ppm).

Diurnal variation in photosynthesis, transpiration and other physiological characters were reported for sclerophytic species in Mediterranean species (Guttenberg and Buhr, 1935) and later studies demonstrated that changes in the net photosynthesis occur simultaneously with change in stomatal conductance (Rouschal, 1938 and Hellmuth, 1971). The result helps to conclude that highest carbon sequestration species are instrumental in maintaining their stomatal regulation, high transpiration rate and high photosynthesis rate. It is also important to note that the rooting behaviour, the root spread in the subsurface layer of the soil also helps trees to absorb excess water.

Conclusion :

The carbon sequestration potential of *Dalbergia sissoo* and *Bambusa vulgaris* var. *vulgaris* was high as they maintained high level of photosynthetic rate, transpiration rate and other eco-physiological activities throughout the day and exhibited their suitability for wasteland afforestation and high carbon sequestration. The poor performing species *Tectona grandis* and *Gmelina arborea* maintained very high eco-physiological activity without any prominent mid day closure leading to failure in regulating the stomata according to the environmental conditions, resulted with very low productivity and their non-suitability for wasteland afforestation and high carbon sequestration.

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