Leaf gas exchange capacity in relation to leaf position on the stem in field grown teak (*Tectona grandis* L.f.)

G RAJENDRA* and C V NAIDU**

Department of Botany, Sri Venkateswara University, Tirupati 517 502, Andhra Pradesh, India*
Biotechnology Centre for Tree Improvement, Tirupati 517 507, Andhra Pradesh, India**

Abstract

Leaf gas exchange patterns in relation to leaf positions on stems were studied in field grown forest tree, teak (*Tectona grandis* L.f.) during first year growth under intensive culture plantation. Net photosynthetic rates (*P*<sub>N</sub>) were low in immature leaves (1-2 from shoot apices), increased basipetally on shoot, peaked in leaves (3<sup>rd</sup> or 4<sup>th</sup> leaves from shoot apices) which had recently reached full expansion, and thereafter declined in lower crown leaves. High *P*<sub>N</sub> found in fully expanded young leaves was associated with increased dark respiration rate (*R*<sub>D</sub>) and high radiation saturation as well as compensating irradiance for *P*<sub>N</sub> when compared to those of aged leaves. Inter-cellular CO<sub>2</sub> concentrations (*C*<sub>i</sub>) determined at ambient CO<sub>2</sub> concentration and saturating irradiance were apparently low for leaves exhibiting high *P*<sub>N</sub> when compared to those of aged leaves. Differences in stomatal conductance (*g*<sub>s</sub>) and the rate of transpiration (*E*) were not apparent between leaves after full expansion. The relationship of *P*<sub>N</sub> with *C*<sub>i</sub> recorded for leaves at different positions on stems and under natural ambient CO<sub>2</sub> concentrations showed a linear decrease in *P*<sub>N</sub> with marked increasing *C*<sub>i</sub> and suggested that increase in mesophyll limitations could cause decline in *P*<sub>N</sub> during aging of teak leaves after full expansion. Highly significant positive linear correlation was found between *P*<sub>N</sub> and *C*<sub>i</sub> determined at below ambient CO<sub>2</sub> concentrations and saturating irradiance for both fully expanded young and aged leaves. The estimate of linear relationship between *P*<sub>N</sub> and *C*<sub>i</sub> often considered as carboxylation efficiency, was higher for fully expanded young leaves characterized by high *I*<sub>N</sub> than for aged leaves exhibiting low *P*<sub>N</sub>. Hence, the increase in mesophyll limitations or decrease in carboxylation efficiency could explain gradual reduction in photosynthetic potential with leaf age after maturation in teak.

Additional key words: carboxylation efficiency; dark respiration; intercellular CO<sub>2</sub> concentration; net photosynthetic rate; stomatal conductance; transpiration.

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*Fax: 91-8574-27499/24111*

*Abbreviations: C*<sub>i</sub> - intercellular CO<sub>2</sub> concentration; CE - carboxylation efficiency; *E* - transpiration rate; *g*<sub>s</sub> - stomatal conductance; *I* - irradiance; *P*<sub>N</sub> - net photosynthetic rate; *R*<sub>D</sub> - dark respiration rate; RUE - radiation use efficiency; WUE - water use efficiency.
Introduction

Growing world demand for energy, wood and wood products and also the ever increasing environmental risks such as air pollution caused by increasing CO₂ concentration in the atmosphere (Baes et al. 1977) suggest the need for expansion and improving tree growth both in and outside the natural forests. Further, the concern about future source of energy stimulates a renewed interest in improving tree growth because trees are more efficient sources than annual crops in terms of the energy harvested per unit energy invested (Smith and Johnson 1977). Therefore, protection of tree growth in their natural environment and new plantations of fast growing and/or economically important tree species would become potential and are of great importance for our future life. Due to growing demand, some of the economically important forest tree species have been planted and grown extensively outside their natural regions both in agricultural and marginal lands. The success of such attempts greatly depends on the productivity of selected tree species which in turn is determined by the magnitude of their annual growth. This might require consideration of potential types of trees for tree improvement programmes.

With the ever increasing demand for its timber, there is a need to expand teak plantations even in regions outside its natural occurrence. Thus, teak is being planted and grown extensively in southern parts of India by farmers and corporate bodies both in agricultural and marginal lands. The success of such teak cultivation depends on its productivity which is in turn determined by the interaction of its physiological processes with environmental factors. Physiological factors that determine productivity of trees include photosynthesis and respiration, partitioning of photosynthates within tree, duration of active growth, and seasonal pattern of CO₂ assimilation (Ledig 1969, Dickmann 1979). The $P_N$ was one of the first selection criteria considered for tree improvement research, however, $P_N$ was often not correlated with yield (Ledig 1969, Gifford and Evans 1981, McDonald 1984). Reasons for these poor correlations include mostly environmental variability, inadequate or differing nitrogen supply, differences in endogenous and diurnal as well as seasonal cycles (Ledig 1969, McDonald 1984), or measurement of $P_N$ under suboptimal conditions and at varying age of leaves (Nelson 1984).

Although several attempts were made to study factors influencing the survival and performance of teak trees in their natural habitat (Trup 1921, Hedegard 1973, Rawat et al. 1992, Rawat 1994), studies to understand physiological basis of teak growth and productivity are limited. The present study therefore determined photosynthetic CO₂ exchange characteristics of teak growing outside its natural regions as well as their variations with the position of leaves on the stem to establish base physiological values for teak improvement and to provide a foundation for more efficient teak cultivation outside its natural regions. Furthermore, we determined the relationship between $P_N$ and both $C_i$ and irradiance ($I$) of two selected attached leaves at different positions (3rd and 6th from shoot apices) on stems which exhibited high and low $P_N$, respectively, in order to assess their photosynthetic potential.
Materials and methods

Plants: Three-month-old teak (Tectona grandis L.F.) seedlings grown from stumps and established in polyethylene bags containing three parts field soil plus one part farm-yard manure mixture were obtained from the forest nursery of the Biotechnology Centre for Tree Improvement, Tirupati (India). Fifty seedlings were transplanted in plots of 25x15 m fertile agricultural land characterized by red sandy loam soil (pH 8.1) and with a spacing of 2.5 m between plants and rows. Seedlings were planted in pits measuring 0.4x0.4x0.4 m and filled with three parts top soil plus one part farm-yard manure mixture, and grown under natural environment. Plants were watered periodically (once in three days) and fertilised bimonthly with 50 g per plant of 17:17:17 N-P-K water soluble commercial fertilizer. Weeds were removed manually to avoid competition for water and nutrients available in the soil.

The experimental planting site was located at 15 km in south-east direction from the University campus (latitude 13°33'N, longitude 79°28'E). During the experimental period, day temperatures ranged from 27 to 39 °C and night temperatures from 19 to 25 °C. The average air temperature, however, during much of this period was 34/23 °C day/night. Daily maximum and minimum atmospheric relative humidities during the experimental period ranged from 63 to 76 % and 31 to 49 %, respectively. Plants received full natural solar irradiance throughout the experimental period and the maximum I was about 1800 μmol(quantum) m⁻² s⁻¹ on a clear sunny day around noon at the top of the canopy. During the experimental period, plants had average height of approximately 0.8 m with 3-4 pairs of leaves at 2 months, 2.0 m with 9-10 pairs of leaves at 5 months, and 3.5 m with 15-17 pairs of leaves at 8 months after transplantation.

Values on gas exchange were recorded for attached leaves at different positions (nodes) on the stem and numbered from shoot apices. The leaf just unfolding at the shoot apex was considered as the first leaf. The concept of leaf plastochron index (LPI), which is an integral count of the number of emerged leaves plus a decimal fraction, represents the progress of an emerging leaf towards full emergence but can not be applied to plants grown under natural conditions (Silk 1980). This is because the traits underlying leaf emergence are often inconsistent during the course of plant growth under natural conditions (Ram et al. 1994). In the present study, therefore, gas exchange characteristics of teak leaves were studied and followed with respect to their position on stems from shoot apices.

Gas exchange measurements: A portable open gas exchange measuring system (model LCA-3, ADC, England) was used for rapid simultaneous determination of CO₂ and water vapour exchange in attached leaves of teak under field conditions. The portable measuring system used was equipped for recording basic data and instantaneous computation as well as storage of leaf gas exchange characteristics, namely Pn, E, C, and E. All leaf gas exchange measurements were made between 10:00 and 11:30 h (IST) on sunny and generally cloud-free days throughout the experimental period. For measuring Pn and E in light, photosynthetic leaf chamber (model PLC-3 (B), ADC, England) was clipped onto the selected attached leaf which
had been exposed to natural sunlight. The chamber was held at such an angle that the enclosed leaf surface directly faced the Sun to avoid the shading inside the cuvette. The \( I \) at the upper surface of leaf chamber was measured by a calibrated sensor (filtered silicon photocell, \( ADC \), England) mounted on the same surface of leaf chamber; it was 1200-1300 \( \mu \text{mol, quantum} \) \( \text{m}^{-2} \text{s}^{-1} \) during most of the photosynthetic gas exchange measurements. Atmospheric air drawn from 3 m height through a telescopic mast was flown through the leaf chamber in order to avoid fluctuations in \( \text{CO}_2 \) concentration of the ambient air which could otherwise arise due to the addition of respired \( \text{CO}_2 \) by the researcher(s) at the time of the measurements. Atmospheric air containing ambient concentrations of \( \text{CO}_2 \) (345 \( \text{cm}^3 \text{ m}^{-3} \)) and \( \text{O}_2 \) (21 \%) was allowed to pass through the photosynthetic chamber at 5 \( \text{cm}^3 \text{ s}^{-1} \) without changing its relative humidity. The \( P_N \) and \( g_s \) became stable within two min after clipping the chamber on to the selected attached leaf experiencing saturating solar irradiance and the values of photosynthetic gas exchange were then recorded. Measurements were repeated at least on five different plants for each selected leaf position on the stem.

The \( P_N \) response to sub-atmospheric \( \text{CO}_2 \) levels was also determined for two selected leaves (3rd and 6th from shoot apices) exhibiting variations in \( P_N \) in order to assess their in \( \text{vivo} \) carboxylation efficiency. Using the \( LCA-3 \) leaf gas exchange measuring system, it was made easy and possible to vary \( \text{CO}_2 \) concentration of the air entering leaf chamber by regulating the air flow passing through a soda-lime (8-14 mesh) column. The \( P_N \) response to \( \text{CO}_2 \) was determined for each selected leaf by lowering \( \text{CO}_2 \) concentration of the air entering leaf chamber in steps from the atmospheric concentration (345 \( \text{cm}^3 \text{ m}^{-3} \)) at each selected \( \text{CO}_2 \) concentration, values of \( \text{CO}_2 \) exchange were recorded after the \( g_s \) and \( P_N \) became stable. All \( \text{CO}_2 \) dependent photosynthetic \( \text{CO}_2 \) exchange measurements for all selected leaves were made at about the same saturating \( I \) \( \approx \) 1700-1300 \( \mu \text{mol, quantum} \) \( \text{m}^{-2} \text{s}^{-1} \). The irradiation dependent \( \text{CO}_2 \) uptake of selected leaves was also determined particularly at solar irradiances lower than the naturally available irradiance. Lowering of natural solar irradiance in steps was achieved by using and varying the number of cloth filters at the upper surface of leaf chamber. At each step of \( I \), \( \text{CO}_2 \) exchange values were recorded after they had become stable. The \( P_N \) response to \( I \) was linear at very low \( I \) for each selected leaf. The slope of linear relationship between \( P_N \) and \( I \) was estimated by least squares linear regression analysis and expressed as radiation use efficiency (RUE).

Leaf dark respiration rates (\( R_D \)) were measured on leaves kept continuously in dark for at least 30 min which was achieved by covering leaves with aluminium foil. Generally, about 15-20 min was required for establishment of steady states that were maintained for at least 2 h. The \( R_D \) values of leaves reported are steady state rates reached after equilibration period. At the time of measuring \( R_D \), the leaf chamber was clipped on to dark equilibrated leaf and the chamber was darkened by using aluminium foil. Atmospheric air containing ambient \( \text{CO}_2 \) (345 \( \text{cm}^3 \text{ m}^{-3} \)) and \( \text{O}_2 \) (21 \%) concentrations was allowed to flow through the leaf chamber at 5 \( \text{cm}^3 \text{ s}^{-1} \). Dark \( \text{CO}_2 \) exchange by leaves became stable at about 3 min after enclosing dark equilibrated leaf in the chamber and the values were then recorded. The \( R_D \)
measurements were repeated for each selected leaf position on at least five different plants.

**Analysis of results:** The relationship of \( P_N \) with \( C_i \) recorded for leaves at different positions on stems of different plants and under natural environmental conditions was analyzed by least square linear regression analysis to establish the relationship, if any, between them. Similarly, least square linear regression analysis was also applied to study the relationship of \( P_N \) with \( C_i \) recorded at different CO\(_2\) concentrations lower than that of ambient air for two selected leaves (3\(^{rd}\) and 6\(^{th}\) from shoot apices) exhibiting high and low \( P_N \). The \( P_N \) response to \( C_i \) for each selected leaf with respect to its position was linear and highly significant and the estimate of such linear relationship between \( P_N \) and \( C_i \) was expressed as in vivo carboxylation efficiency (Farquhar and Sharkey 1982) of the respective leaf samples.

*Table 1* Net photosynthetic CO\(_2\) exchange (\( P_{N} \)) [\( \mu \text{mol}(\text{CO}_2) \text{ m}^{-2} \text{ s}^{-1} \)] in relation to leaf position on stems in field grown teak during its eight months growth after transplantation. The \( P_N \) measurements were made at ambient CO\(_2\) concentration and under natural environmental conditions [33 ± 1 \(^{\circ}\)C, 50-55 % RH, 1250±50 \( \mu \text{mol} \) (quantum) m\(^{-2} \) s\(^{-1} \)]. Values were recorded at three months interval starting two months after transplantation. Values are means ± SD of at least five replicated measurements made on different plants. – – values not recorded due to lack of healthy leaves.

<table>
<thead>
<tr>
<th>Time since transplantation (month)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>12.3±1.2</td>
<td>17.8±1.3</td>
<td>16.5±0.9</td>
<td>15.9±1.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>11.3±1.5</td>
<td>16.6±1.2</td>
<td>16.9±0.8</td>
<td>15.2±0.7</td>
<td>14.2±0.6</td>
<td>13.4±1.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>10.6±2.1</td>
<td>14.2±1.8</td>
<td>17.3±1.7</td>
<td>16.2±1.9</td>
<td>15.2±1.1</td>
<td>13.5±1.8</td>
<td>12.6±1.4</td>
<td>10.5±1.7</td>
<td>9.1±1.2</td>
</tr>
</tbody>
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**Results and discussion**

A clear understanding of the photosynthetic potential of leaves at different positions on the stem is fundamental in assessing the contribution of an individual leaf to plant growth and carbon economy of whole plant. There is abundant literature concerning the changes in \( P_N \) during leaf ontogeny (Šesták 1985, Čatský and Šesták 1997), but little information is available with respect to tropical tree species, particularly in teak. We estimated \( P_N \) for different leaves with respect to their position on stems at three times during 8 months growth of teak after transplantation (Table 1). The \( P_N \) was low for youngest leaves (1\(^{st}\) from shoot apices) at all times of growth/measurements, it increased in 2\(^{nd}\) leaves on 2 months old plants, exhibited gradual increase up to 3\(^{rd}\) leaves on 5 and 8 months old plants, and then it declined gradually with leaf age after maturation. A similar decline in \( P_N \) with leaf aging and towards senescence was also reported for other tree species (Nelson 1985, Lange 1988).
Changes in $P_N$ with leaf age and position on the plant are related with anatomical and morphological alterations. Increased $P_N$ observed with gradual increase in leaf age up to maturity during the course of leaf expansion is related to development of internal leaf structure, synthesis of chlorophyll, decrease in diffusion resistance, increase in photosynthetic phosphorylation, increase in protein synthesis and RuBP carboxylase activity, and decrease in mitochondrial respiration. The gradual decrease in $P_N$ after leaves had become fully expanded may be mainly due to decrease in photophosphorylation and RuBP carboxylase activities as well as to a significant decrease in protein and RNA turnover. Furthermore, marked decrease in mitochondrial respiration and relative increase in photorespiration which could occur after leaf expansion are also cited for decreased $P_N$ with leaf aging and towards senescence (Dickmann et al. 1975).

![Graph showing the relation between net photosynthetic rate ($P_N$) and intercellular CO$_2$ concentration ($C_i$) in field grown teak. The $P_N$ measurements were made on leaves at different positions on the stem and with normal atmospheric CO$_2$ concentration (340 cm$^3$ m$^{-2}$) entering the leaf chamber and under natural environmental conditions [50-55 % RH, 33±1 °C and 1250±50 µmol(quantum) m$^{-2}$ s$^{-1}$]. Points are results pooled from measurements made on different plants and at different times during 8 month growth of plants after transplantation. Solid line through points represent first order regression, $Y = 30.76 - 0.0686 X$, $r = 0.75$.

The $P_N$ was related with $C_i$ in leaves at different positions on stems, of different individual plants, and under natural environmental conditions (Fig. 1). Thus the decrease in $P_N$ of aged leaves was commensurate with marked increase in their $C_i$ values. Although marked differences were found in $P_N$ and $C_i$ of leaves with respect to their positions on stems, $g_s$ of these leaves did not vary significantly at all times of measurements (results not presented). A decline in $P_N$ with a marked increase in $C_i$ and without apparent change in $g_s$ found under natural environmental conditions.
during the course of aging of teak leaves pointed out that increase in mesophyll limitations could cause decline in $P_N$ during aging of leaves.

![Graph showing $P_N$ response to irradiance (PPFD) in 3rd (●) and 6th (▲) leaves from shoot apices in teak. Measurements were made under conditions similar to those specified in Fig. 1 except of varying I. The values are means of 3-5 measurements made on different plants and on different days.](image)

The $P_N$ of both fully expanded young (3rd from shoot apex) and aged (6th from shoot apex) leaves increased with $I$ (Fig. 2). Yet young and fully expanded leaves showed much higher saturation radiation for $P_N$ than the aged leaves. Compensating $I_S$ for $P_N$ of the 3rd and 6th leaves were about 70 and 55 μmol(quantum) m$^{-2}$ s$^{-1}$, respectively (Table 2). Furthermore, the initial slope of $P_N$ response to $I$ was greater for fully expanded young leaves than for aged leaves. A similar relationship between $P_N$ and $I$ was also reported for other tree species (Sharkey and Ogawa 1987, Tenhunen et al. 1987, Michael et al. 1990, Masarovičová 1992). These results indicate that radiant energy is apparently one of the principal factors governing the photosynthetic potential of fully expanded leaves in teak.

The $P_N$ response to $C_i$ recorded at CO$_2$ concentrations lower than the ambient air CO$_2$ concentration for two selected leaves on the stem (3rd and 6th leaves from shoot apices) characterised by high and low $P_N$ (Fig. 3) was linear and highly significant ($r = 0.98$). However, the $P_N$ response to $C_i$ was apparently higher for the fully expanded young (3rd) leaves than for the aged (6th) leaves. The estimate of linear relationship between $P_N$ and $C_i$ determined at extremely low ambient CO$_2$
concentrations is often considered as in vivo carboxylation efficiency or mesophyll conductance (Farquhar and Sharkey 1982). Differences in $P_N$ response to $C_i$ found between leaves exhibiting high and low $P_N$ apparently reflect physiological characteristics of the CO$_2$ exchange properties of these two leaf types. The decrease

<table>
<thead>
<tr>
<th>Gas exchange characteristic</th>
<th>Leaf position on the stem from shoot apices</th>
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<tr>
<td></td>
<td>3rd</td>
</tr>
<tr>
<td>$P_N$ [mmol(CO$_2$) m$^{-2}$ s$^{-1}$]</td>
<td>18.50 ± 0.99</td>
</tr>
<tr>
<td>Intercellular CO$_2$ concentration, $C_i$ [cm$^3$ m$^{-3}$]</td>
<td>185 ± 9</td>
</tr>
<tr>
<td>$F$ [mmol(H$_2$O) m$^{-2}$ s$^{-1}$]</td>
<td>9.30 ± 1.41</td>
</tr>
<tr>
<td>Stomatal conductance, $g_s$ [mol m$^{-2}$ s$^{-1}$]</td>
<td>0.79 ± 0.16</td>
</tr>
<tr>
<td>$R_D$ [mmol(CO$_2$) m$^{-2}$ s$^{-1}$]</td>
<td>2.30 ± 0.35</td>
</tr>
<tr>
<td>Saturating irradiance$^a$ [mmol (quantum) m$^{-2}$ s$^{-1}$]</td>
<td>1050</td>
</tr>
<tr>
<td>Compensating irradiance$^a$ [mmol (quantum) m$^{-2}$ s$^{-1}$]</td>
<td>70</td>
</tr>
<tr>
<td>Carboxylation efficiency$^b$, CE [mmol(CO$_2$) s$^{-1}$ cm$^{-3}$ m$^{-2}$]</td>
<td>0.127</td>
</tr>
<tr>
<td>Water use efficiency$^c$, WUE [mmol(CO$_2$) mol$^{-1}$ (H$_2$O)]</td>
<td>1.989</td>
</tr>
<tr>
<td>Radiation use efficiency$^c$, RUE [mmol(CO$_2$) mol$^{-1}$ (quantum)]</td>
<td>22.8</td>
</tr>
</tbody>
</table>

$^a$ Estimated from $P_N/I$ curves. $^b$ Estimated from initial slope of $P_N/C_i$ curves. $^c$ Calculated from mean values. $^d$ Estimated from initial slope of $P_N/I$ curves.

in $P_N$ response to $C_i$ from the 3rd to the 6th leaves represented a change in mesophyll conductance or carboxylation efficiency. Since leaves at 6th node of stems (from shoot apices) had grown and over-matured, anatomical and physiological alterations associated with aging of leaves could have decreased mesophyll conductance or carboxylation efficiency of these leaves. In addition, since the I saturated $P_N$ was reduced in aged leaves (Table 2, Fig. 2), the carboxylation might have been reduced to balance the effects of reduced electron flow capacity (Sharkey 1985, Wulmschleger 1993). A marked decrease in $P_N$ of aged leaves without an apparent change in $E$ (Table 2) found in comparison with that of fully expanded young leaves clearly indicated that low $P_N$ of aged leaves was related to increase in mesophyll limitations rather than to stomatal limitations. Values on CO$_2$ and water vapour exchange characteristics of two selected leaf types with respect to their age and position on stems (Table 2) showed that $P_N$, $R_D$ and radiation saturation as well as compensating irradiance for $P_N$ were consistently higher for fully expanded young leaves than for aged leaves. The increased $R_D$ found in fully expanded young leaves is thought to be due to their increasing demand for metabolic energy and may be mediated by high amounts of saccharides generated by increased $P_N$ in these leaves (Irubec et al.
1985, Rajendrudu et al. 1987, 1996). On the other hand, \( C_i \) determined at ambient CO\(_2\) concentration and saturating \( I \) was apparently low for young and fully expanded leaves compared to those of aged leaves. However, the differences in \( E \) and \( g_s \) were not apparent between the two selected leaf types in the present study. The CE determined based on \( P_N \) response to \( C_i \) at low ambient CO\(_2\) levels, the WUE calculated as the ratio of \( E/P_N \), and the RUE estimated based on initial slopes of \( P_N \) response to \( I \) were also higher for fully expanded young leaves than for aged leaves. These results indicated that fully expanded young leaves usually located at 3\(^{rd}\) node (from shoot apices) on stems had high photosynthetic potential, and these could be selected and used for studies related to teak improvement. Because of complex interactions among factors governing the productivity of tree species, it is doubtful whether any single gas exchange or morphological variable can be a useful and reliable indicator of productivity of tree species. However, we believe that our approach of determining high photosynthetic potential characteristic to a fixed leaf position on the stem shows promise for use as a criterion in clonal selection and for explaining inherent growth differences among clones or between plants growing under the same or different environment.

![Graph](image)

Fig. 3. Intercellular CO\(_2\) concentration (\( C_i \)) response of net photosynthetic rate (\( P_N \)) in 3\(^{rd}\) (●) and 6\(^{th}\) (▲) leaves (from shoot apices) on the stem in teak. The \( P_N \) measurements were made with air containing various CO\(_2\) concentrations below to that of normal air and under natural environmental conditions (33 ± 1°C, 50-55 % RH, 1250±30 µmol(quantum) m\(^{-2}\) s\(^{-1}\)). Values are means of at least three measurements made on different plants. Solid lines through data points represent first order regressions: ●, \( Y = 0.127X - 7.29; r = 0.988 \). ▲, \( Y = 0.109X - 7.91; r = 0.984 \).
References


