SHORT COMMUNICATION

Scaling to a common temperature improves the correlation between the photosynthesis parameters \( J_{\text{max}} \) and \( V_{\text{cmax}} \)

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Abstract

A strong correlation between the photosynthetic parameters \( J_{\text{max}} \) and \( V_{\text{cmax}} \) was found by Wullschleger (1993) in a survey of 109 plant species. Measurements were made at various leaf temperatures, but the temperature dependence of \( J_{\text{max}} \) and \( V_{\text{cmax}} \) differ. Once values for \( J_{\text{max}} \) and \( V_{\text{cmax}} \) in Wullschleger's analysis were adjusted to a common temperature, using an equation for the temperature dependence of these parameters, the slope of the linear regression for \( J_{\text{max}} \) versus \( V_{\text{cmax}} \) forced through the origin increased from 1.97 to 2.68, and \( r^2 \) increased from 0.79 to 0.87.

Key words: Temperature, photosynthesis parameters.

Introduction

In a recent review of data obtained from 109 species of \( \text{C}_3 \) plants, Wullschleger (1993) obtained a strong correlation between the parameters \( J_{\text{max}} \) and \( V_{\text{cmax}} \) used in the photosynthesis model of Farquhar et al. (1980). \( J_{\text{max}} \) is the maximum electron transport rate and \( V_{\text{cmax}} \) is the maximum catalytic activity of the enzyme Rubisco. This correlation has a distinct advantage when modelling leaf and canopy photosynthesis (Hollinger, 1992; Sellers et al., 1992; Harley and Baldocchi, 1995; Leuning, 1995; Leuning et al., 1995; Lloyd et al., 1995), because it reduces by one the number of parameters to be specified. It also has implications for the optimal allocation of leaf nitrogen between the biochemical compounds involved in light harvesting and \( \text{CO}_2 \) uptake (von Caemmerer and Farquhar, 1981).

The data compiled by Wullschleger (1993) were collected over a range of leaf temperatures and no attempt was made in the original article to scale results to a common temperature (Wullschleger, 1996, personal communication). Part of the scatter found by Wullschleger (1993) may arise because the temperature dependency for \( J_{\text{max}} \) is generally different to that for \( V_{\text{cmax}} \) (Farquhar et al., 1980; Kirschbaum and Farquhar, 1984; Harley et al., 1992), or it may arise due to natural variability between plants. In this note it is examined whether the correlation between \( J_{\text{max}} \) and \( V_{\text{cmax}} \) is improved when the values of these parameters are adjusted to a common temperature.

Materials and methods

Dependence of \( J_{\text{max}} \) and \( V_{\text{cmax}} \) on leaf temperature

Following Harley et al. (1992), the temperature dependence of the normalized value of \( J_{\text{max}} \) may be expressed as

\[
J_{\text{max}} = \frac{J_{\text{max}_0}}{1 + \exp[(S_T - H_T)/(RT_0)]} \quad (1)
\]

where \( J_{\text{max}_0} \) is the value of \( J_{\text{max}} \) at the reference temperature \( T_0 \) (°K), \( H_T \) is the energy of activation, \( H_0 \) is the energy of deactivation, \( S_T \) is an entropy term, and \( T_L \) is leaf temperature (°K). Harley et al. (1992) used a similar expression for the temperature dependence of \( V_{\text{cmax}} \), while Farquhar et al. (1980) adopted an Arrhenius function (Equation 1 with the denominator of the last term set to unity). In contrast, Kirschbaum and Farquhar (1984) used third-order polynomials of the form

\[
J_{\text{max}} = 1 + a_1(T_L - T_0) + a_2(T_L - T_0)^2 + a_3(T_L - T_0)^3 \quad (2)
\]

where \( a_1, a_2, a_3 \) are empirical coefficients and \( T_0 \) is a reference temperature. A similar expression was used for \( V_{\text{cmax}} \).
Results and discussion

Parameter values are not available for the 109 C₃ species surveyed by Wullschleger (1993), so those reported by Harley et al. (1992) for cotton, and values adopted by Farquhar et al. (1980) were used with Equation 1, while values found for Eucalyptus pauciflora by Kirschbaum and Farquhar (1984) were used in Equation 2. (The above four papers will be referred to as W, H, F, and K hereafter.) With parameter values for cotton (H, Table 1), Equation 1 predicts that the peak in V₉₅₉₉₅ is reached around 40°C, while the peak in Jₙₙ₉₉₅ occurs at 34°C (Fig. 1a, b). When the parameter values of F are used (Table 1), the predicted range in Jₙₙ₉₉₅ and V₉₅₉₉₅ is far less than for the previous case although peaks in Jₙ₉₉₅ and V₉₅₉₉₅ occur at similar temperatures to those predicted by H. Variation in both these parameters is least according to K, and their formulae suggest an increase in both Jₙₙ₉₅ and V₉₅₉₉₅ at temperatures below 10°C. This unexpected result arises from the extrapolation of fitted cubic equations beyond the range over which data were collected (15-35°C), but will have little impact on the current analysis because data compiled by W were collected at leaf temperatures varying from 13-35°C.

A monotonic decline in the ratio Jₙₙ₉₅/V₉₅₉₉₅ from a value of 3.0 at 0°C to 0.24 at 40°C is indicated using parameter values from H (Fig. 1c), with the curve passing through unity at the reference temperature of 20°C. A steady decline from 1.9 to 0.17 is also obtained using parameters from F, whereas a parabolic response is predicted using the results of K in the range 10-40°C. Clearly, the ratio of Jₙₙ₉₅ and V₉₅₉₉₅ is not constant with temperature.

Equation 1 with parameter values from H and from F (Table 1) was used to adjust values of Jₙₙ₉₅ and V₉₅₉₉₅ tabulated by W to a common temperature of 20°C. The resultant correlation between Jₙₙ₉₅ and V₉₅₉₉₅ is shown in Table 1.

![Fig. 1. Response of normalized photosynthetic parameters to temperature according to predictions of Equations 1 and 2 with parameter values from Harley et al. (1992, H), Farquhar et al. (1980, F), and for Equation 2 from Kirschbaum and Farquhar (1984, K) (see Table 1) (a) V₉₅₉₉₅ (b) Jₙₙ₉₅ and (c) Jₙₙ₉₅/V₉₅₉₉₅.](https://academic.oup.com/jxb/article-abstract/48/2/345/652862)

![Fig. 2b (using parameter values from H), while the unscaled results are shown in Fig. 2a for comparison. Scaling reduces the scatter in the data (Fig. 2b) and increases the slope and the r² value of the linear regression relative to the unscaled data when Equation 1 is used with parameter values from either H or F (Table 2). As expected from Fig. 1c, using the temperature formulation of K provides no substantial improvement over the correlation observed by W (Table 2).

In conclusion, scaling observed values of Jₙₙ₉₅ and V₉₅₉₉₅ to a common temperature has substantially improved the correlation between these parameters when Equation 1 is used, even with quite different parameter values. However, this is not confirmed when simple polynomials are used to describe the temperature dependence of Jₙₙ₉₅ and V₉₅₉₉₅. It is expected that plants adapted to different climatic zones will have different temperature optima for photosynthesis, and possibly different relationships between
Correlation of photosynthesis parameters

Fig. 2. Correlation between the photosynthetic parameters \( J_{\text{max}} \) and \( V_{\text{cmax}} \) for 109 species of C\(_3\) plants when (a) as compiled originally by Wullschleger (1993), and (b) data have been scaled to a common temperature using Equation 1 and parameters from Harley et al. (1992). Results for linear regression lines forced through the origin are given in Table 2

Table 2. Slopes and \( r^2 \) values of linear regression of \( J_{\text{max}} \) versus \( V_{\text{cmax}} \) using data as collated by Wullschleger (1993) and adjusted to a common temperature of 20°C using the temperature functions of Harley et al. (1992), Farquhar et al. (1980) and Kirschbaum and Farquhar (1984); the regression line has been forced through the origin.

<table>
<thead>
<tr>
<th>Source</th>
<th>Slope</th>
<th>( r^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wullschleger (1993)</td>
<td>1.97</td>
<td>0.79</td>
</tr>
<tr>
<td>Harley et al. (1992)</td>
<td>2.68</td>
<td>0.87</td>
</tr>
<tr>
<td>Farquhar et al. (1980)</td>
<td>2.44</td>
<td>0.86</td>
</tr>
<tr>
<td>Kirschbaum and Farquhar (1984)</td>
<td>2.16</td>
<td>0.80</td>
</tr>
</tbody>
</table>

There is a clear need for further studies on the temperature response of photosynthesis to clarify these issues and improve model predictions of the uptake of carbon by various ecosystems. This note shows that photosynthetic parameters for different species should be scaled to a common temperature to eliminate one source of variability in any correlation analysis between these parameters.

References


