Supplementary Material

Photosynthesis of an Epiphytic Resurrection Fern (Davallia angustata (Wall, ex Hook. & Grev.).

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Theory of Measurement of Photosynthetic Parameters using PAM technology

The fluorescence yield is part of the WinControl software output as the effective quantum yield (Y or ΦPSII, Schreiber et al., 1995). Effective quantum yield have ranges from 0 to 1 (maximum usually no higher than ≈ 0.85). It is found experimentally that if Y is plotted against irradiance (E), it follows a simple exponential decay function of the form $y = e^{-ky}$,

$$Y = Y_{max} \times e^{-k_y E}$$

Equation 1

where, $Y$ is the effective quantum yield,

$Y_{max}$ is the effective quantum yield at theoretical zero irradiance,

$k_y$ is a scaling constant, and $E$ is the irradiance (µmol photons m$^{-2}$ s$^{-1}$, PPFD).

The ETR is an estimate of the light reactions of photosynthesis and is defined as:

$$ETR = Y \times E \times (PSI/PSII \text{ allocation factor}) \times (\text{leaf absorptance factor})$$

Equation 2

where, $Y$ is the effective quantum yield,

$E$ is the irradiance (mol quanta m$^{-2}$ s$^{-1}$ PPFD).

The PSI/PSII allocation factor is about 0.5 (Melis, 1989; Ritchie, 2008) and allows for absorption of ≈50% of quanta by PSII, and the leaf absorptance factor (Abt$\lambda_\nu = 0.84$) is the default absorptance factor for a variety of plants used by the Walz software. To properly estimate ETR it is necessary to allow for the Absorptance (Abt$\lambda_\nu$) of the leaves and it is better to measure this experimentally (Ritchie and Runcie, 2014) rather than rely on a default value (Abt$\lambda_\nu = 0.84$). Absorptance of leaves is now known to be more variable than previously thought and actual measurements of Abt at the blue
wavelength used by a blue diode PAM (465 nm) are in general considerably higher than the default value (Ritchie and Runcie, 2014). Relative ETR (rETR) is calculated using the standard default absorptance factor (Abt). rETR as calculated by the software is converted into the actual ETR by multiplying rETR by the ratio of the experimentally measured Abt465nm and the default value (Abt465 nm/0.84). POER can then be estimated as mol O₂ per meter squared per second (Ritchie, 2014; Ritchie and Runcie, 2014) by dividing ETR by 4 based on the basic relationship of the light reactions of photosynthesis, 2H₂O → O₂ + 4e + 4H⁺. POER is a high estimate of gross photosynthesis because it does not take into account oxygen consumption by photorespiration and possible Mehler reactions (Atwell et al., 1999).

Since Yield is of the form \( y = e^{-x} \), then since photosynthesis is proportional to the product of the yield and irradiance then an appropriate model for photosynthesis is of the form \( y = x . e^{-x} \) (Ritchie, 2008). The equation \( y = x . e^{-x} \) has a maximum at \( x = 1 \) and the slope of the line at \( x = 0 \) is 1 and there is a point of inflection \( (d^2y/d^2x = 0) \) at \( x = 2 \). A form suitable for modeling photosynthesis with experimentally determinable constants that are easily recognizable on a graphical representation of the data (Ritchie and Bunthawin, 2010a, b; Ritchie, 2012, 2014; Ritchie, 2015b) is,

\[
ETR = \frac{ETR_{\text{max}} \times E}{E_{\text{opt}}} \times e^{1-E/E_{\text{opt}}} \quad \text{Equation 3}
\]

where, ETR is electron transport rate as a measure of gross photosynthesis,

- \( E \) is the Irradiance (\( \mu \text{mol m}^{-2} \text{s}^{-1} \) 400 – 700 nm PPFD),
- \( E_{\text{opt}} \) is the optimum irradiance,
- \( ETR_{\text{max}} \) is the maximum gross photosynthesis.

The maximum photosynthetic efficiency (\( \alpha_0 \)) is the initial slope of the curve at \( E = 0 \) (\( \alpha = ETR_{\text{max}} \times e/E_{\text{opt}} \)). It can be shown by analysis of Equation 3 that the half-maximum photosynthesis (ETR\(_{\text{half-max}} \)) occurs at 0.231961 \( \times E_{\text{opt}} \) and that photosynthesis is also inhibited by 50% at 2.67341 \( \times E_{\text{opt}} \). Hence good rates of photosynthesis (>50% of maximum) are found under irradiances ranging from \( \frac{1}{4} \) to 2.5 times the optimum irradiance. The asymptotic photosynthetic efficiency at zero irradiance (\( \alpha_0 \)) is theoretically useful but perhaps a more informative expression for productivity studies.
is the photosynthetic efficiency at optimum irradiance (\( \alpha_{E_{opt}} \)). It can be shown that \( \alpha \times E_{opt} \) is equivalent to \( \alpha_{E_{opt}} = \frac{\alpha_0}{e} \). For example, if \( \alpha_0 = 0.2 \) then the photosynthetic efficiency at Optimum Irradiance (\( \alpha_{E_{opt}} \)) is 7.4%.

The equations used to estimate the two non-photochemical quenching parameters \( qN \) (known as Variable Fluorescence NPQ) and NPQ are calculated by the Walz software and are discussed by Ritchie and Bunthawin (2010a, b), Beckett et al. (2012) and Brestic and Zivcak (2013) and are based on Genty et al. (1989). \( qN \) and NPQ vs. irradiance best fit a simple exponential saturation curve of the form \( y = y_{max} (1-e^{-kE}) \)

where \( y \) is \( qN \) or NPQ and \( E \) is the irradiance.

\[
qN = qN_{max} \left(1 - e^{-k_{qN}E}\right)
\]

Equation 4

\[
NPQ = NPQ_{max} \left(1 - e^{-k_{NPQ}E}\right)\]

Equation 5

Equations 1 and 3, 4 and 5 curves are best fitted using non-linear least squares methods and the asymptotic estimates of the errors of the fitted parameters calculated by matrix inversion. EXCEL routines are available on the Internet (Ritchie 2015b).

**Supplementary Material References**


