The basic relationships between chlorophyll fluorescence and photosynthesis in plants:

some theory and experimental evidence

- background
- examples
chlorophyll fluorescence in higher plants:

- red, far-red emission by Chl a

- radiative de-excitation of absorbed light in antenna of photosystems
\[
\begin{align*}
\text{PSII} + \text{PSI} &\quad \text{Fluorescence yield} \\
\text{Relative fluorescence yield} &\quad \frac{[\text{PSII}]}{[\text{PSI}]} \approx 1.5 \\
\Phi_{\text{PSII}} &\approx 5 \Phi_{\text{PSI}} 
\end{align*}
\]
but in leaf, strong re-absorption!

(from Pedros et al. 2004)
\[ \text{NADP}^+ \rightarrow \text{NADPH} + \text{ADP} + \text{Pi} \rightarrow \text{ATP} \]

\[ 2 \text{H}^+ \rightarrow 2 \text{H}_2 \text{O} \]

\[ 2 \text{H}_2 \text{O} \rightarrow \text{O}_2 + 4 \text{H}^+ \]
- in vivo, at PSII, fluorescence yield is variable and is modulated by competitive pathways for de-excitation at PSII: photochemistry and thermal dissipation.
the fluorescence yield at PSII can be described as:

\[ \Phi_F = \frac{F}{I_a} = \frac{k_F}{k_F + k_D + k_P} \]

with

F and I\( _a \): intensity of fluorescence and absorbed light respectively

\( k_F, k_D \) and \( k_P \): rate constants for de-excitation through fluorescence, thermal dissipation and photochemistry respectively

\( q_P \): photochemical quenching

\( q_N \): non-photochemical quenching (NPQ)
(Genty et al. 1994)
at PSII:

\[ \Phi_P \] probability of de-excitation through photochemistry (non radiative dissipation)

\[ \Phi_D \] probability of de-excitation through thermal dissipation (non radiative dissipation)

\[ \Phi_F \] probability of de-excitation through fluorescence (radiative dissipation)
at steady-state:

\[ \Phi_P + \Phi_D + \Phi_F = 1 \]

at saturation of photochemistry:

\[ \Phi_P \to 0 \]

\[ \Phi_D^M + \Phi_F^M = 1 \]

assumption:

\[ \frac{\Phi_D}{\Phi_F} = \frac{\Phi_D^M}{\Phi_F^M} \]

then:

\[ \Phi_P = \Delta \Phi_F \frac{\Phi_F}{\Phi_F^M} = \Phi F^M_F - \Phi F = \Delta \Phi_F \]

(Genty et al. 1989)
\( \Phi_{Fm} \)

\[
(\Phi_P)_i = 1 - \frac{(\Phi_F)_i}{(\Phi_{Fm})_i}
\]

\( \Phi_F \)

(Genty et al. 1994)
\[ 2 \text{H}_2\text{O} \rightarrow \text{O}_2 + 4 \text{H}^+ + 2 \text{H}_2\text{O} \]

\[ 2 \text{H}^+ + 2 \text{H}_2\text{O} \rightarrow 2 \text{H}_2\text{O} \]

\[ \text{NADP}^+ + \text{ADP} + \text{Pi} \rightarrow \text{NADPH} + \text{ATP} \]
(Genty et al. 1992)
French bean in air

\(1 - \Phi_F / \Phi_{Fm}\) vs. Quantum yield (mol O\(_2\) mol\(^{-1}\) photon)
French bean in air

\[ 1 - \Phi_F / \Phi_{Fm} \]

\[ \Phi_{O_2} (\text{mol} \ O_2 \text{mol}^{-1} \text{ photon}) \]

60 \( \mu \text{mol photon m}^{-2} \text{ s}^{-1} \)

Increasing irradiance
\[ \Phi_{PSII} \]

\[ \Phi_{CO_2} ? \]

\[ \Phi \]

\[ P_680 \]

\[ P_700 \]

\[ Q_a \]

\[ PSII \]

\[ cytb_6 \]

\[ cytf \]

\[ RuBP \]

\[ CO_2 \]

\[ + O_2 \]

\[ carboxylation + oxygenation \]

\[ & \]

\[ carbon reduction cycle \]

\[ 2H^+ \]

\[ 2O_2 \]

\[ + 4H^+ \]

\[ 2H^+ \]

\[ NADP^+ \]

\[ NADPH \]

\[ ADP+Pi \]

\[ ATP \]

\[ H^+ \]

\[ P_{CO_2} \]
Variations induced by irradiance, atmospheric $CO_2$ concentration, variable photosynthetic induction, DCMU feeding

\[ \Phi_{PS2} \]

with $\Phi_e = 4 \Phi_{CO2}$

(Genty et al. 1989, 1994)
maize in 21% $O_2$

(from Genty & al. 1989)
(calculated from Valentini et al. 1995)
Vitis vinifera L.

(from Flexas & al. 2000)
Vitis vinifera L.

(recalculated from Flexas & al. 1999)
\[ \Phi_P = 1 - \frac{\Phi_{F_S}}{\Phi_{F_M}} \]

\[ \Phi_{F_S} = (1 - \Phi_P) \Phi_{F_M} \]

\[ NPQ = \frac{\Phi_{F_M^{dark}}}{\Phi_{F_M}} - 1 \]

\[ \Phi_{F_S^{rel}} = \frac{\Phi_{F_S}}{\Phi_{F_M^{dark}}} = (1 - \Phi_P)(NPQ + 1)^{-1} \]

with \[ NPQ = f(\Phi_P) \]
**C3:** *Flaveria pringlei*  
**C4:** *Flaveria bidentis*  

*Vitis vinifera* L.  

(Aresheva & al. 2012)
take home

Chl fluorescence:

- probe for non-invasive quantification of plant photochemical efficiency including temporal and spatial variations from molecular to global scales.

- Using active probing, potential for estimation of photosynthetic electron transport rate and CO$_2$ assimilation rate.

- Using passive probing, the variation of fluorescence yield is small as a result of 2 convoluted factors, photochemical quenching & non-photochemical quenching. Solving requires to describe NPQ.

more work!!!