Chlorophyll Fluorescence Monitoring at Selected LTER Network Sites

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Quick & Dirty Intro to Chl F

• When a leaf is exposed to PAR, emits light ~680-760 nm
  – Fluorescence
  – Mainly from PSII
• This light can be used for probing state photosynthetic machinery in vivo
• For ecophysiologists, useful for quantifying effect of plant stress on photosynthesis in the field

Fate of Light absorbed by Chlorophyll

• Energy channeled to reaction center of PSII, used for photosynthesis
  – \( \Phi_P \)
• Thermal dissipation
  – \( \Phi_D \)
• Fluorescent emission
  – \( \Phi_F \)
• All quantum yields that sum to 1
  \( \Phi_P + \Phi_D + \Phi_F = 1 \)
Fate of Light absorbed by Chlorophyll

\[ \Phi_p + \Phi_d + \Phi_r = 1 \]

- Because 1st two processes are regulated by plant, and all 3 are competitive, fluorescence depends on photosynthesis & dissipation

Chlorophyll Fluorescence Terminology

It's a jungle out there!!

Fluorescence Parameters

![Fluorescence Parameters Graph](image)
In Dark

• Dark-adapted leaf
  – Weak intermittent (modulated) light gives rise to $F_0$
  – Indicates open reaction centers, as the primary electron acceptor $Q_A$ in PS II is fully oxidized

Fluorescence Parameters

In Dark

• Dark-adapted leaf
  – Pulse of strong (saturating) light gives rise to $F_m$
  – $Q_A$ is fully reduced, all reaction centers are closed
  – So no energy can go to photosynthesis
    • Thermal dissipation processes are usually minimal in the dark
    • So most energy goes to fluorescence
In Dark

- Dark-adapted leaf
  - Since no light goes to photosynthesis,
    \( \Phi_{Dm} + \Phi_{Fm} = 1 \)
  - \( \Phi_{Dm} \) = quantum yield of thermal dissipation at saturating light pulse
  - \( \Phi_{Fm} \) = quantum yield of fluorescence at saturating light pulse

- Also assume that there's no change in relative quantum yields of dissipation & fluorescence during saturating pulse

\[
\frac{\Phi_{Dm}}{\Phi_{Fm}} = \frac{\Phi_D}{\Phi_F}
\]

- Combining this with 3-process equation:

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

- Gives the following:

\[
\Phi_{PSII} = \Phi_{Fm} - \Phi_F
\]

- (where \( \Phi_{PSII} \) is substituted for \( \Phi_P \), since originates mainly from PS II)

- In dark, \( \Phi_{PSII} = F_m \) and \( \Phi_F = F_o \), maximum quantum yield (\( \Phi_{PSII} \) or \( F_v/F_m \)) is

\[
\Phi_{PSII} = \frac{F_v}{F_m} - \frac{F_o}{F_m}
\]
In Light

- Light-adapted leaf
  - Sub-saturating light level gives rise to constant fluorescent level $F$ (also called $F_s$ or $F_i$)
  - A pulse of saturating light gives rise to $F_m$
  - Lower than $F_m$
  - Why?
    - Reaction centers are closed, but...
    - Thermal dissipation now competes with fluorescence

In Light

- Light-adapted leaf
  - Gives the following:
    \[ \Phi_{PSII} = \frac{\Phi_m - \Phi} {\Phi_m} \]
  - In light, $\Phi_{PSII} = F_m$ and $\Phi = F$, actual quantum yield (\(\Phi_{PSII}\)) is
    \[ \Phi_{PSII} = \frac{F_m - F} {F_m} = \frac{\Delta F} {F_m} \]
In Light

• Light-adapted leaf
  – Not all reaction centers in PS II are “open”
  – Some are reduced with excited electrons
  – The fraction that are open is given as:
    \[ q_P = \frac{F_m' - F_m}{F_m' - F_o} = \frac{\Delta F}{F_m'} \]
  – \( F_o' \) measured by exposing leaf to far-red light for a few seconds, then covering with cloth

Fluorescence Parameters

In Light

• Light-adapted leaf
  – You may also calculate a ratio similar to that seen in dark-adapted foliage, the intrinsic quantum yield:
    \[ \frac{F_m'}{F_m} = \frac{F_m' - F_o'}{F_m'} \]
  – This is the quantum yield you would have gotten were all the reaction centers open (they aren’t)
In Light
• Light-adapted leaf
  – Actual quantum yield, $q_P$ and intrinsic quantum yield are all related:
  \[
  \frac{F_v}{F_m} = \frac{\Phi_{PSII}}{q_P}
  \]

Behavior of Fluorescence Parameters
• $F_v/F_m$ (maximum quantum yield)
  – Typically ~ 0.8 in healthy, unstressed leaves
  – Decreases caused by **photoinhibition**
    • Shunting of light energy away from photochemistry caused by protective mechanisms and/or damage
    – Various stresses can cause photoinhibition
    – Usually changes slowly

Behavior of Fluorescence Parameters
• $\Phi_{PSII}$ (actual quantum yield)
  – $< F_v/F_m$
  – Decreases caused by
    • Decreases in $F_v/F_m$
    • Closure of reaction centers
  – Shunting of excess light energy away from photochemistry during the day
    • Generally decreases with increasing light
  – Changes quickly
  – Can be used to derive electron transport rate
    • Roughly proportional to photosynthetic rate
Behavior of Fluorescence Parameters

- $F'/F_m$ (intrinsic quantum yield)
  - $\approx \Phi_{PSII}$
  - Decreases caused by photoprotective xanthophyll cycle
  - Shunting of excess light energy away from photochemistry during the day
  - Generally decreases with increasing light
  - Usually correlated with de-epoxidation of xanthophylls
  - Papers by Demmig-Adams & Adams claim thermal dissipation of captured light is proportional to $1 - F'/F_m$

Behavior of Fluorescence Parameters

- $qP$ (proportion of open reaction centers)
  - Decreases from 1 (in dark) to about 0.5-0.95 in light

Uses of Fluorescence Parameters

- $F/F_m$ (maximum quantum yield)
  - Cold temperatures/freezing stress
  - Excess light (with cold stress)
  - UV light
  - Nutrient stress
    - N, P, Ca
  - Pollutants
  - Drought (extreme)
  - Most responsive to stress?
**Arctostaphylos in Summer & Winter**

Zarter et al. 2006

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**Red Spruce & Balsam Fir at HBEF**

Ca Fertilization Watershed Experiment

August 2005

Ca-treated > Control

$P = 0.002$

$P. \ rubens > A. \ balsamea$

$P = 0.004$

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**Uses of Fluorescence Parameters**

- $\Phi_{\text{PSII}}$ (actual quantum yield)
  - Nitrogen deficiencies
  - Temperature
  - Drought
Uses of Fluorescence Parameters

• $F'_v/F'_m$ (intrinsic quantum yield)
  – Nitrogen deficiencies
  – Foliar Uptake
  – Temperature
  – Drought

Uses of Fluorescence Parameters

• $q_P$ (proportion of open reaction centers)
  – Nitrogen deficiencies
  – Temperature
  – Drought

Response of Chl F parameters to temperature

- Quercus ilex
- Corcuera et al. 2005
Effect of Canopy N Uptake

Proposed Work

- Pre-dawn, mid-day (high light) measurements
  - Because we don’t know which parameter will respond best to stress
- Do by ecosystem type
  - Coordinate with monitoring
  - Statistical modeling of potential stressors

Proposed Work

- Where should this be done?
  - Niwot
  - Andrews, Harvard Forest: interested
  - Elsewhere?
Proposed Work

- A good start for a longitudinal study
- But sparse!

Equipment Options

- Two instruments
  - Both use pulse amplitude modulation system
  - Both are portable and versatile enough for our uses
  - Both are relatively inexpensive

OS5-FL

- Manufactured by Opti-Sciences, Inc.
  - http://www.optisci.com/5fl.htm
- ~ $12.5 k
- Currently used by Boyce
PAM-2100

- Manufactured by Walz GmbH
- Successor to popular PAM-2000
- ~ $14k
- Currently used by Sievering

Protocols

- Types of measurements to make
  - Predawn
    - Fv/Fm
  - Mid-day
    - \( \Phi_{psii} \), \( F_p/F_m \), \( q_P \)
- When to make them
  - Once (twice?)/week during growing season
  - Once/month during dormant season
- What to make it on?
  - Dominant vegetation of ecosystem at each LTER