# Understanding Non-linear Chlorophyll Fluorescence Dynamics for Water Stress Detection


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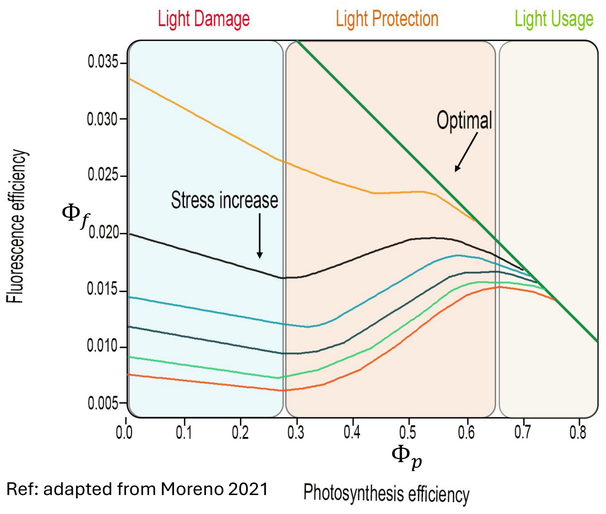
## Introduction




Ref: adapted from Moreno 2021

The ESA **FLEX** mission will provide **spatiotemporal measurements** of solar-induced chlorophyll fluorescence (**SIF**), offering **new insights** into **photosynthetic activity** at the global scale. However, **FLEX measurements represents only a single snapshot of fluorescence at a given time and does not directly reflect the dynamic and nonlinear nature of photosynthesis.**

Plant **photosynthetic efficiency** is highly sensitive to **environmental stress**, and the fluorescence signal can vary significantly depending on the **physiological state** of the plant. As a result, interpreting **SIF as a proxy for photosynthesis** requires a deeper understanding of how **stress conditions modulate** this relationship. In this context, fluorescence-light response curves reveal a consistent **triphasic pattern** aligned with physiological zones: **light usage** (Phase I), **light protection** (Phase II), and **light damage** (Phase III).

## Objectives

This study explores how the **nonlinear dynamics** between **chlorophyll fluorescence and photosynthetic efficiency** shift under distinct environmental stress scenarios. Across three experimental designs, we characterize dynamic responses under varying **light and abiotic stress conditions, with drought** serving as a baseline, to enhance the physiological interpretation of FLEX-derived SIF observations.

## Methods

### Experiment 1




- **Light Curves (0-1800 µmol $m^{-2}s^{-1}$)** Tomato, **water deficit** and **low light** growing conditions.

#### Measured parameters

- **Fs:** steady-state fluorescence
- **Fm-Fm'**: maximum fluorescence (dark adapted and light adapted)
- **Fo-Fo'**: minimum fluorescence (dark adapted and light adapted)

#### Derived parameters

- **Photosynthetic quantum yield** $(\Phi_p)$
- **Fluorescence quantum yield** $(\Phi_f)$
- **NPQ quantum yield** $(\Phi_D = NPQtot_{al})$

#### Phases characterization

- First derivative

### Experiment 2 and Experiment 3

**Plant screening chamber: Active fluorescence, hyperspectral, and thermal imaging.**




#### Measured parameters

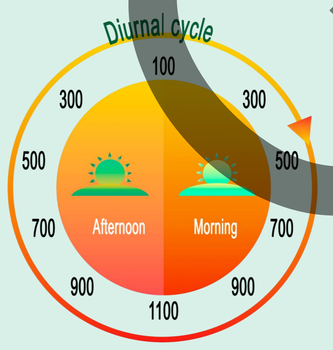
- Steady-state fluorescence (**Fs**)
- **Fm-Fm'**: Maximum fluorescence (dark adapted and light adapted)
- **Fo-Fo'**: Minimum fluorescence (dark adapted and light adapted)

#### Derived parameters

- **Quantum yield of total NPQ** $(\Phi NPQ_t)$
- **Quantum yield of reversible NPQ** $(\Phi NPQ_r)$
- **Fluorescence quantum yield** $(\Phi_F)$

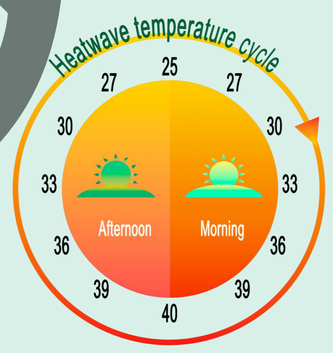
#### Experiment 2: Diurnal cycle

- **Tomato | High light**
- **PAR: 0 – 1100 µmol $m^{-2}s^{-1}$**
- **Control** and **drought**.

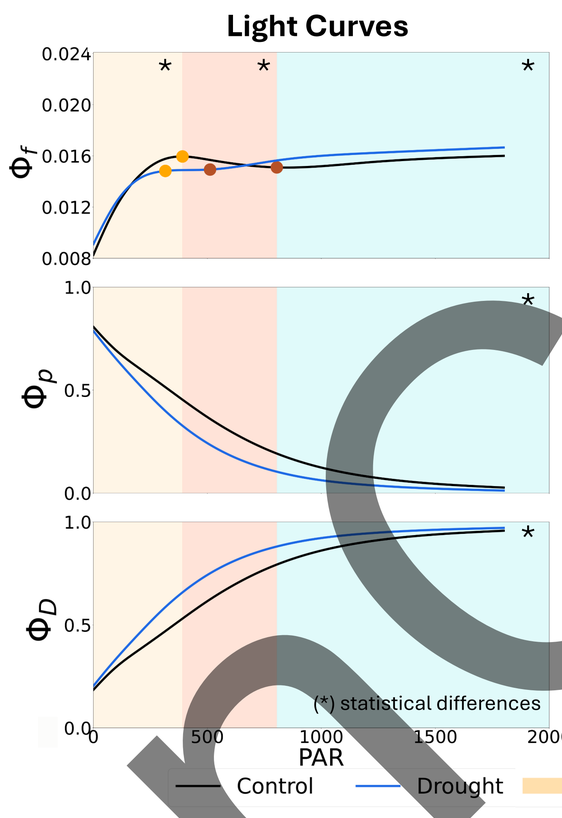


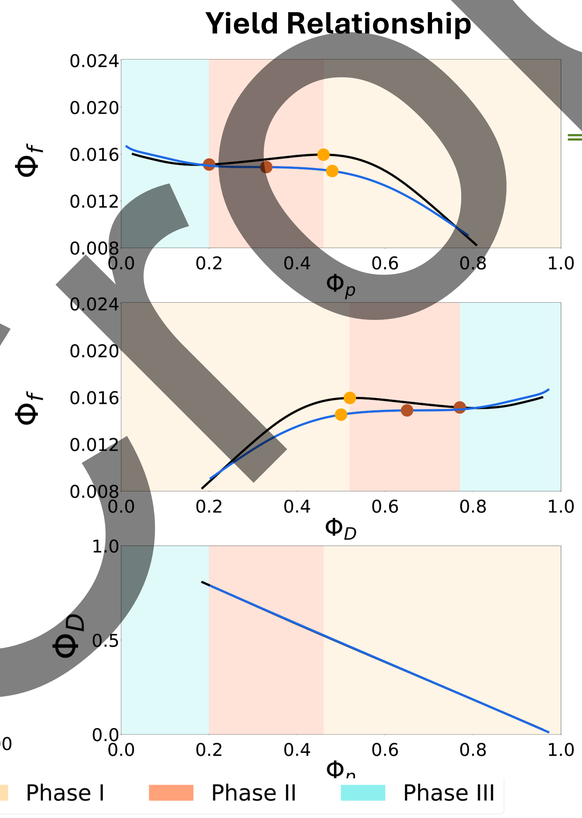

#### Experiment 3: Heatwave

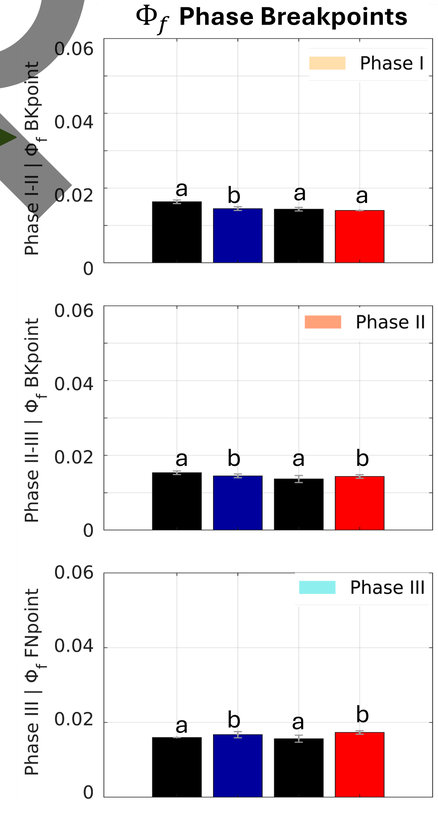
- **Tomate | Low light (500 µmol $m^{-2}s^{-1}$)**
- **Control** and **drought**.
- **Temperature : Normal : 18 – 25 ºC** and **Heatwave : 25 – 40 ºC**

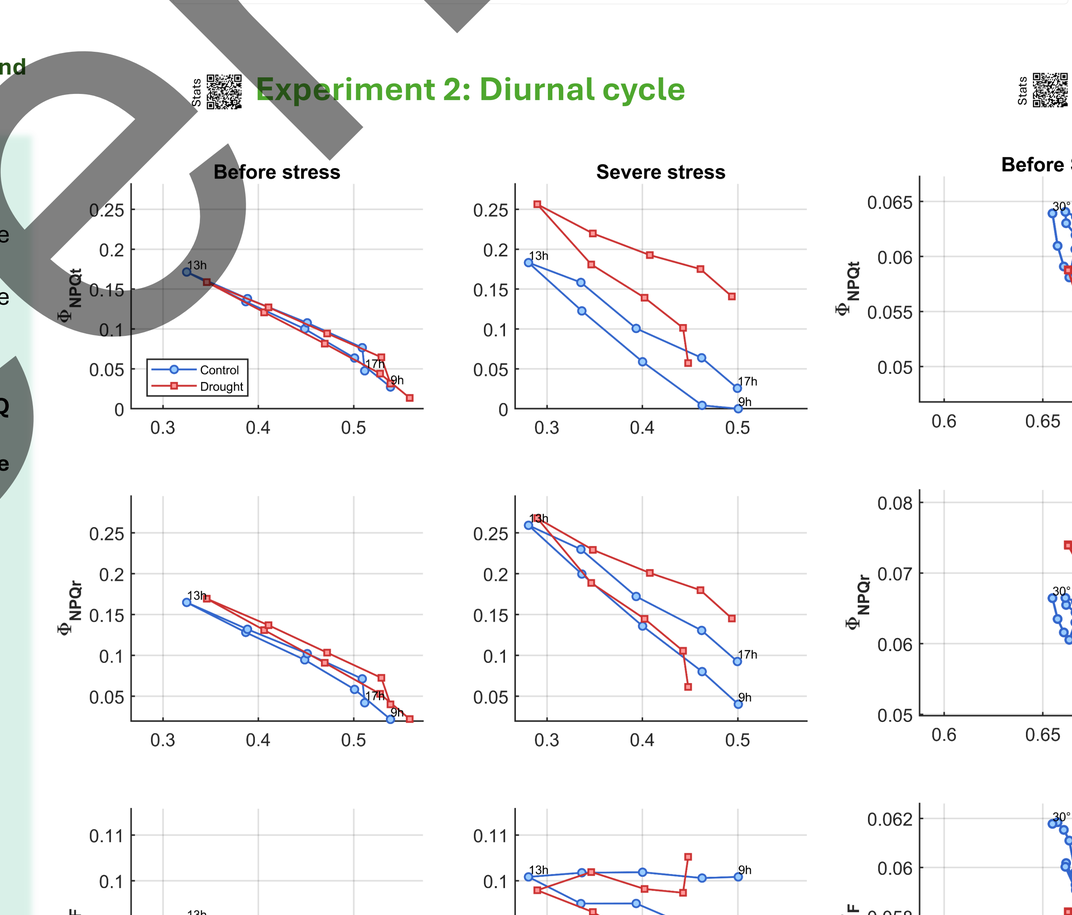



## Results



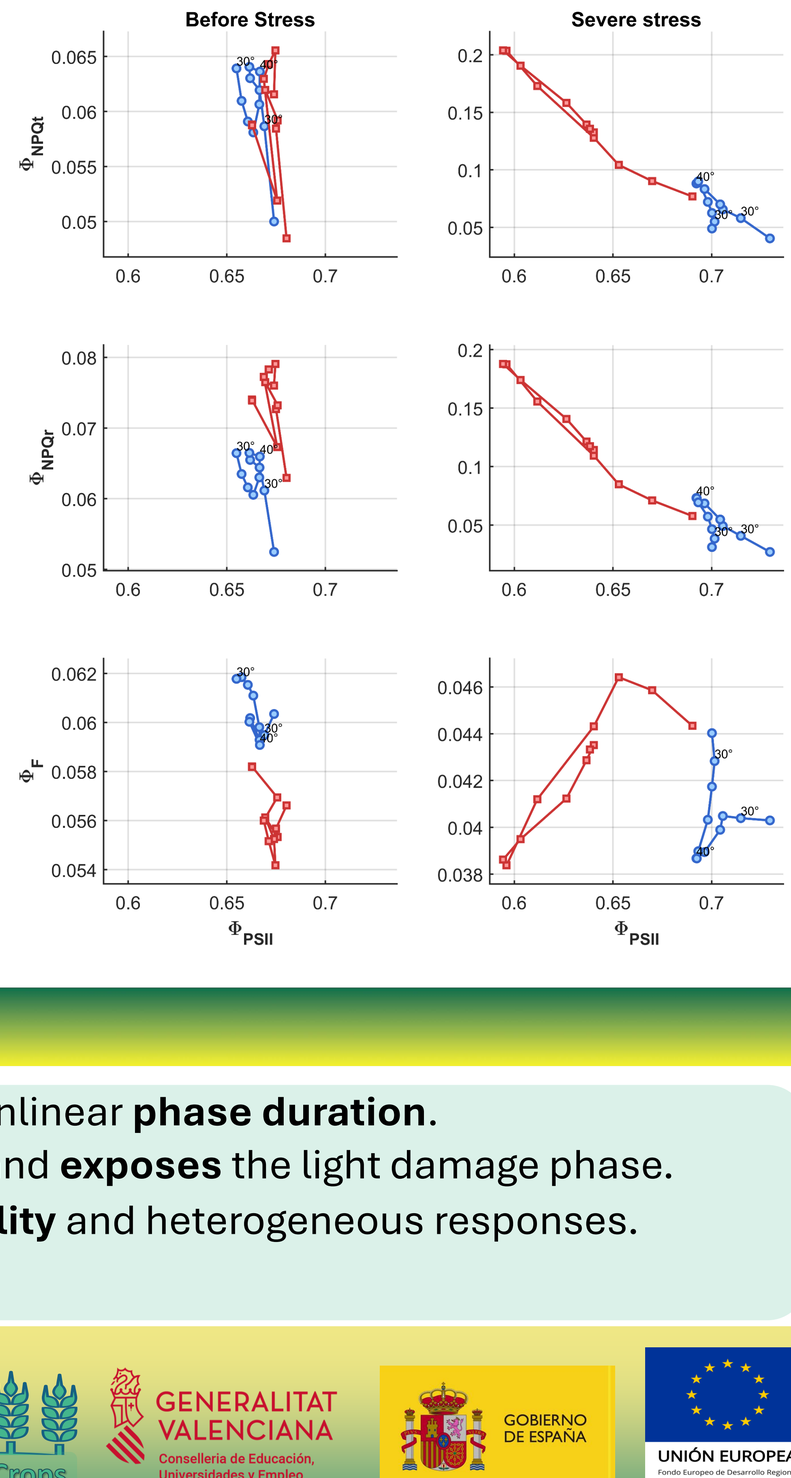

Stats

#### Experiment 2: Diurnal cycle




Stats

#### Experiment 3: Heatwave




## Conclusions

- **Exp. 1: Growth light determined light-curve** shape; **drought** shortened and shifted nonlinear **phase duration**.
- **Exp. 2: Daily light cycling** confirmed **growth-light control of $\Phi_p$–$\Phi_f$–$\Phi_{NPQ}$** dynamics and **exposes** the light damage phase.
- **Exp. 3: Heatwave** intensified drought effects; **stressed plants showed greater instability** and heterogeneous responses.
- **The nonlinear phase dynamics reflect physiological acclimation to stress.**

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