Non-monotonic relationship of sun-induced fluorescence to photosynthesis

Sebastian Wieneke

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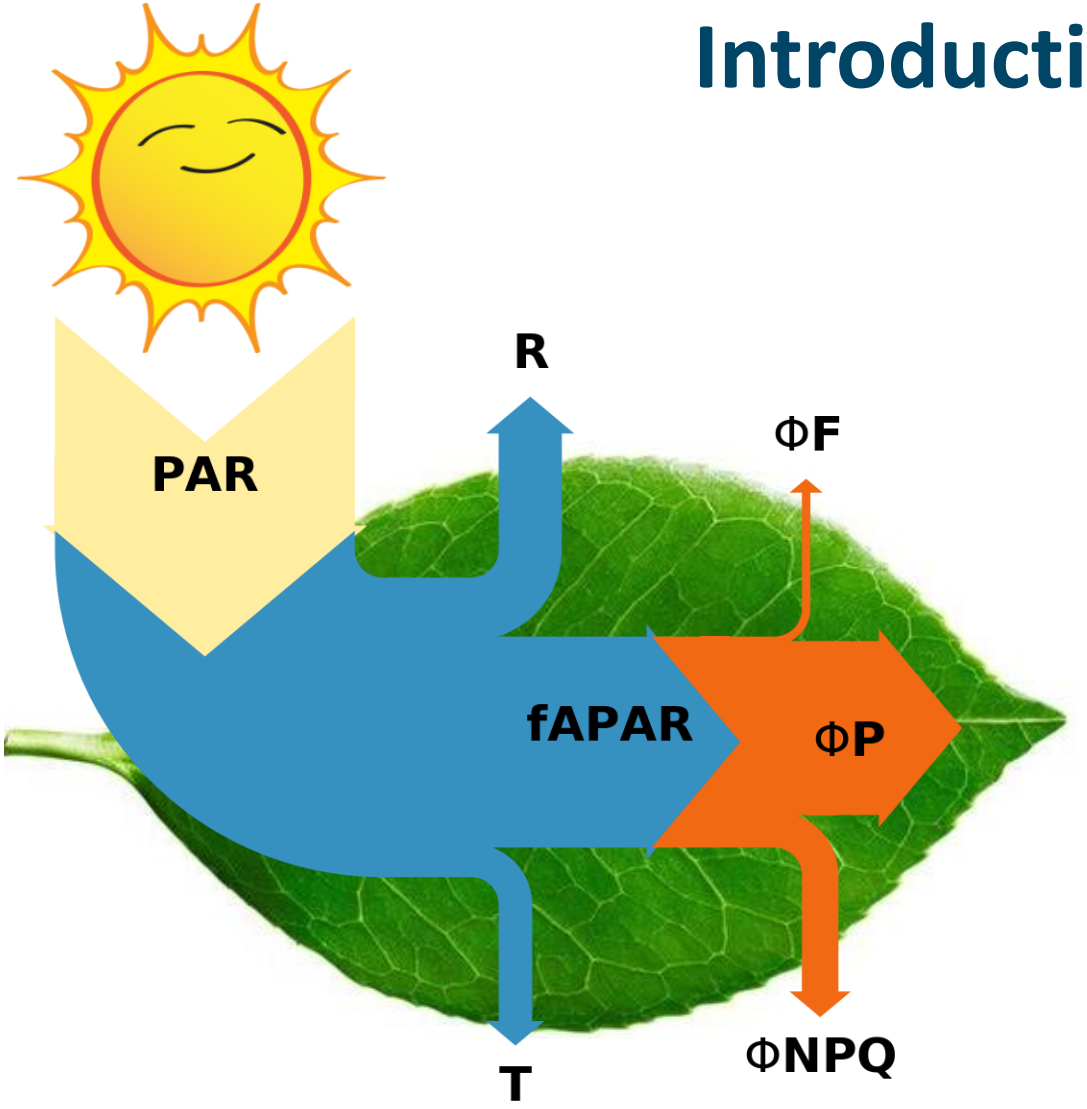
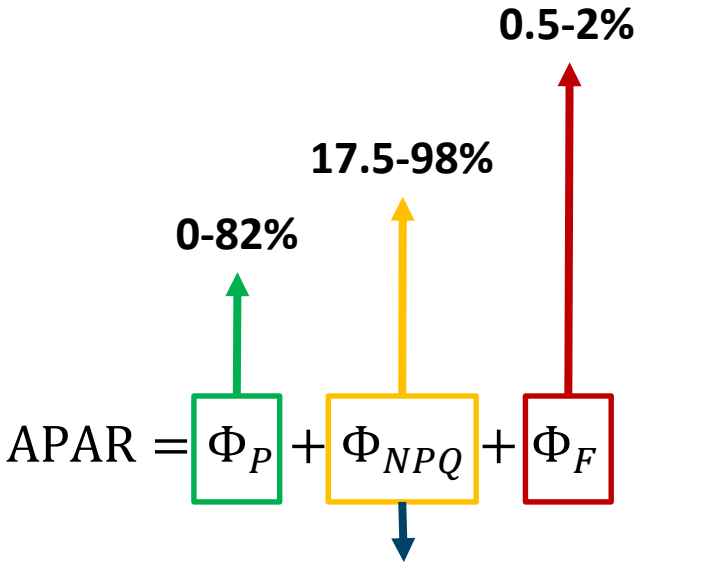
Introduction



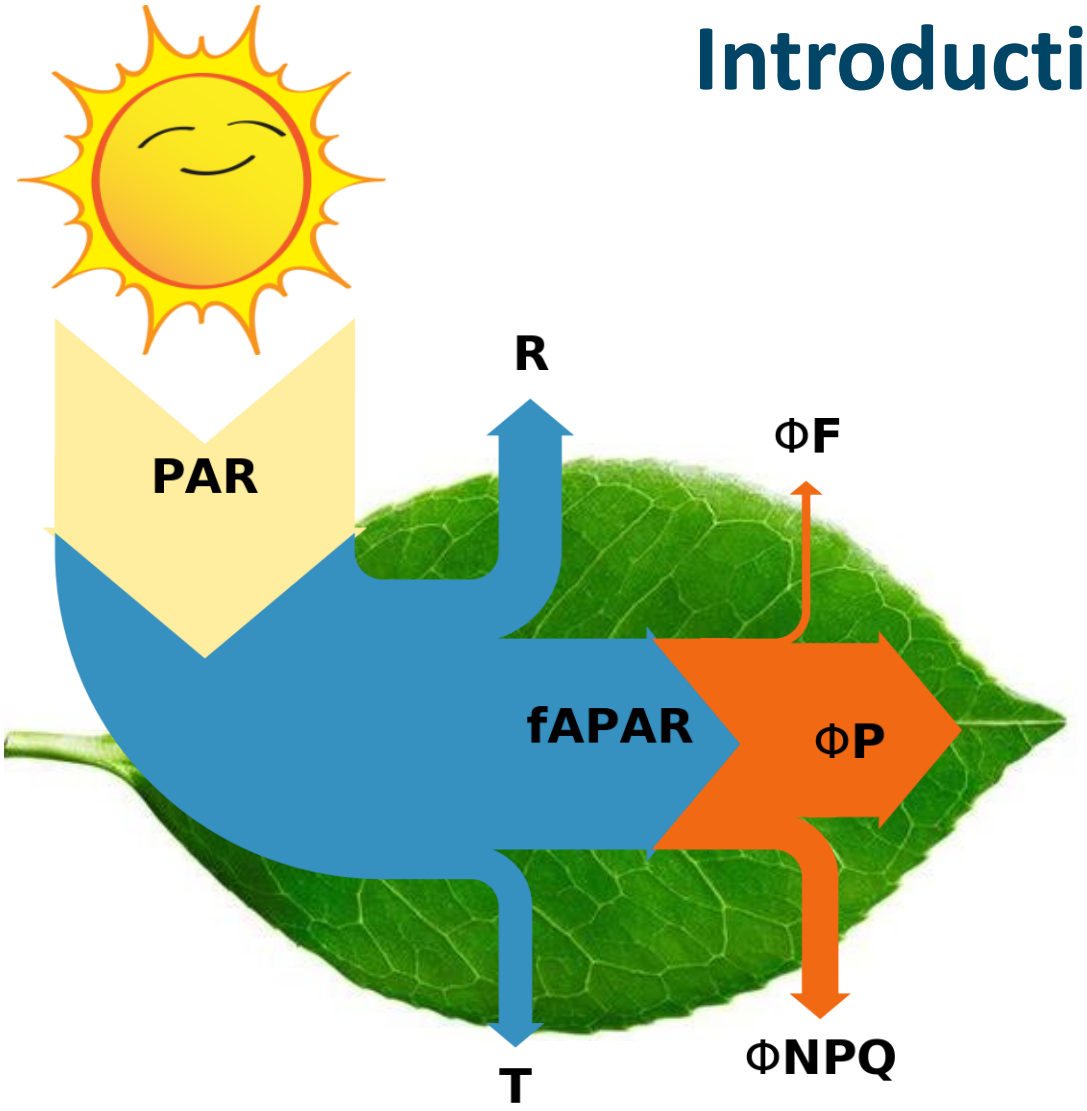


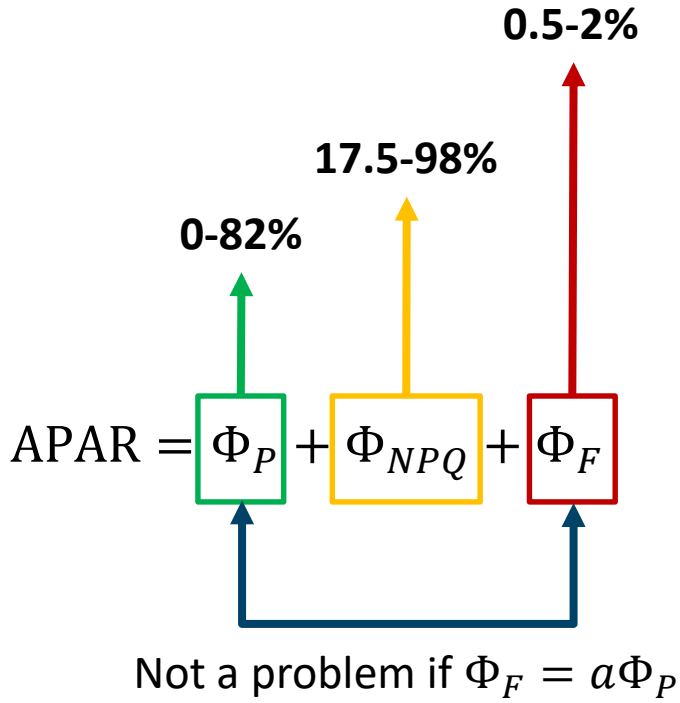
- Can be measured at the leaf
- Estimation by RS proxies (still) not feasible

PAR = photosynthetic active radiation
fAPAR = fraction of absorbed PAR
R = reflectance
T = transmittance

Φ_F = fluorescence yield
Φ_P = photochemical yield
Φ_{NPQ} = non-photochemical yield

Introduction





PAR = photosynthetic active radiation
fAPAR = fraction of absorbed PAR
R = reflectance
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Φ_F = fluorescence yield
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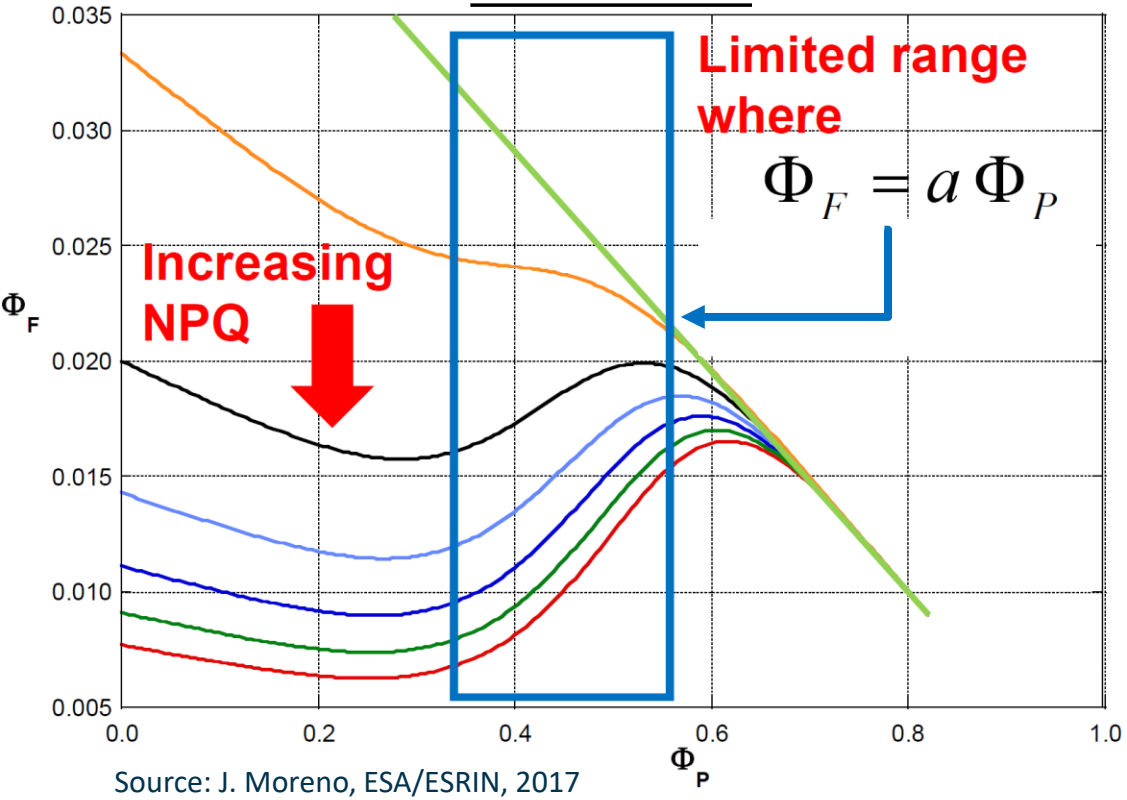
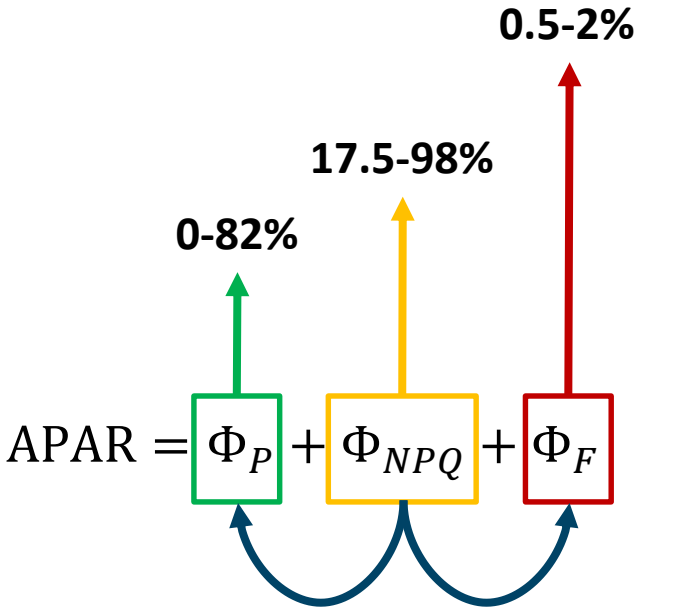
Energy balance of the photosynthetic light reaction

Concept model based on actively induced fluorescence



Source: J. Moreno, ESA/ESRIN, 2017



From actively induced fluorescence we know that $\boldsymbol{\Phi_F = a\Phi_P}$ changes with NPQ

APAR = absorbed photosynthetic active radiation
Φ_F = fluorescence yield
Φ_P = photochemical yield
Φ_{NPQ} = non-photochemical yield

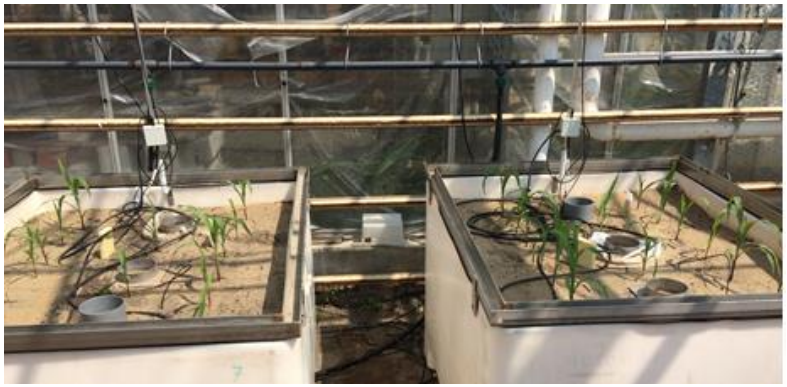
Research question:

1. Can we find the shown non-monotonic behavior between Φ_P,Φ_{NPQ} and Φ_F with passive fluorescence measurement techniques?

2. If so, how can we estimate photosynthesis from fluorescence under increasing NPQ?

Sun induced fluorescence at the leaf

Phosphorous gradient experiment 2017 (*Zea mays)*

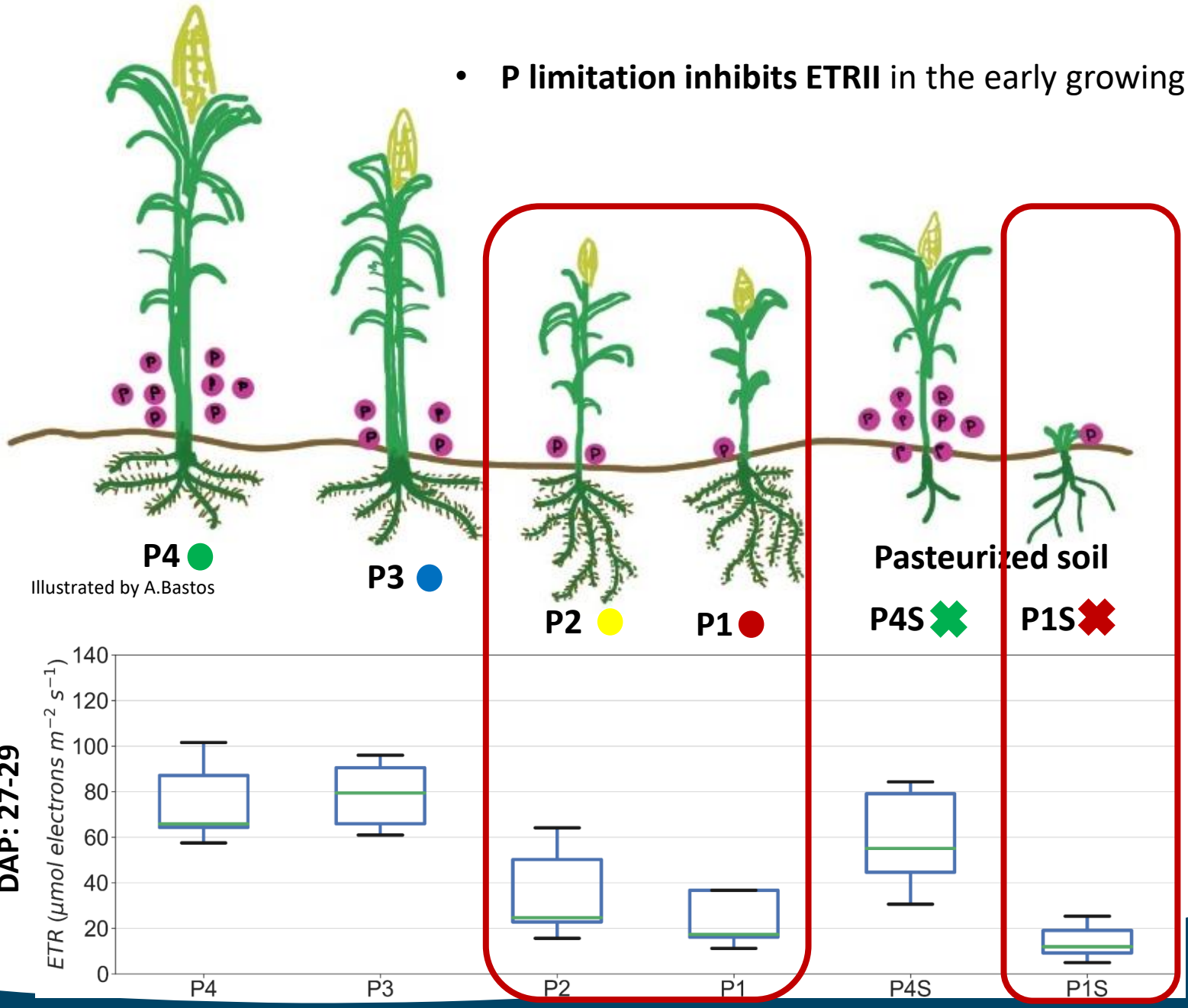


Label	P treatment (kg P ha^{-1})	Arbuscular Mycorrhizal funghi	Replicates
P4	20	Yes	5
P4S	20	No AMF	5
P3	10	Yes	5
P2	5	Yes	5
P1	2.5	Yes	5
P1S	2.5	No AMF	5

- Two measurement campaigns (27 DAP & 57 DAP)
- Key Parameters: ETR (Licor 6400XT), FY (FluoWat & ASD)
- 10 leaves per treatment and campaign (104 leaf samples)

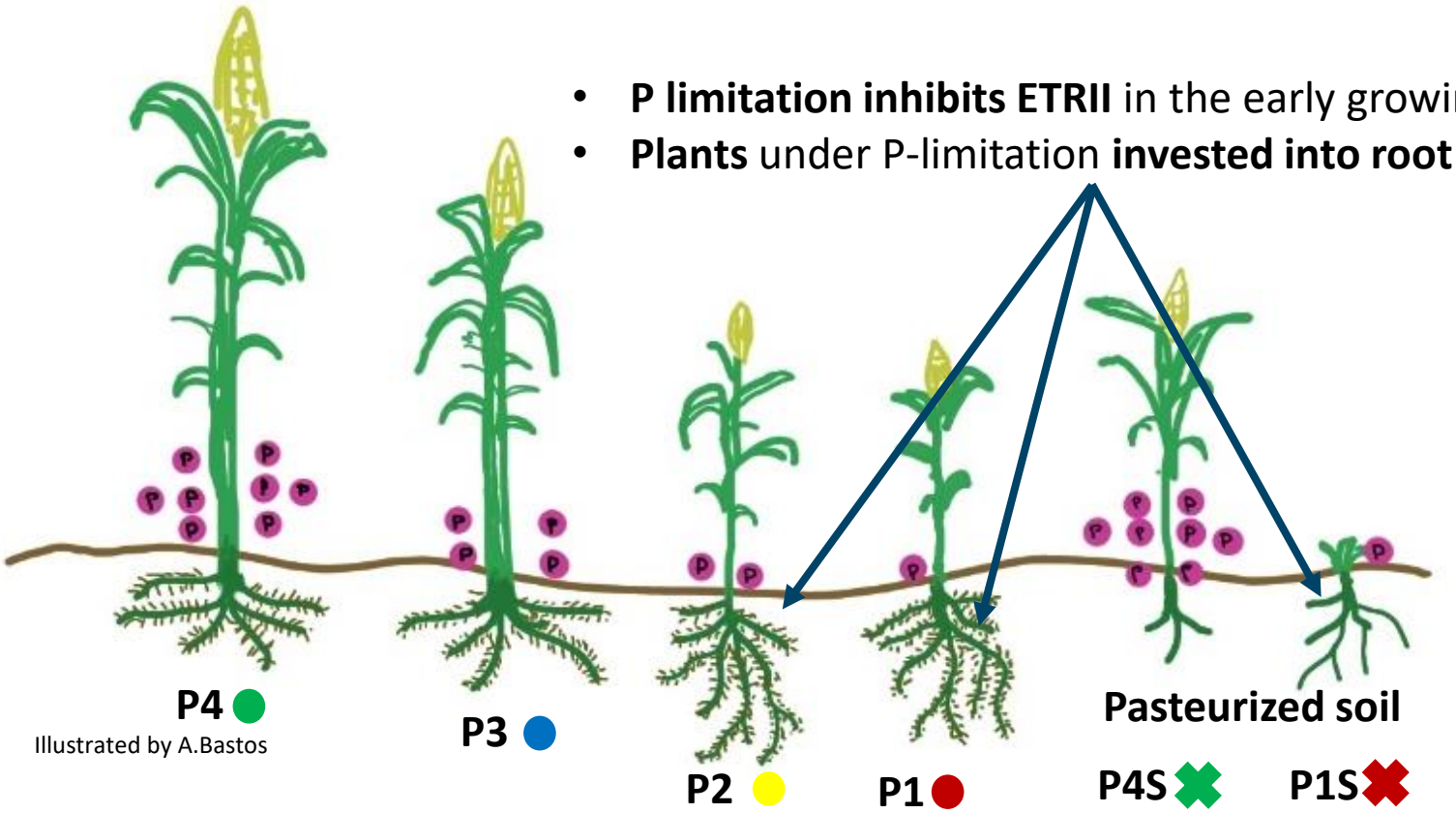
Phosphorous gradient experiment 2017 (*Zea mays*)

- **P limitation inhibits ETRII** in the early growing stage



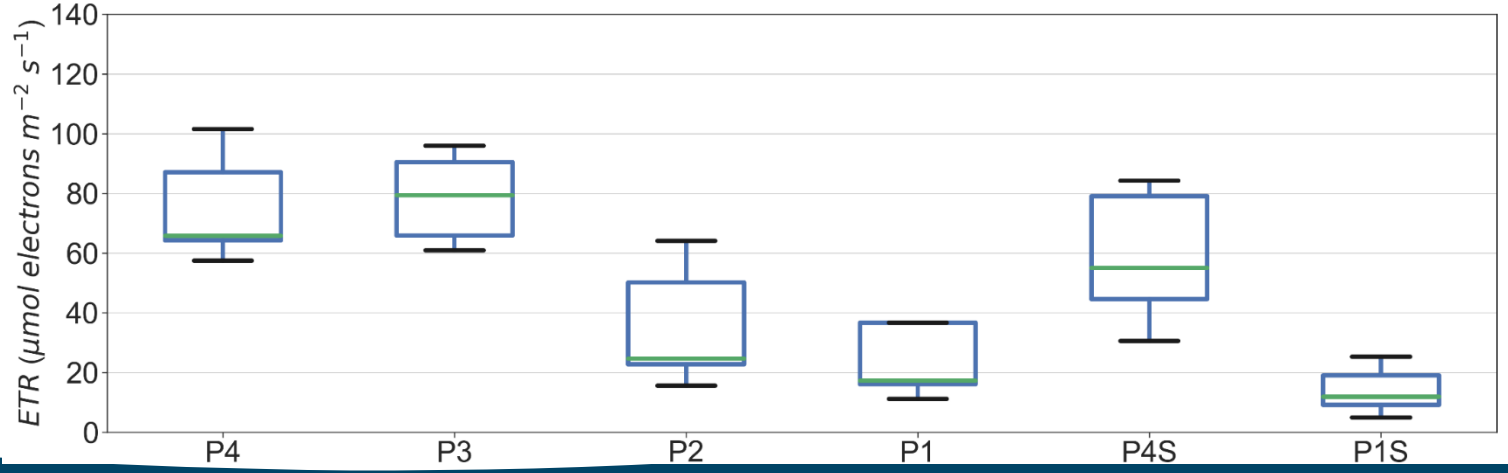
Phosphorous gradient experiment 2017 (*Zea mays*)

- **P limitation inhibits ETRII** in the early growing stage
- **Plants** under P-limitation **invested into root** systems



Illustrated by A.Bastos

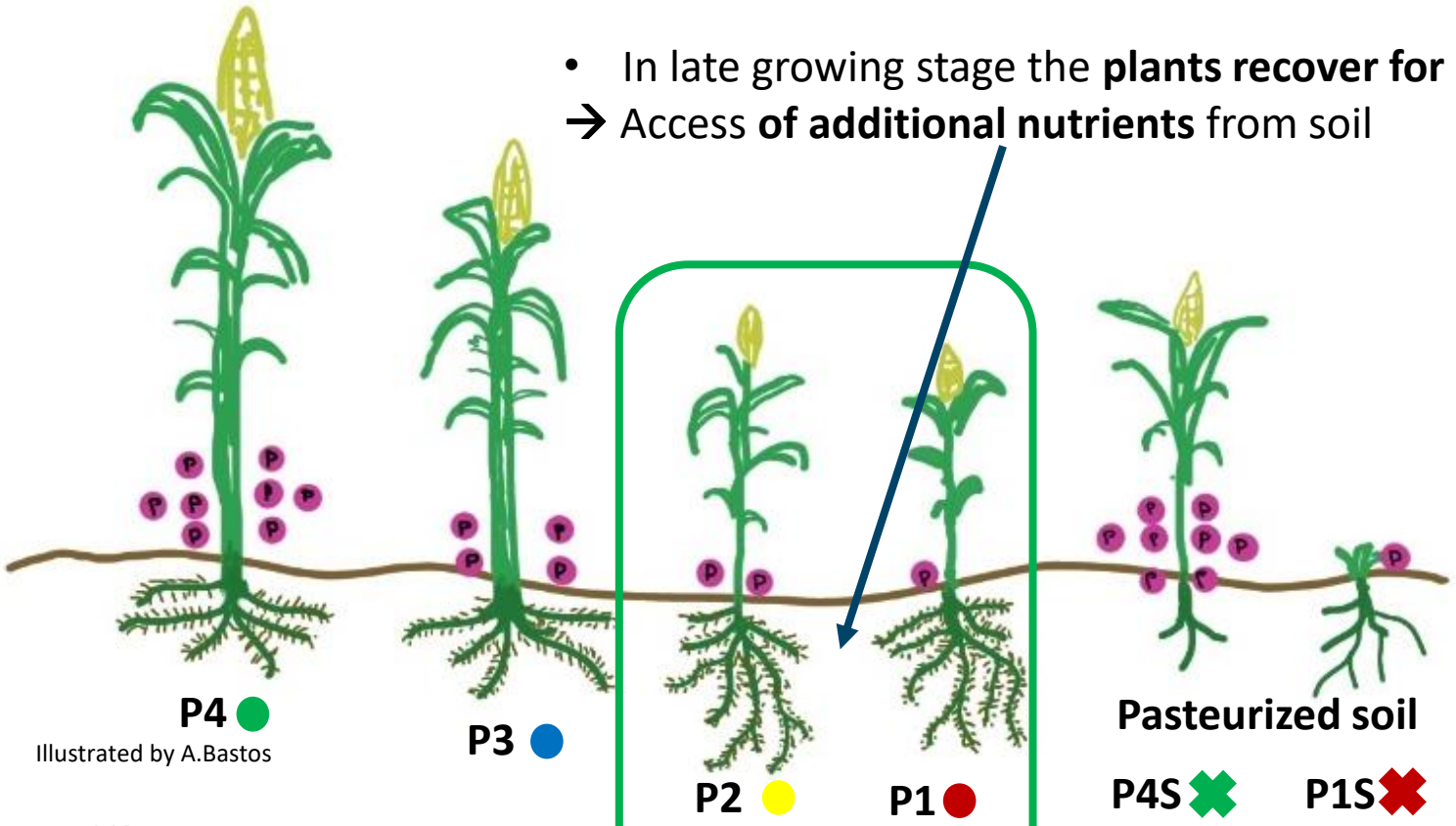
early growing stage
DAP: 27-29



Phosphorous gradient experiment 2017 (*Zea mays*)

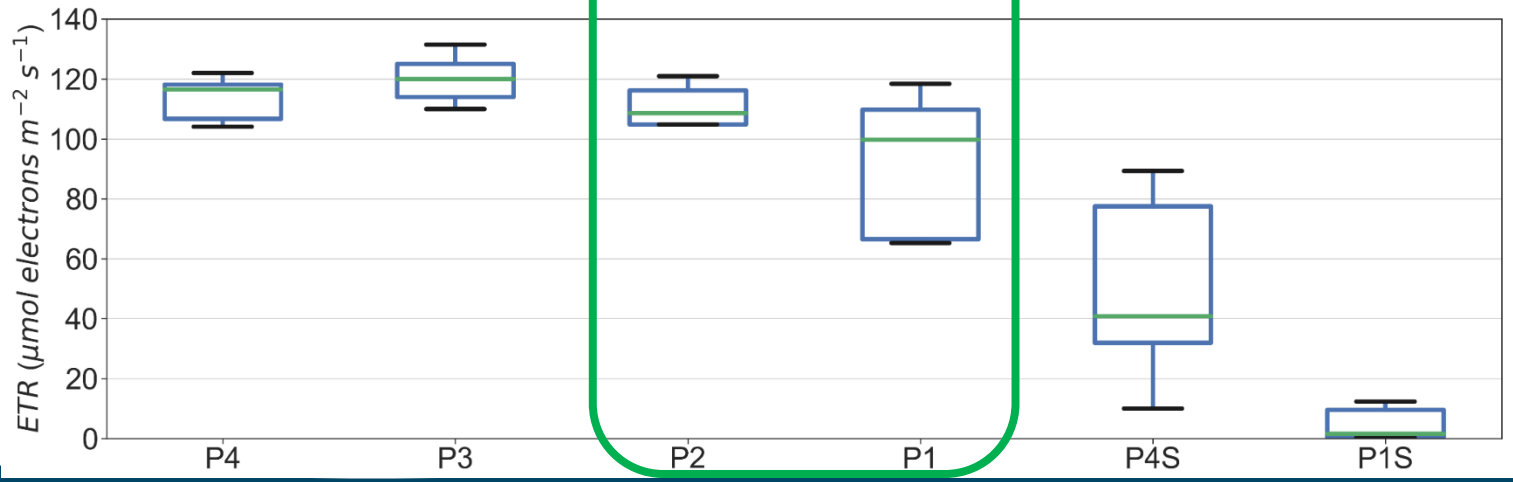
- In late growing stage the **plants recover for P-limitation**

→ Access **of additional nutrients** from soil



Illustrated by A.Bastos

late growing stage
DAP: 57-61

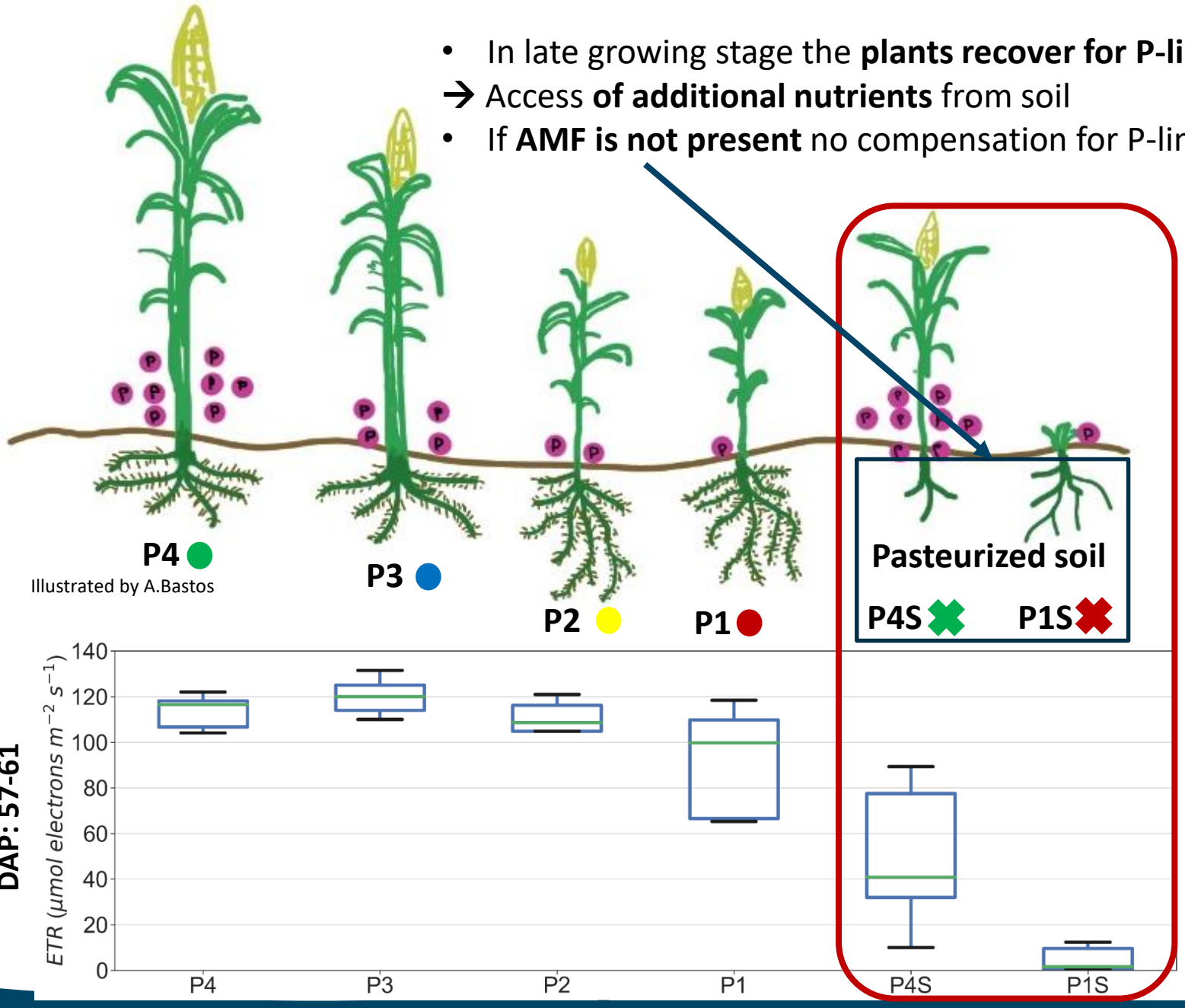


Phosphorous gradient experiment 2017 (*Zea mays*)

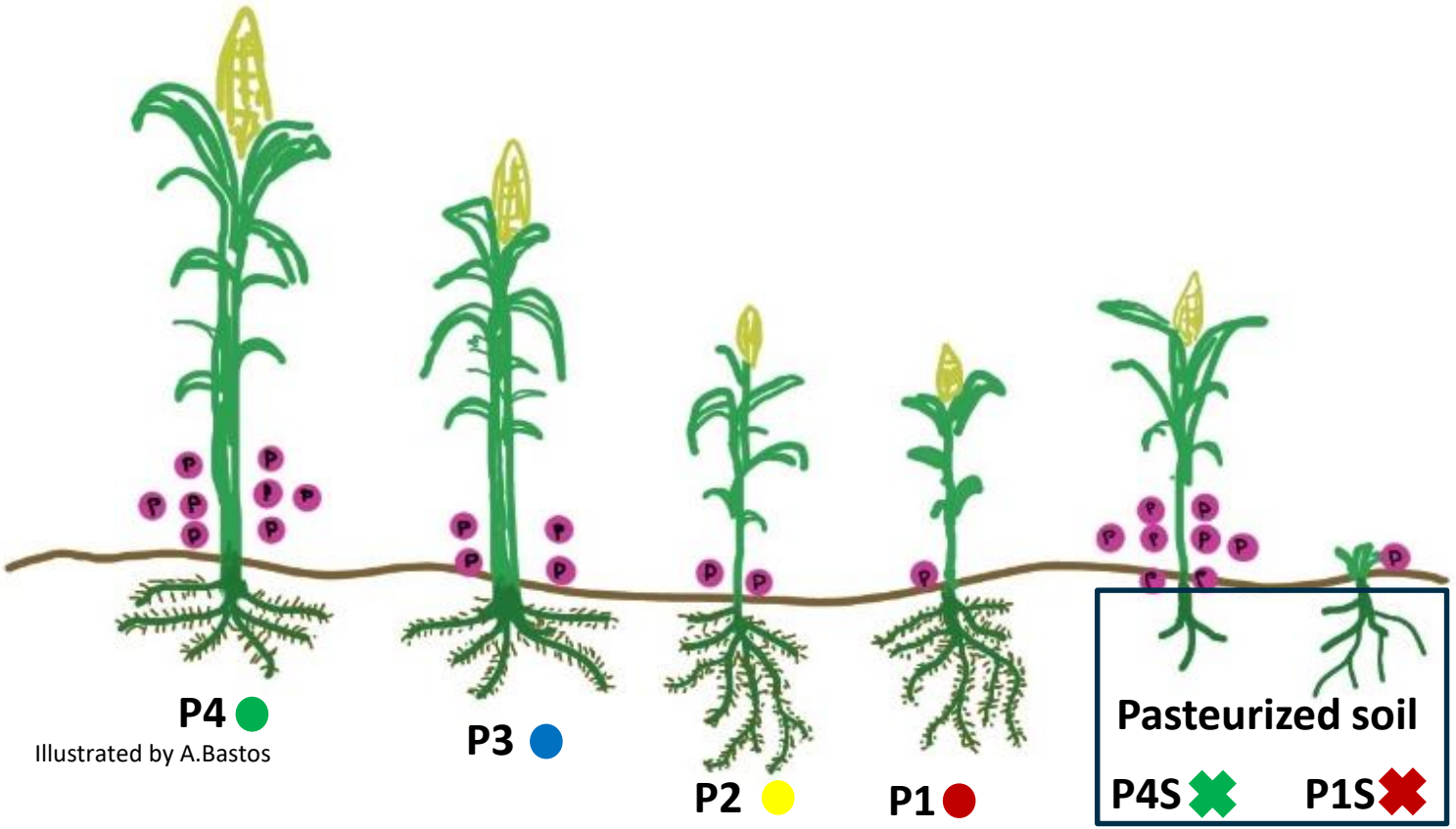
- In late growing stage the **plants recover for P-limitation**

→ Access **of additional nutrients** from soil

- If **AMF is not present** no compensation for P-limitation

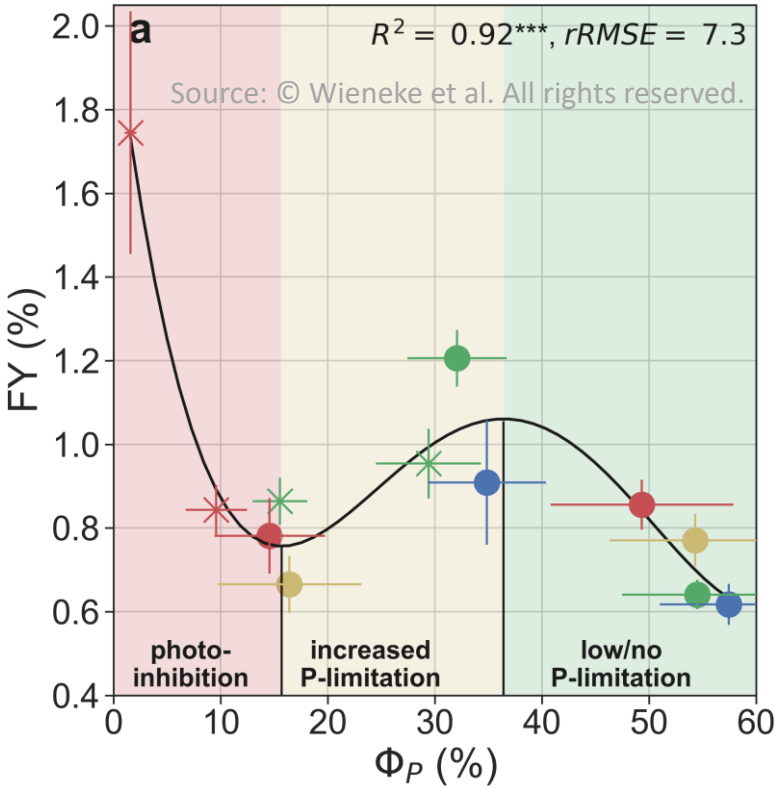


Phosphorous gradient experiment 2017 (*Zea mays*)

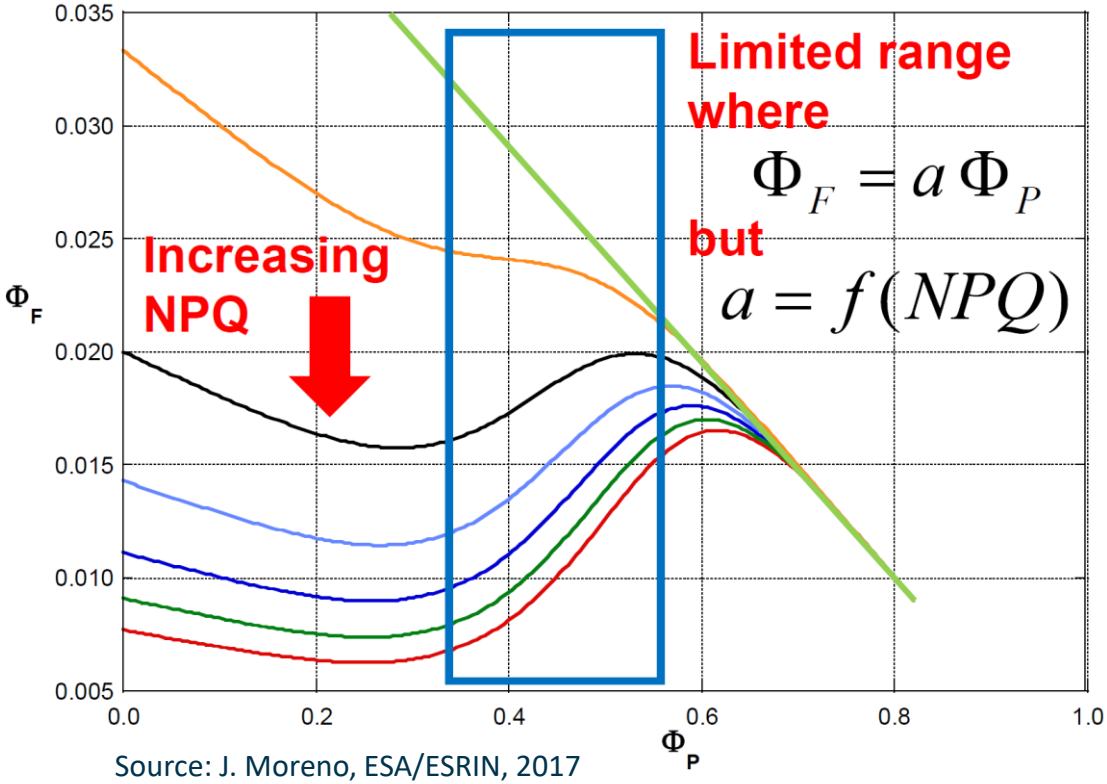


We successfully created a strong gradient in photosynthesis

Non-monotonic relationship of FY to Φ_P



Concept model based on active *Fs* research

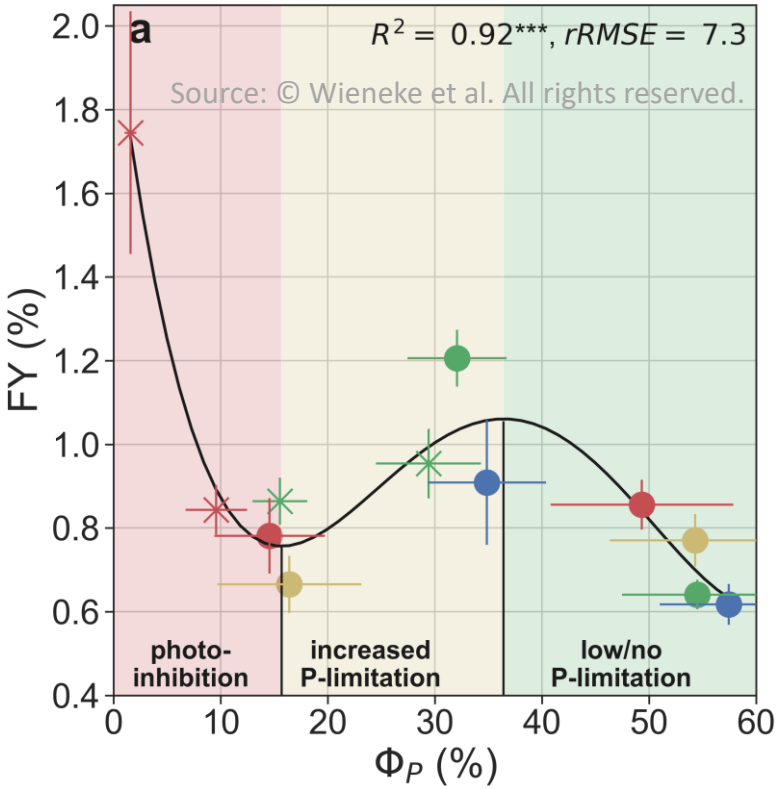


Source: J. Moreno, ESA/ESRIN, 2017

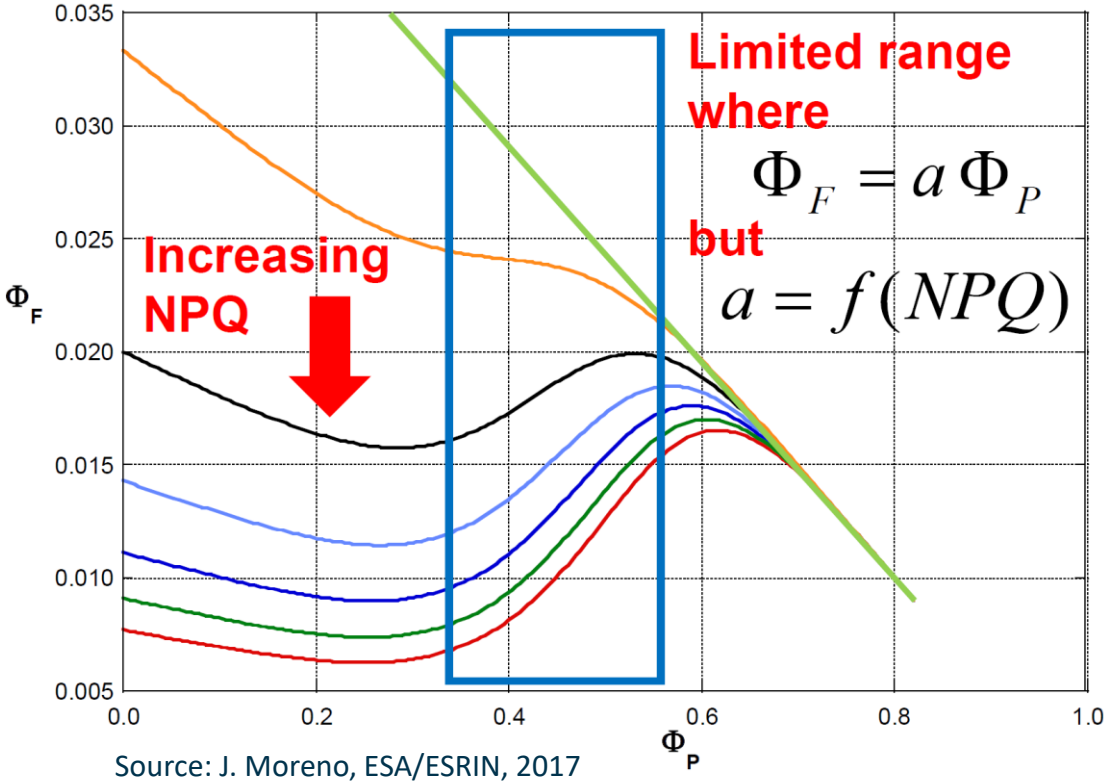
We found a relationship between FY and Φ_P which is in agreement with the concept model

FY = fluorescence yield
Φ_P = photochemical yield

Non-monotonic relationship of FY to Φ_P



Concept model based on active *Fs* research



Source: J. Moreno, ESA/ESRIN, 2017

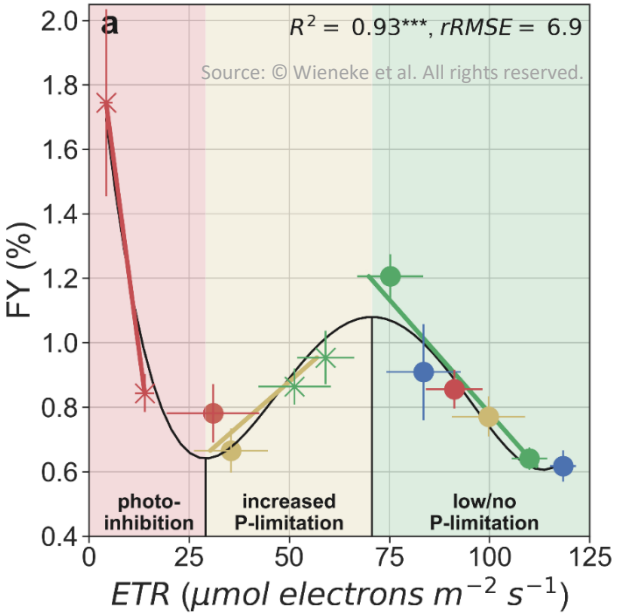
We found a relationship between FY and Φ_P which is in agreement with the concept model

How to model photosynthesis from FY?

FY = fluorescence yield

Φ_P = photochemical yield

Estimating ETR by FY and pigment corrected PRI



Stepwise model:

1) Local min and max from first derivative of polynomial
2) Local min and max used to decompose polynomial into three linear models

High P

High P no AMF

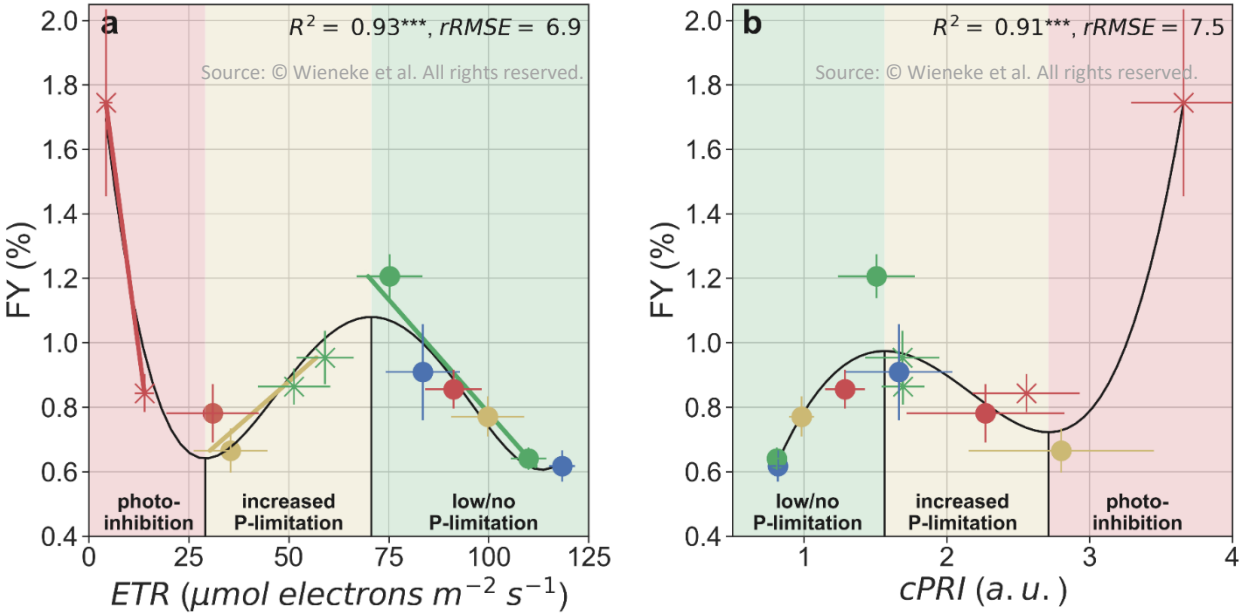
Med. P

Low P

lowest P

lowest P no AMF

Estimating ETR by FY and pigment corrected PRI

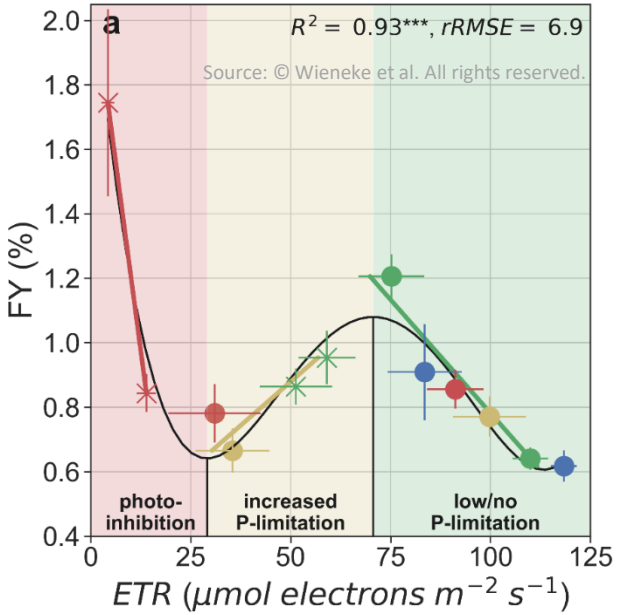


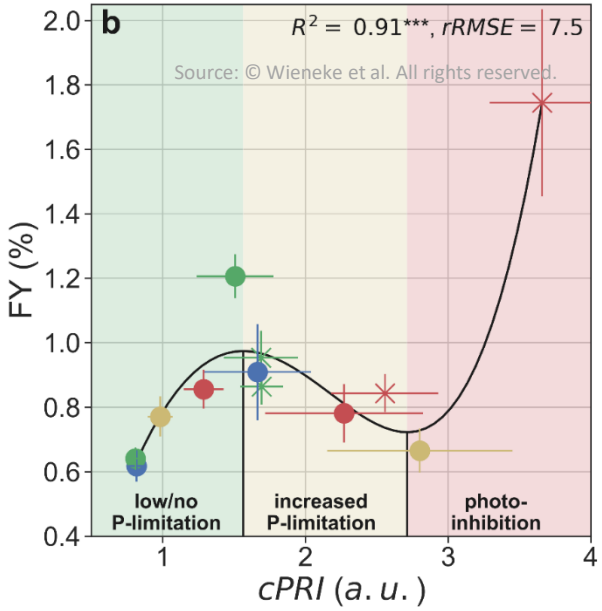
Stepwise model:

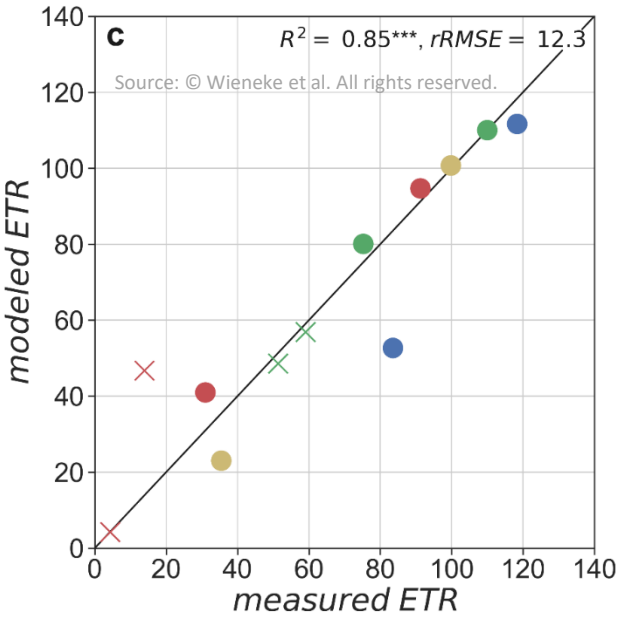
1) Local min and max from first derivative of polynomial
2) Local min and max used to decompose polynomial into three linear models
3) Pigment corrected PRI (cPRI) used to classify the three stress phases of FY

High P
High P no AMF
Med. P
Low P
lowest P
lowest P no AMF

Estimating ETR by FY and pigment corrected PRI





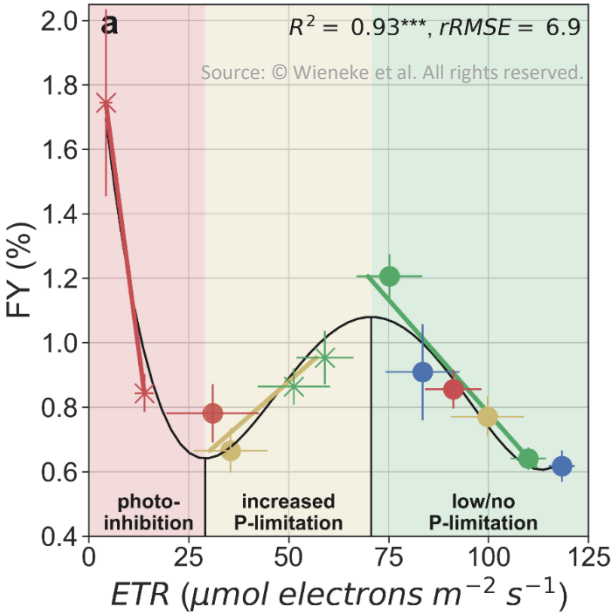


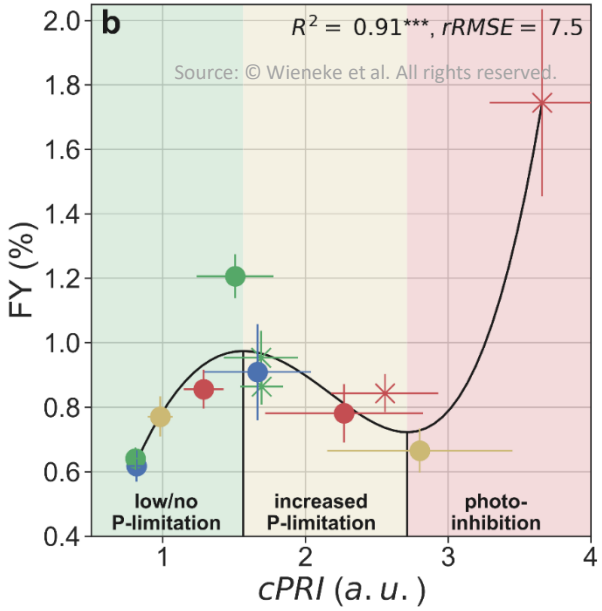
Stepwise model:

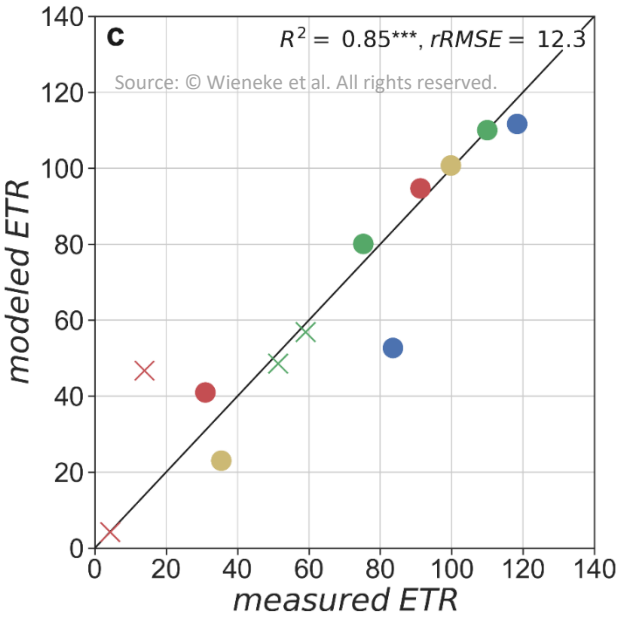
1) Local min and max from first derivative of polynomial
2) Local min and max used to decompose polynomial into three linear models
3) Pigment corrected PRI (cPRI) used to classify the three stress phases of FY
4) ETR is estimated from FY by using the according linear model

High P
High P no AMF
Med. P
Low P
lowest P
lowest P no AMF

Estimating ETR by FY and pigment corrected PRI







High P

High P no AMF

Med. P

Low P

lowest P

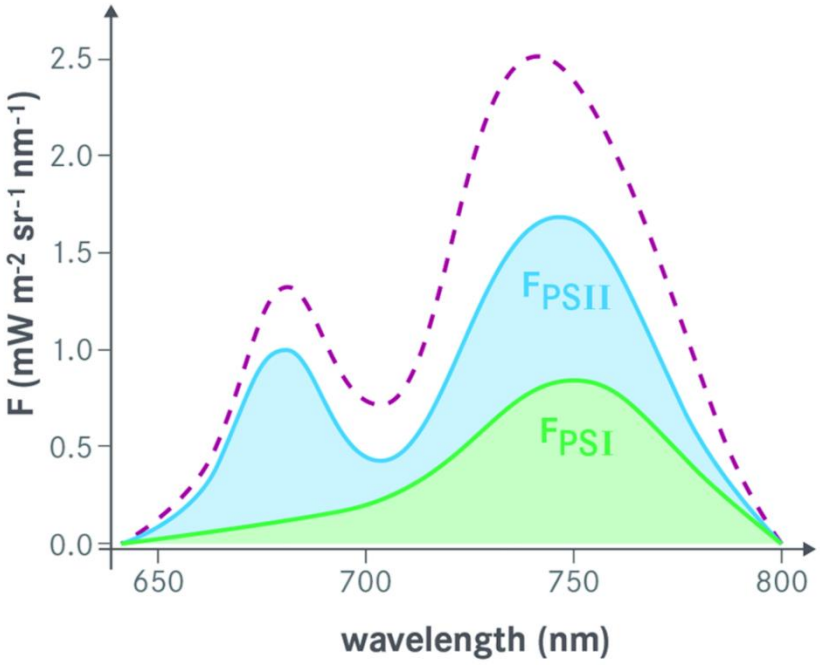
lowest P no AMF

The stepwise model is highly sensitive towards stress phase detection

→ How reliable is pigment corrected PRI in detecting stress phases

→ Monte Carlo analysis showed that uncertainties in cPRI result in strong Bias

Estimating ETR by cF_{ratio}



Source: ESA, 2015

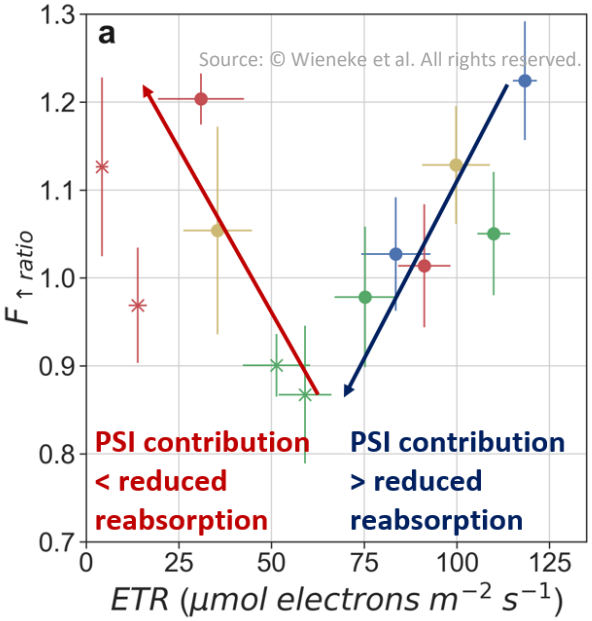
$$F_{\uparrow ratio} = \frac{F_{\uparrow 680}}{F_{\uparrow 740}}$$

- P-limitation affects PSII stronger than PSI (Carstensen et al., 2018)
- The first fluorescence peak (F_{680}) consists mainly of emission by PSII
- The second fluorescence peak (F_{740}) consists of emission by PSII and PSI
  - → With increasing P limitation F_{680} decreases faster than F_{740}
  - → **With increasing P limitation the F_{ratio} will decrease**

Problem:

→ F_{680} is strongly affected by reabsorption effects

Estimating ETR by cF_{ratio}



Source: Wieneke et al. (submitted)

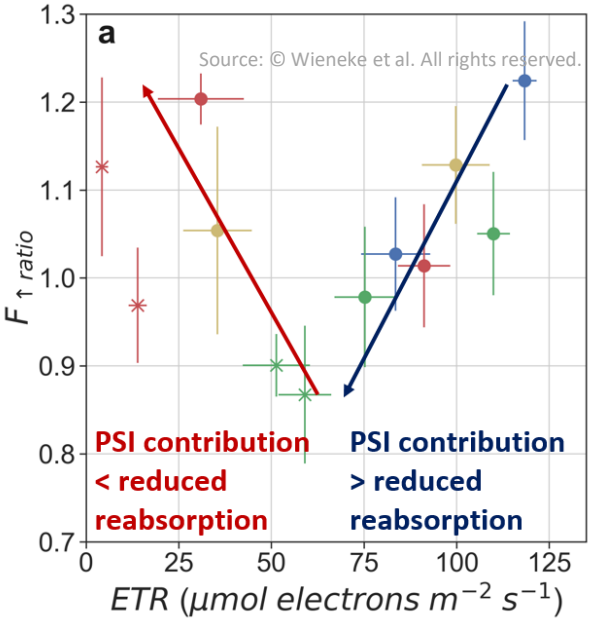
With increasing P-limitation:
→ Chlorophyll content decreases
→ Reabsorption of F_{680} decreases
→ F_{ratio} increases

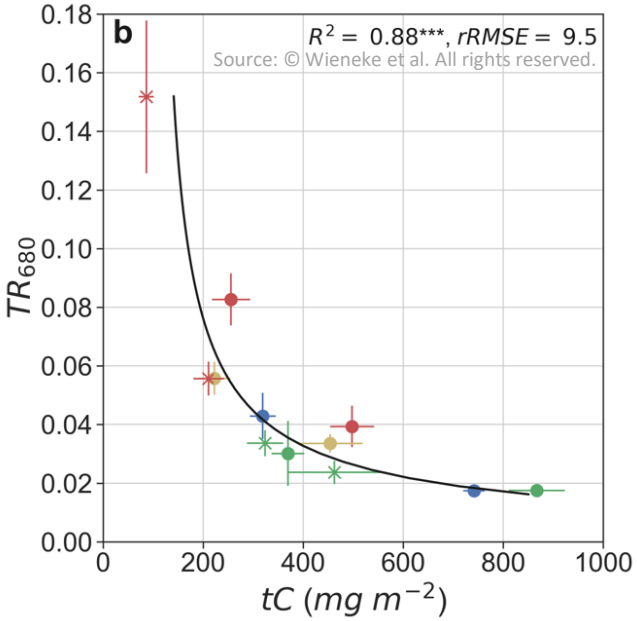
We corrected for the reduced reabsorption effect by using an empirical correction factor derived from the transmittance at 680nm, the total chlorophyll content and the red-edge chlorophyll index

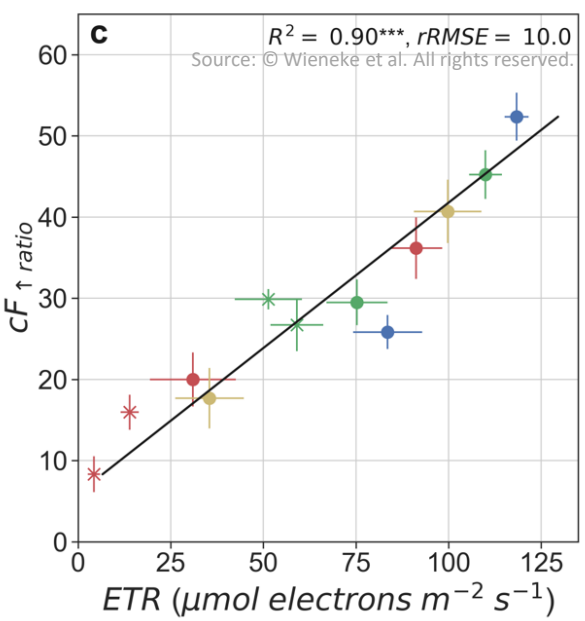
$$F_{\uparrow \mathrm{ratio}} = \frac{F_{\uparrow 680}}{F_{\uparrow 740}}$$

F_{ratio} = ratio of the two fluorescence peaks
ETR = Electron Transport Rate
TR_{680} = Transmittance at 680 nm
tC = total Chlorophyll content

Estimating ETR by cF_{ratio}







Source: Wieneke et al. (submitted)

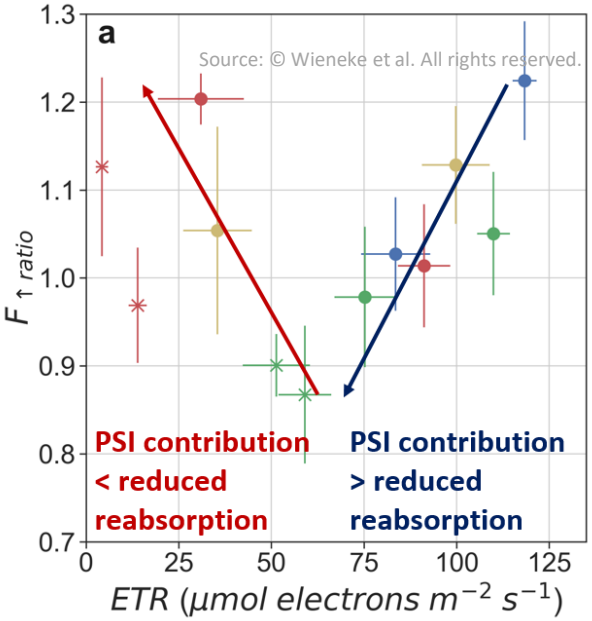
$$F_{\uparrow \mathrm{ratio}} = \frac{F_{\uparrow 680}}{F_{\uparrow 740}}$$

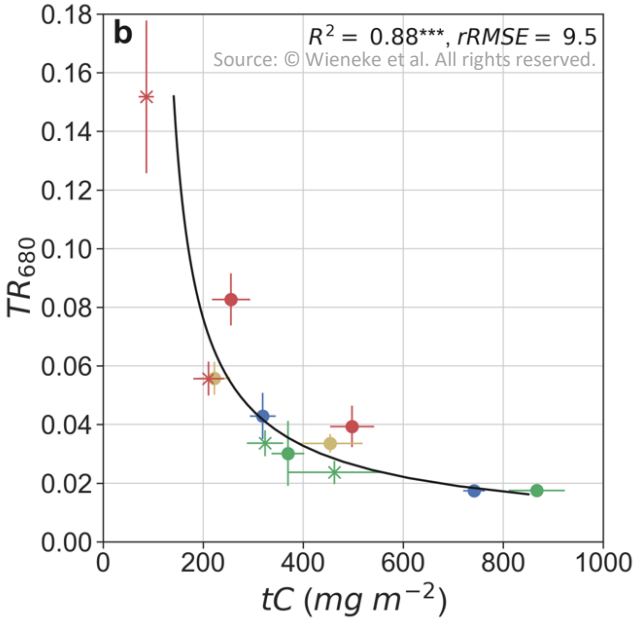
$$cf = \frac{1}{0.02 + 0.0003 \cdot CI_{red-edge}{}^{-2.2}}$$

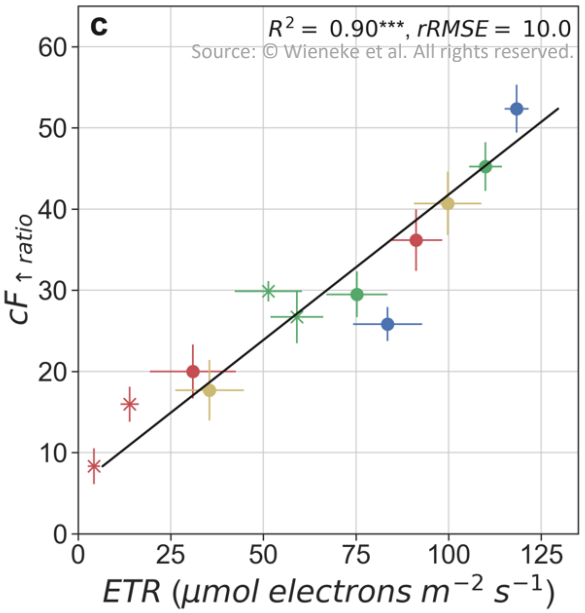
$$cF_{\uparrow \mathrm{ratio}} = \frac{F_{\uparrow 680} \cdot cf}{F_{\uparrow 740}}$$

F_{ratio} = ratio of the two fluorescence peaks
ETR = Electron Transport Rate
TR_{680} = Transmittance at 680 nm
tC = total Chlorophyll content

Estimating ETR by cF_{ratio}







Source: Wieneke et al. (submitted)

- More robust than the FY/cPRI stepwise model
- APAR is not needed
- **But how well does it work at canopy?**

IMBALANCE-P

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