Estimating Photosynthetic Capacity using Reflectance Spectra and Machine Learning
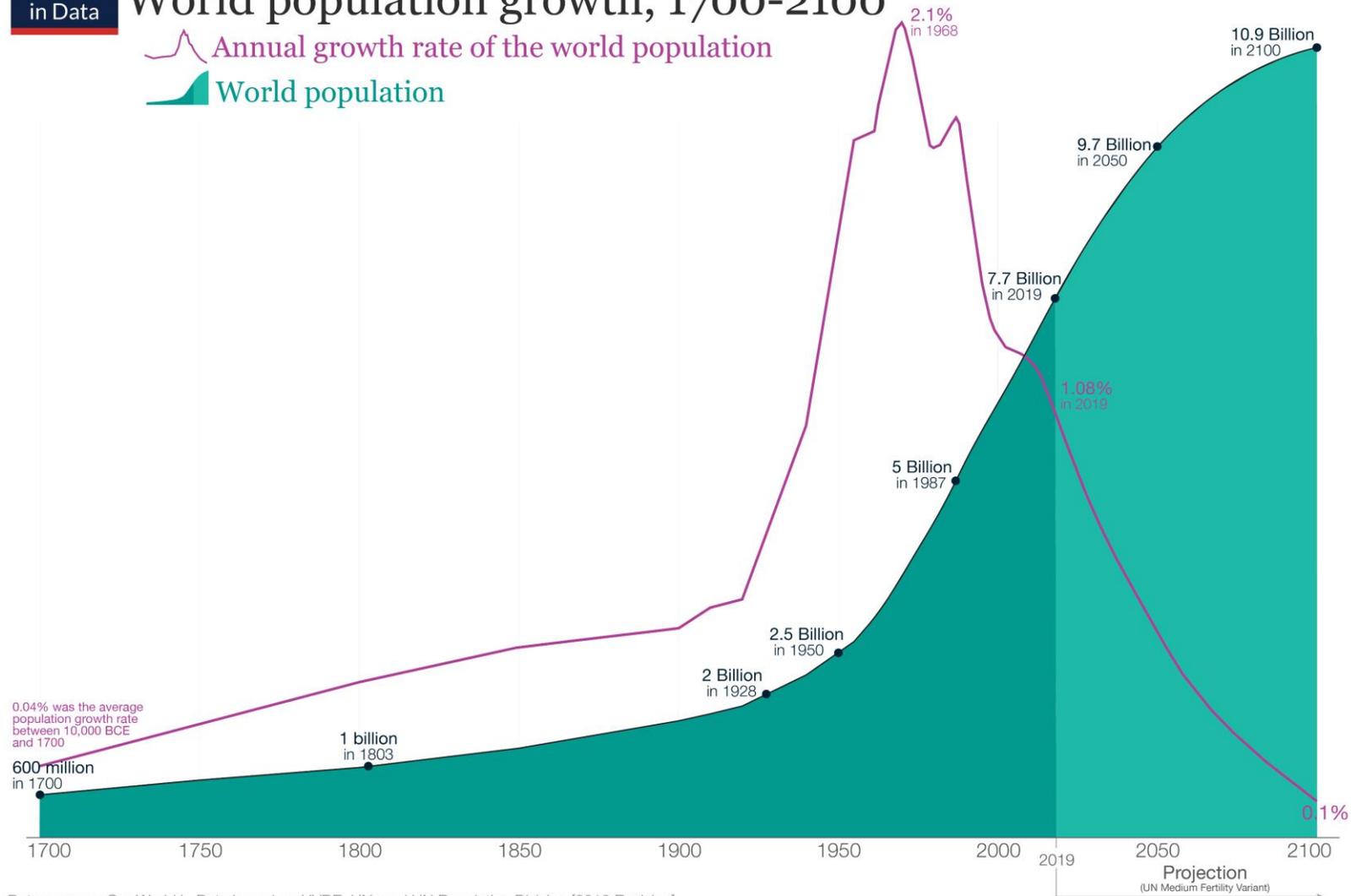
Peng Fu

Assistant Professor
School of Plant, Environmental and Soil Sciences
Louisiana State University AgCenter,
Louisiana State University, Baton Rouge, LA

Explosion of population growth

Published online at OurWorldInData.org.

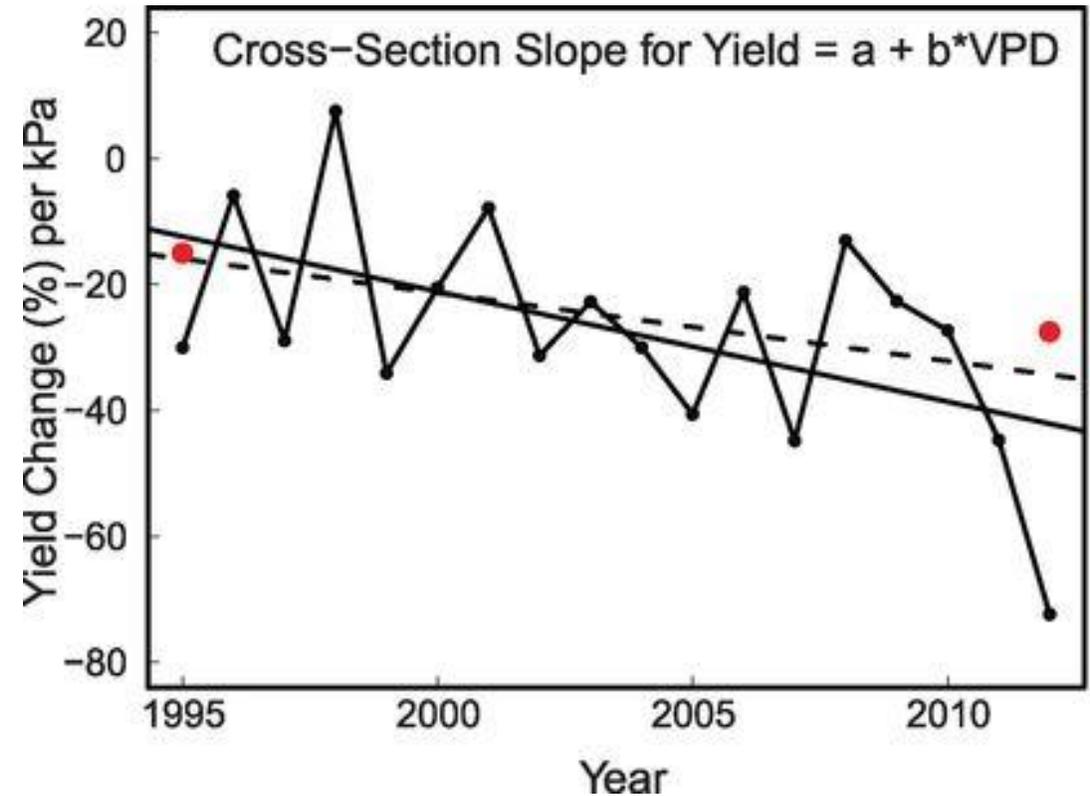# Crop yield is sensitive to extreme weather conditions

Warming impacts
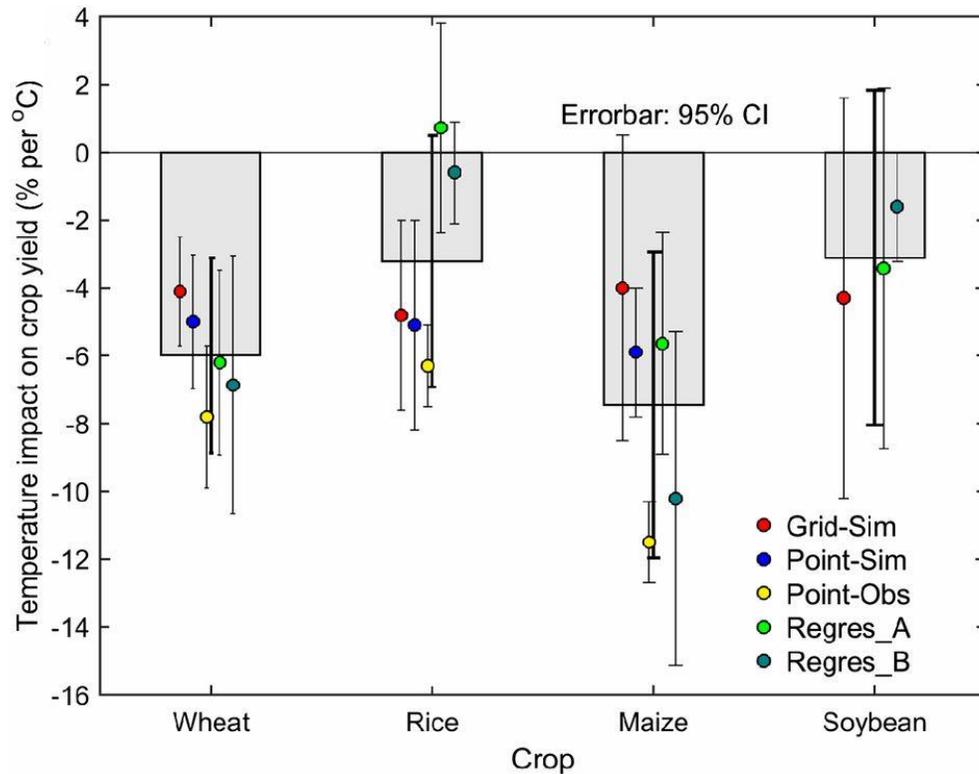
Drought impacts

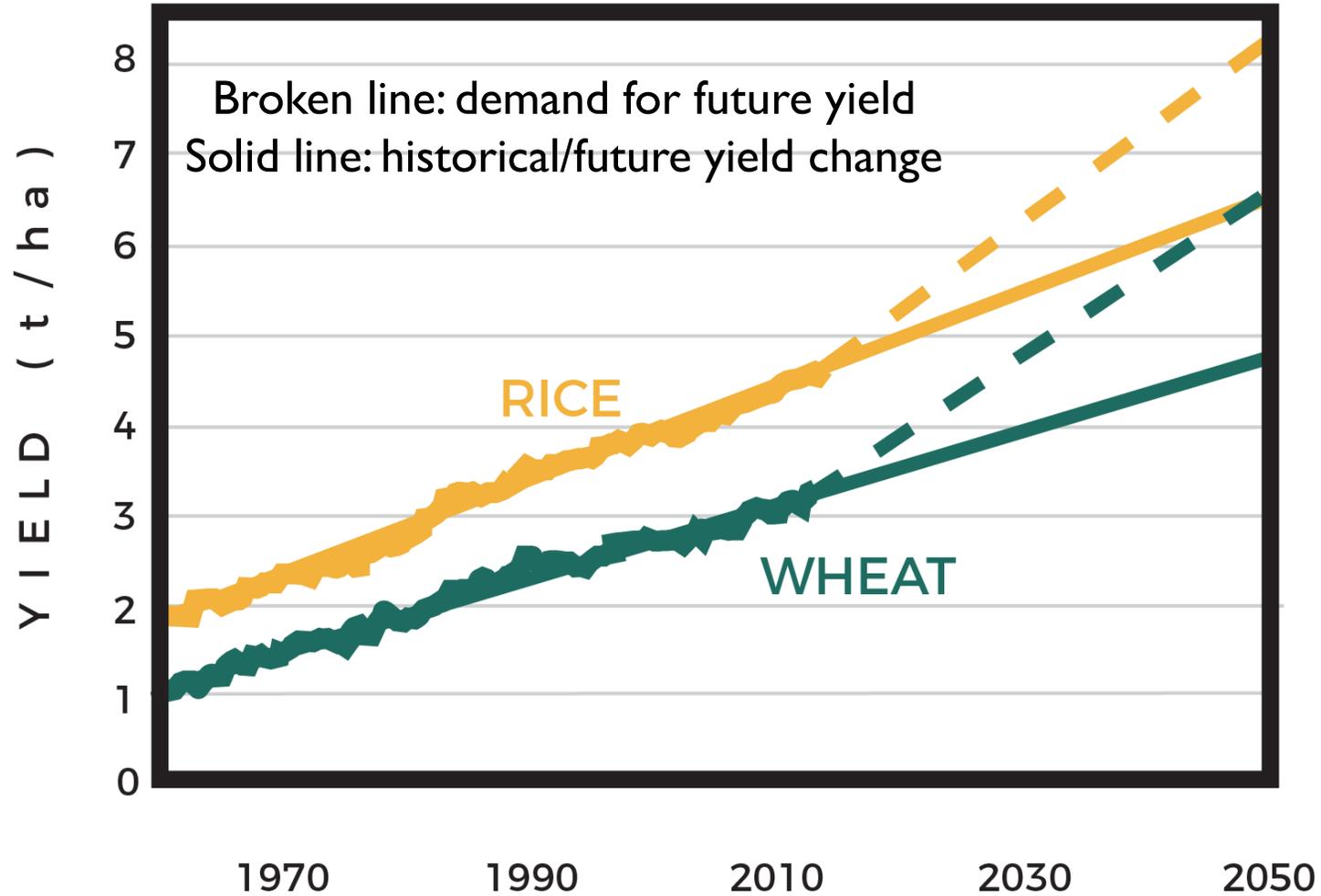Zhao et al. 2017 in PNAS

Lobell et al. 2014 in Science

We need double our crop production

Broken line: demand for future yield
Solid line: historical/future yield change

RICE

WHEAT

YIELD (t/ha)

1970 1990 2010 2030 2050

Long et al. 2015 Cell
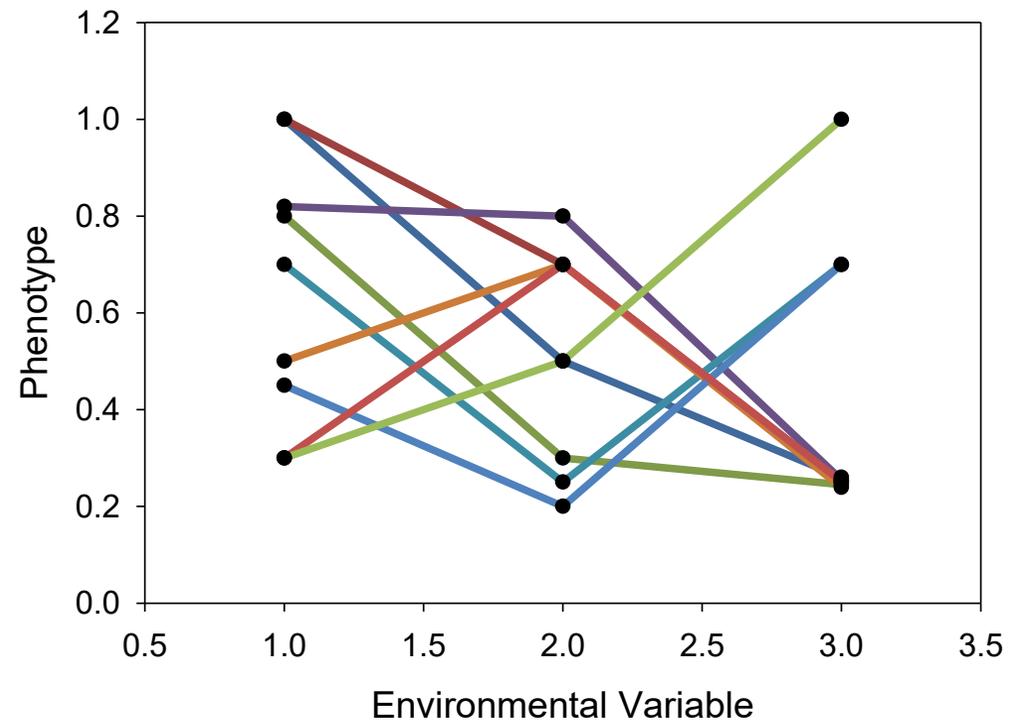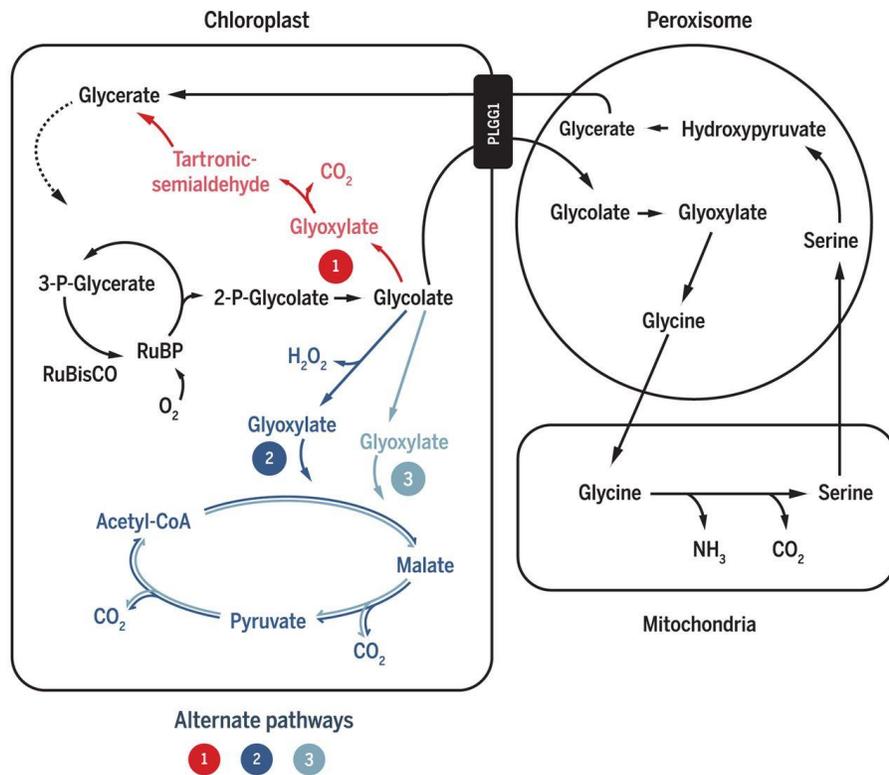
Strategies for crop improvement: photosynthesis as an untapped solution

Focused approaches to address known challenges

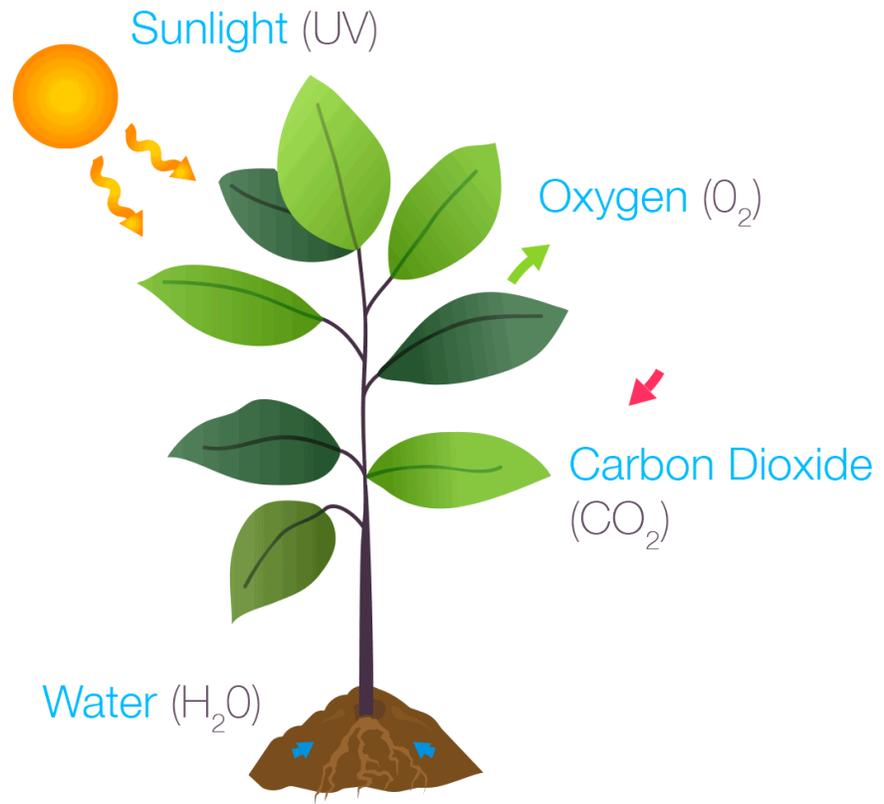**Better understanding genetic interactions with the environment**

Increasing crop production from improved photosynthesis

$$Yield = Q * \varepsilon_i * \varepsilon_c * HI$$
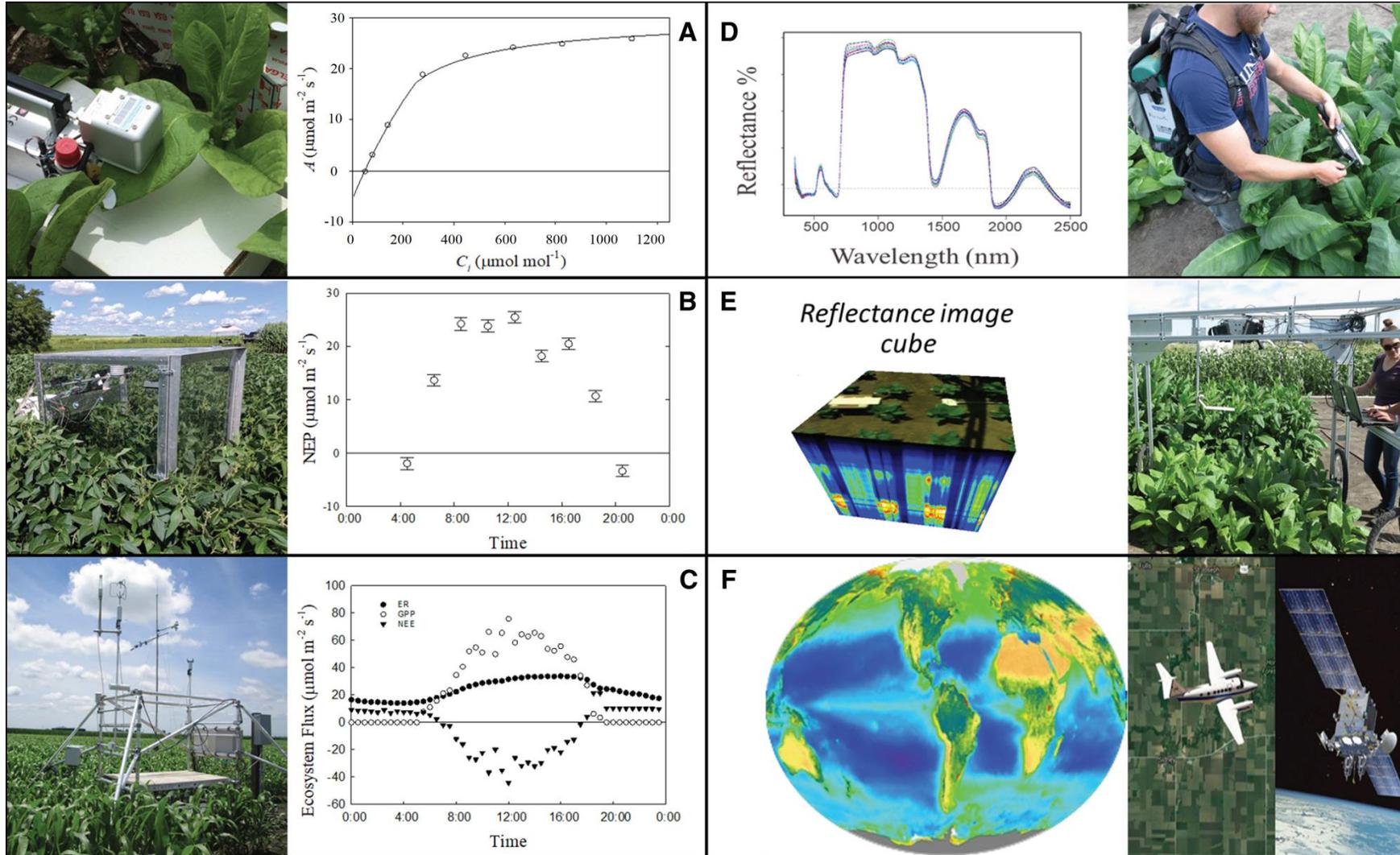
- Q: Solar radiation received per unit land,
- HI: harvest index (already stable at ~0.6)
- ε_i: the efficiency with which crop intercepts radiation (0.8-0.9 for modern crops)
- ε_c: the efficiency with which crop converts radiation to biomass (photosynthesis process)

ε_c is only around one-fifth of the theoretical limit.

Long et al. 2015 Cell

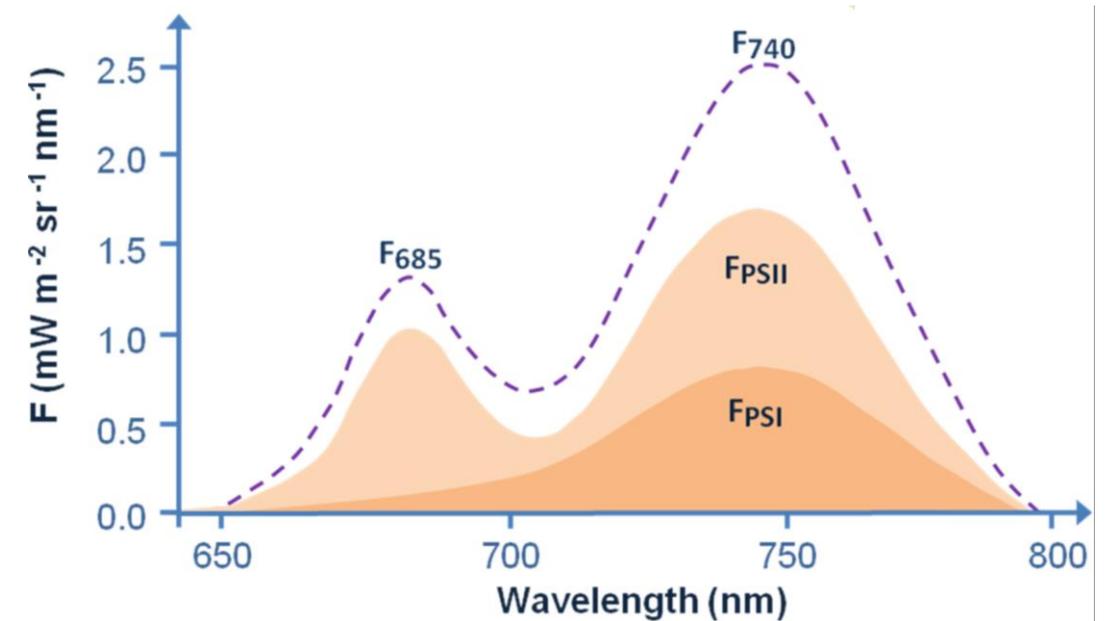# What is photosynthesis?

Sunlight (UV)

Oxygen (O_2)

Carbon Dioxide (CO_2)

Water (H_2O)

Emerging techniques to measure photosynthesis

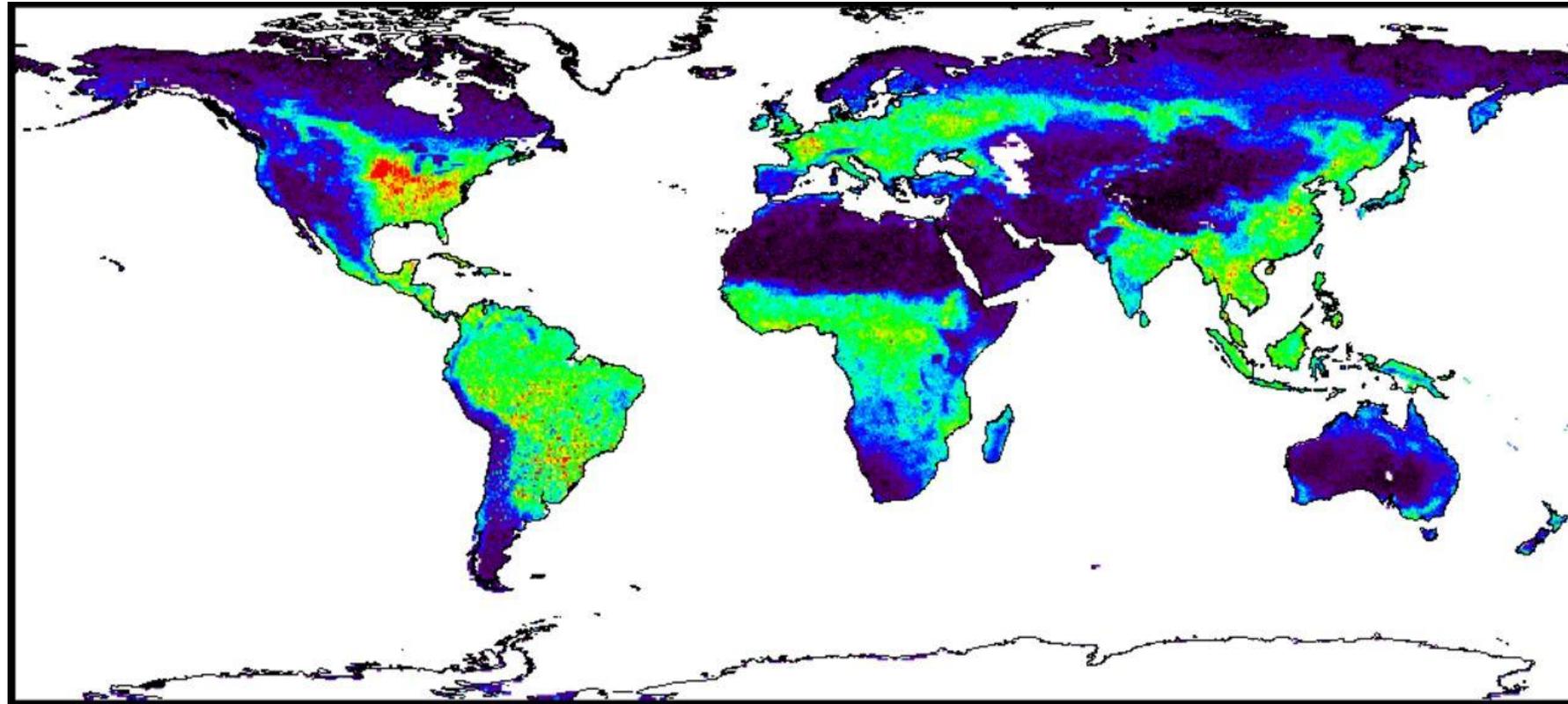Siebers et al. 2021. Emerging Topics in Life Sciences

Energy partitioning for light absorbed by plants
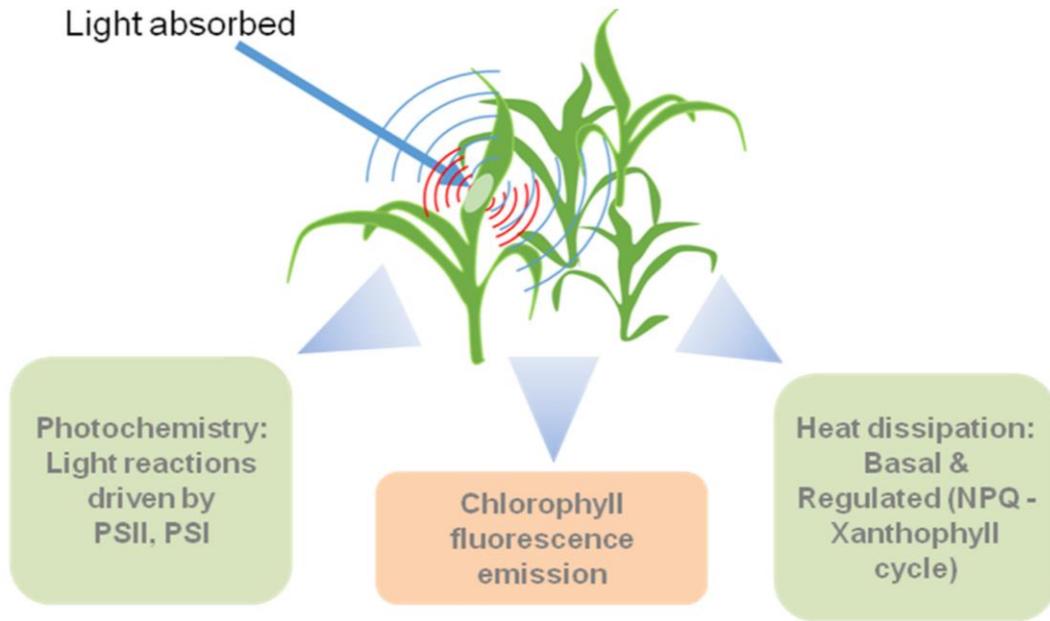
Solar-induced fluorescence (SIF) as a proxy for photosynthesis

max(SIF) (mW/m²/sr/nm)

0.0   0.9   1.8   2.7   3.6   4.5

Guanter et al. (2014) PNAS

Genetically diverse bioenergy sorghum panel

Image from:
James Baltz
Instructional Design Specialist

Working in the fields is great but…

➢ Gas exchange: Leaf level carbon assimilation 30+ mins per leaf measurement: LI-COR 6800

➢ Photosynthetic parameters: Vcmax (maximum carboxylation rate of Rubisco) and Jmax (maximum electron transport rate)
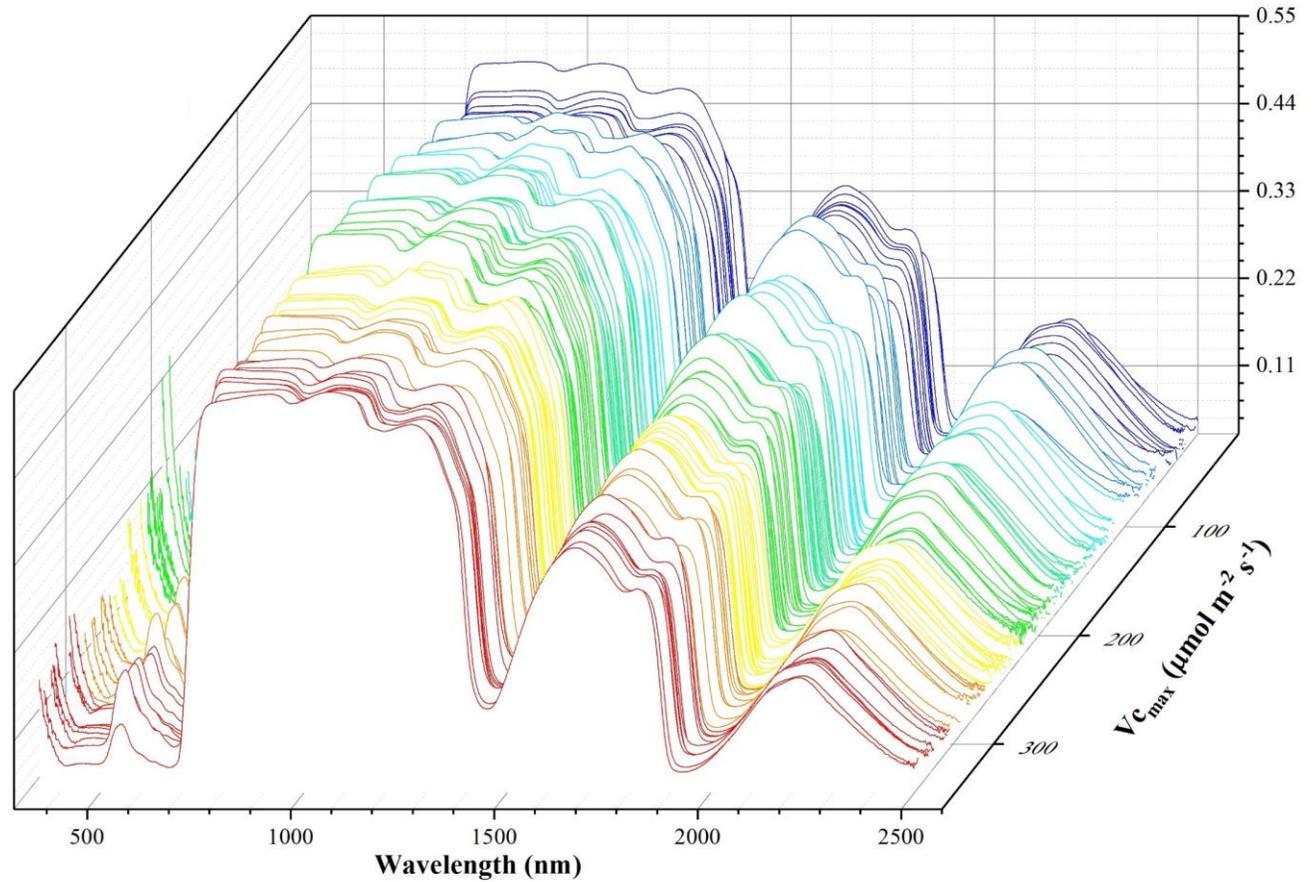
Photosynthesis is not just one simple variable…
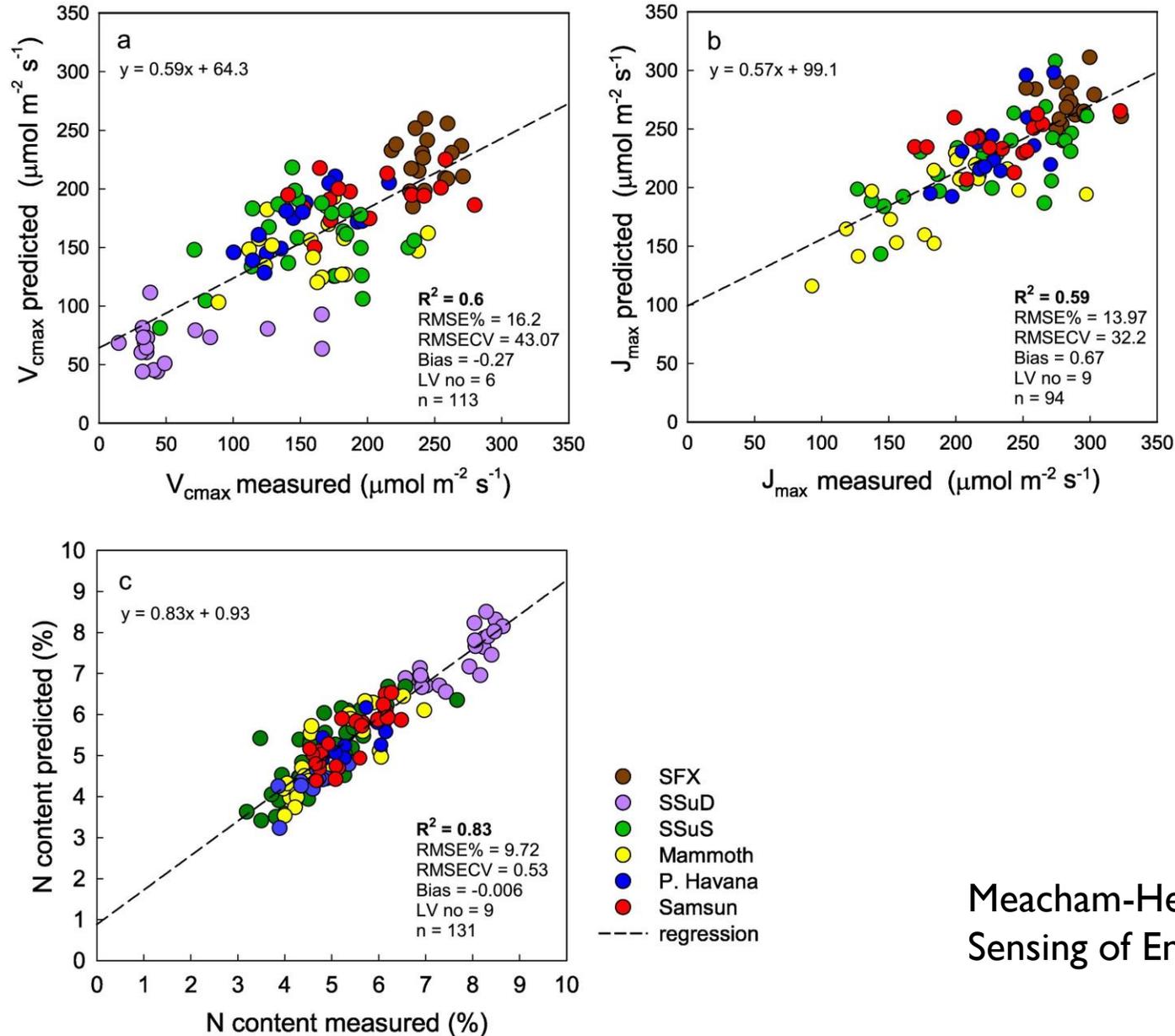
Leaf-level reflectance

30 minutes per measurement.

3 seconds per measurement.

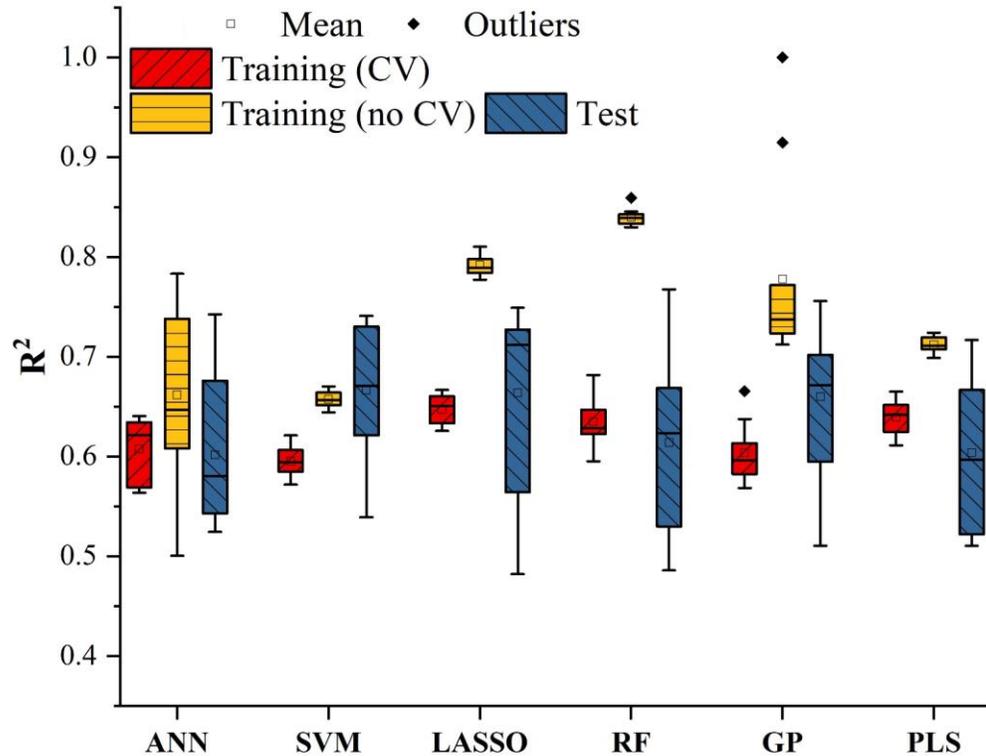# Leaf-level estimations of photosynthetic capacity and nitrogen

a

$y = 0.59x + 64.3$

V_{cmax} predicted (μmol m^{-2} s^{-1})

V_{cmax} measured (μmol m^{-2} s^{-1})

$R^2 = 0.6$
RMSE% = 16.2
RMSECV = 43.07
Bias = -0.27
LV no = 6
n = 113

b

$y = 0.57x + 99.1$

J_{max} predicted (μmol m^{-2} s^{-1})

J_{max} measured (μmol m^{-2} s^{-1})

$R^2 = 0.59$
RMSE% = 13.97
RMSECV = 32.2
Bias = 0.67
LV no = 9
n = 94

c

$y = 0.83x + 0.93$

N content predicted (%)

N content measured (%)

$R^2 = 0.83$
RMSE% = 9.72
RMSECV = 0.53
Bias = -0.006
LV no = 9
n = 131

- SFX
- SSuD
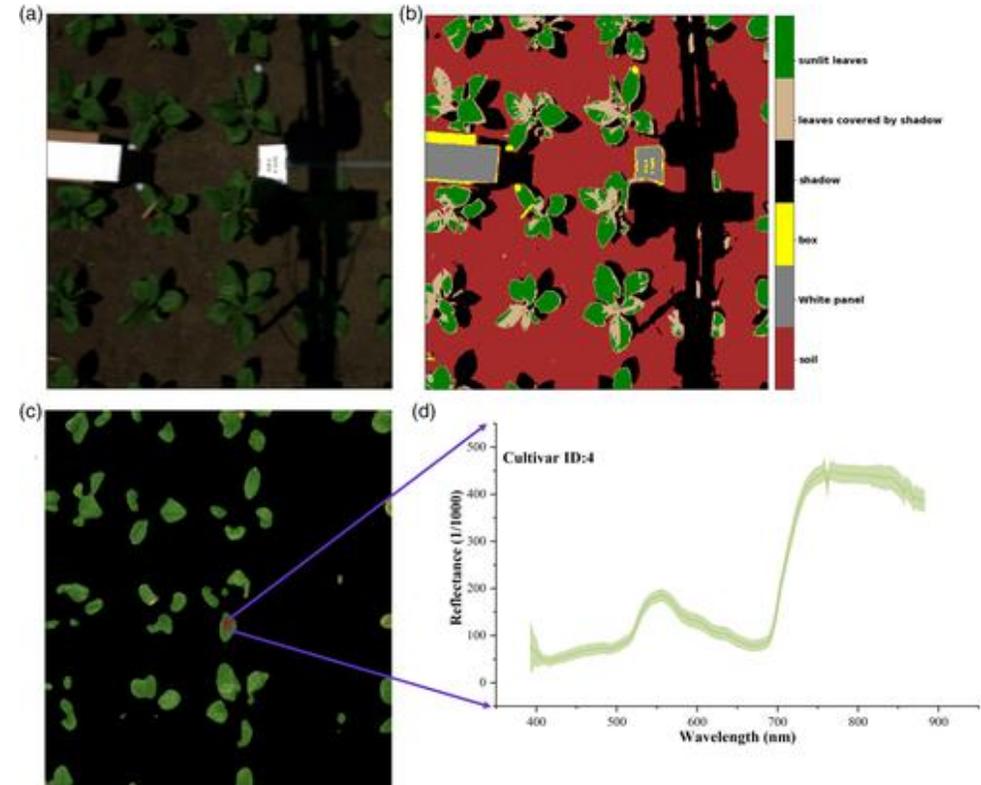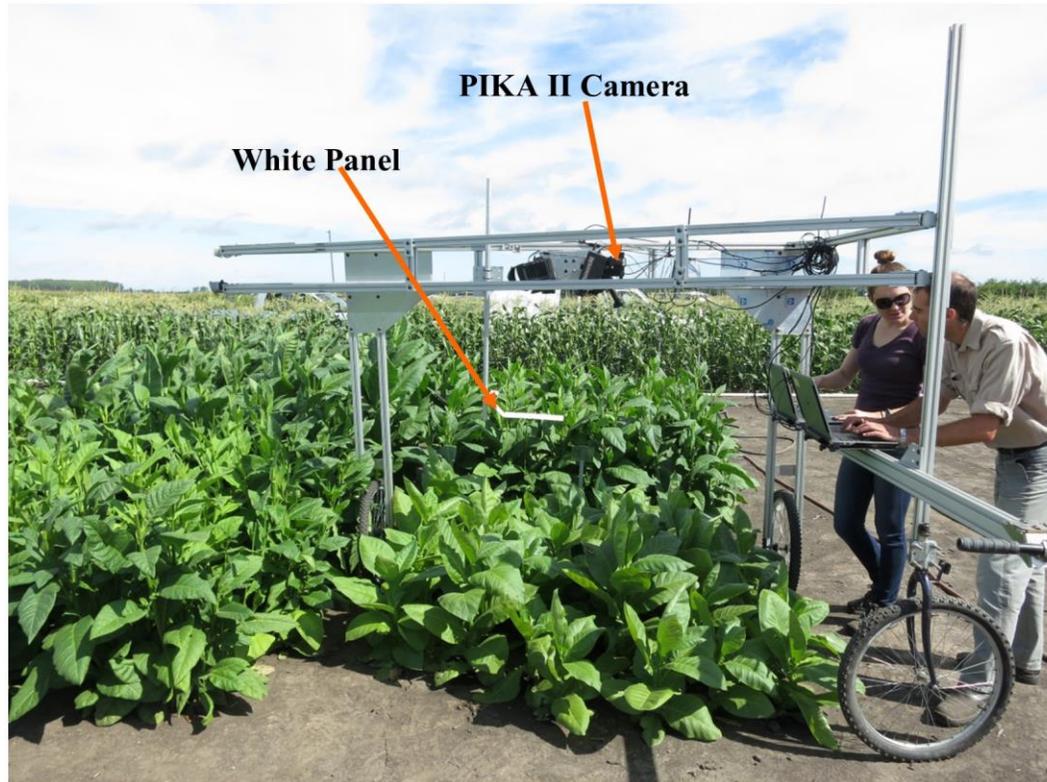- SSuS
- Mammoth
- P. Havana
- Samsun
- - - - regression

Meacham-Hensold et al. Remote Sensing of Environment

14

Ensemble learning algorithm yields better performance
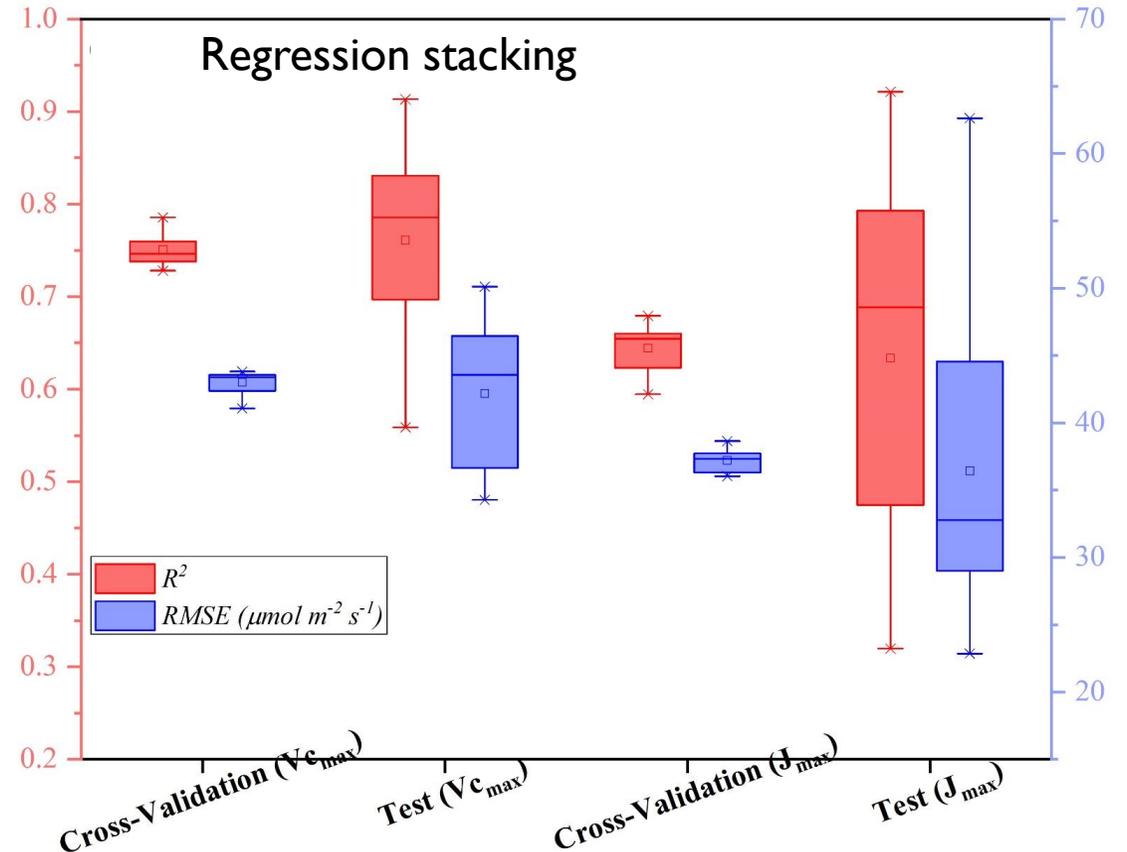
8% increase in R^2 for V_{cmax} predictions
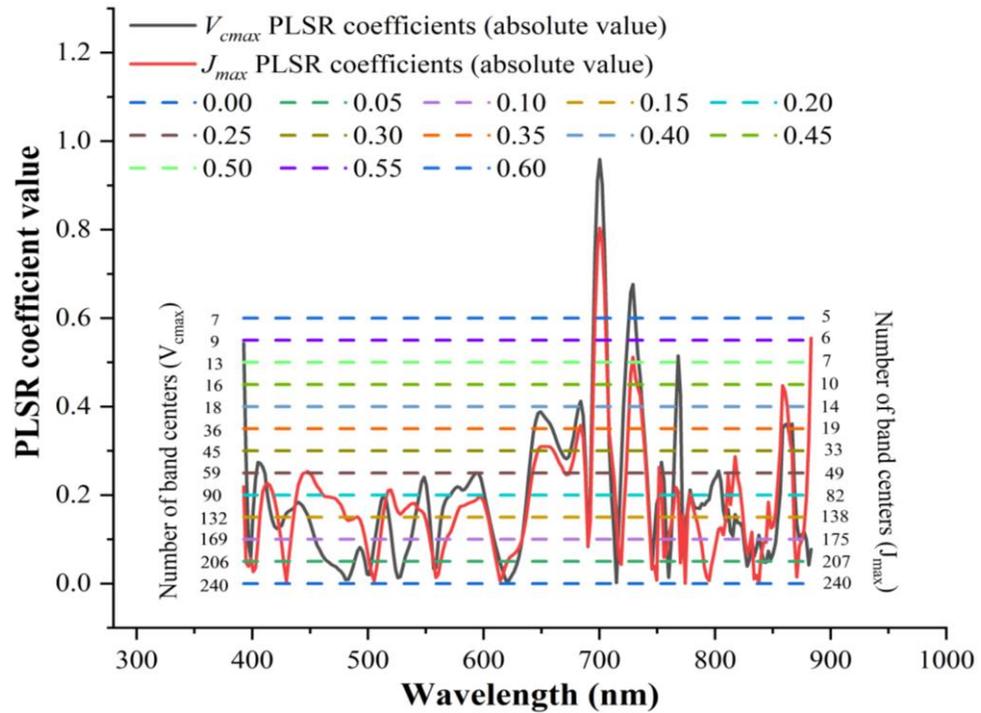15% increase in R^2 for J_{max} predictions

Fu et al. Frontiers in Plant Science
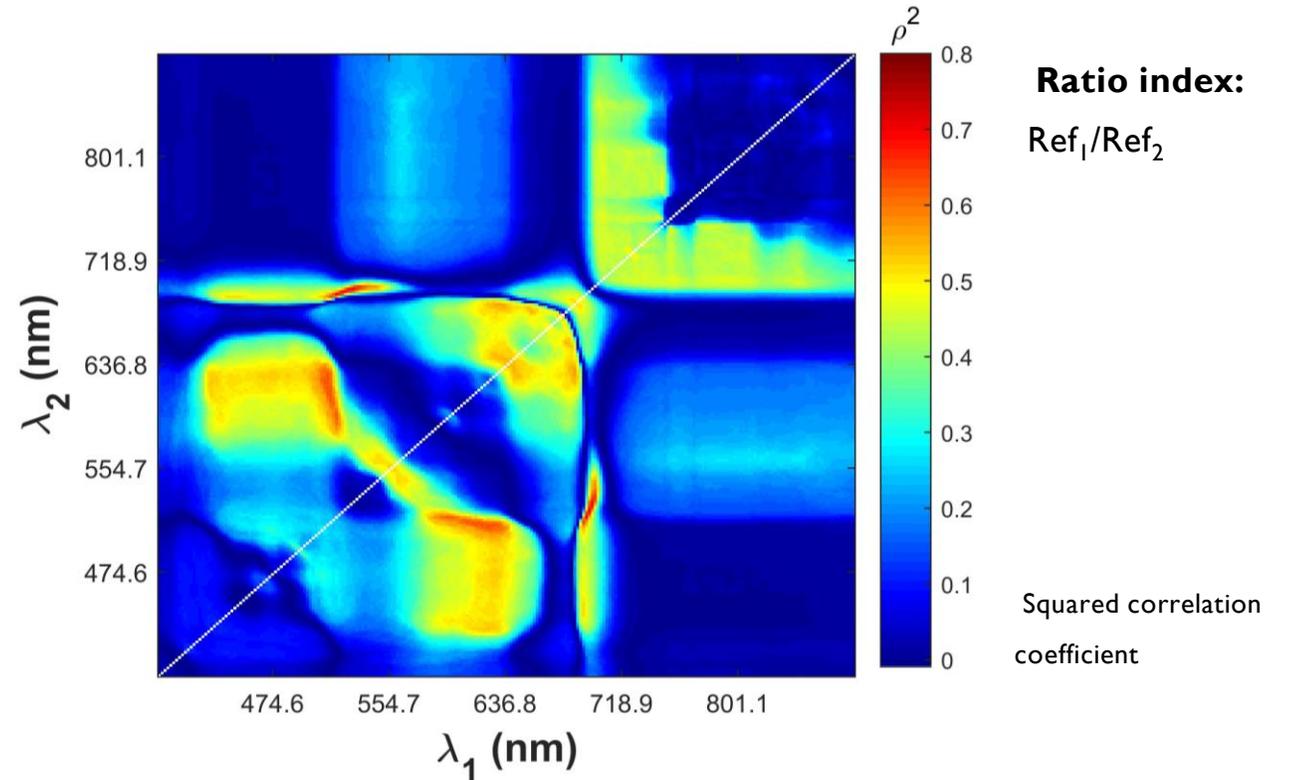
Customized platform for proximal sensing of photosynthesis

Estimation of photosynthetic capacities at the canopy level

Partial least square-based approach
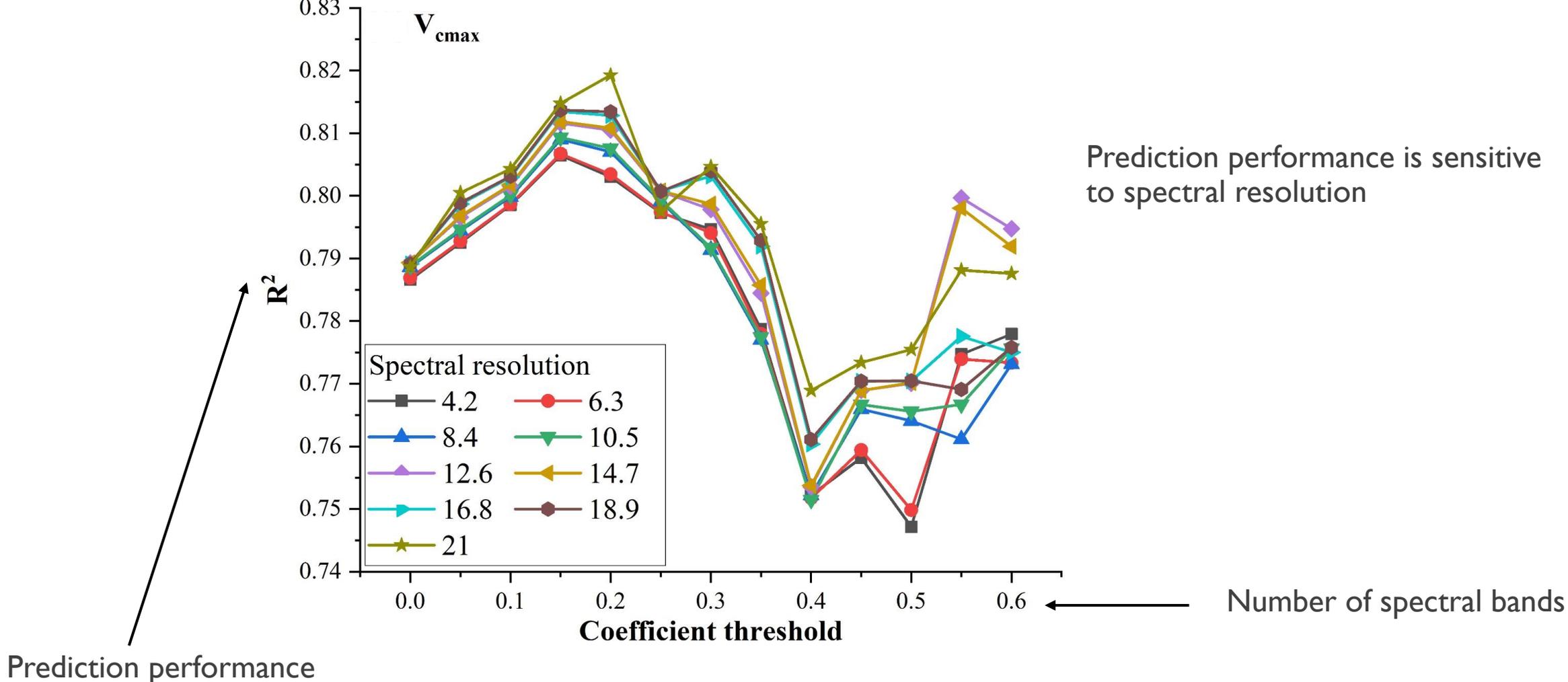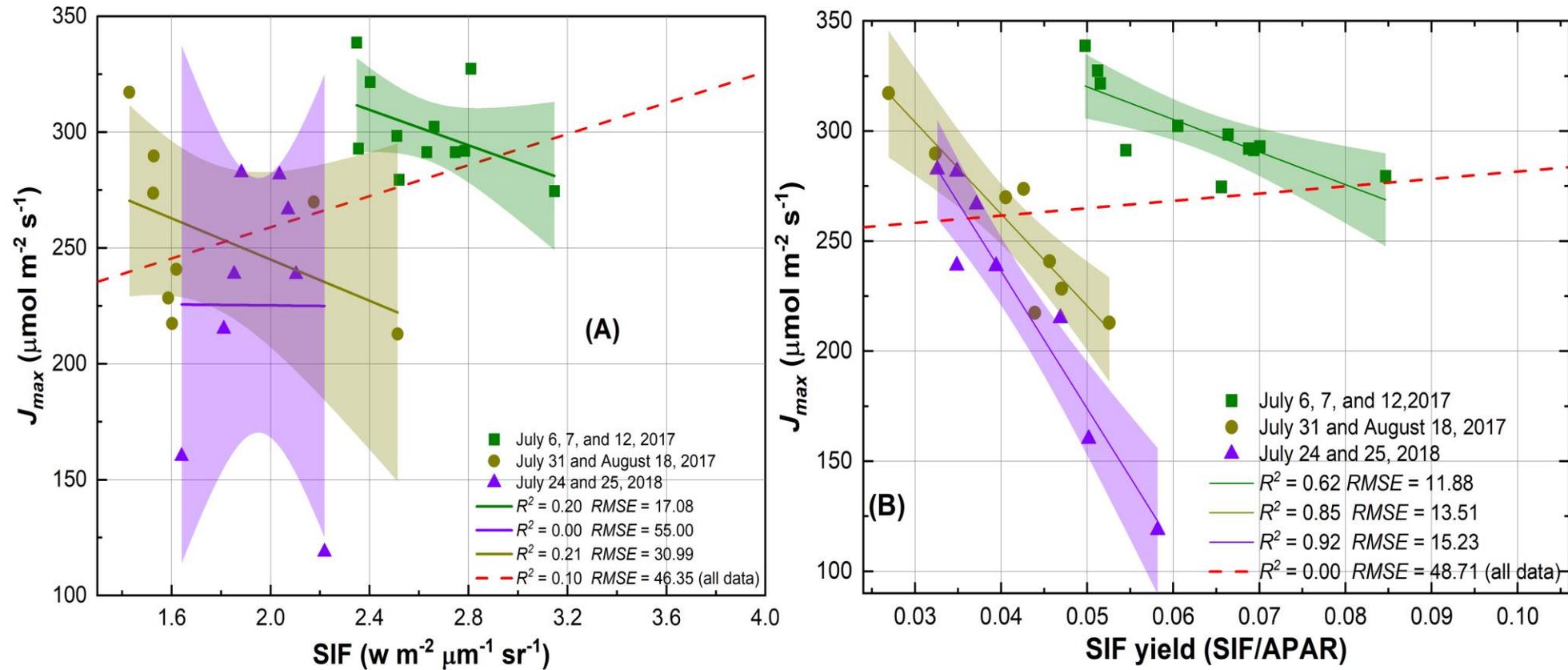
Spectral index-based approach

Ratio index:

Ref_1/Ref_2

Squared correlation coefficient

Impact of spectral resolution on photosynthesis estimations

Prediction performance is sensitive to spectral resolution

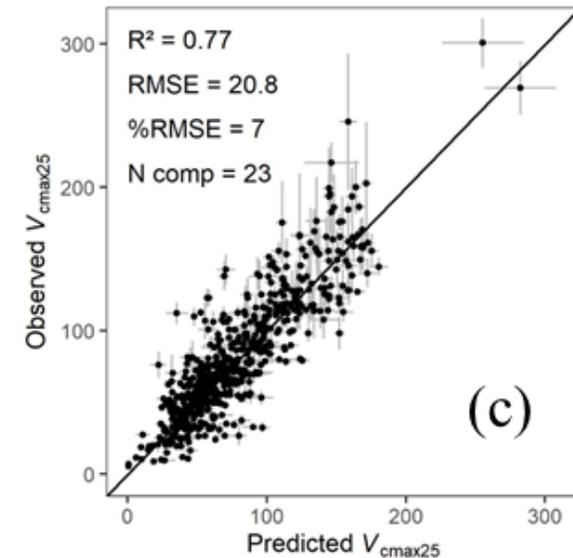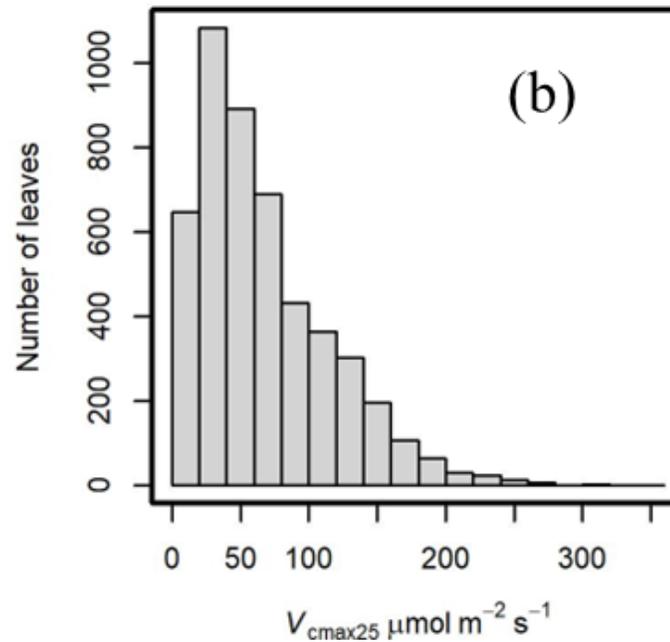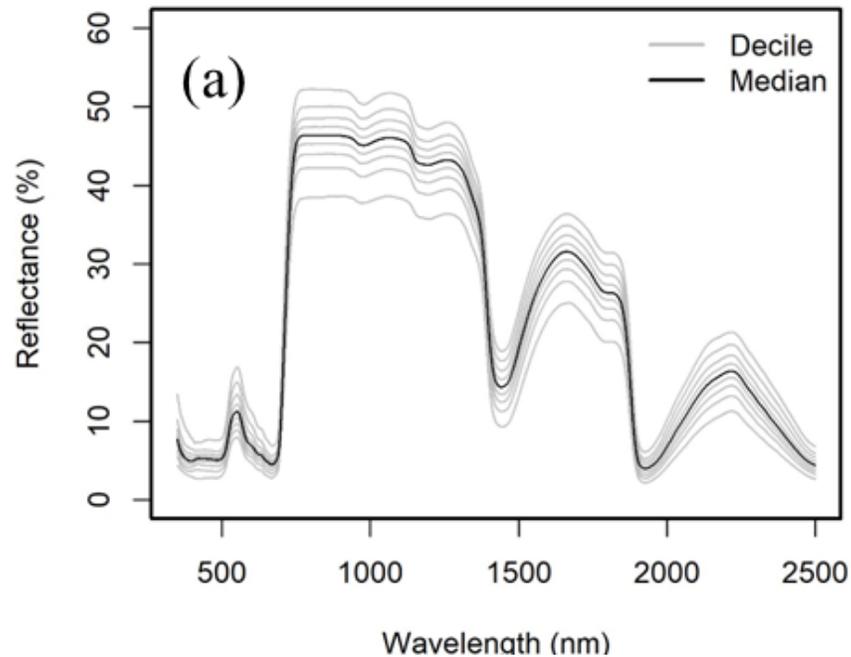Prediction performance

Number of spectral bands

Solar-induced fluorescence yield is inversely related to photosynthetic capacity

- SIF computed using the improved Fraunhofer line discrimination method (760 nm)
- $SIF_y = SIF/APAR$ (with APAR = PAR * NDVI)

Fu et al. 2022

Generalizing Models to Agroecosystems Using Satellite Data

Further details can be found in a poster led by Chi Qiu

Lamour et al. in ESSD 2025

Takeaway messages

➢ We need to double our crop production as population/demand rises.

➢ Approaches to improving crop production include metabolic engineering and identifying natural variation – both of which require accurate estimations.

➢ Proximal Sensing has been developed for high-throughput phenotyping of photosynthetic capacity.

➢ Challenges remain to be solved for remote sensing: scaling uncertainty, data/model standardization, and model generalization to understand agroecosystems for crop production.

Questions?

Peng Fu, Ph.D.
(pfu@agcenter.lsu.edu)