# Improving crop productivity:
## Photosynthesis only?

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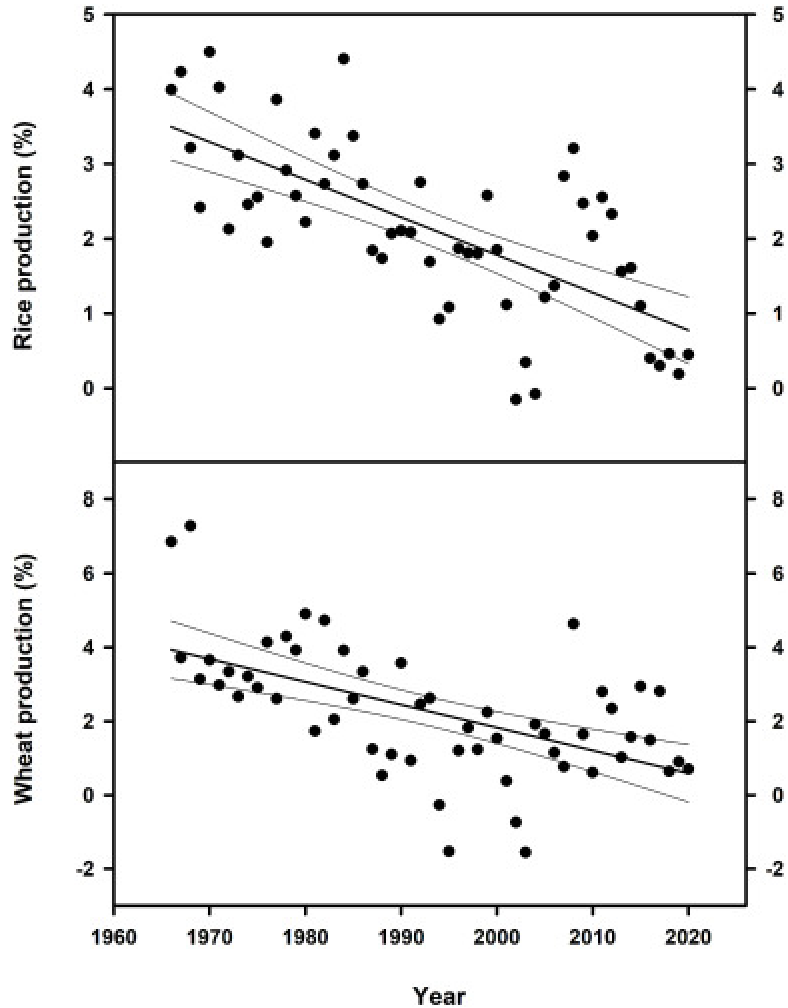
# % changes in global production of rice and wheat




(Ziska 2022)

$$\text{Yield potential} = PAR \times \alpha \times \varepsilon \times HI$$

$\alpha$ = interception efficiency
$\varepsilon$ = conversion efficiency (RUE)
$HI$ = Harvest index (partitioning efficiency)

(Monteith 1977; Long et al. 2006)

# Recap of earlier CropBooster-P reports:

## -Modelled impacts of improving photosynthesis parameters

### Taylor et al.
### (29 sites, wheat, APSIM)

| | CC Scenario | % increase over baseline |
|---|---|---|
| Default photosynthesis | RCP2.6 | 11-22 |
| | RCP8.5 | 20-33 |
| Improved photosynthesis | RCP2.6 | 21-31 |
| | RCP8.5 | 29-41 |

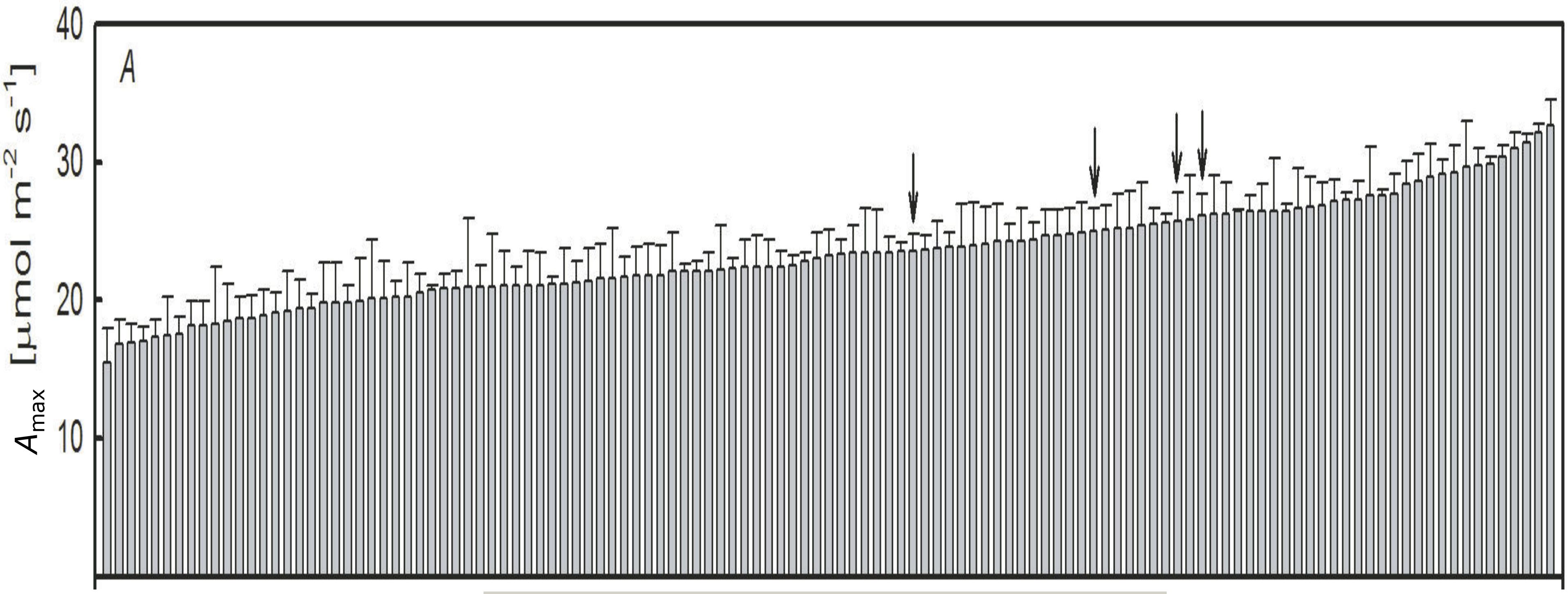
### Harbinson & Yin
### (66 sites, 3 crops, GECROS)

| | Baseline yield (t/ha) | % increase over baseline |
|---|---|---|
| Wheat | 9.2 | 18 |
| Potato | 13.0 | 15 |
| Maize | 11.3 | 19 |

# Further questions to be addressed?

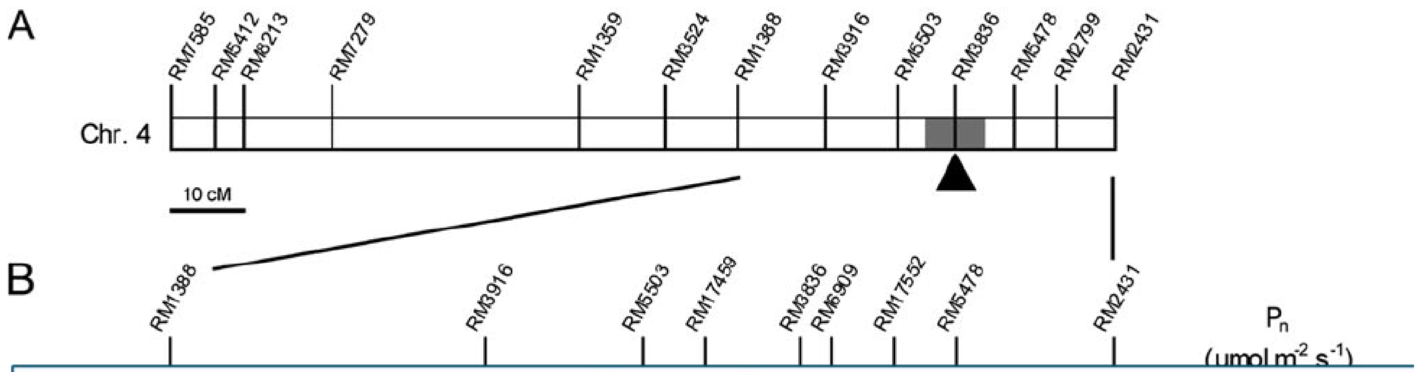
- Is there significant natural variation of photosynthetic $CO_2$-assimilation rate (*A*)?
- If so, can QTL for *A* be identified?
- What are physiological basis of QTL?
- What else should be co-selected so that the benefit from improved *A* is maximal?

# Natural variation of photosynthesis




(Ye et al. 2019. Photosynthetica 57: 311-319)

# Genetic mapping of $A_{max}$ to identify QTL (quantitative trait locus)

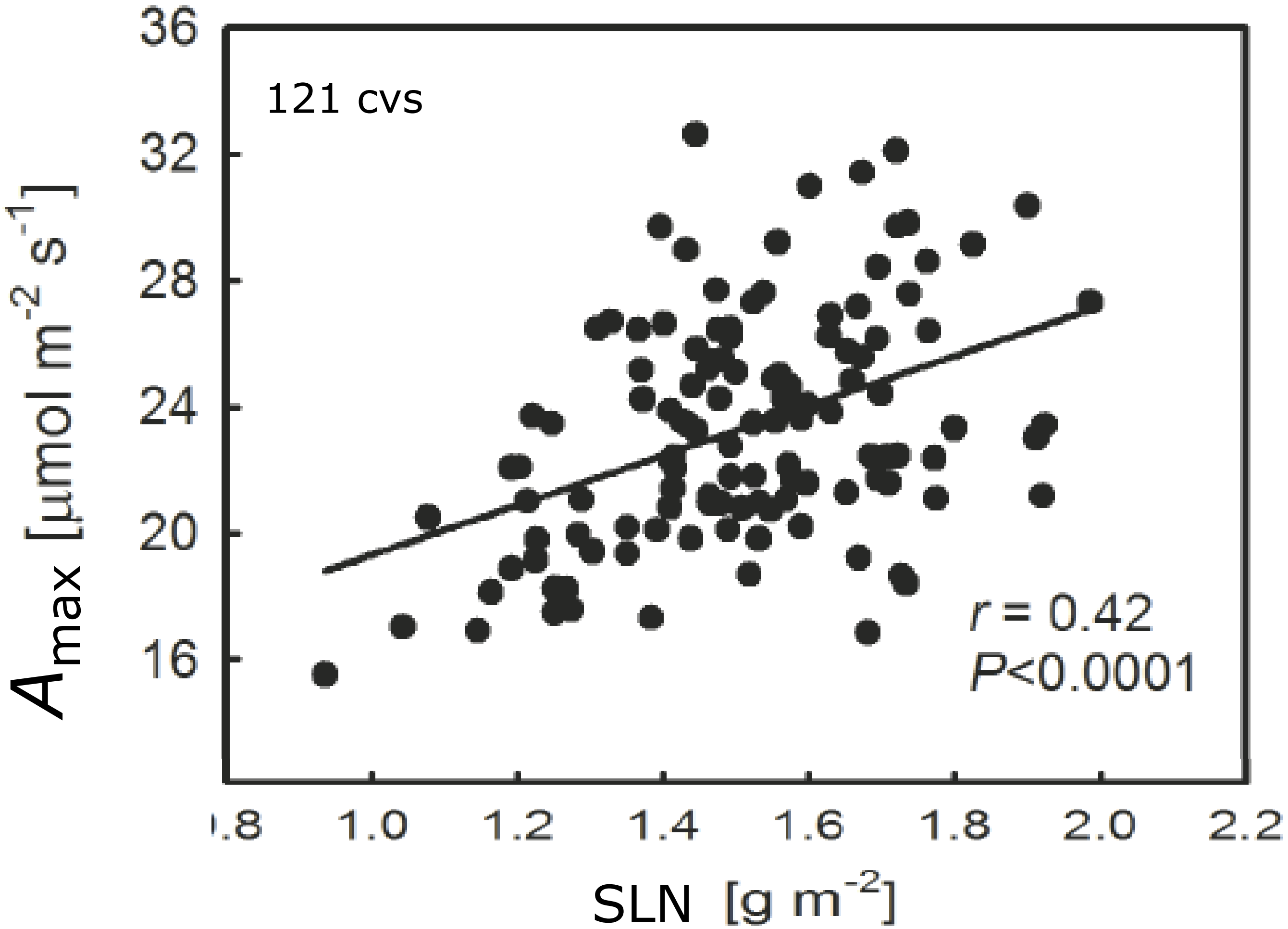



| | $C_p$ ($10^{-6}$ $m^3$ $MPa^{-1}$ $s^{-1}$) | Root length (m) | Root area ( |
|---|---|---|---|
| Koshihikari | 9.8±0.9 | 88.3±1.4 | 0.060 |
| Habaraki | 22.4±1.0*** | 211.8±8.8*** | 0.156 |
| T4-8 | 11.5±1.0* | …0.2±11.7* | 0.077 |

$R^2$ = 9%

(Adachi et al. 2011. JXB 62: 1927-1938)

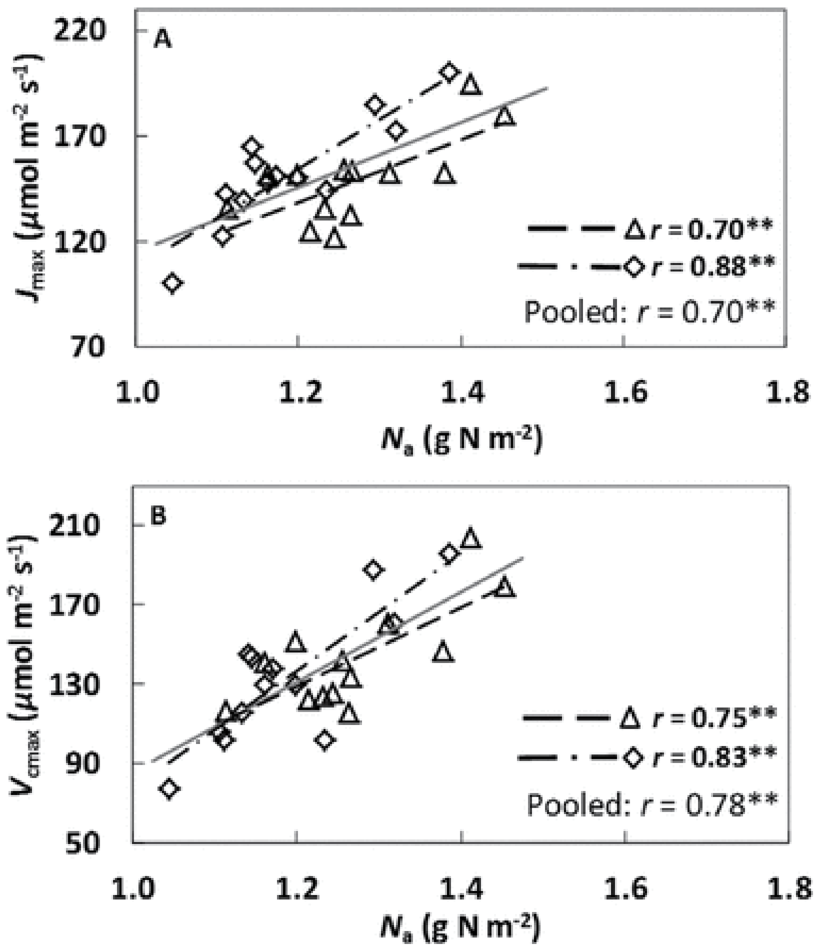
# Variation of photosynthesis may be related to N uptake




(Ye et al. 2019. Photosynthetica 57: 311-319)

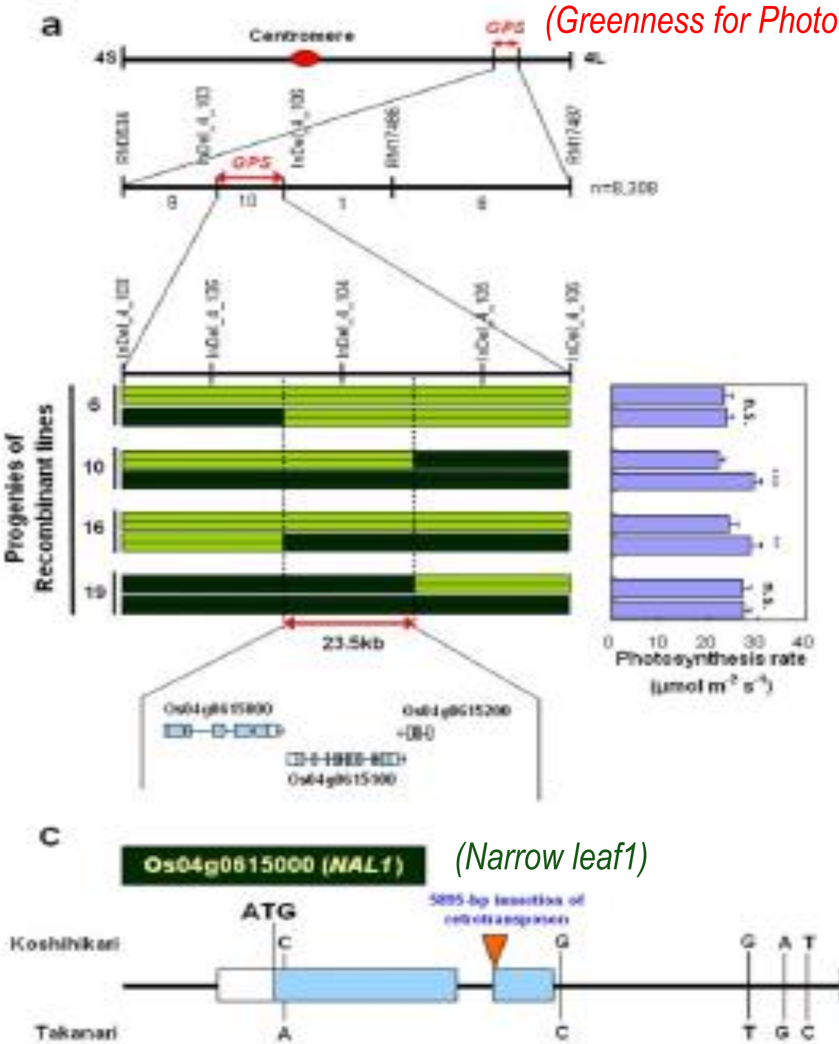
# Variation of photosynthesis may be related to N uptake

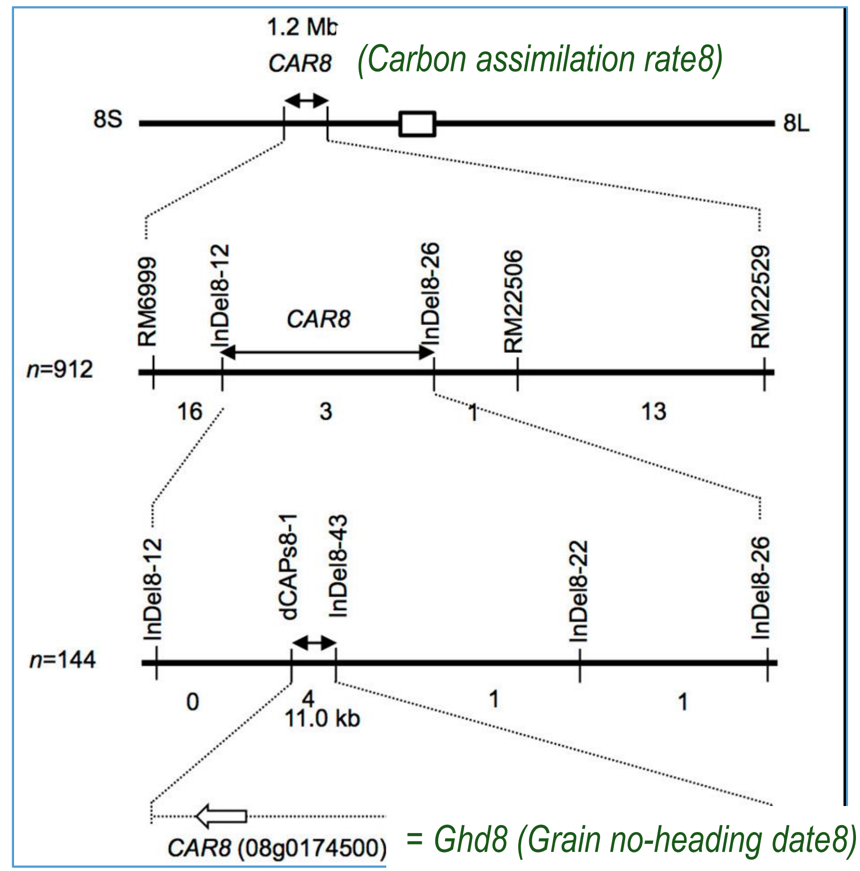
13 introgression lines




(Gu et al. 2012. JXB 63: 5137–5153)

# Fine (molecular) mapping of photosynthesis




(Takai et al. 2013. Sci Reports 3: 2149)

(Adachi et al. 2017. Frontiers Plant Sci 8: 60)

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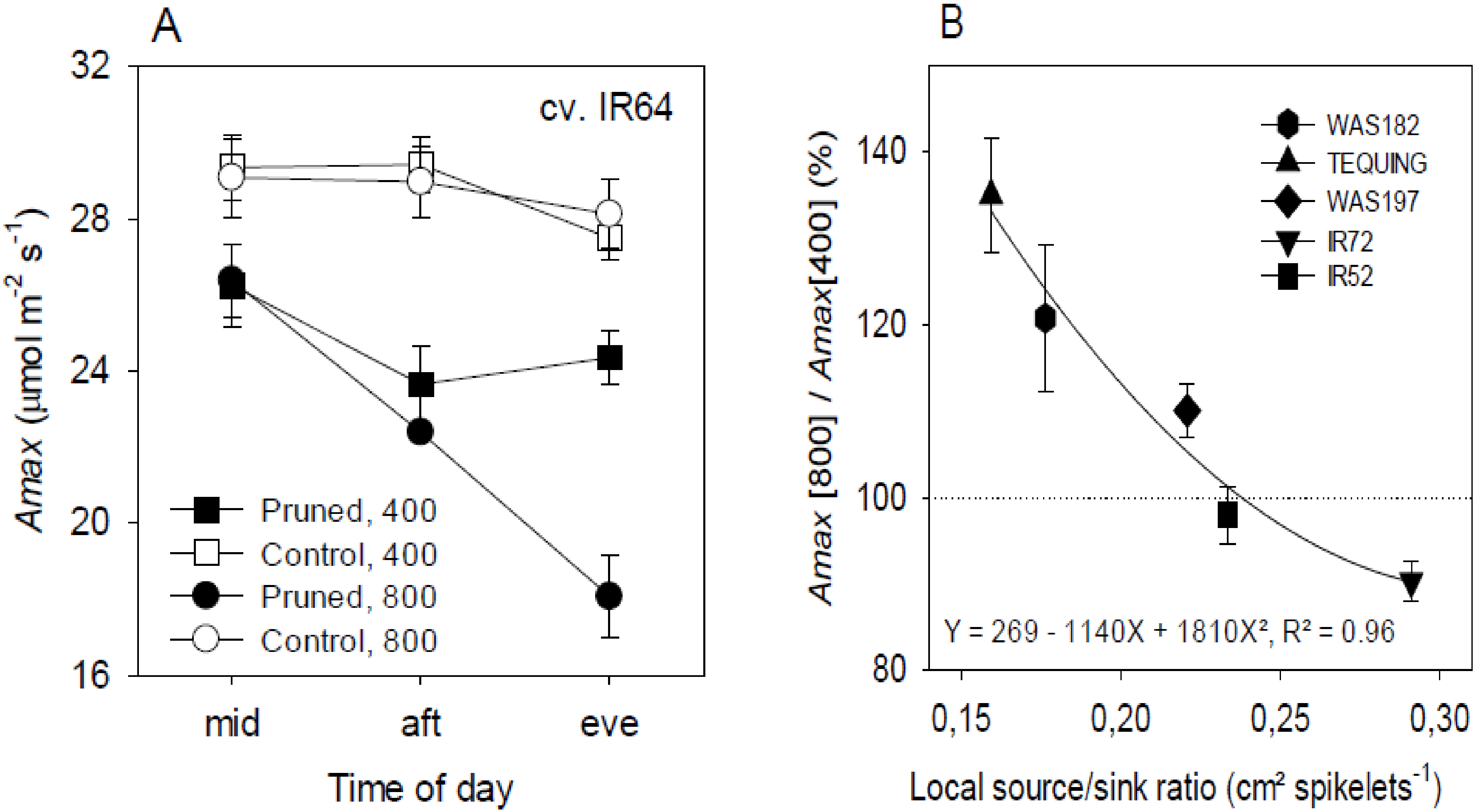
# Physiological evidence for sink feedback effect on photosynthesis




(Fabre et al. 2019. JXB 70: 5773-5785)

(Fabre et al. 2020. PCE 43: 579-593)

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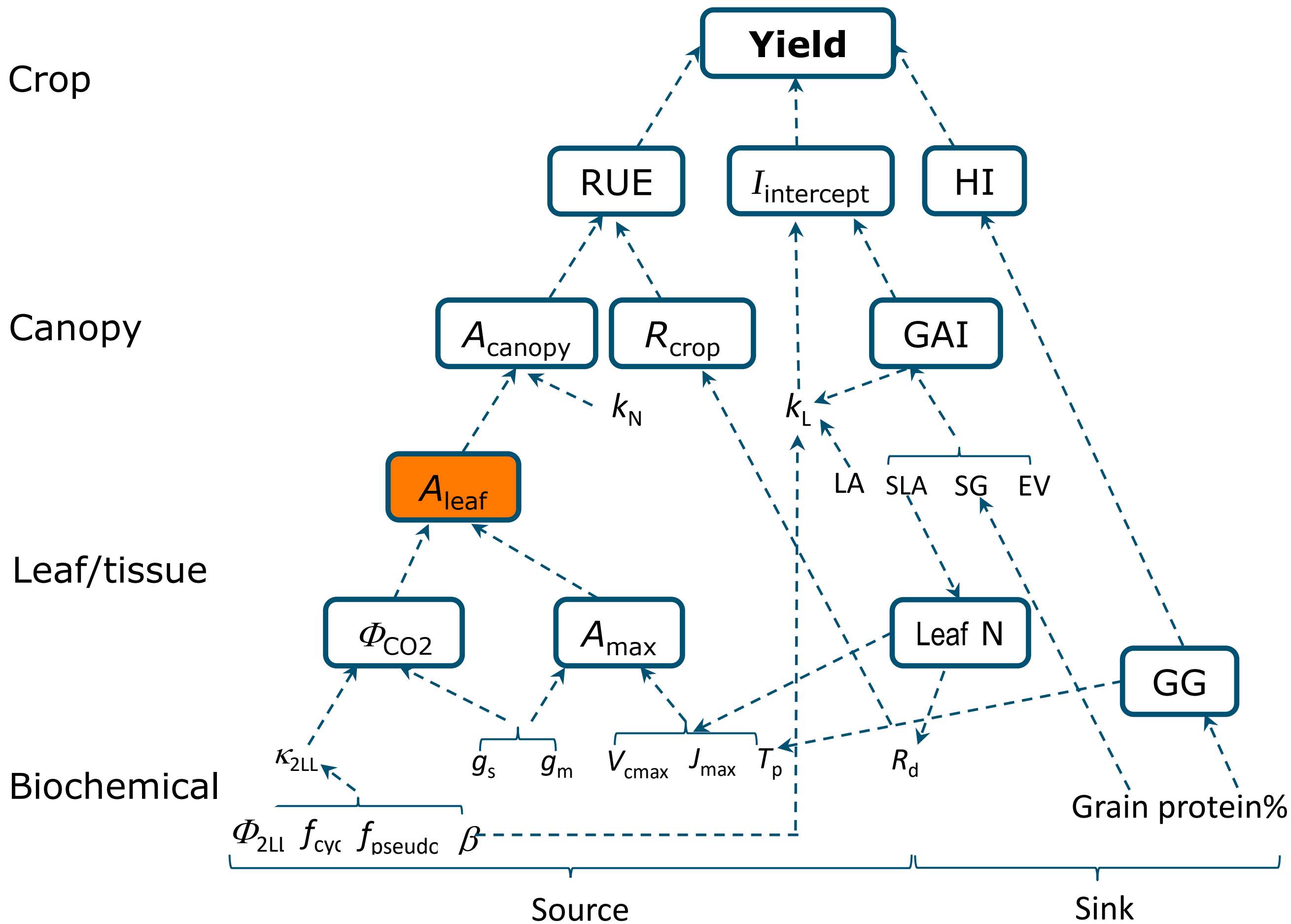
# A whole-crop physiology of yield hierarchy

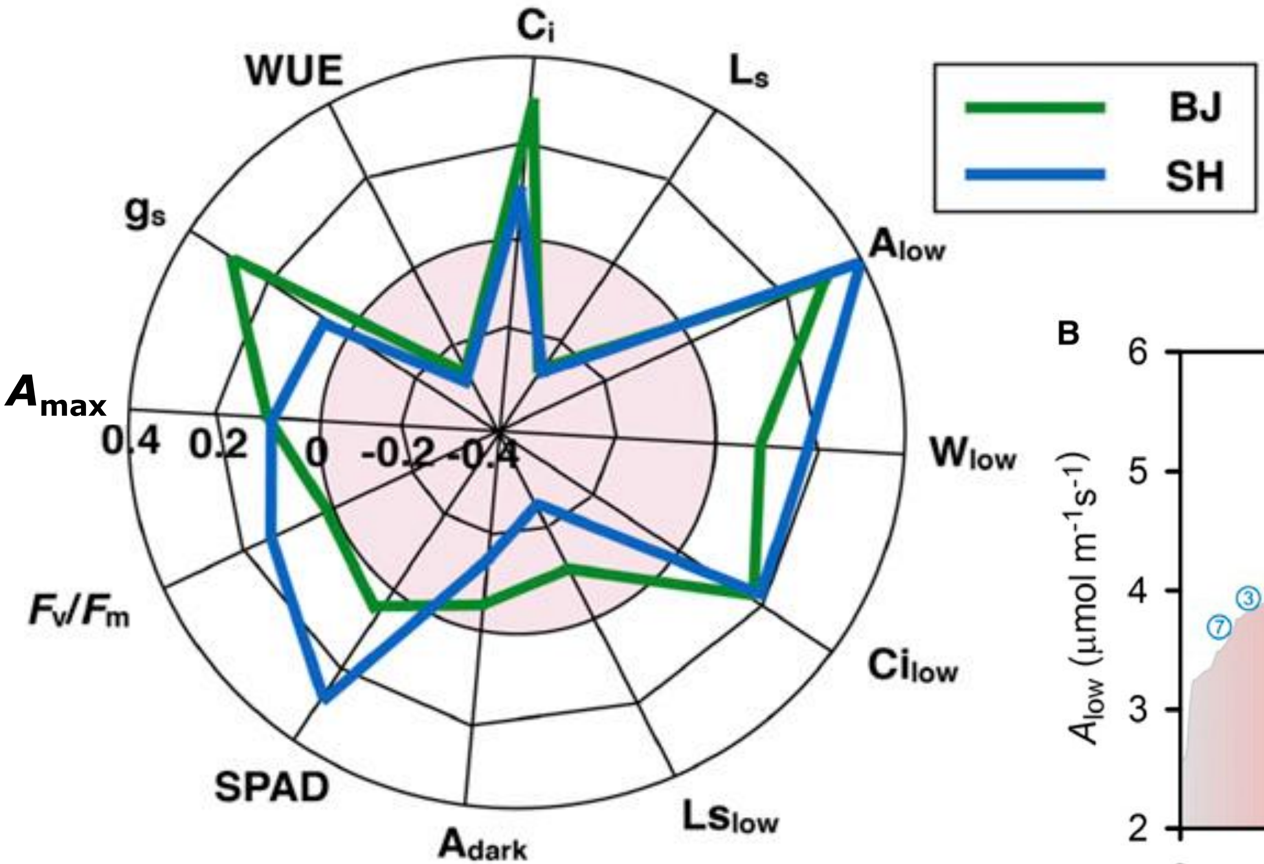


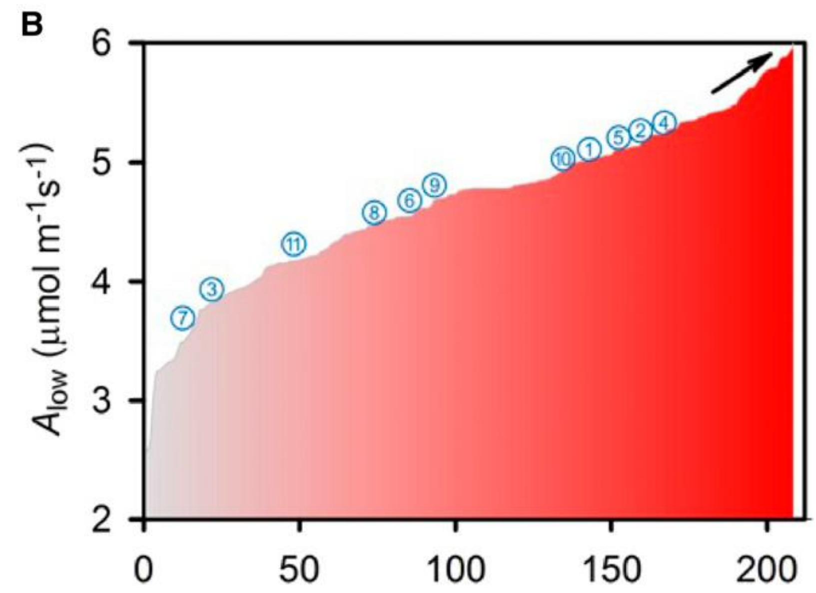
# GECROS modelled advantage (%) from trait improvement by 20%

| Trait type | Parameter | Advantage over the baseline (%) | |
|---|---|---|---|
| | | RUE | Yield |
| Photosynthetic | Maximum Rubisco activity ($\chi_{Vcmax}$) | 0.2 | 0.0 |
| | Maximum electron transport rate ($\chi_{Jmax}$) | 3.7 | 5.0 |
| | PSII light-use efficiency ($\Phi_{2LL}$) | 2.8 | 3.0 |
| | Stomatal conductance ($g_s$) | 0.8 | 1.0 |
| | Mesophyll conductance ($\chi_{gm}$) | 0.8 | 1.0 |
| | TPU limitation | 1.1 | 1.3 |
| | All photosynthetic parameters | 14.0 | 13.0 |
| Morpho-physiological | | 6.9 | 6.7 |
| Nitrogen uptake | | 10.7 | 14.6 |
| Photosynthetic + morpho-physiological | | 21.9 | 19.1 |
| Photosynthetic + morpho-physiological + nitrogen uptake | | 37.2 | 39.1 |

# Empirical evidence for the importance of $A_{low}$

## Correlation with biomass (204 rice genotypes from 67 countries)




(Qu et al. 2017. Plant Physiology 175: 248-258)

# Summary points

- Large phenotypic variations (often > 2-fold) exist for photosynthesis
  - much of the basis of photosynthesis-QTL resides in genes controlling nitrogen use, source-sink relations, leaf morphology;
- Crop modelling showed that improving photosynthesis can enhance yield, but under-studied electron transport parameters were much more effective than the commonly studied $A_{max}$.
- To increase yield, multiple parameters should be improved synergistically, allowing for high canopy photosynthesis and duration.
- Proportionally increased root nitrogen uptake is required to significantly improve yield.

# Improving crop productivity: via photosynthesis only?

- Not really; others (morpho-physiological traits and root N uptake) should be co-selected.

- Of the real photosynthesis traits, selecting for high $A_{low}$ (instead of $A_{max}$) should be a priority.

# The impact of transforming for ‘$C_4$ rice’ with **CCM** on productivity

% of increase relative to the $C_3$ standard cultivar, 31-year weather data

| Production level | | Potential | |
|---|---|---|---|
| Climate | | Present | 2050[a] |
| Site | Los Baños, Philippines (tropics) | 38.0 | 23.1 |
| | Nanjing, China (subtropics) | 33.0 | 21.9 |
| | Shizukuishi, Japan (temperate) | 39.8 | 25.4 |

Yin & Struik 2017. J Exp Bot 68: 2345-2360.

| Trait type | Parameter [a] | Parameter values | | Advantage over the baseline (%) [b] | |
|---|---|---|---|---|---|
| | | Baseline | Improved | RUE | Biomass |
| Morpho-physiological | 7 Leaf angle | 65 | 52 | -0.3 | 0.0 |
| | 8 $k_N$:$k_L$ | 0.80 | 0.96 | 2.4 | 2.5 |
| | 9 Stay-green [d] | Baseline | Improved | 1.6 | 2.1 |
| | 10 SLA | 0.030 | 0.036 | -1.9 | -1.8 |
| | 11 Non-leaf tissue [d] | Baseline | Improved | 2.8 | 3.1 |