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Nitrogen use & GHG efficiency of oilseed rape cultivars evaluated using experimental data and simulation modelling

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Outline

- Nitrogen use efficiency and GHG emissions
- Experiments and data
- Genotypic calibration of HUME-OSR
- Scenario calculations for NUE and GHG indicators
- Summary and Conclusions

Nitrogen use efficiency

Agronomic

$$NUE_{ag} = \frac{Y}{N_f}$$

N-based

$$NUE_N = \frac{N_y}{N_f}$$

Y = seed yield, N_f = nitrogen in fertilizer

Agronomic nitrogen use efficiency (NUE_{ag}) as a function of N fertilization rate

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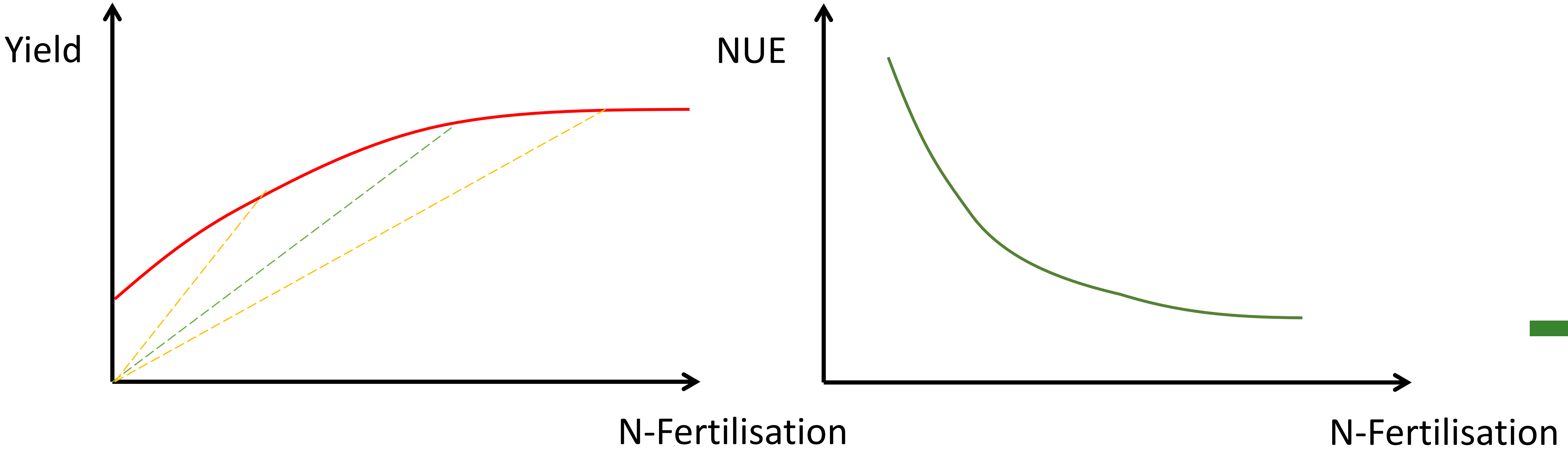
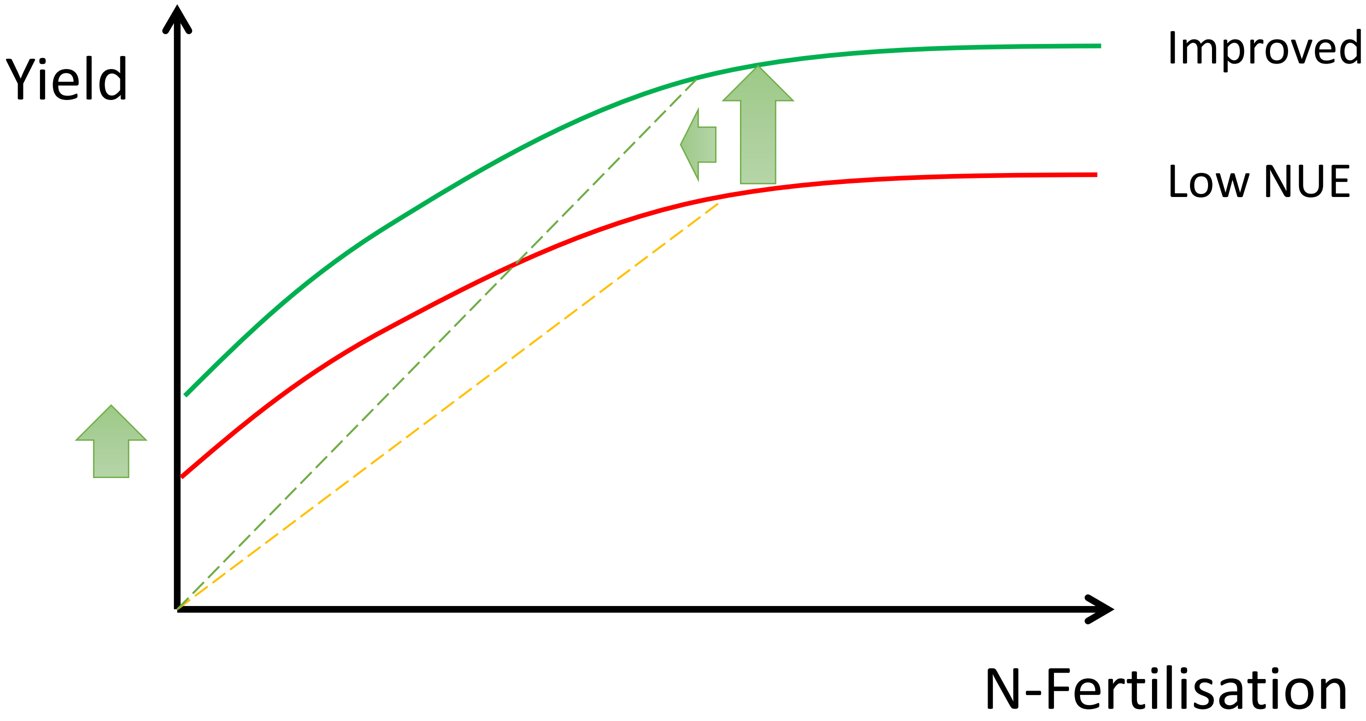
$$NUE_{ag} = \frac{Yield}{N - Fertilisation}$$



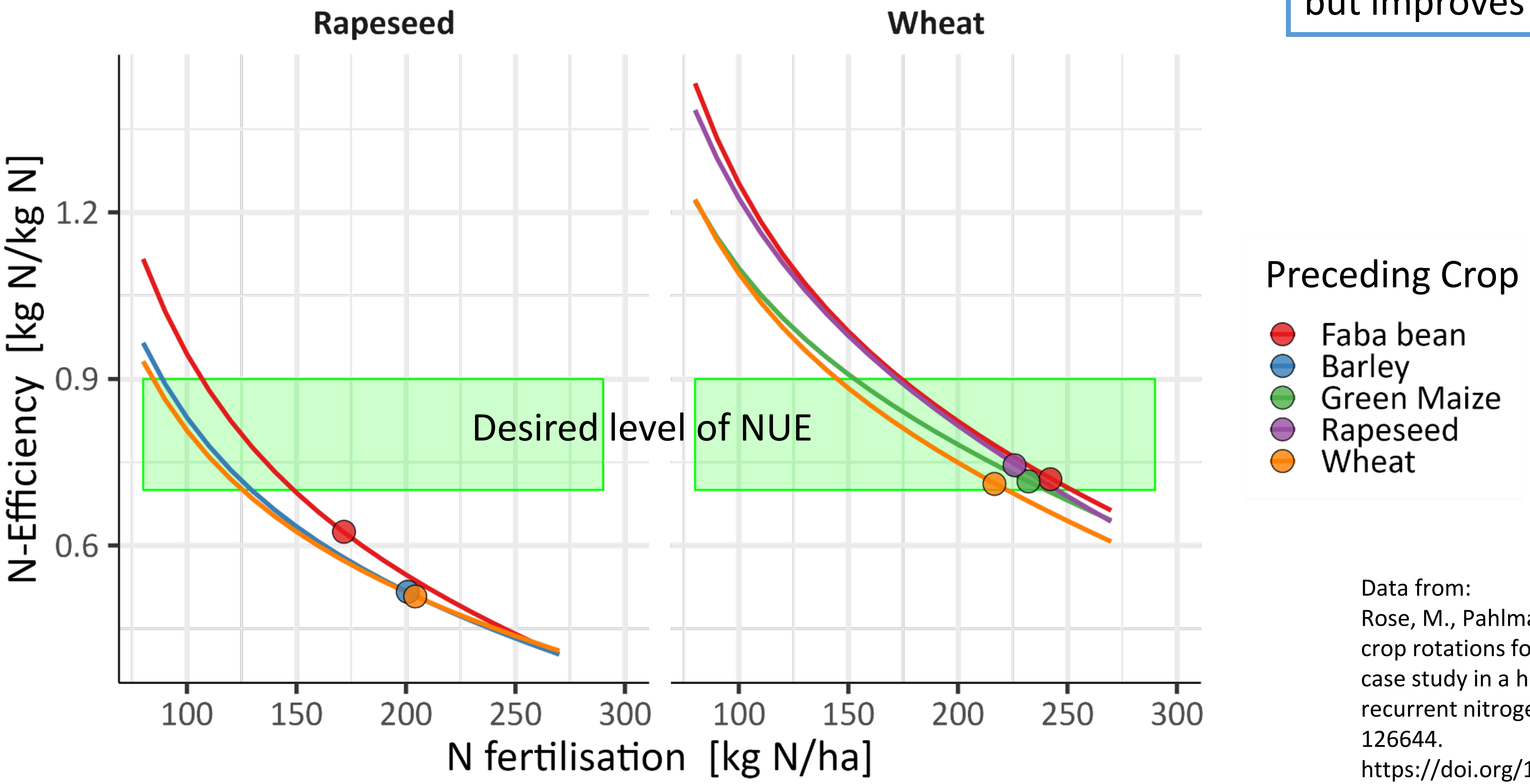
Agronomic nitrogen use efficiency (NUE_{ag}) as a function of N fertilization rate



$$NUE_{ag} = \frac{Yield}{N - Fertilisation}$$

Comparison of NUE_N for rapeseed and wheat

Rapeseed has low NUE
but improves NUE of wheat



Points indicate economic optimum N rate

Data from:
Rose, M., Pahlmann, I., Kage, H., 2023. Modified crop rotations for a sustainable intensification? A case study in a high-yielding environment with recurrent nitrogen surplus. Eur. J. Agron. 142, 126644. https://doi.org/10.1016/j.eja.2022.126644.

GHG-indicators as a function of N fertilisation rate

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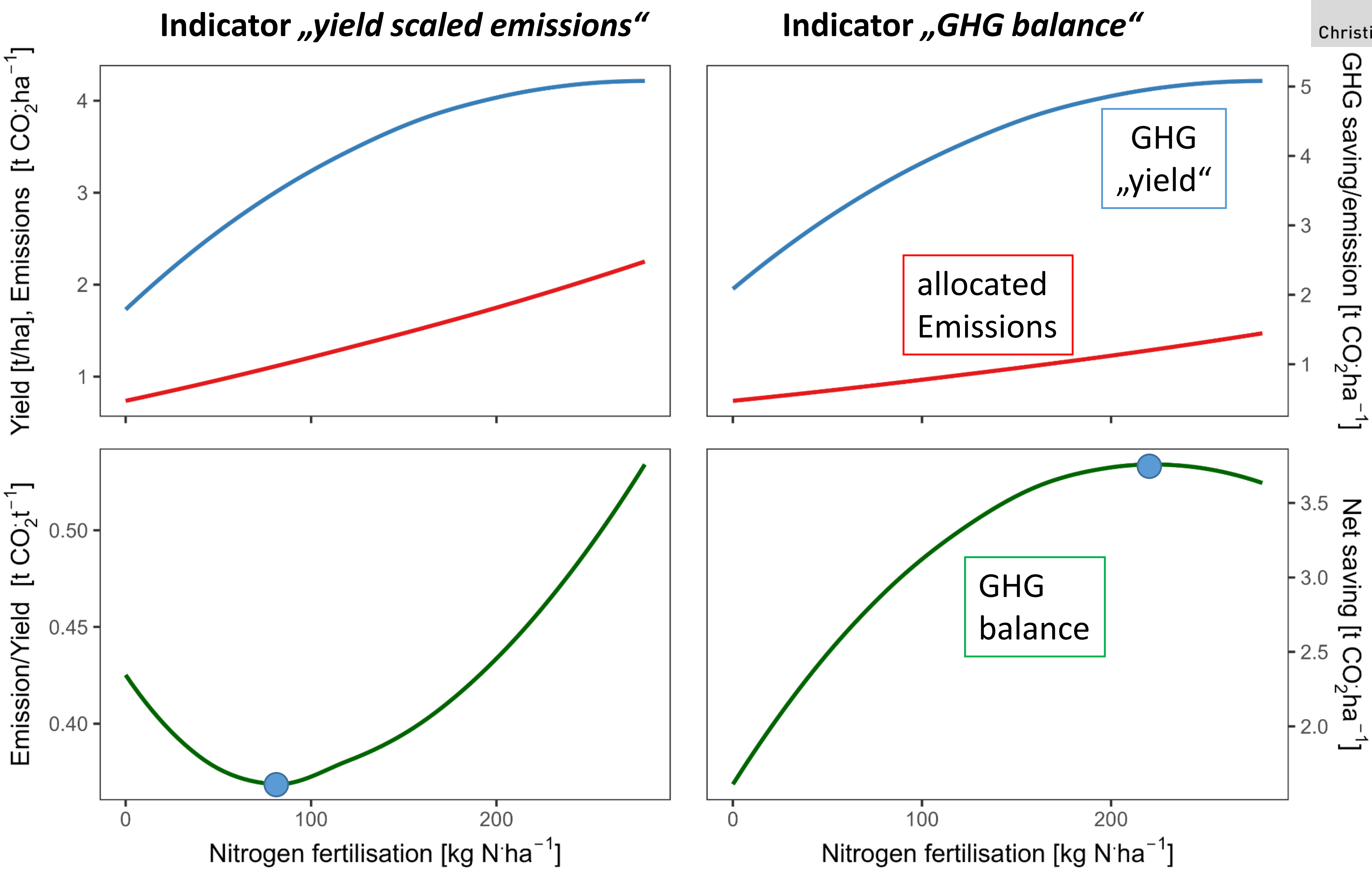

GHG balance from ***scenario biofuel production***

Research questions

- **Are there differences in NUE between OSR cultivars?**
  - Hybrids vs. OP cultivars?
  - Old vs. new cultivars?
- **Which traits of OSR cultivars affect NUE?**
- **How differences in NUE contribute to GHG balance and yield related emissions?**
- **Which consequences arise for optimal production intensity?**

Experimental Approach

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- **N rate experiments**
  - 3 sites (one site only one year)
  - 2 years
  - 8 cultivars
    - For 3 cultivars on 1 site sequential harvests
  - 5 N-rates
- **MicroNAM population**
  - 6 sites
- **Additional data from other field experiments**
  - Calibration data for spectral reflection models
  - Calibration data for old hybrid cultivar TALENT

Cultivars used in field experiments for parameterisation

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Cultivar	Cultivar type	Year of release
Talent	Hybrid	1999
Arsenal	Hybride	2012
Patron	OP	2014
DK Expansion	Hybride	2015
Advocat	Hybrid	2017
Architect	Hybrid	2017
Puzzle	Hybride	2017
Fossil	Hybride	2018
Violin	Hybrid	2018

Sites of the experiments and scenario study

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Site	Temperature [°C]	Precipitation [mm/a]	Soil texture	PASW [mm]	Humus [%]
Groß-Gerau	11.0	598	Silty Sand	183	2.95
Gülzow	9.6	658	Loamy Sand	170	2.77
Hohenschulen	9.4	811	Loamy Sand	170	2.77
Lauenau	10.2	722	Claey silt	198	2.56
Moosburg	9.2	770	Claey silt	224	2.86
Rauischholzhausen	9.4	672	Claey silt	193	2.56
Rosenthal	10.1	607	Loamy Sand	180	2.77

Seed yield and nitrogen use efficiency
as a function of N fertilisation rate for different Rapeseed genotypes

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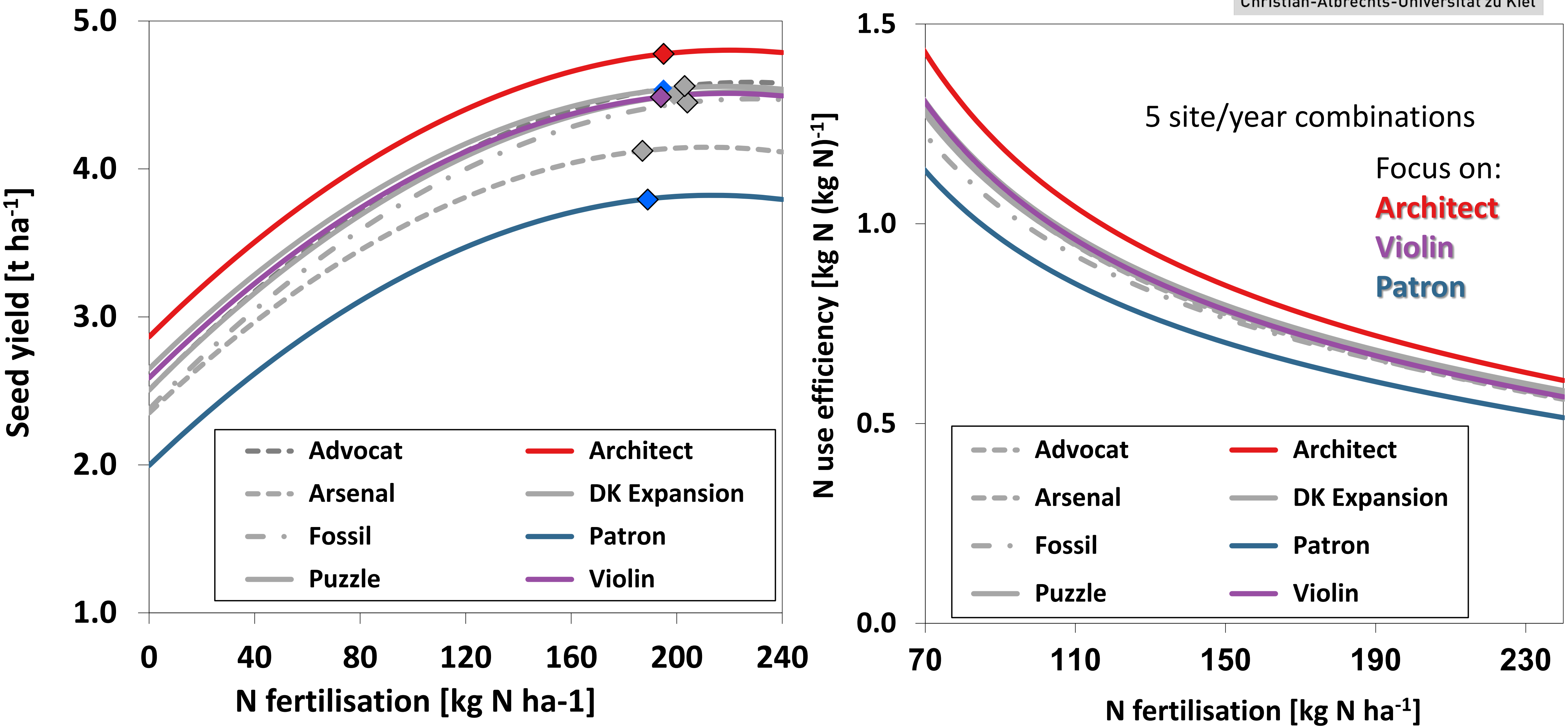


Klaus Sieling, Till Rose, Andreas Stahl, Björn Reddersen, Henning Kage, 2023. Differences in N use efficiency, N translocation and N immobilization capacity of their residues of oilseed rape varieties due to N fertilization. Arch. Agron. Soil Sci. 69, 3300–3313. https://doi.org/10.1080/03650340.2023.2228257.

Genotypic differences in NUE

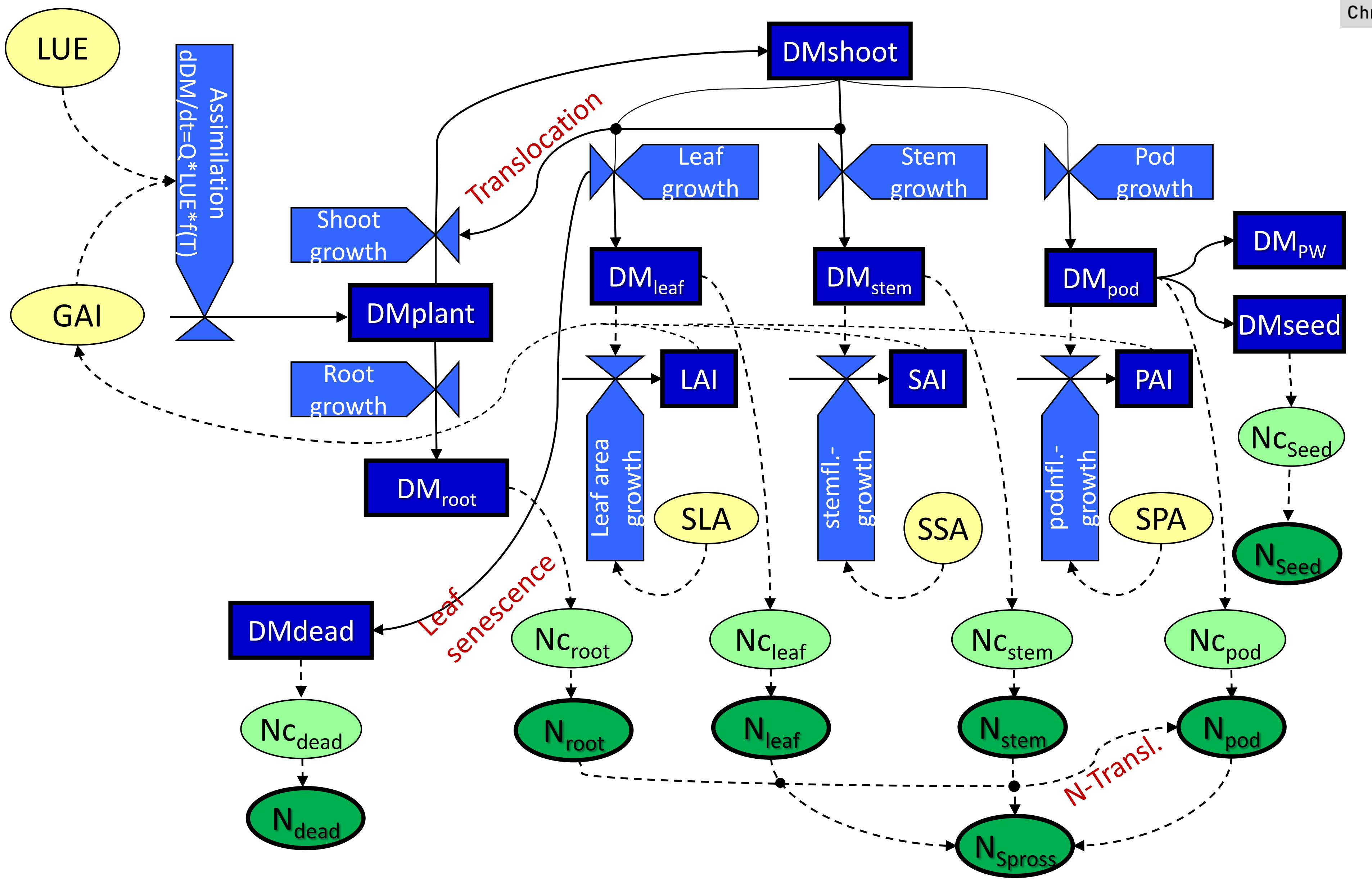
- **Tested cultivars differed in NUE**
- **Which traits differ/changed during breeding progress?**
  - No historic cultivars were included in the project
  - But: we reused data from older field experiments at Hoheschulen experimental station for the cultivar **Talent**
  - Same site and methods but different years!

The Monteith (source focussed) yield model

$$Y = HI \cdot \int Q \cdot LUE \cdot f(T, \theta)$$

- Y = Yield
- HI = Harvest Index
- Q = absorbed Radiation
- LUE = Light Use Efficiency
- $f(T, \theta)$ = Stress factors
    - Temperature
    - Drought

Extended Model: HUME-OSR



Weymann, W., Sieling, K., Kage, H., 2017. Organ-specific approaches describing crop growth of winter oilseed rape under optimal and N-limited conditions. Eur. J. Agron. 82, 71–79. https://doi.org/10.1016/j.eja.2016.10.005.

Böttcher, U., Weymann, W., Pullens, J.W.M., Olesen, J.E., Kage, H., 2020. Development and evaluation of HUME-OSR: A dynamic crop growth model for winter oilseed rape. Field Crop. Res. 246, 107679. https://doi.org/10.1016/j.fcr.2019.107679.

HUME-OSR:

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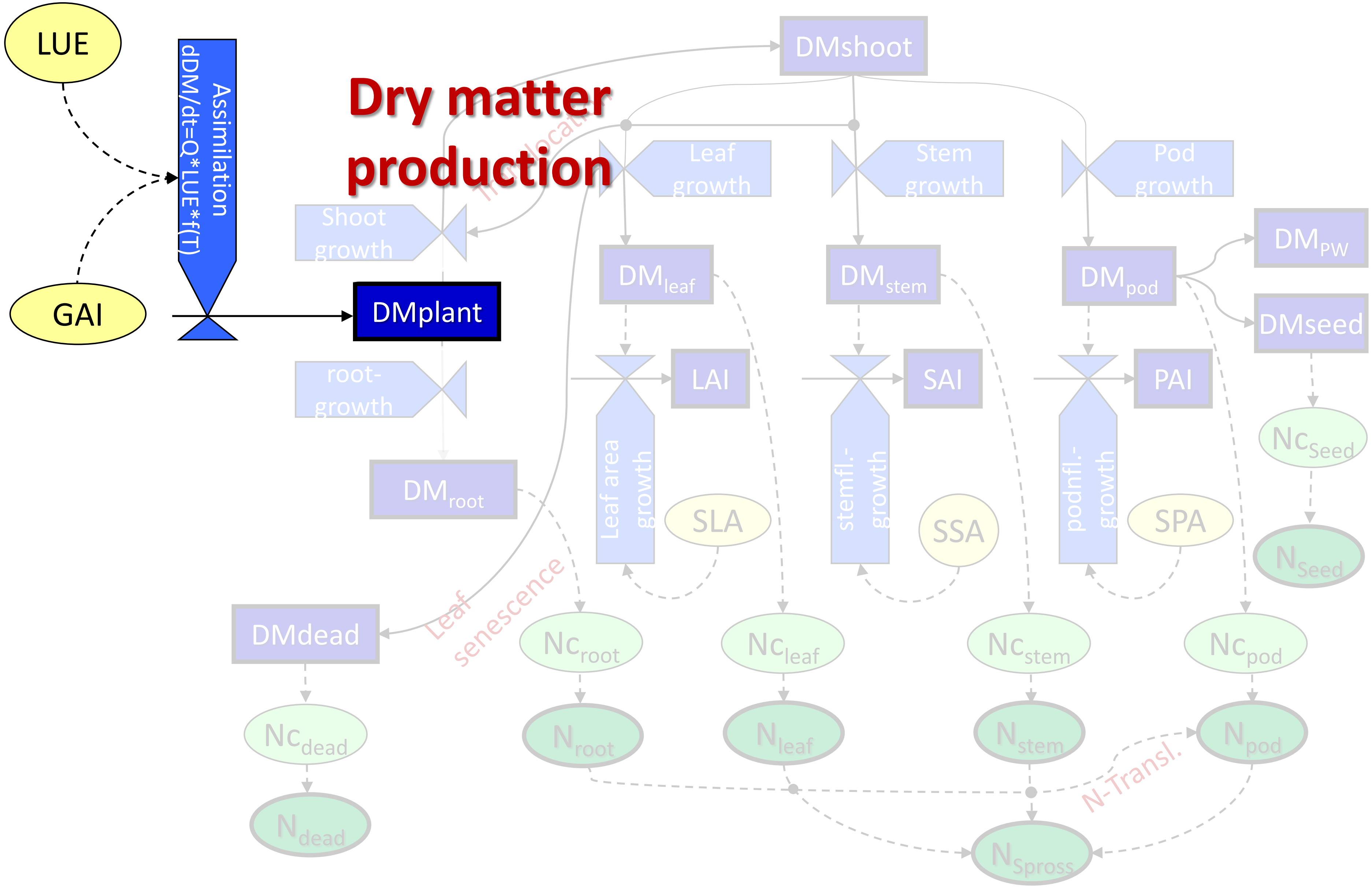
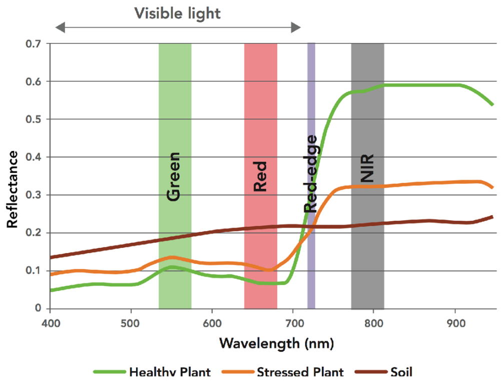
Dry matter production



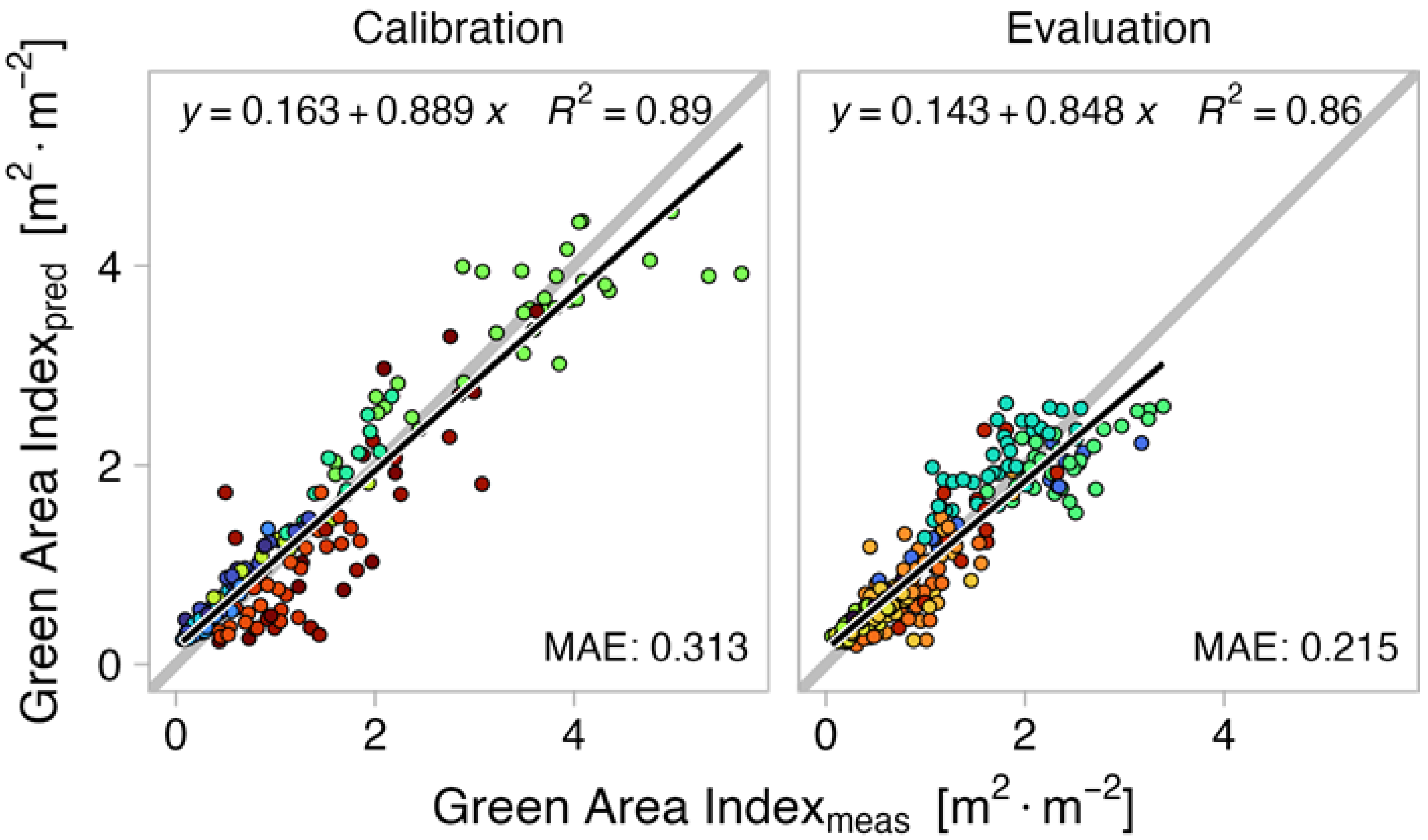
GAI-Calibration and Independent Evaluation

- **Spectral reflection measurements**
  - Parrot Sequoia
    - 4 spectral wavebands
  - EbeeX drone
  - Pix4D for stitching
- **Seasons**
  - 2017–2022
- **Sampling dates**
  - 23
- **Samples calibration**
  - 175
- **Samples evaluation**
  - 278



Pictures: https://www.parrot.com/de/shop/zubehoer-ersatzteile/andere-drohnen/sequoia

GAI-Calibration and Independent Evaluation



Whole season model
(flowering period excluded!)

2017-10-09, 2017-10-18, 2017-11-03, 2017-11-06, 2019-11-11, 2019-11-26, 2020-03-03, 2020-03-04, 2017-11-20, 2018-03-26, 2018-04-09, 2018-10-16, 2020-03-25, 2022-03-15, 2022-03-23, 2022-03-29, 2018-10-22, 2018-11-07, 2019-04-02, 2019-10-23, 2022-04-05, 2022-04-11, 2022-04-20

$$GAI[m^2m^{-2}] = 9.5272 + 0.1376 \times \frac{NIR}{Red} - 17.5829 \times \frac{NIR}{RE} + 8.0972 \times (\frac{NIR}{RE})^2$$

Bukowiecki et al. (in prep.)

Green area index
over time for 3 selected N rates

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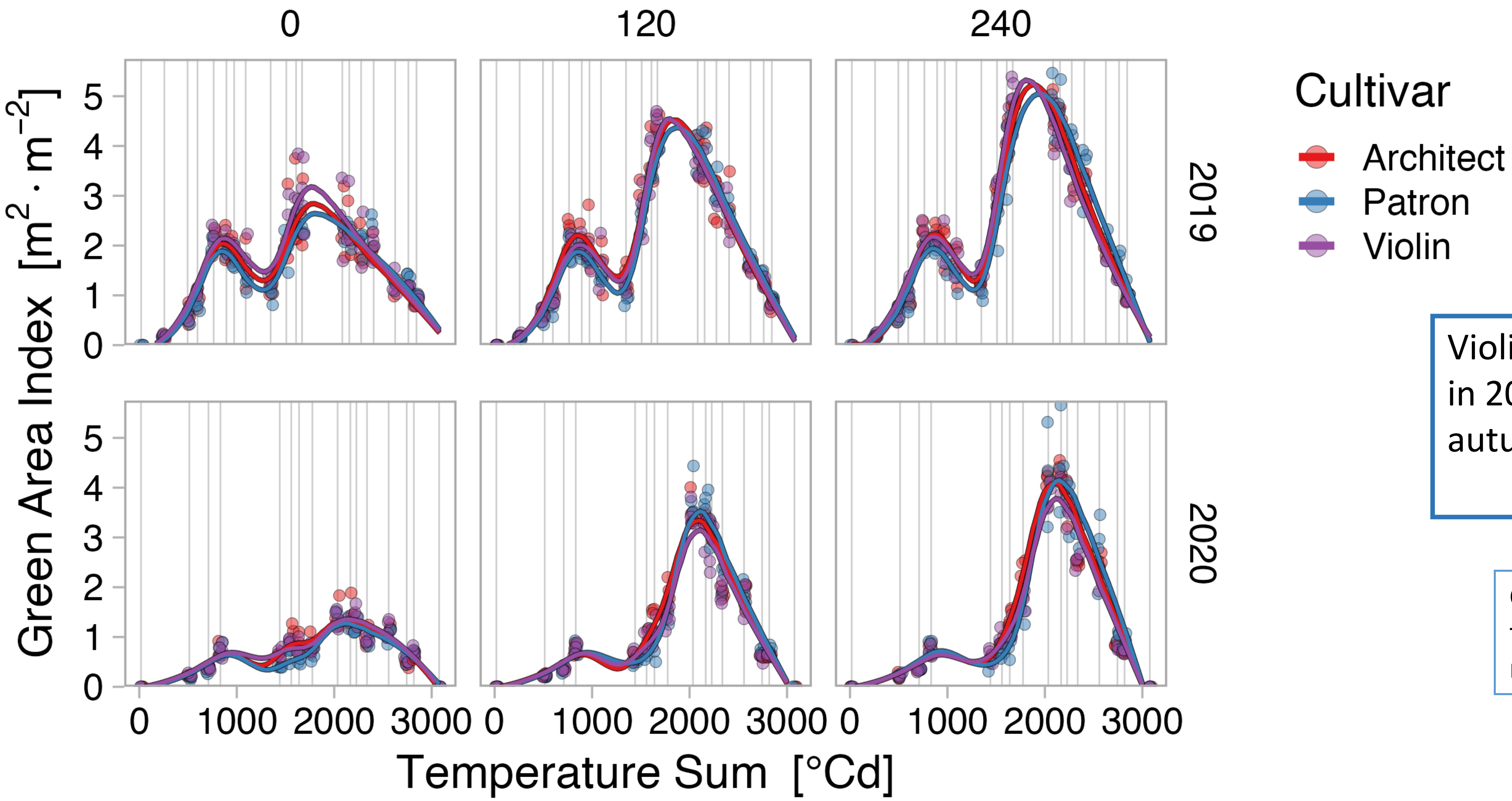


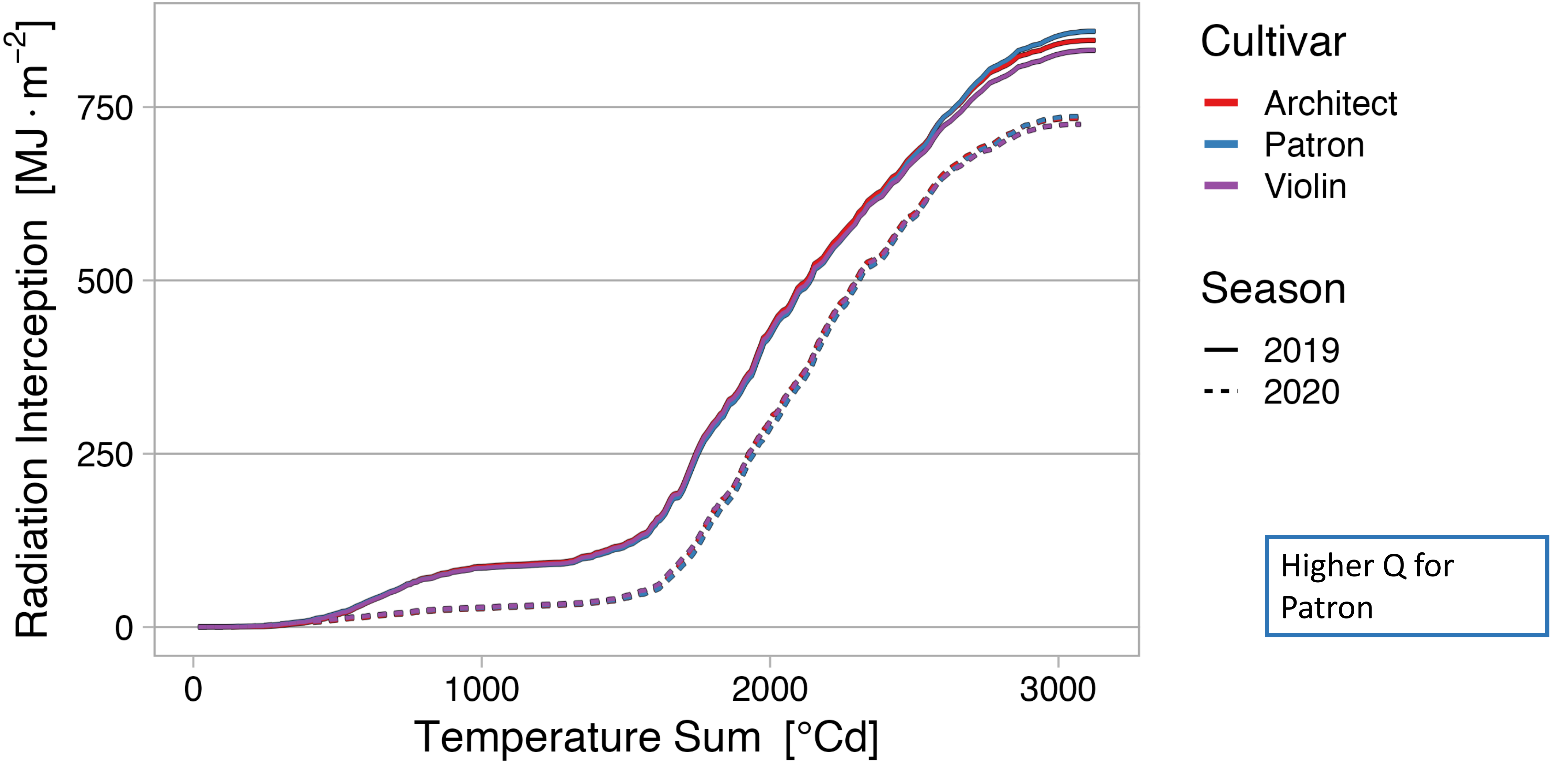
Violin and Architect: in 2019 higher GAI in autumn

Cultivar Talent parameterised from old experimental data, not included!

Grey lines indicate flying dates

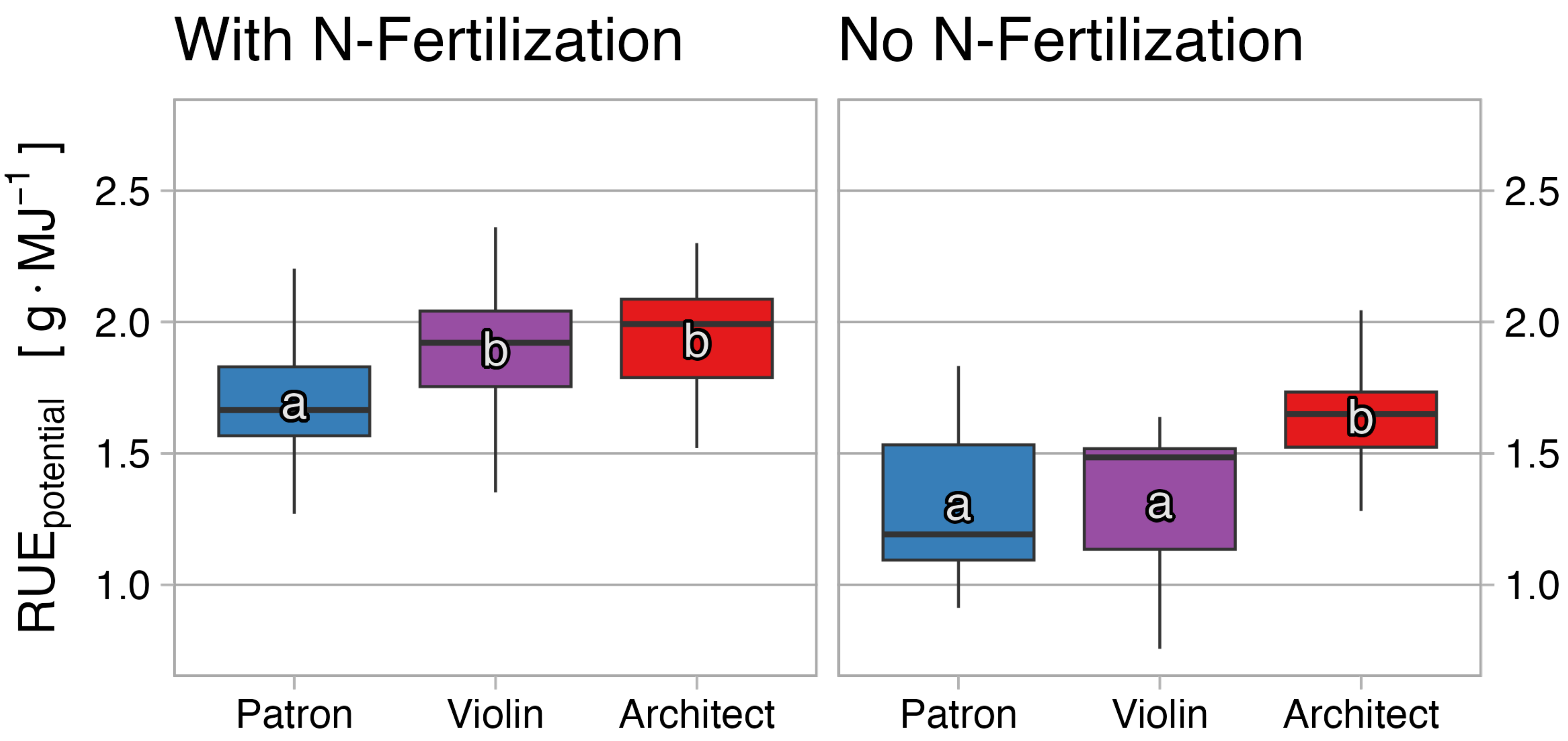
Cumulative radiation uptake

For 3 selected cultivars at high N supply in two seasons



Higher Q for Patron

Estimated RUE
for 3 selected cultivars at high N rates and without N fertilisation



OP cultivar Patron with lower RUE

RUE = Shoot DM/radiation uptake (PAR)

$RUE_{potential}$ = RUE corrected for suboptimal temperatures

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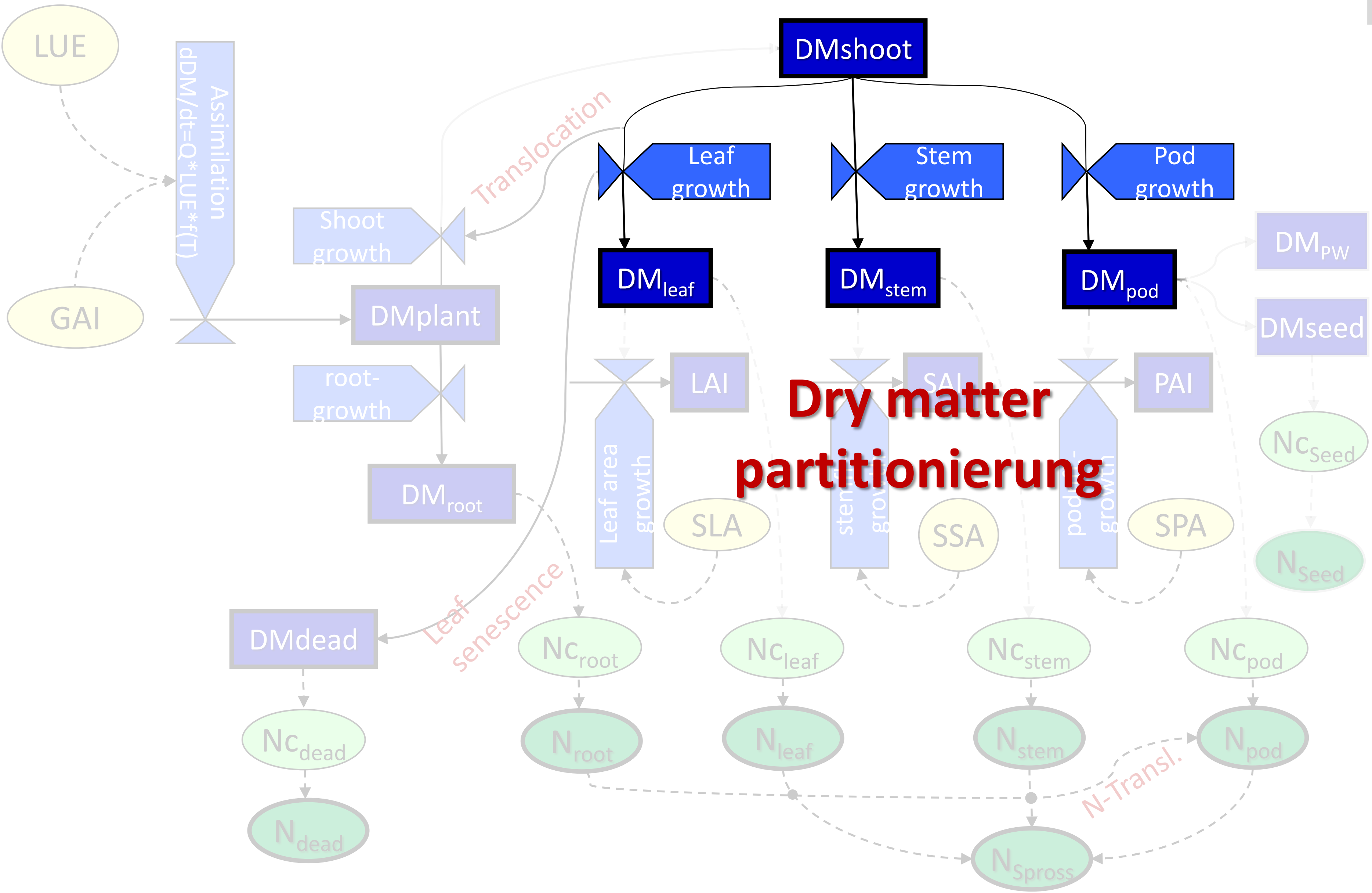
Dry matter partitionierung



Allometric relationship between leaf and stem biomass

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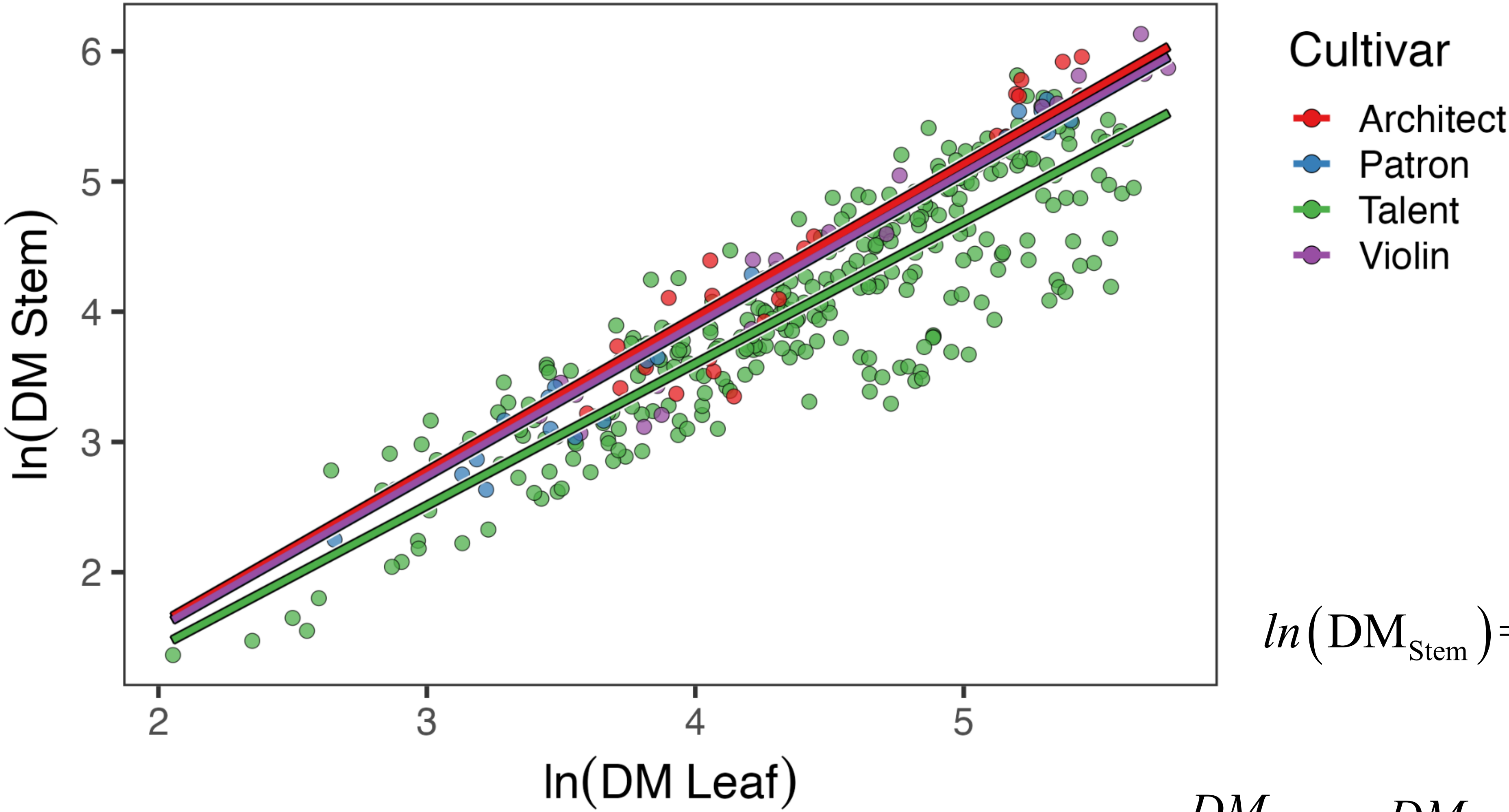


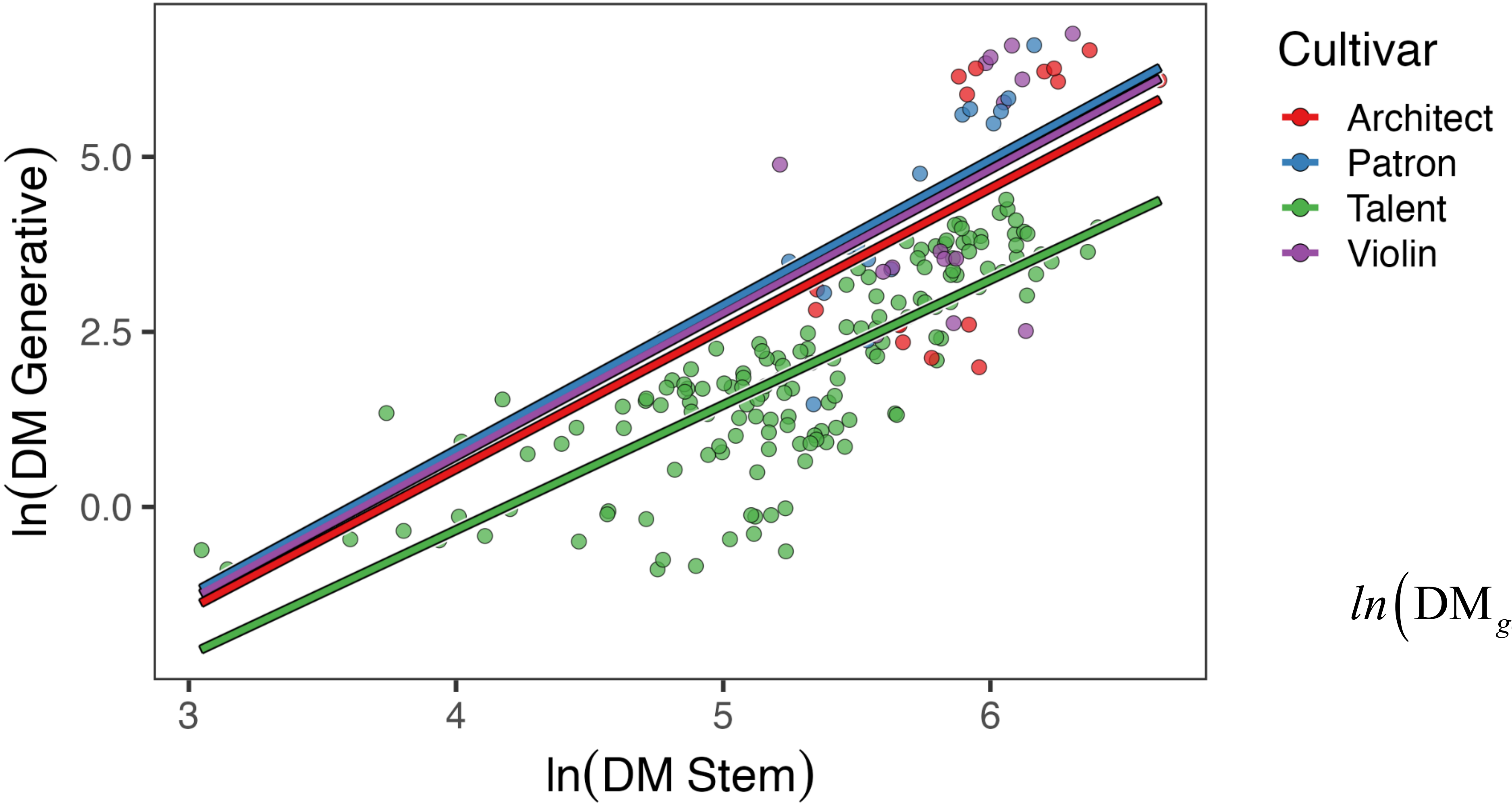
Old Hybrid „Talent“:
„More Leafy“

$$ln\left(DM_{Stem}\right)=g\times \ln\left(DM_{Leaf}\right)+h$$

$$\frac{DM_{Leaf}}{dt}=\frac{DM_{shoot}}{dt}\frac{1}{\left(1+e^{h}*g*DM_{Leaf}^{(g-1)}\right)}$$

See also: Weymann, W., Sieling, K., Kage, H., 2017. Organ-specific approaches describing crop growth of winter oilseed rape under optimal and N-limited conditions. Eur. J. Agron. 82, 71–79. https://doi.org/10.1016/j.eja.2016.10.005.

Allometric relationship between generative organs (pod + seed) and stem biomass



Old Hybrid „Talent“:
„lower harvest index“

$$ln\left(DM_{gen}\right)=a\times \ln\left(DM_{Leaf}\right)+b$$

$$\frac{DM_{stem}}{dt}=\frac{DM_{shoot}}{dt}\frac{1}{\left(1+e^{b}*a*DM_{Stem}^{(a-1)}\right)}$$

HUME-OSR:

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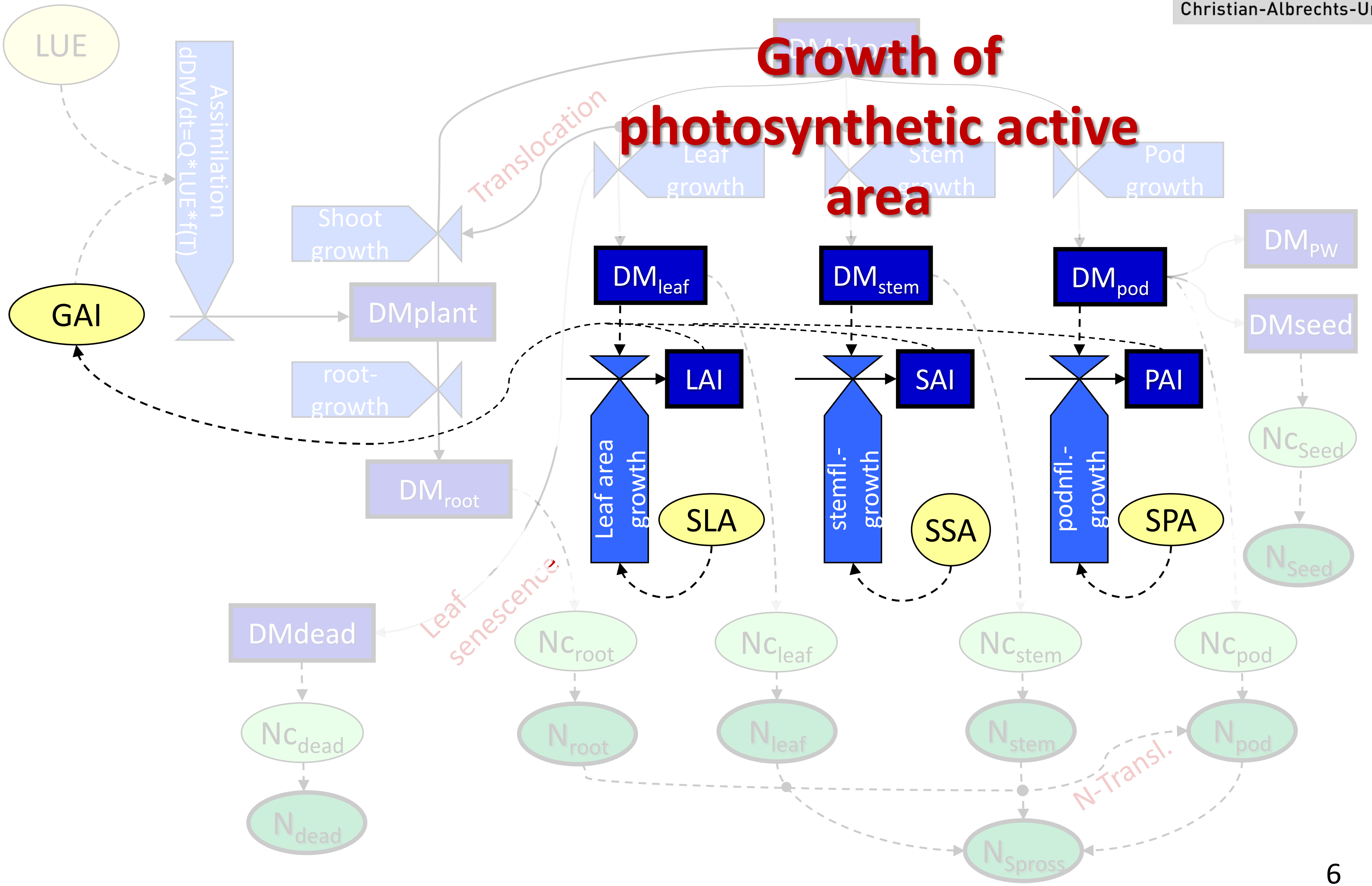
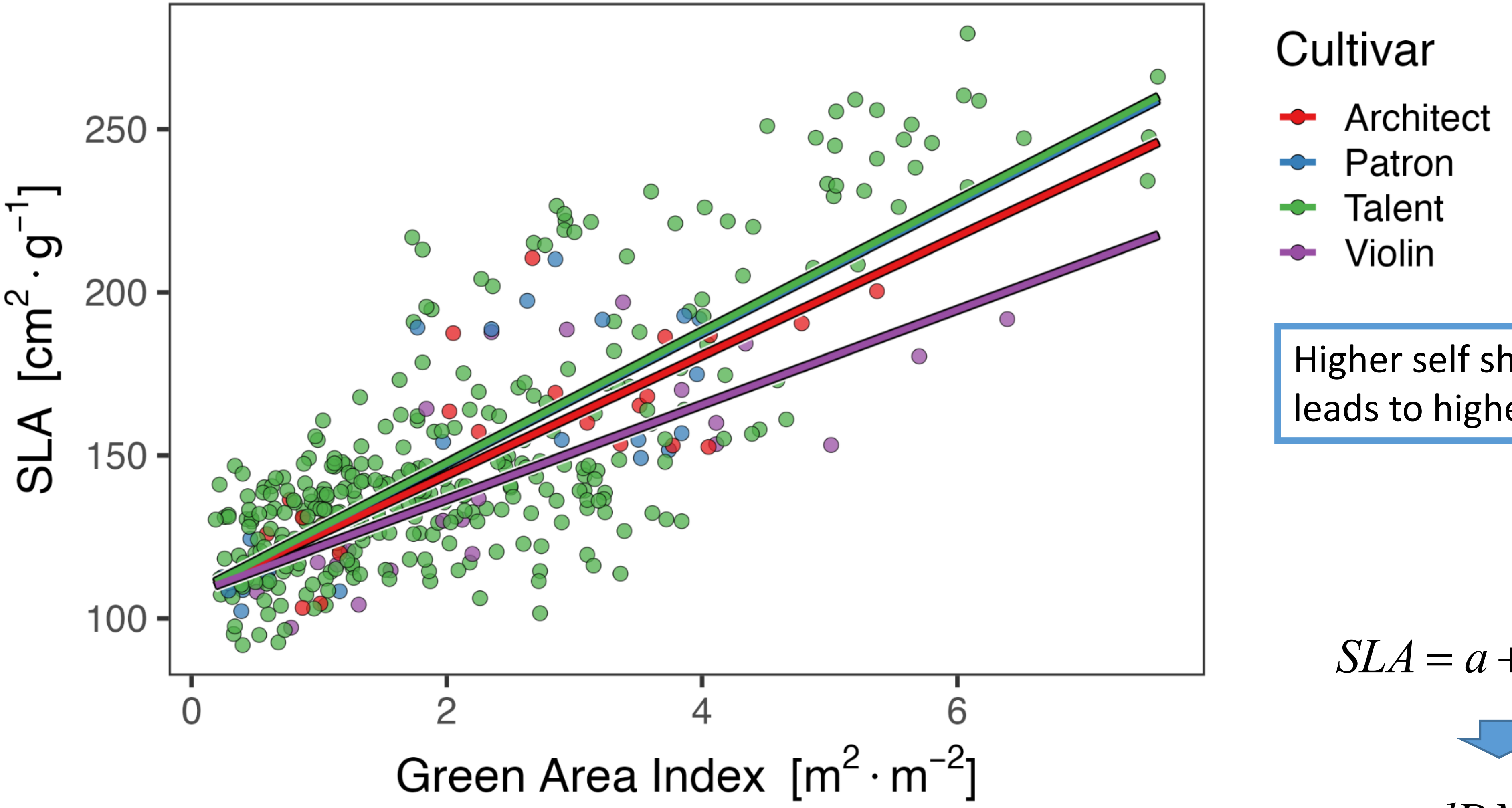
Growth of photosynthetic active area



Specific leaf area as a function of green area index for spring leaf area formation



Higher self shading leads to higher SLA for Talent

$$SLA = a + b \cdot GAI$$

$$\frac{dLAI}{dt} = SLA \frac{dDM_{leaf}}{dt} + DM_{leaf} \frac{dSLA}{dt}$$

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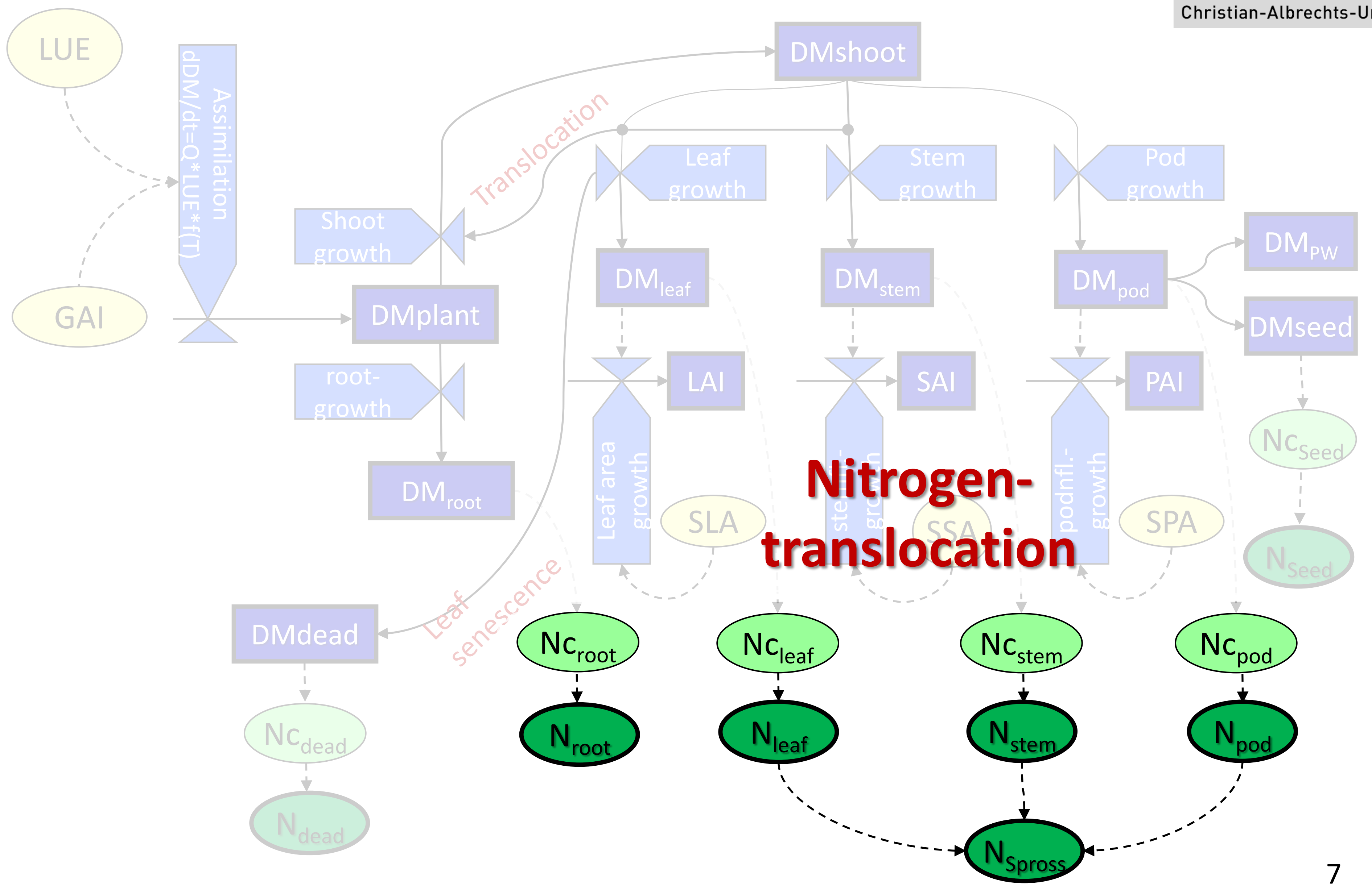

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Stem N concentration as a function of stem DM

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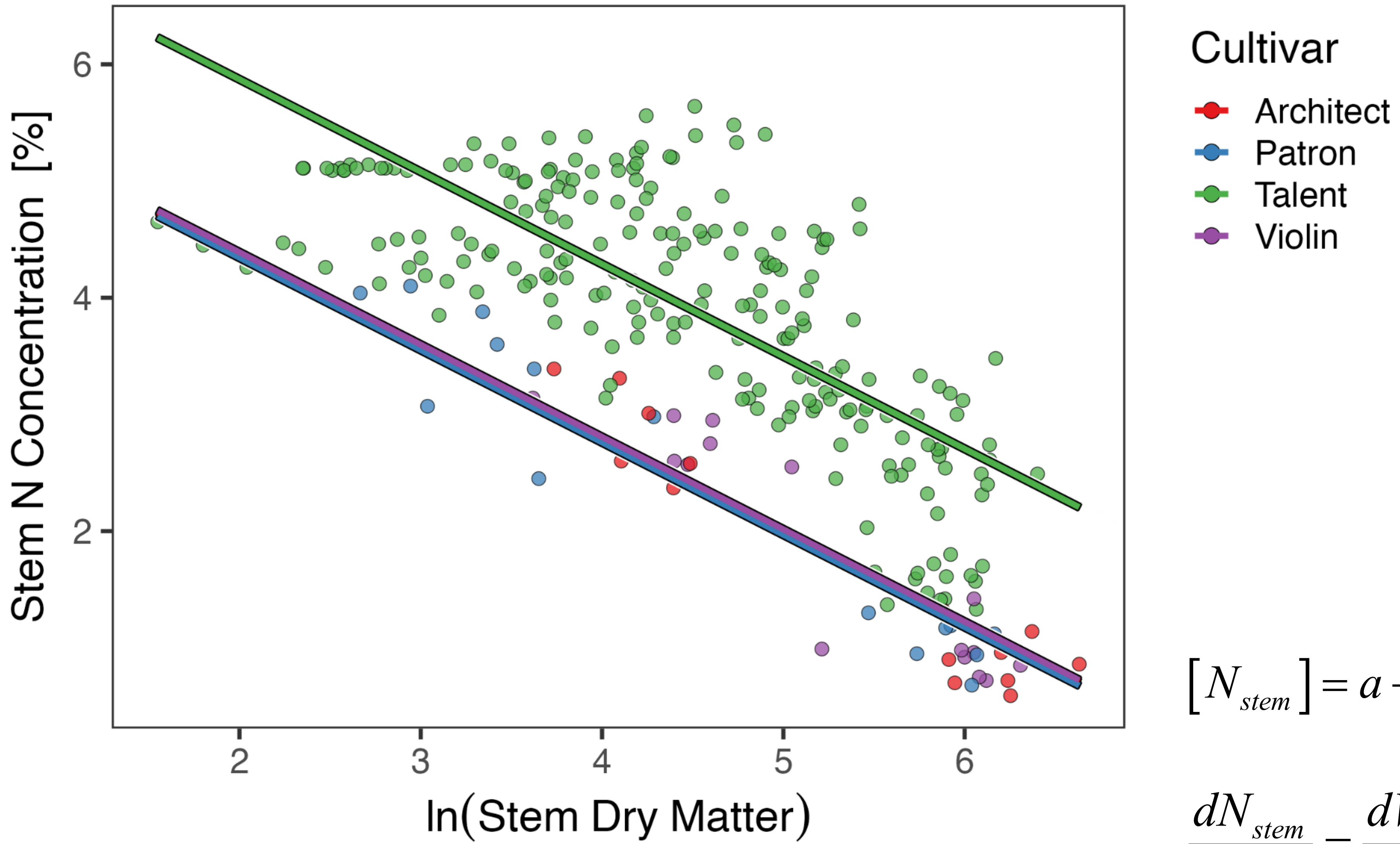

Old Hybrid „Talent“: „higher [N_{stem}]“

$$[N_{stem}] = a + b \cdot \ln(DM_{stem})$$

$$\frac{dN_{stem}}{dt} = \frac{dW_{shoot}}{dt}\left(a + b\ln(W) + b\right)$$

Leaf nitrogen concentration during spring growth

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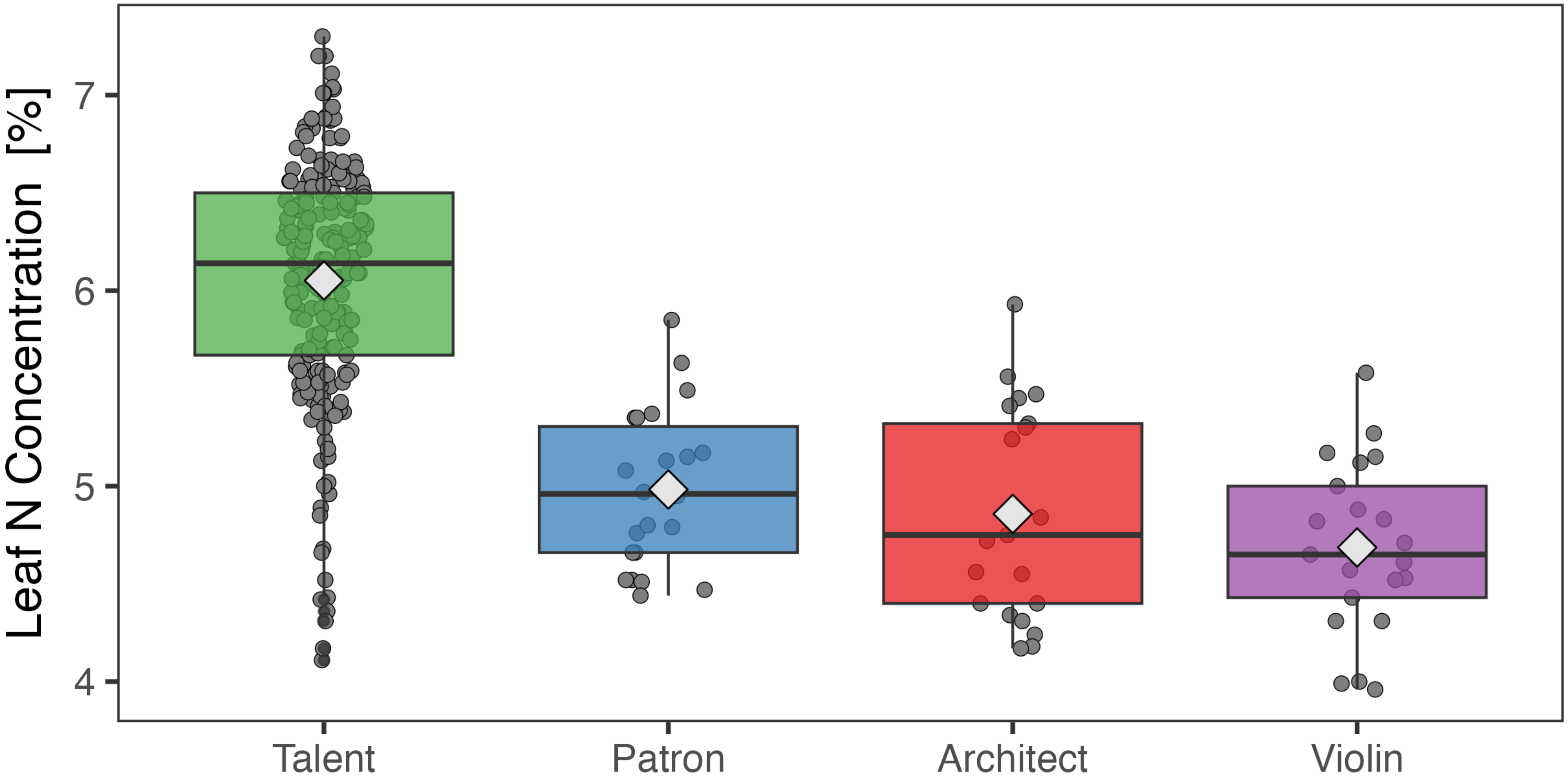

Genotype-Specific-Parameters

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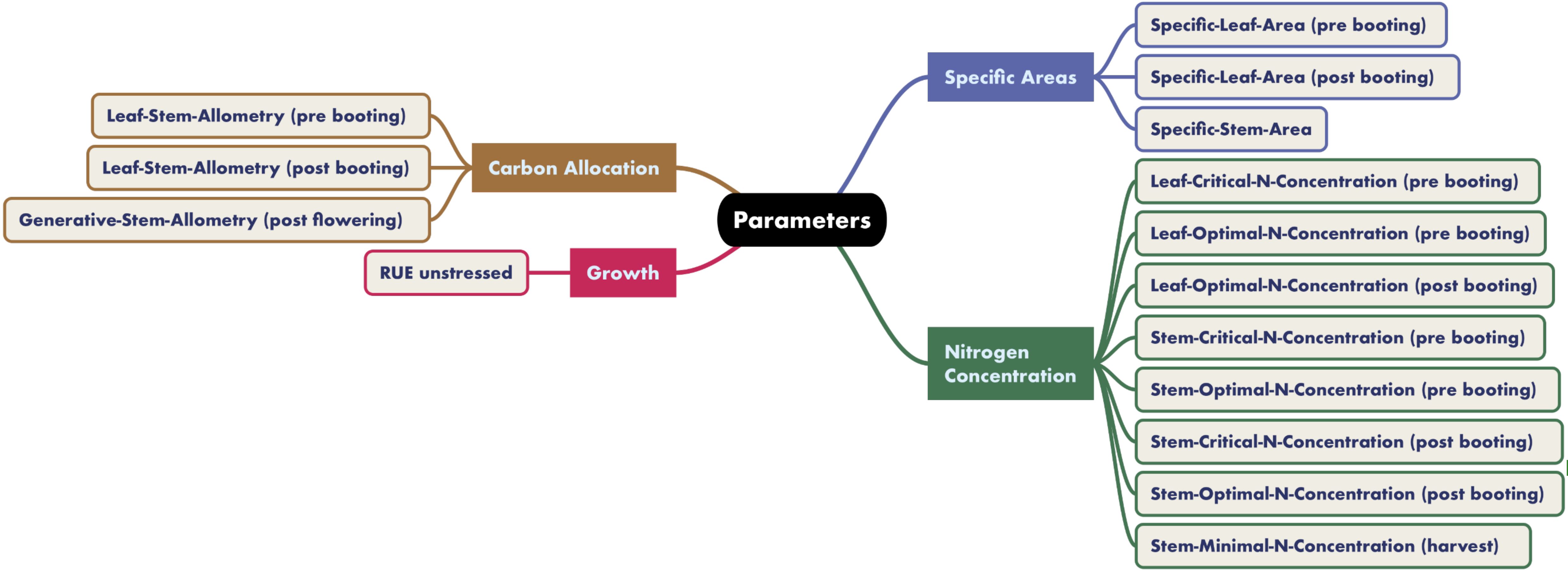
- In total 15 model parameters were genotypic specifically estimated
- Significant effect of genotype as condition



Evaluation of genotypic parameterisation HUME-OSR

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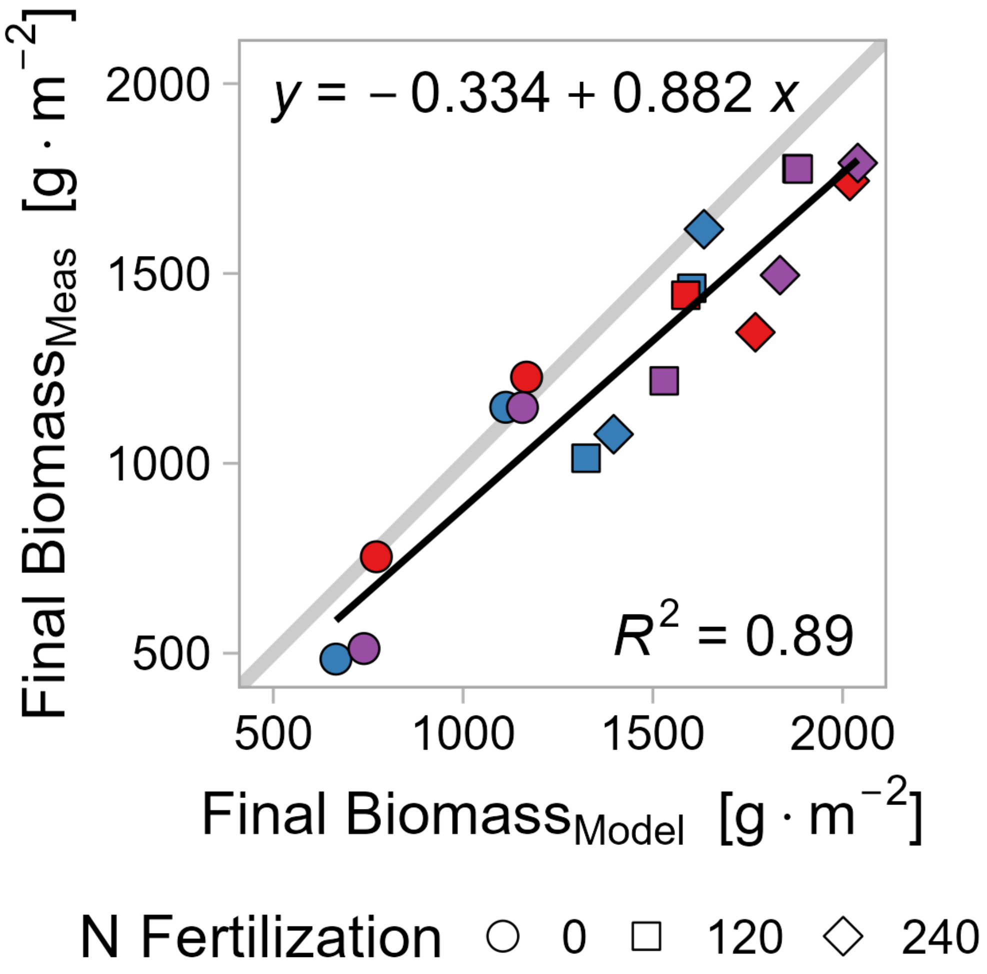

Evaluation of genotypic parameterisation HUME-OSR

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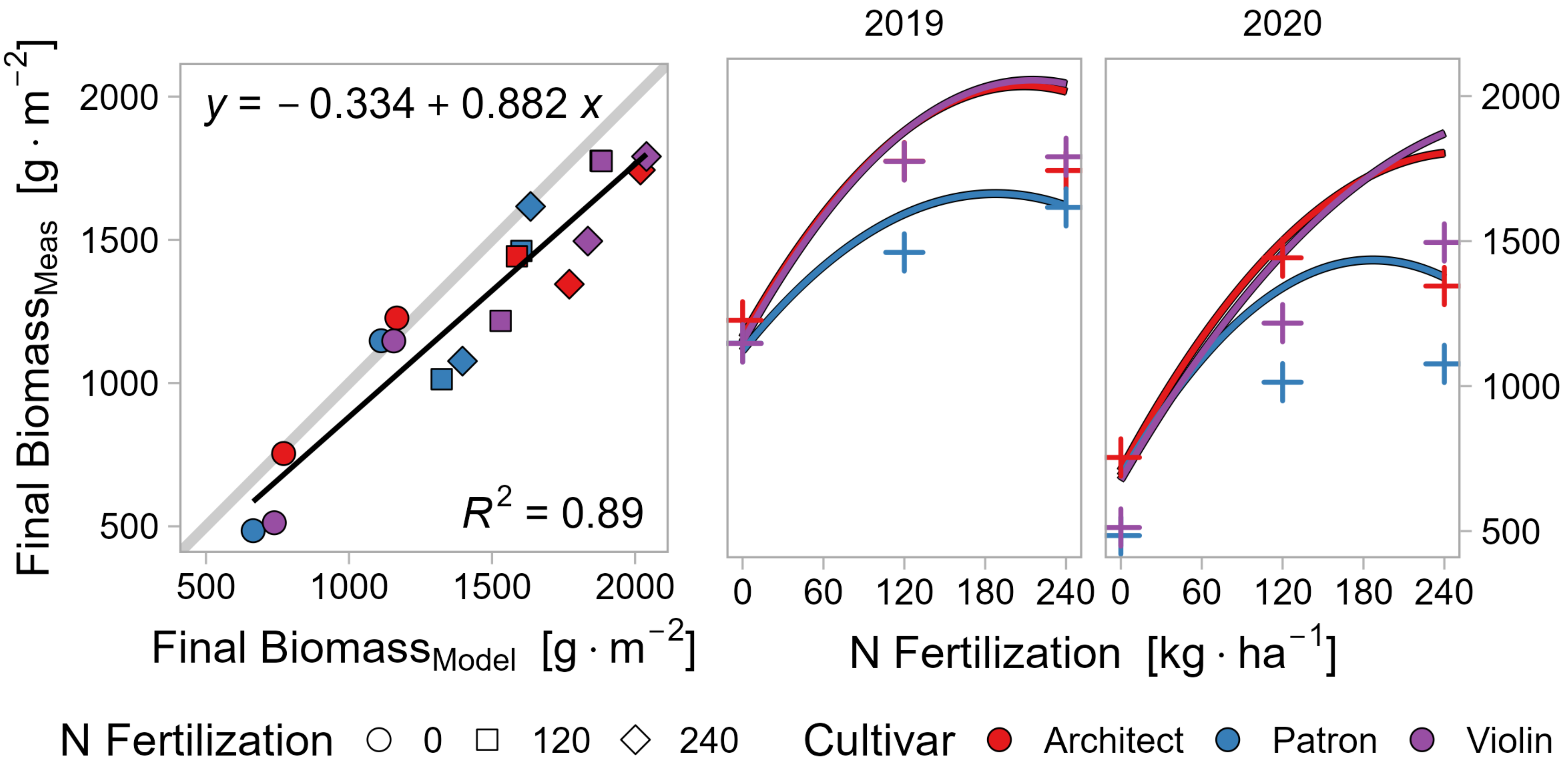
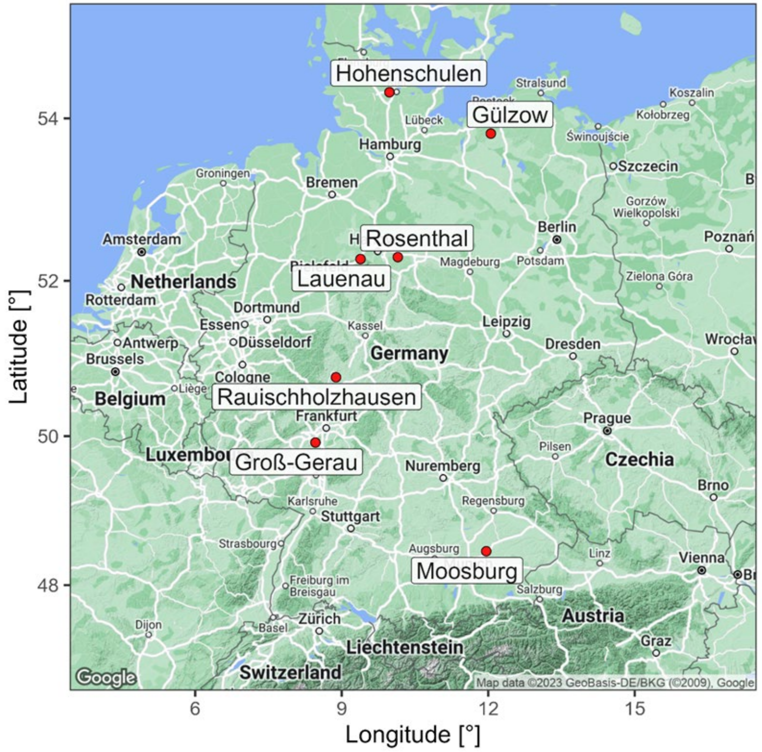


Scenario analysis

- **Sites**
  - 7
- **Weather data**
  - German weather service
  - 1992-2022
- **Soil data**
  - German soil data base BUEK5000
- **Initialisation**
  - Soil water contents: from previous simulation
  - Soil N & C: each year the same



Simulated green area index
by genotypic parameterised crop growth model HUME-OSR

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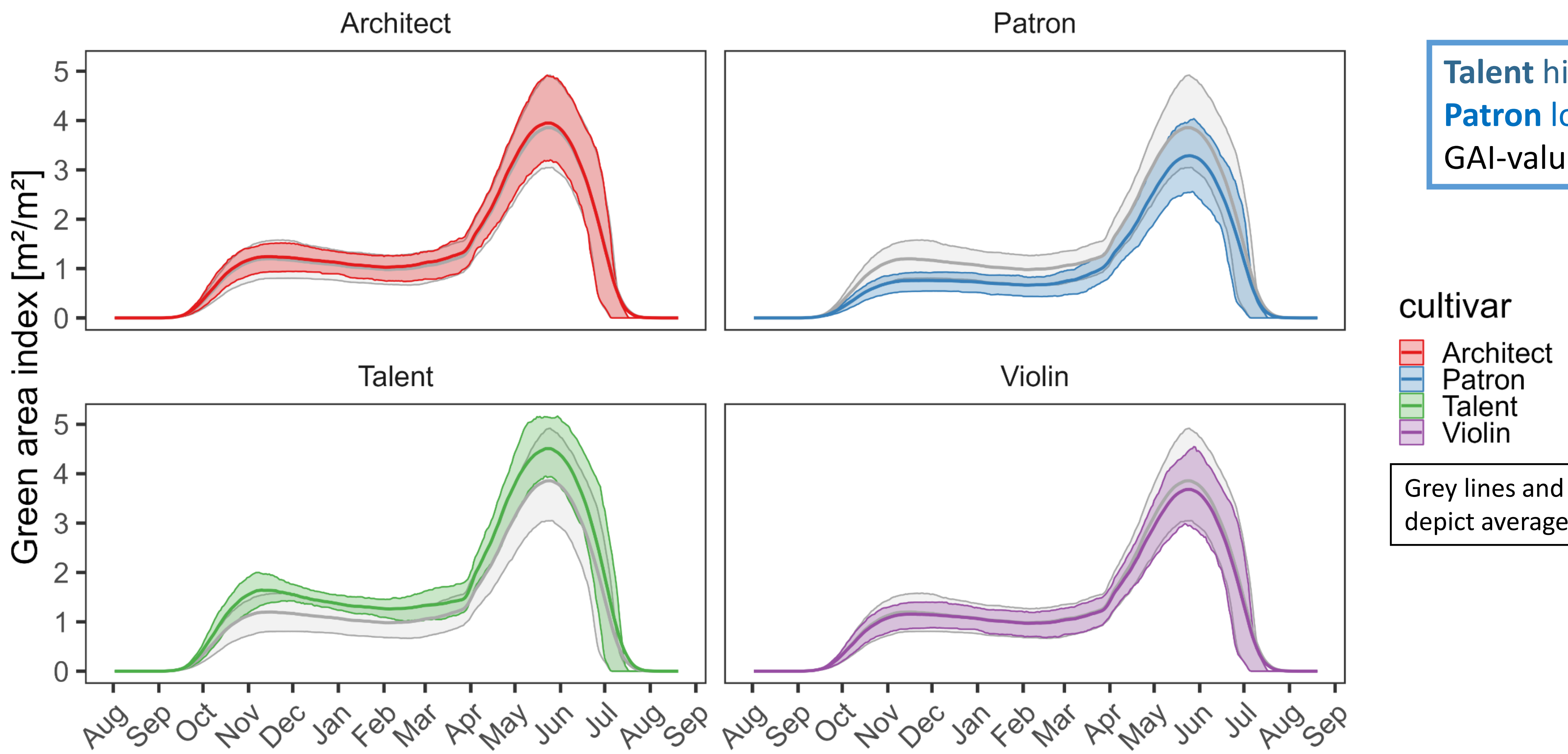
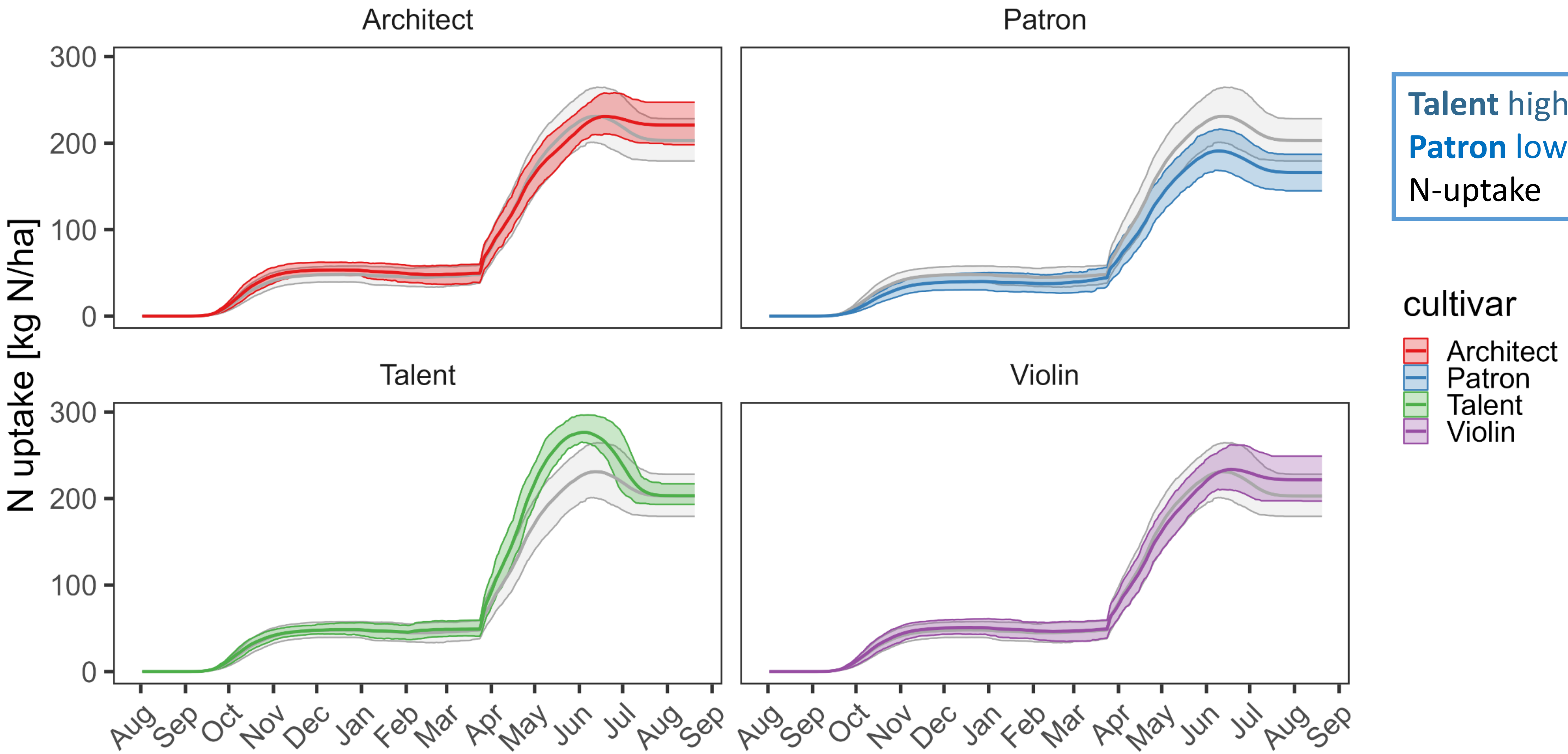


Talent highest
Patron lowest
GAI-values

Grey lines and area depict average over cultivars

Simulated nitrogen uptake
by genotypic parameterised crop growth model HUME-OSR



Talent highest
Patron lowest
N-uptake

Simulated nitrogen partitioning
by genotypic parameterised crop growth model HUME-OSR

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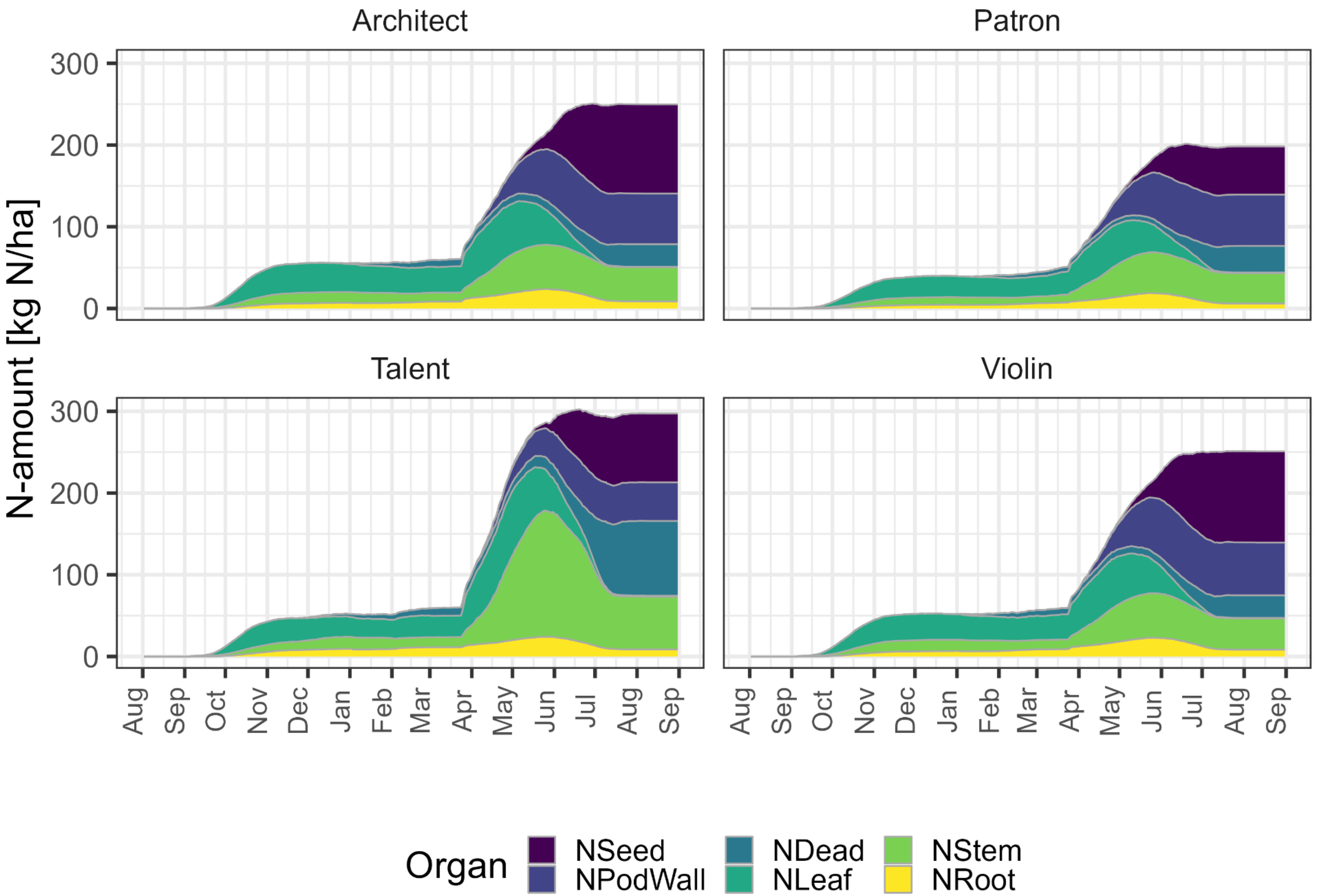

Old cultivar Talent:

- Highest N-uptake
- High Leaf-N loss
- High N-amounts in stem

Simulated N response of seed yield
by cultivar specific parameterised model HUME-OSR

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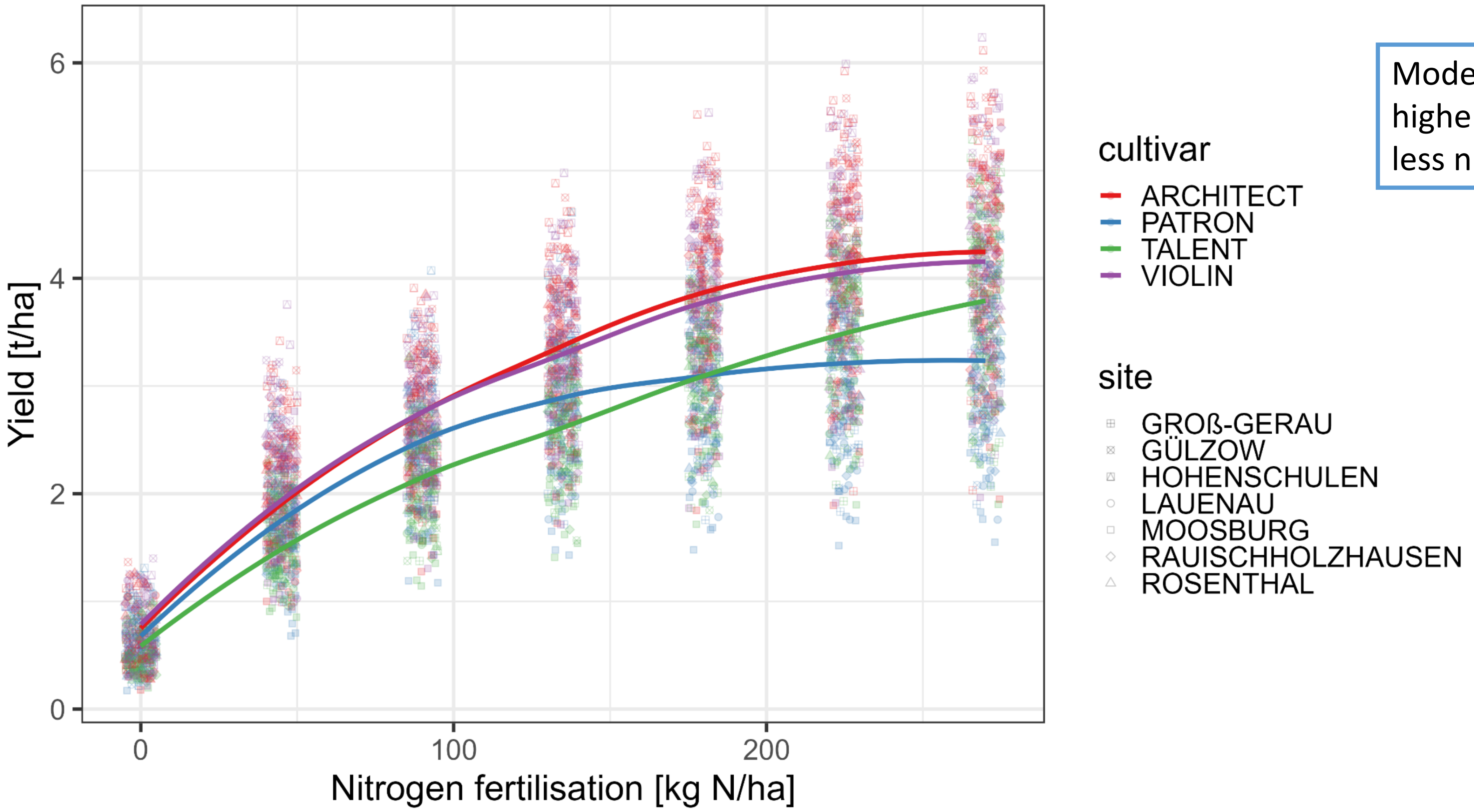

Modern hybrids: higher yields with less nitrogen!

Indicators for GHG efficiency

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- ***Yield scaled emissions***

$$\frac{Emissions}{Yield}$$

- ***Unit: t CO_2-eq. / t seed yield***

- ***GHG-balance***

$$+\left(Energy\,yield \cdot Emissions_{fossile\,fuel}\right)$$
$$-\left(Emissions \cdot Allocation\,factor\right)$$

- ***Unit: t CO_2-eq. / ha***

Calculation aproach: BioGrace 1 & 2 (+ updated Parameters, 3469 gCO_{2eq}/kg N production)

Simulated N response of yield scaled GHG-emissions
by cultivar specific parameterised model HUME-OSR

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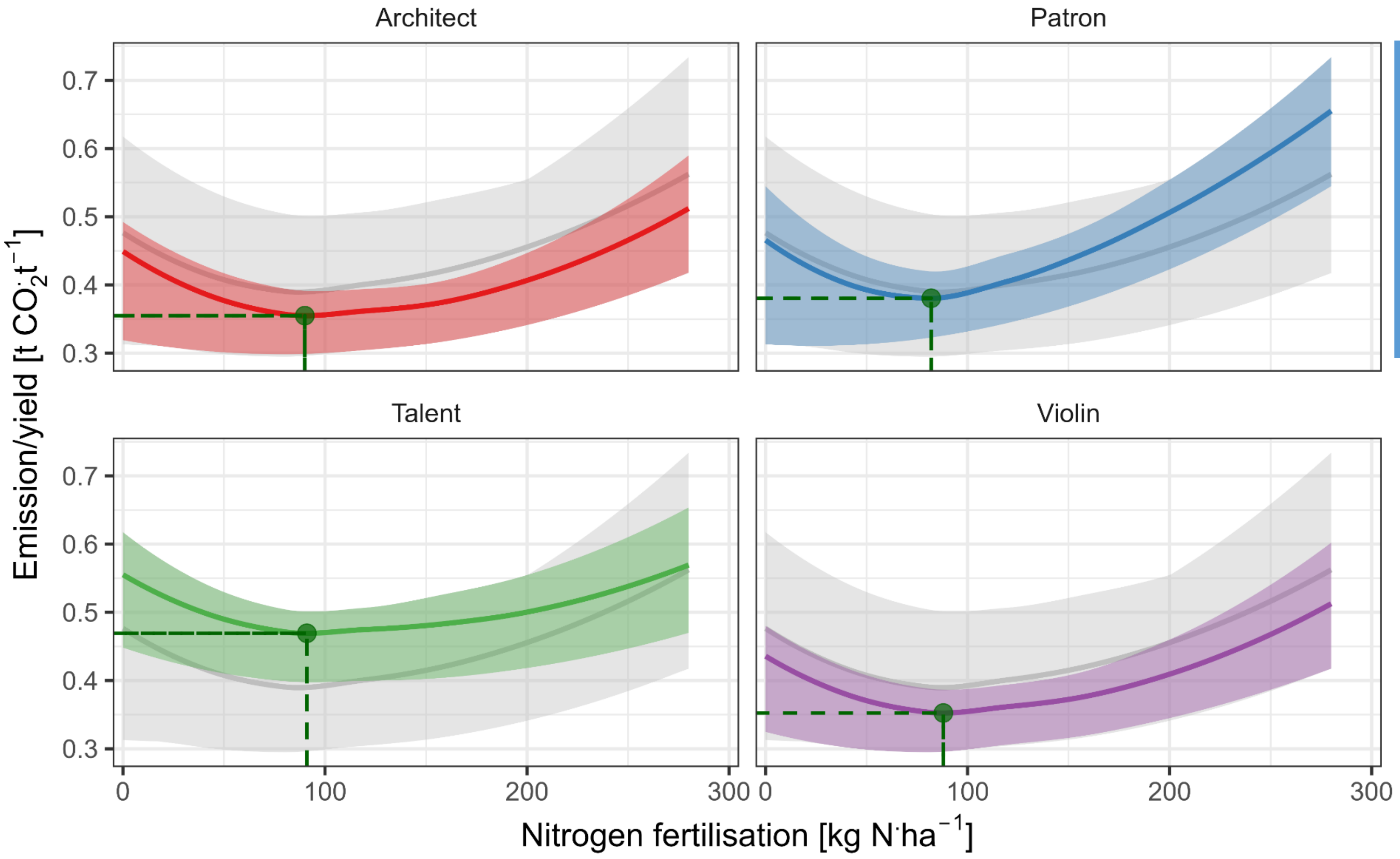

Band describes 50% Confidence intervall, linie is mean

- Minima of yield scaled emissions at relatively low N rates (< 100 kg N/ha)
- Modern hybrid cultivars (Architect, Violin) have lowest values

Simulated N response of GHG-saving per area (GHG balance)
by cultivar specific parameterised model HUME-OSR

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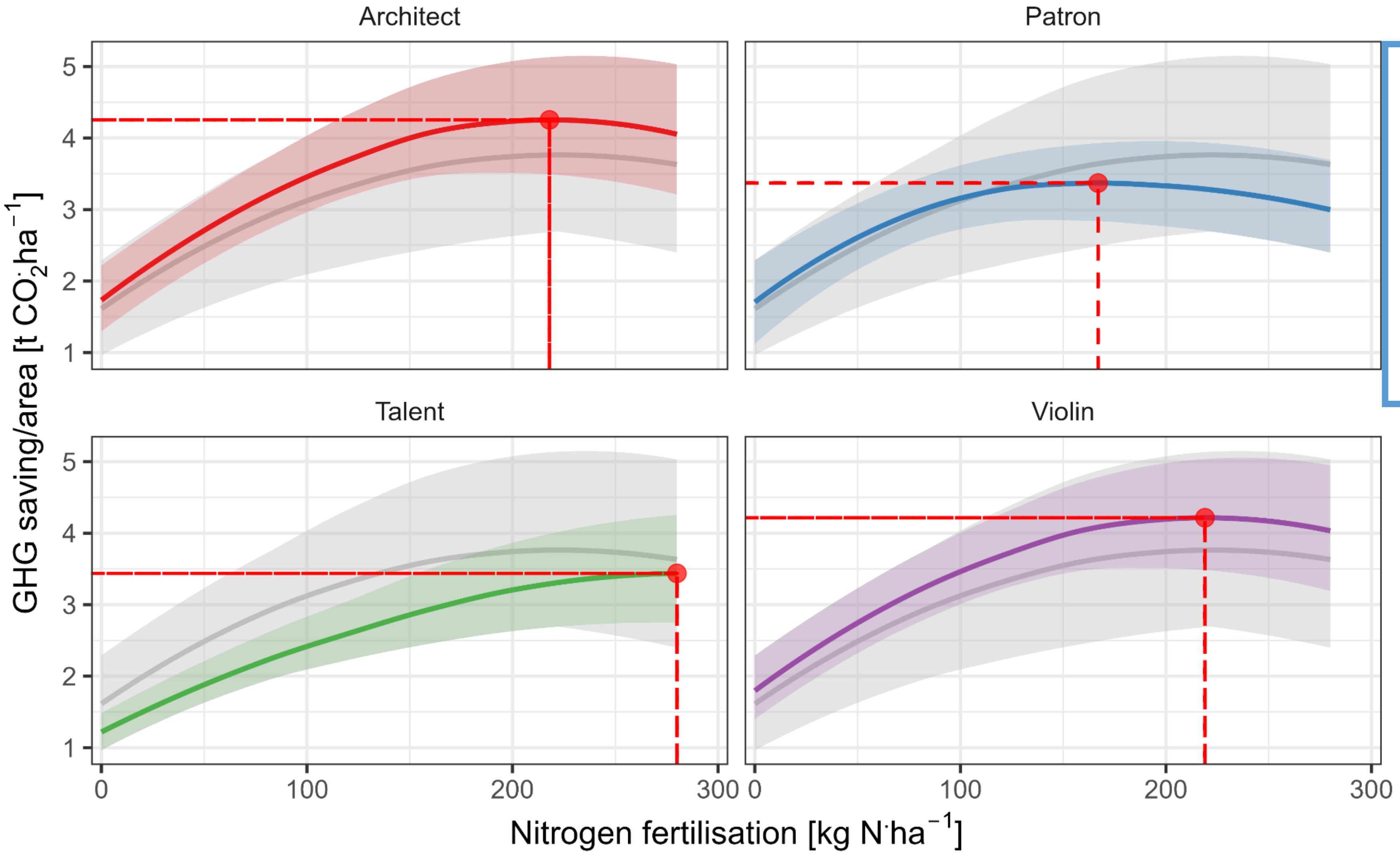

Band describes 50% Confidence intervall, linie is mean

- Ranking of cultivars similar as for yield scaled emissions
- Maxima much higher as Minima for yield scaled emissions

Simulated N response of nitrate leaching
by cultivar specific parameterised model HUME-OSR

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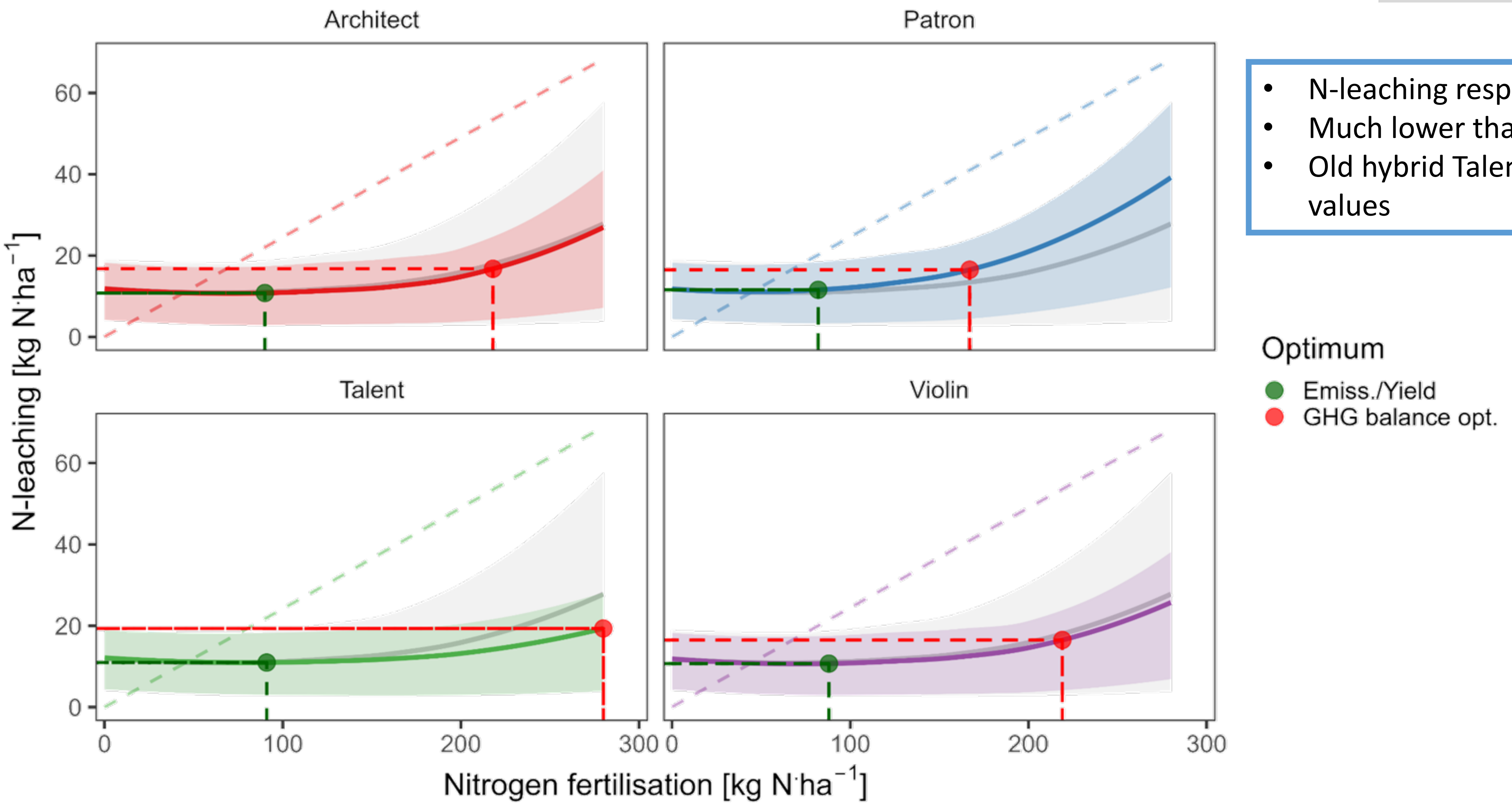

Band describes 50% Confidence intervall, linie is mean, dotted line is IPCC estimate

- N-leaching responds non-linear
- Much lower than IPCC estimate
- Old hybrid Talent with lowest values

Simulated N response of direct N_2O-emissions
by cultivar specific parameterised model HUME-OSR

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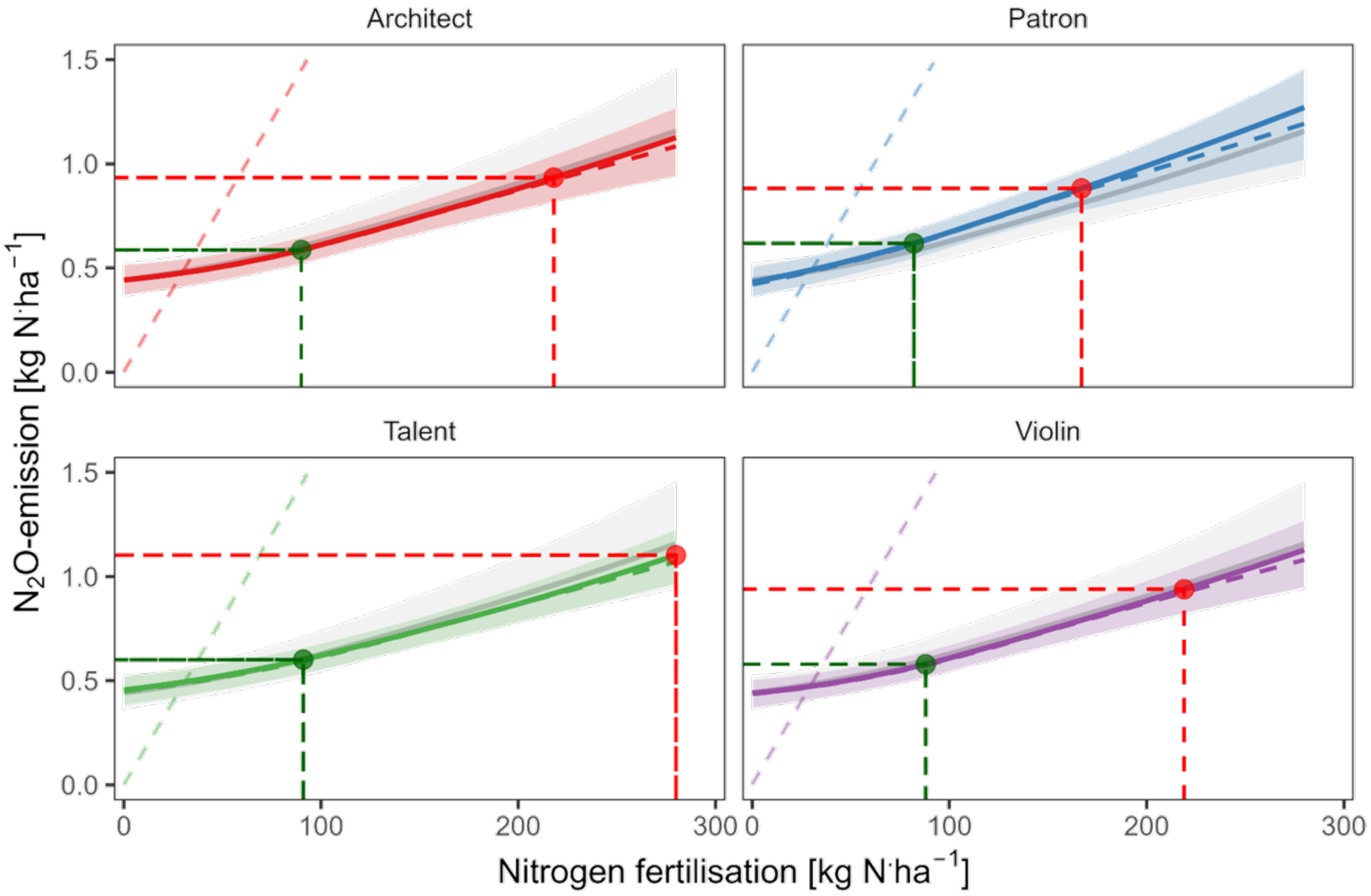

Band describes 50% Confidence intervall, linie is mean, dotted line the IPCC estimate

- Direct N_2O emissions respond more linear
- Much lower than IPCC estimate
- Minor differences between cultivars

Summary/Conclusions

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- **Modern Hybrid cultivars**
  - More N-Efficient
    - Less GHG emissions per unit yield
    - Higher GHG savings per hectare
  - Mechanisms
    - Higher radiation use efficiency (complex trait)
    - Better DM and N allocation
      - Increased N-Harvest index
      - Less leafy
      - N in crop residues is not the problem but N is better invested into seed
    - ***Higher yield potential!***
- **Optimum N intensity**
  - Relatively high for indicator GHG balance
  - Clearly below Ag practice for yield related emissions

Summary/Conclusions

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- **Cultivar specific parameterisation of Crop Growth Model**
  - Feasible, but only for limited number of cultivars
    - Allometric approach of HUME-OSR helpful
    - Failed for NAM population (for several reasons)
  - Trait variation in cultivars originally used for the project was relatively low
  - Opens new avenues for understanding trait effects
- **Remote sensing**
  - Was helpful (RUE estimate)
  - Potential not yet fully exploited
- **What to do better?**
  - Better selection for trait variation in genotypes
  - More focussed approach

Thank you for your interest

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Model Low N

NPZ INNOVATION
Wir forschen für Qualität.

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

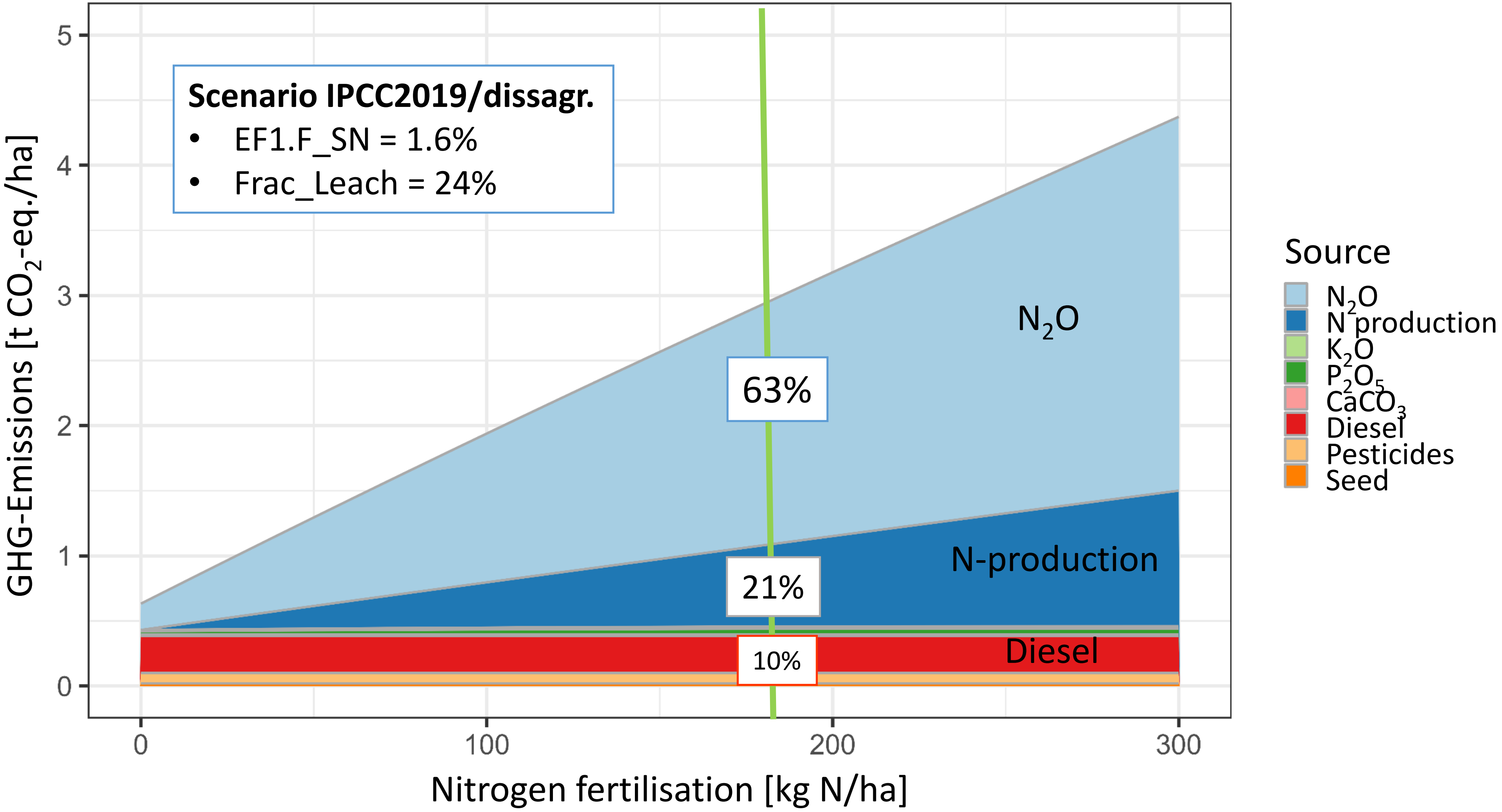
Thanks to the team of ModelLowN
Amine Abadi, Stefan Abel, Reinhard Hemker, Andreas Stahl, Rod Snowdon, Sven Weber, Lennard Ehrig, Milka Malenica, Katrin Beckmann, Björn Reddersen and others.

Funding:

Bundesministerium für Ernährung und Landwirtschaft

Composition of GHG emission in oilseed rape production

as a function of nitrogen fertilisation



According to IPCC2019, dissaggr./BioGrace, Rapeseed production

Components of NUE_{ag}

$$NUE_{ag} = \frac{Y}{N_f} = \frac{N_s}{N_f} \cdot \frac{N_u}{N_s} \cdot \frac{N_y}{N_u} \cdot \frac{Y}{N_y}$$

Agronomic NUE (Y/N_f) =

N_s/N_f (Soil fertility/N transformation efficiency) *

N_u/N_s (N uptake efficiency) *

N_y/N_u (N harvest index) *

Y/N_y ($1/[N]_{seed}$)

N supply (Ns), N uptake (Nu), N yield (Ny), yield (Y)

Adapted from Huggins & Pan (1993)

Genotype effects on NUE

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N Efficiency component	Genotype specific traits	Alternative measures
• N_s/N_f • Soil fertility/ N transformation efficiency)	• Only indirect effects	• Crop rotation • Efficient fertilisers • Adopted tillage
• N_u/N_s • (N uptake efficiency)	• Morphological and physiological root parameters • Phenology/Harvest date • Vigorous vegetative growth	• Precice N rates • Reducing N losses • (Irrigation)
• N_y/N_u • (N harvest index)	• N-translocation efficiency	• Precice N rates
• Y/N_y • $(1/[N]_{seed})$	• Low protein concentration	• Precice N rates