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CROP SCIENCE

High throughput phenotyping to improve genetic gain in wheat – prospects and challenges

March 9th 2023

PD Dr. Andreas Hund and Olivia Zumsteg

Outline

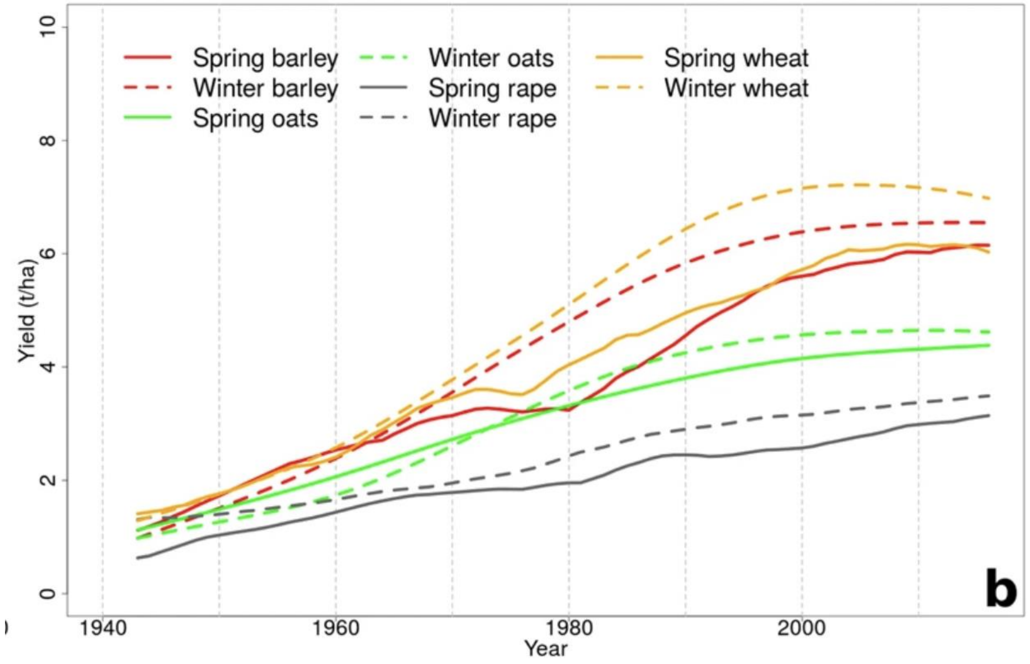
Motivation

Stagnating wheat yield

Increasing global food demand and climate change impacts

Phenotypic and genomic prediction methods could help to cope with this challenge

Stagnating wheat yield in France



(Bernhard Schauberger et al. (2018). Yield trends, variability and stagnation analysis of major crops in France over more than a century)

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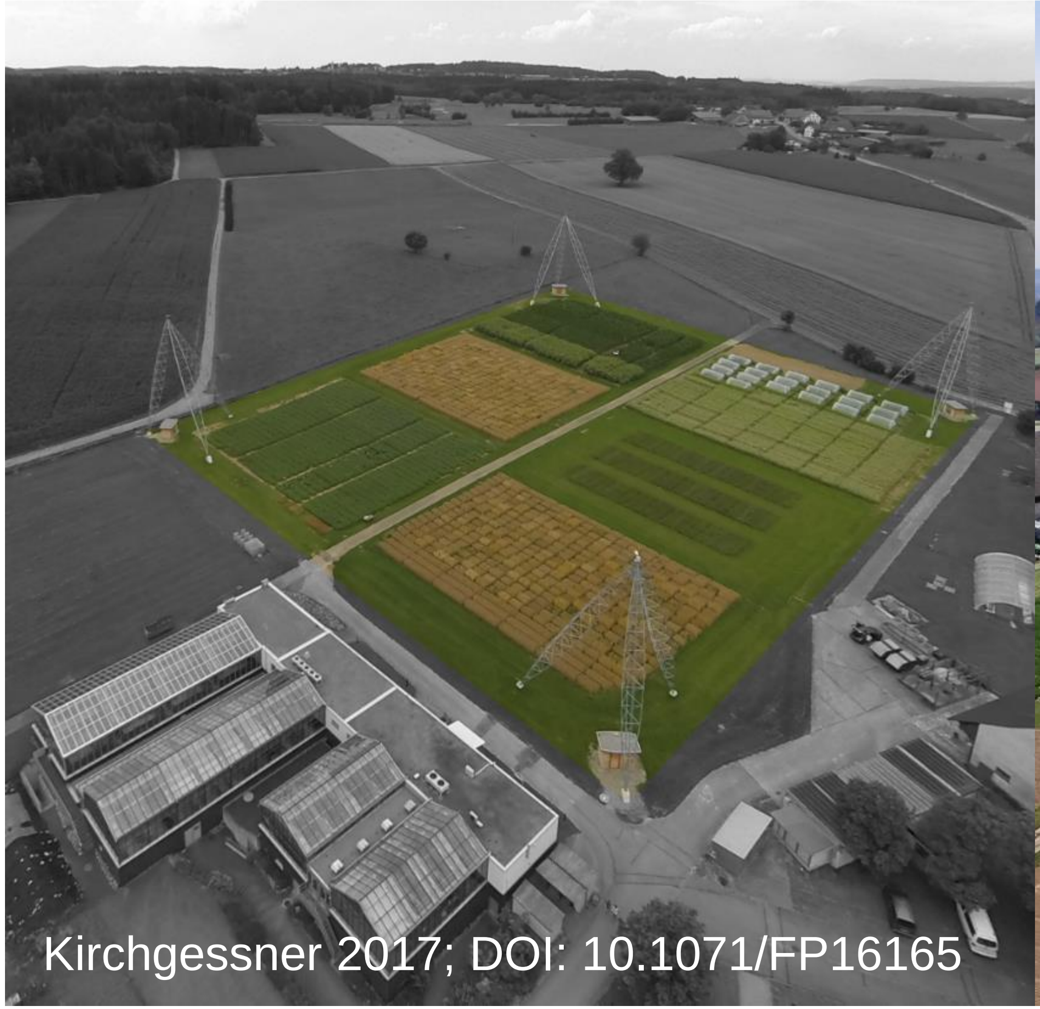
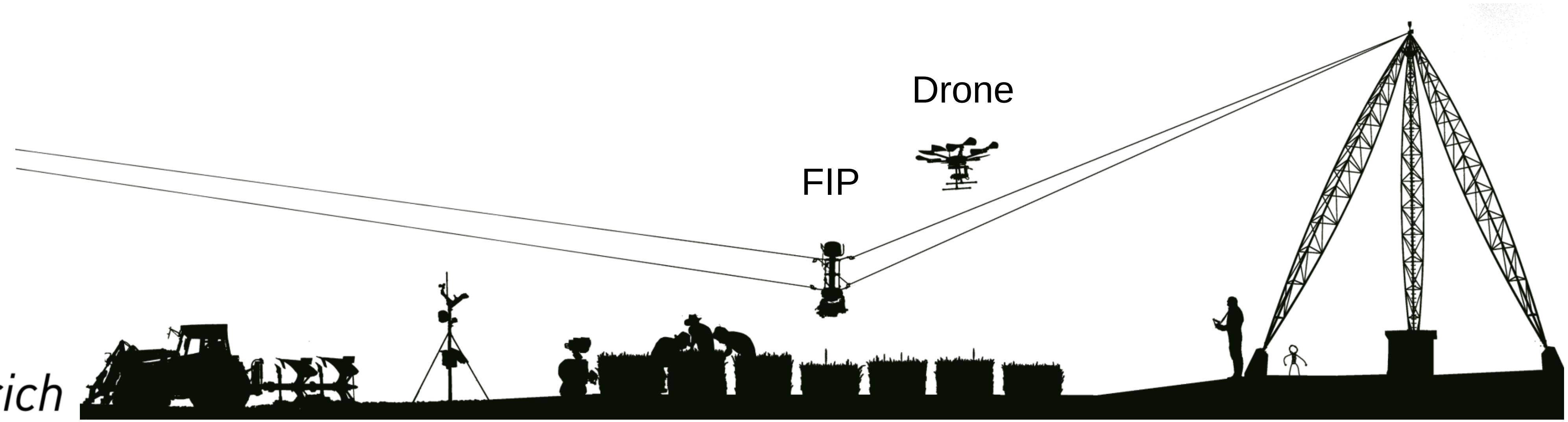
1) Research Site and High Throughput Phenotyping



Hight Throughput Phenotyping (HTP)

Possibility to asses crop growth under realistic conditions with high temporal and spatial resolution



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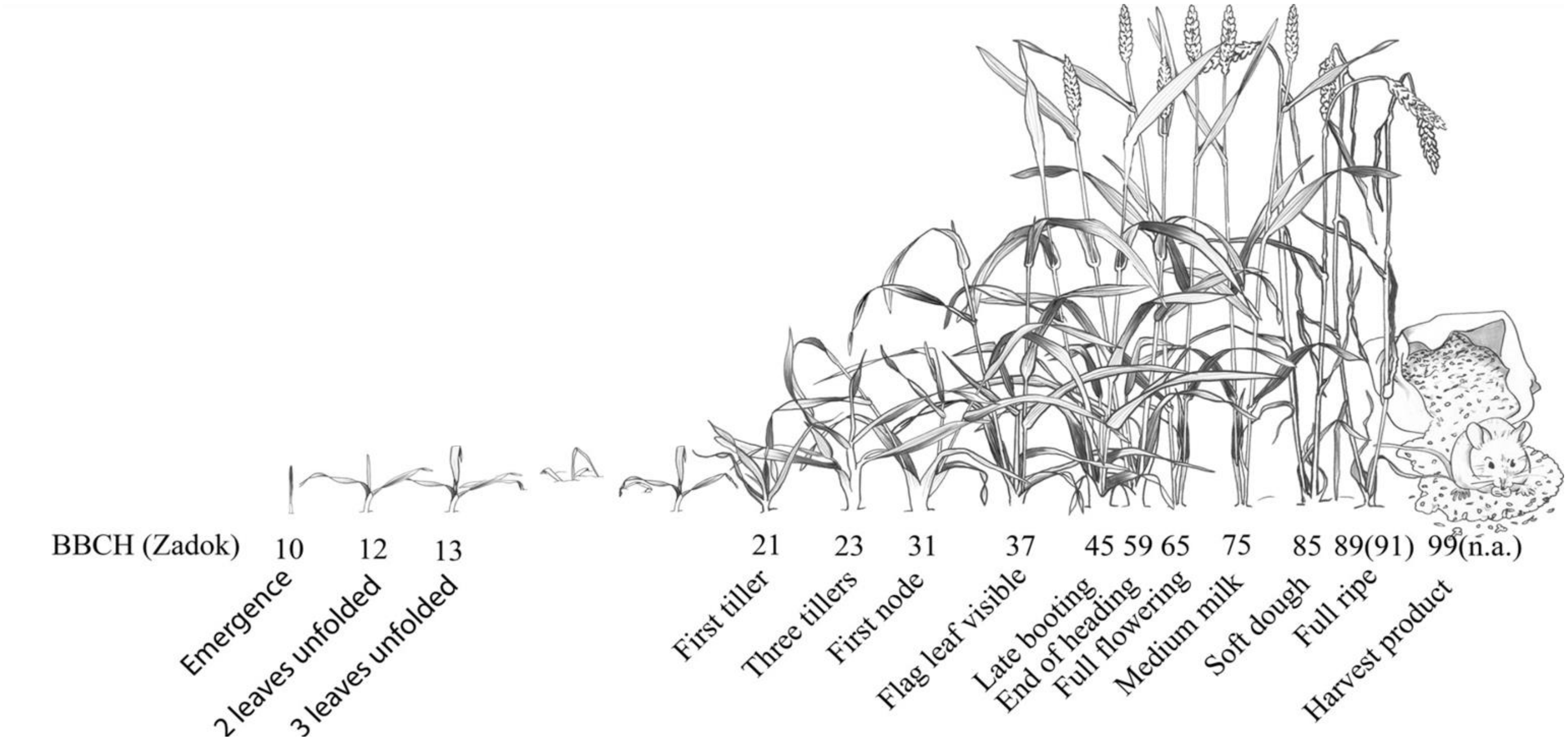
HTP: Drone

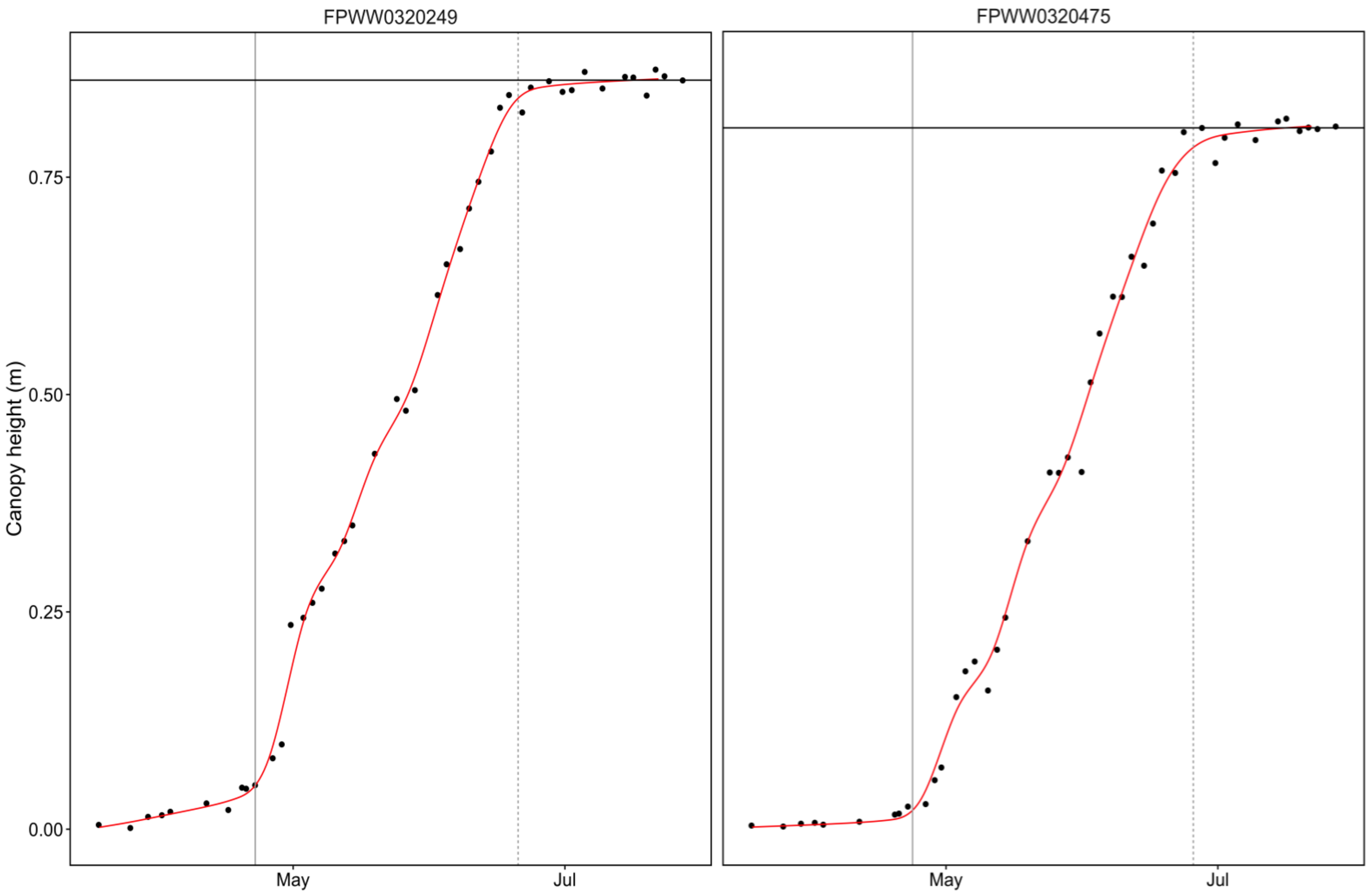
Derived Traits from Drone

Height related traits	Final plant height	
	Start stem elongation	
	Stop stem elongation	
	Temperature response parameters:	Maximum growth rate Steepness ofn response Base Temperature

Crop development: Height



Extraction of Height and Temp. Related Traits



1) Height Related Traits:

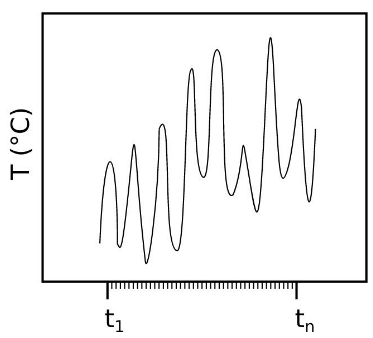
— final height (PH_{max})

start growth phase ($t_{PH_{start}}$)

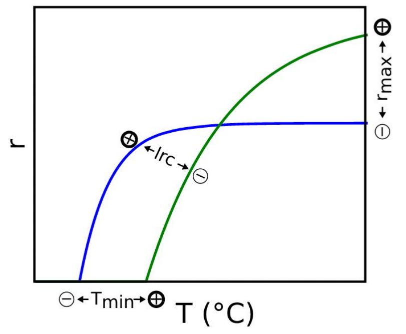
stop growth phase ($t_{PH_{stop}}$)

2) Temp. Related Traits:

(b) Covariate measurement



(c) Dose-response curve



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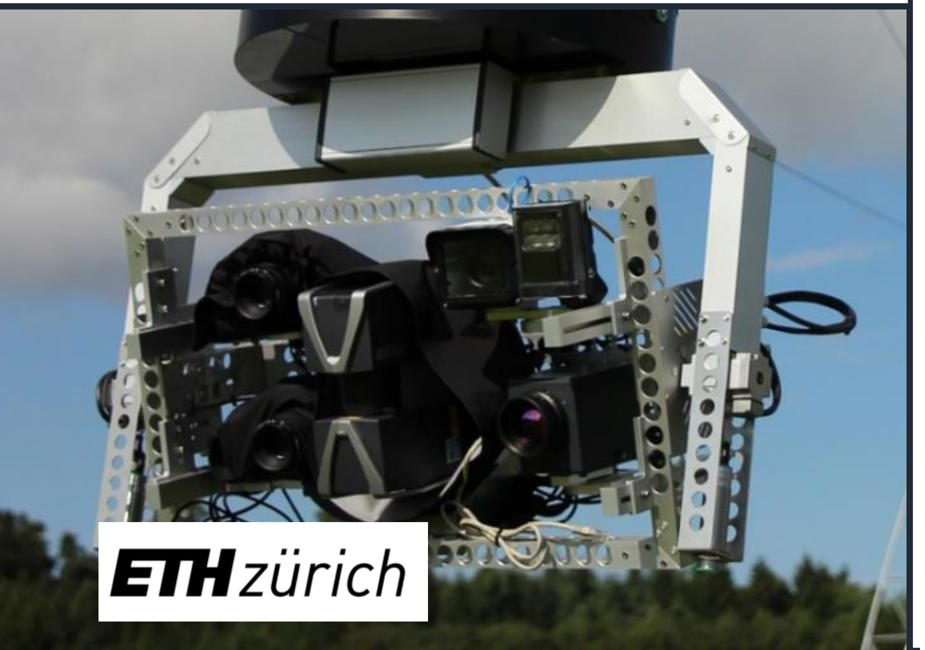
HTFP: Field phenotyping platform (FIP)

- 4 poles of 24 m height
- 4 lots
- Operating on regular basis
- 3 m distance to the ground

Sensor:

- High-resolution RGB images

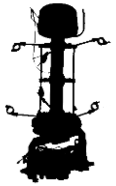


Derived Traits from FIP

Height related traits

- Final plant height
- Start stem elongation
- Stop stem elongation
- Temperature response parameters

Canopy cover related traits



- Time point when apparent leaf area increase is maximized
- Maximum apparent leaf area after canopy closure
- Leaf area at 15 % final height
- Time of canopy closure

HTFP: Field phenotyping platform (FIP)

The new FIP sensor head: Bringing multi-view imaging into the field

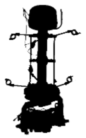
13 machine-vision camera triggered synchronously

Additional Traits to Establish

Height related traits

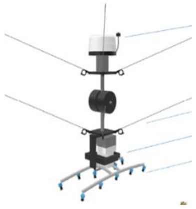
- Final plant height
- Start stem elongation
- Stop stem elongation
- Temperature response parameters

Canopy cover related traits



- Time point when apparent leaf area increase is maximized
- Maximal apparent leaf area after canopy closure
- Leaf area at 15 % final height
- Time of canopy closure

Traits to establish



- Number of plants / tillers and spike volume
- Plant height and biomass
- Architecture

ClimBreed

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Outline

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2.1 Caterra

ETH Pioneer Fellows of Aurel Neff and Patrick Barton

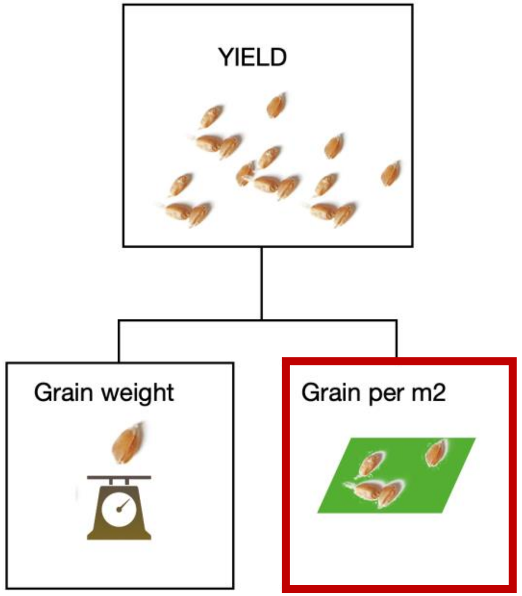
Useful carriers for phenotyping in nurseries?

Laser-based weeding robot

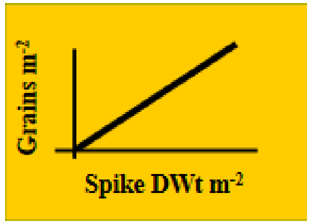
Stefan G. with Literal device

2.2 ClimBreed

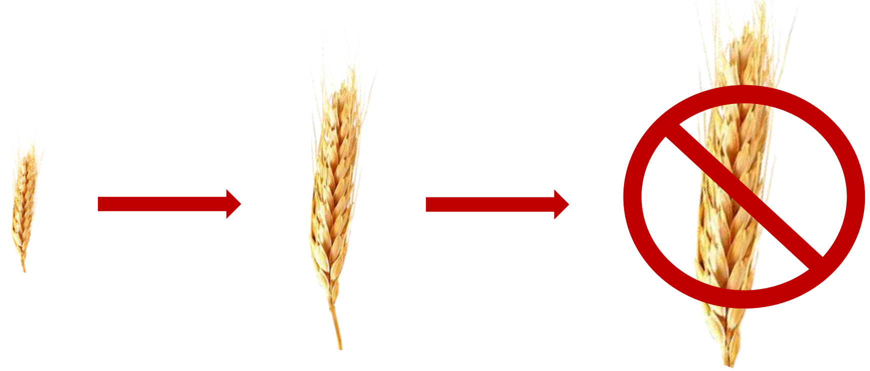
WP1: Estimate Fruiting Potential and Efficiency



Increase in genetic gain related increase in grain number



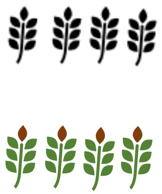
Positive relationship between number of grains and spike weight at flowering



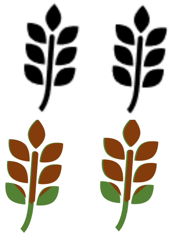
Higher number of grains through increased growth of spikes

Further increase not possible

Fruiting efficiency:
Grains per unit of spike dry weight at anthesis



VS



Same fruiting potential

Different fruiting efficiency

Many small spikes

Few and large spikes

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Slafer et al. (2015) Fruiting efficiency: an alternative trait to further rise wheat yield

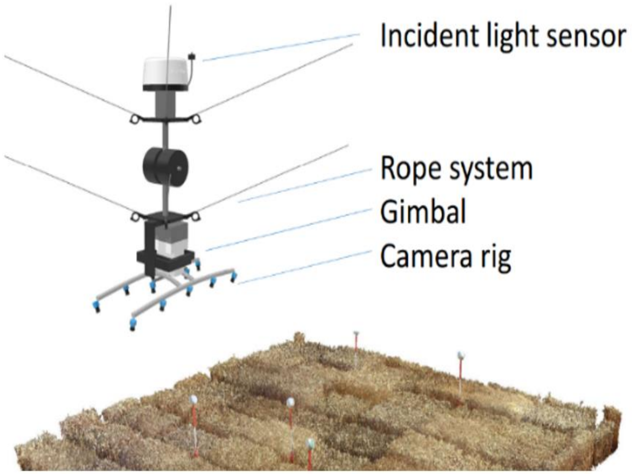
WP1: Measuring Fruiting Potential and Efficiency

Estimating fruiting potential:

 vs 

Number and volume of spikes

Biggest challenge!

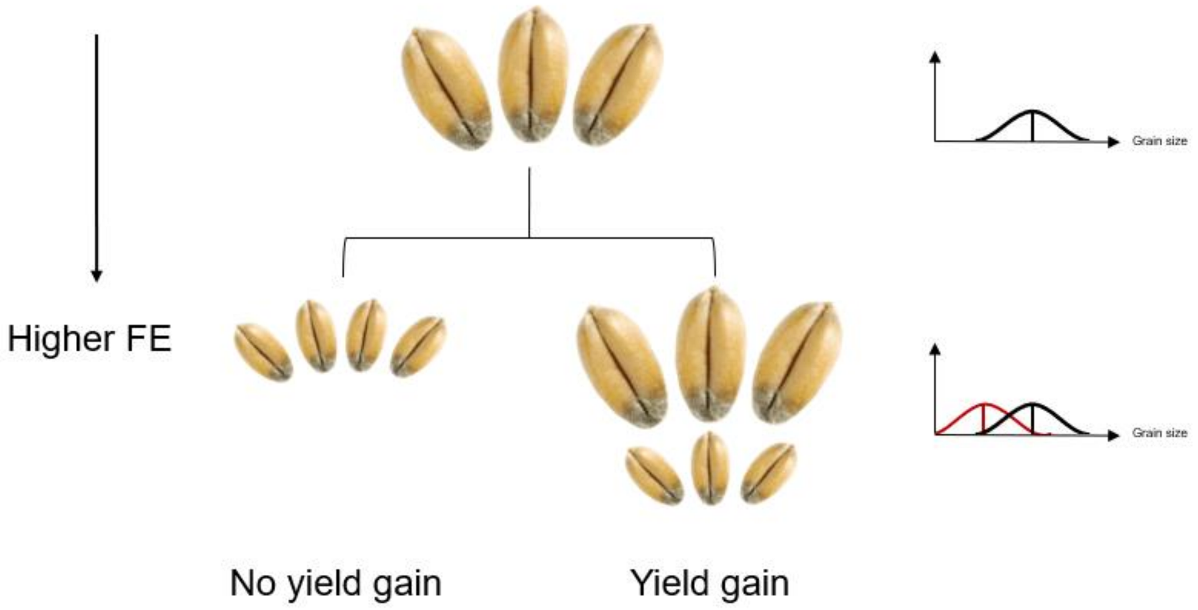


Estimating fruiting efficiency:

 vs 

Grain number

Potential trade-off:

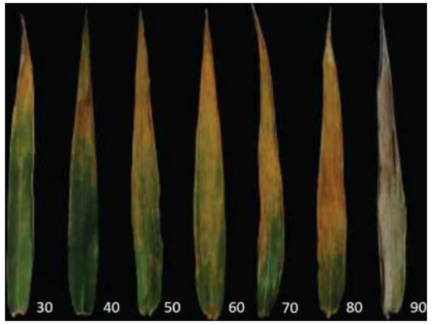


WP2: Traits related to Fruiting Efficiency

Protein content

https://www.indiamart.com/proddetail/wheat-grains-19327420562.html

Senescence



Chapmann et al. (2021) Capturing and Selecting Senescence Variation in Wheat

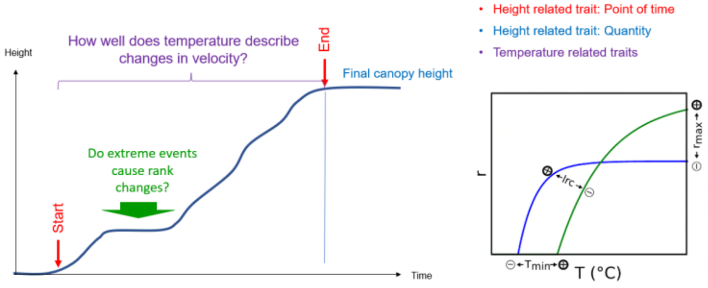
Heading

https://site.extension.uga.edu/wilcoxcoag/2019/03/wheat-heading/

Grain size

https://jasoncholewa.com/2013/02/08/early-humans-wheat-cultivation-and-your-health/

Height and temperature related traits



Lukas Roth et al. (2021) Phenomics data processing: A plot-level model for repeated measurements to extract the timing of key stages and quantities at defined time points, visualized by Andi Hund.

https://www.freepnglogos.com/pics/wheat

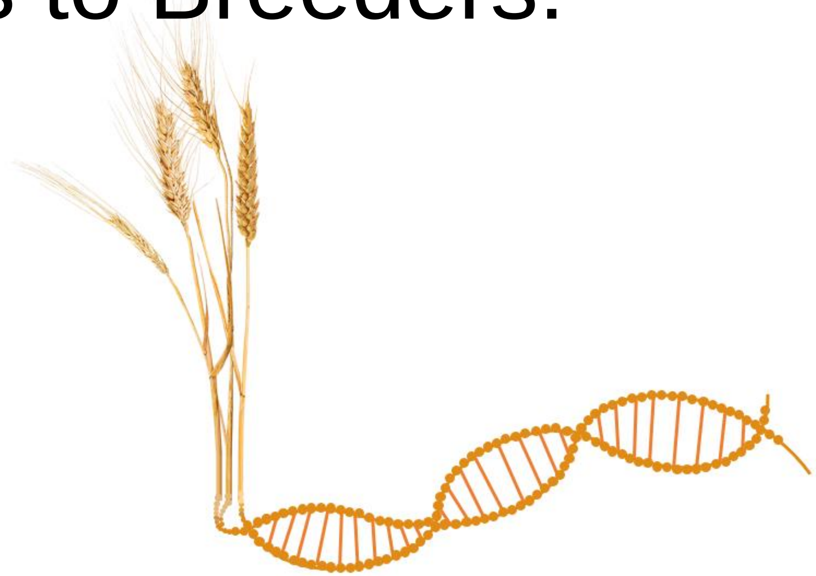
WP3: How to Deliver New Traits to Breeders: Genomic Prediction

Which traits are heritable?

Index to predict low / high fruting efficiency

Select these genotypes and
confirm genomic prediction

Cultivation in France as a validation site

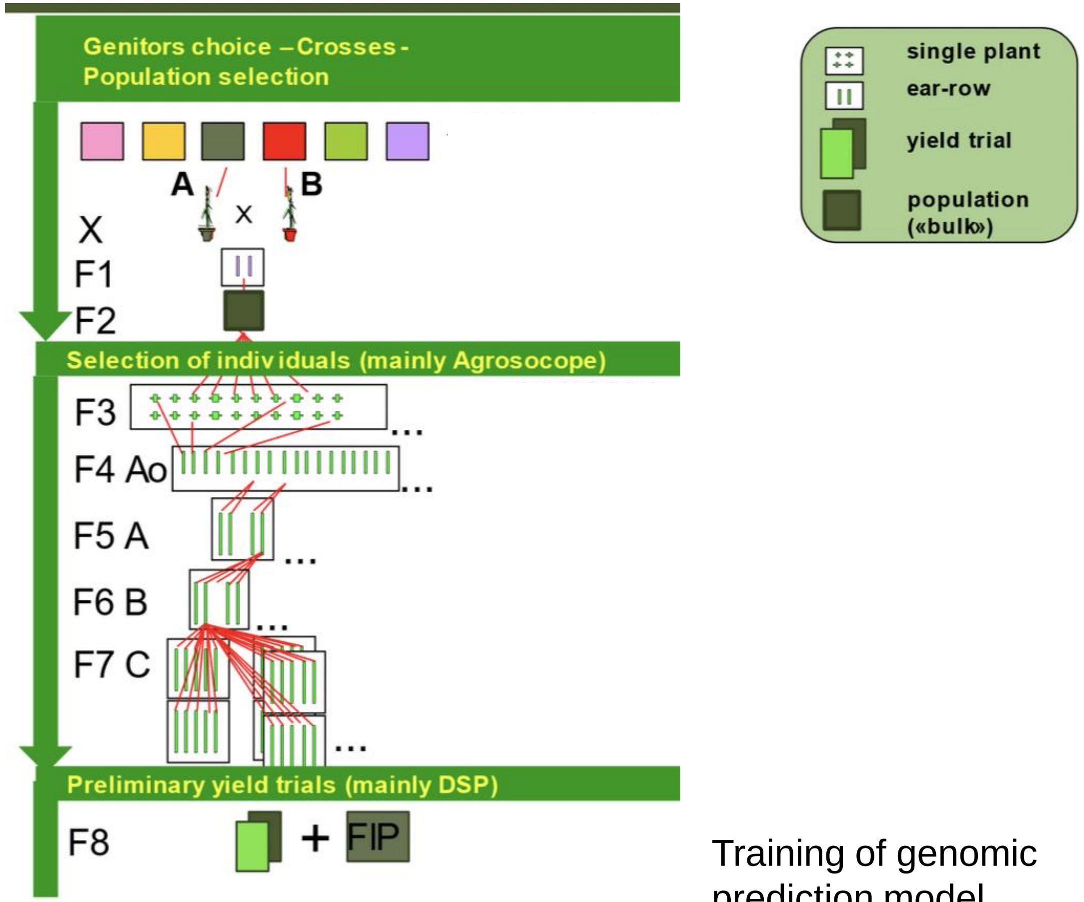


https://www.freepnglogos.com/pics/wheat

Future-climate site at *Gréoux-les-Bains*

20

2.3 Genomic Prediction



Training of genomic prediction model

(Dario Fossati, Agroscope)

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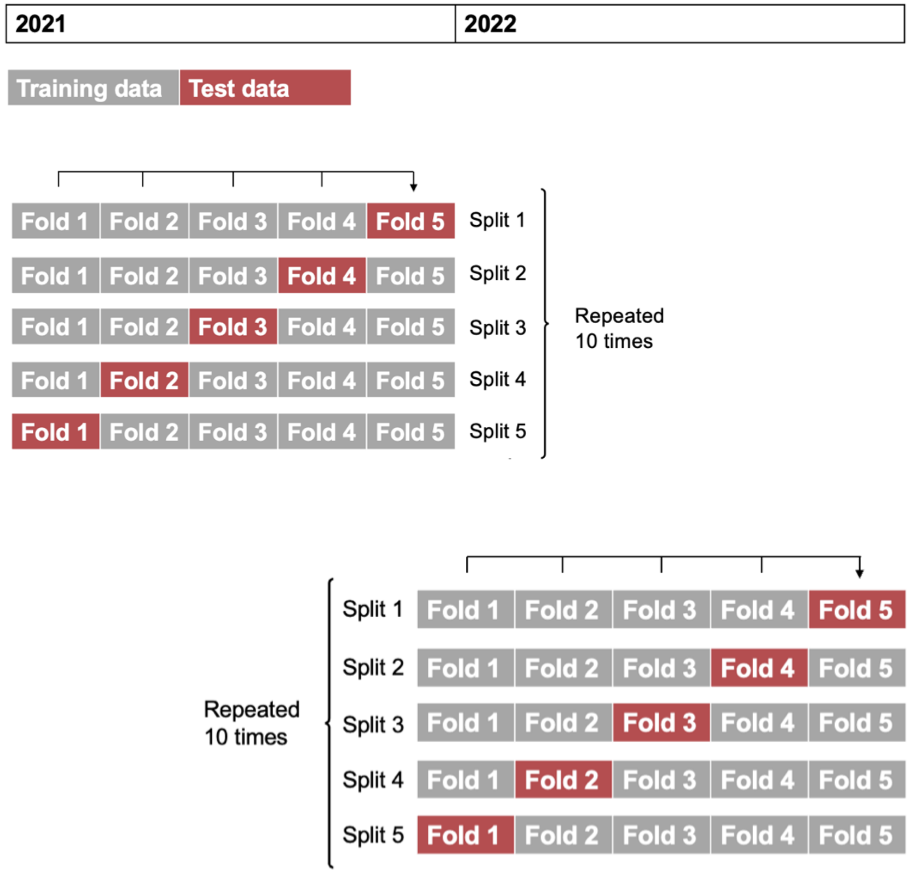
F8: Cross-Validation and Prediction of Unseen Years



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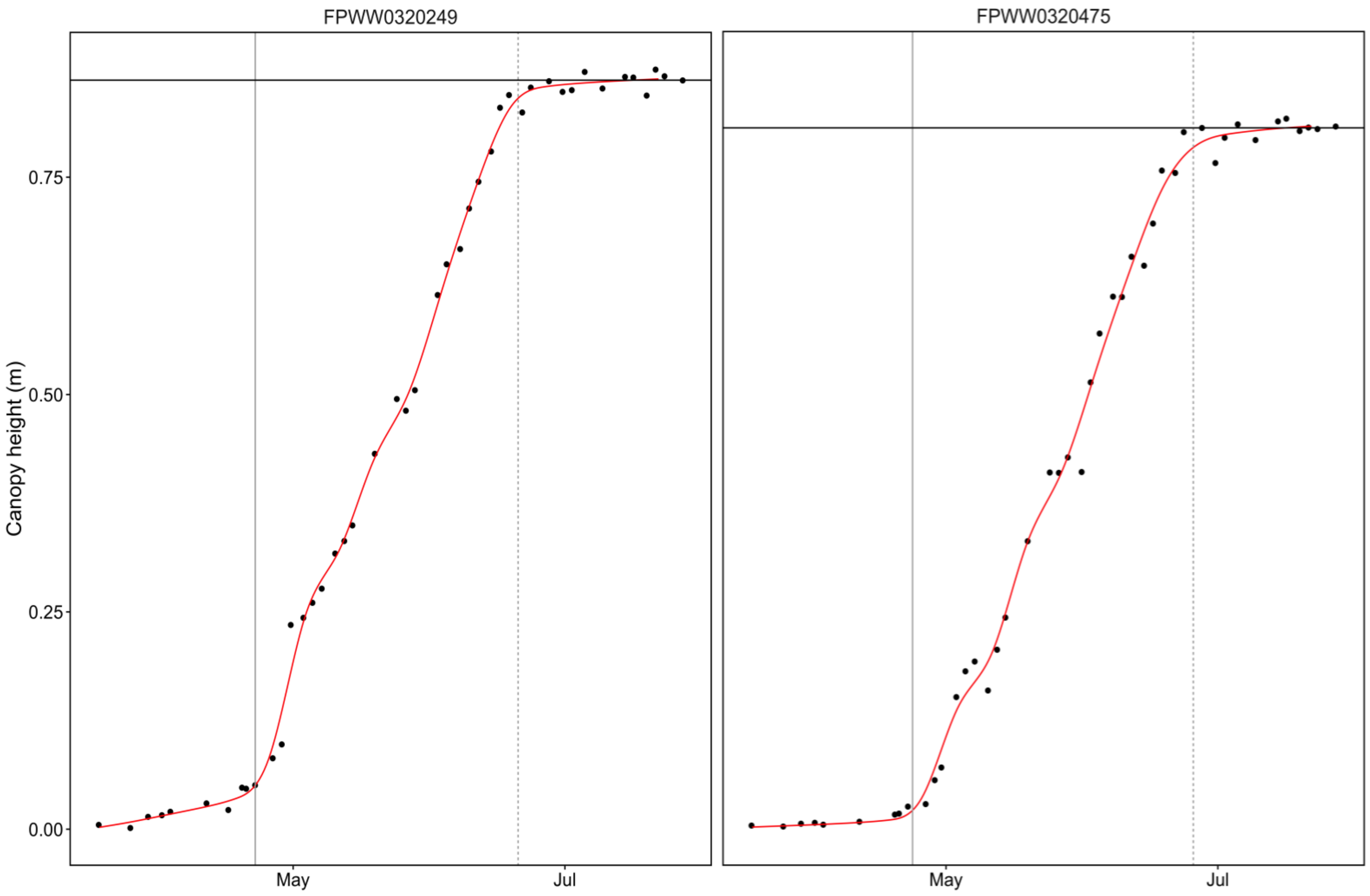

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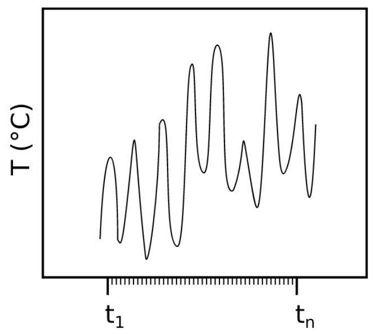
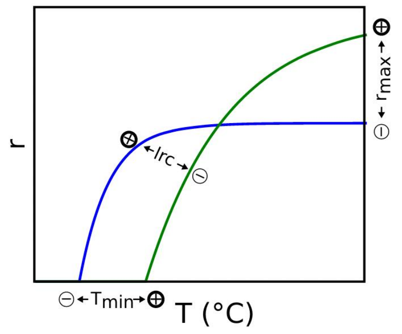
(b) Covariate measurement



(c) Dose-response curve



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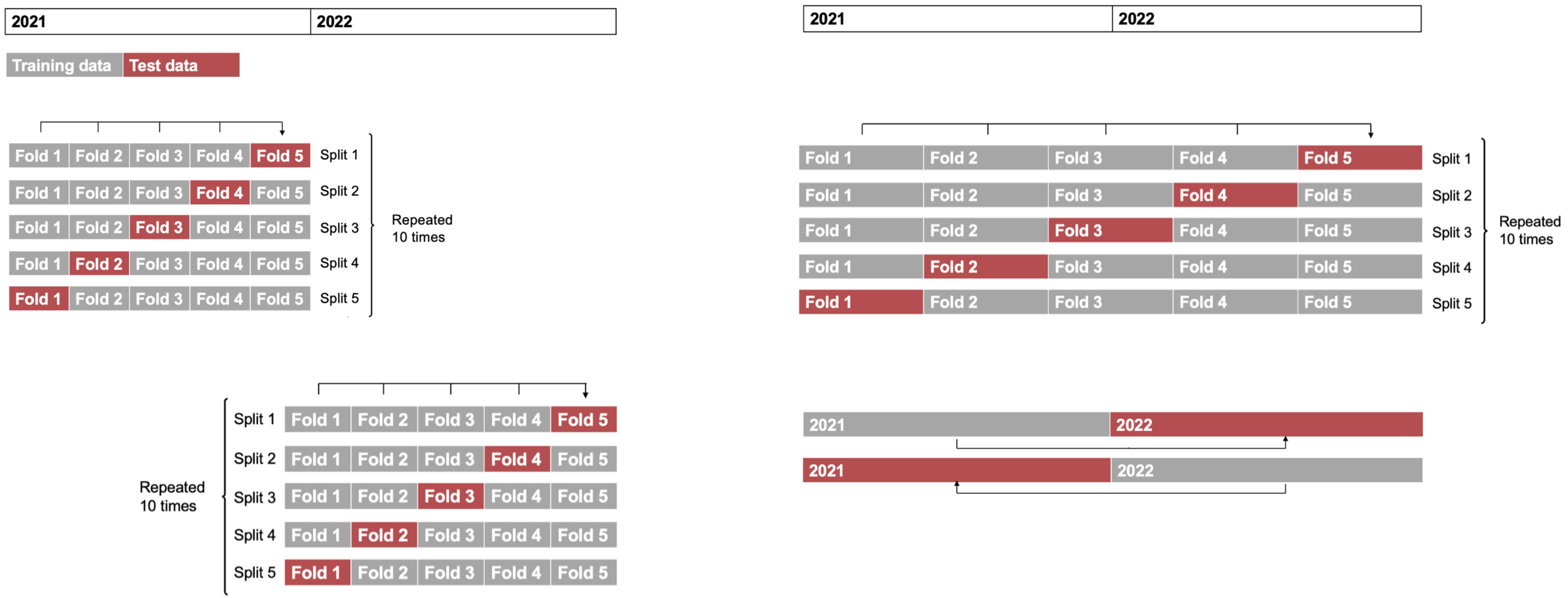
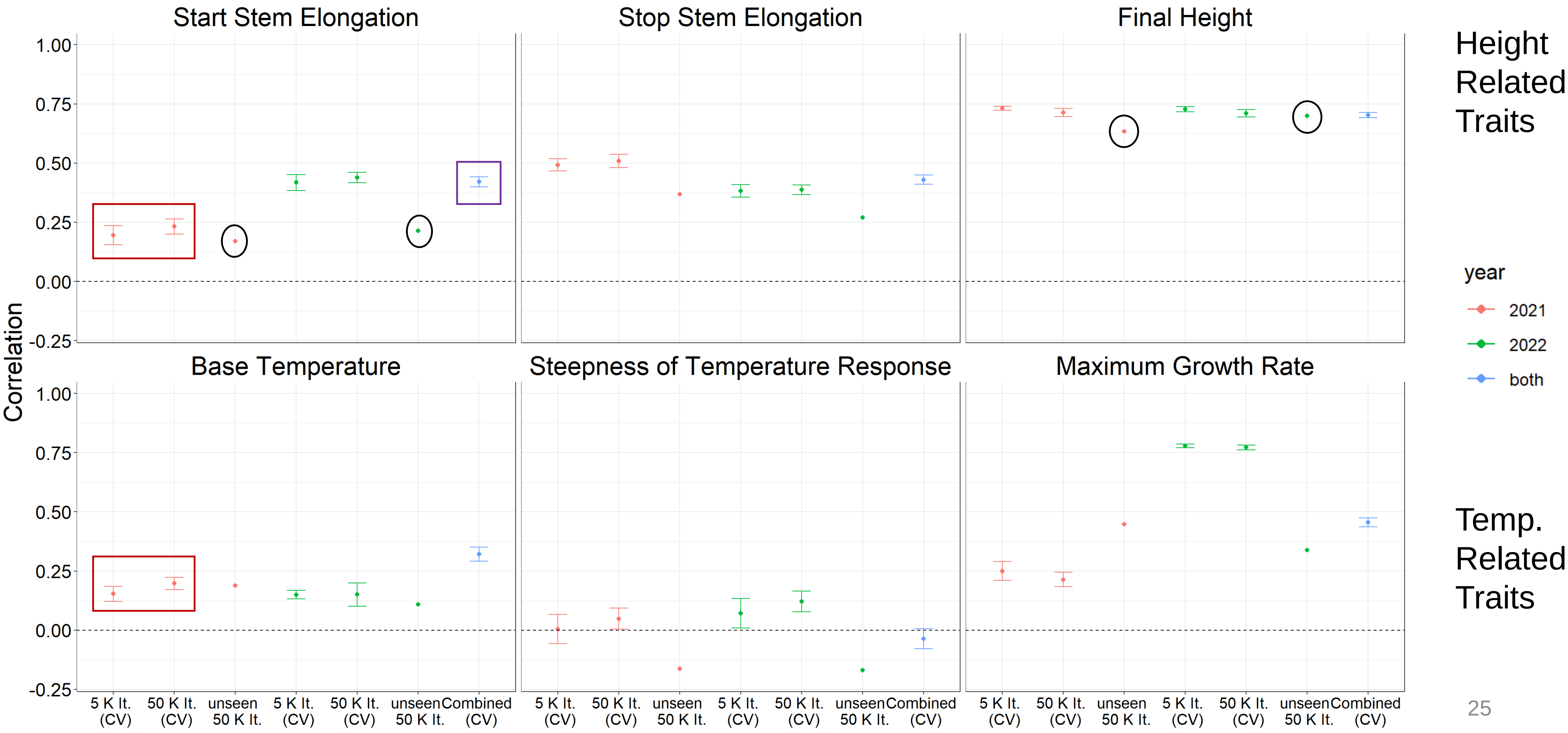


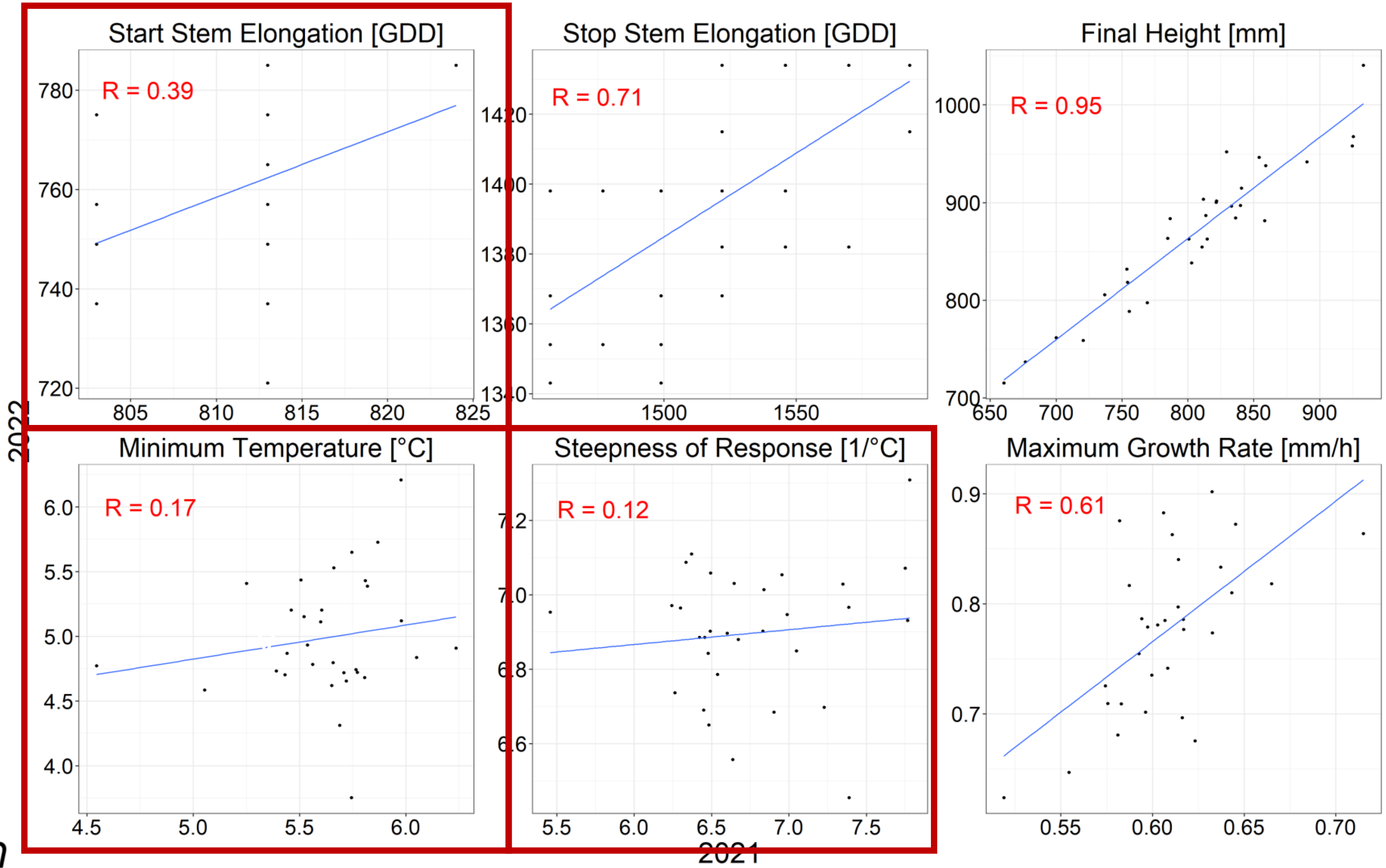
F8: CV and Prediction of Unseen Genotypes 2021 and 2022 with BayesB



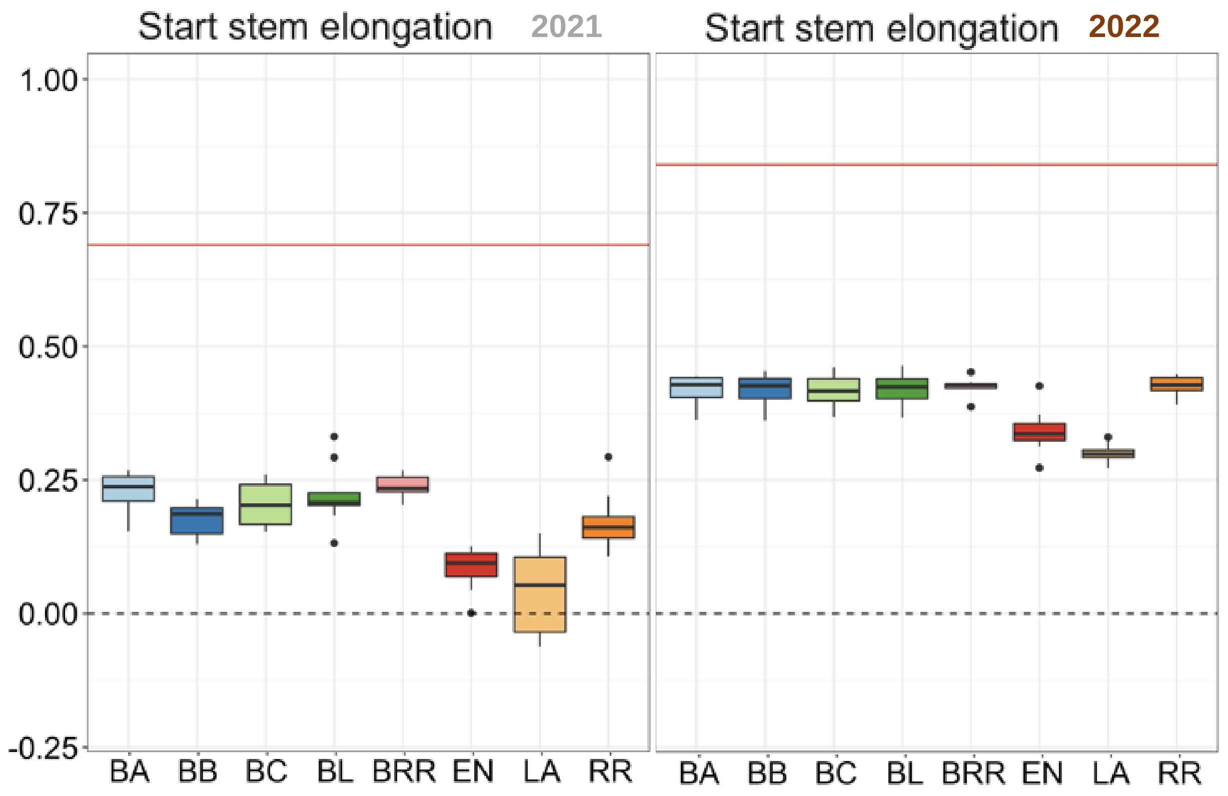
Height Related Traits

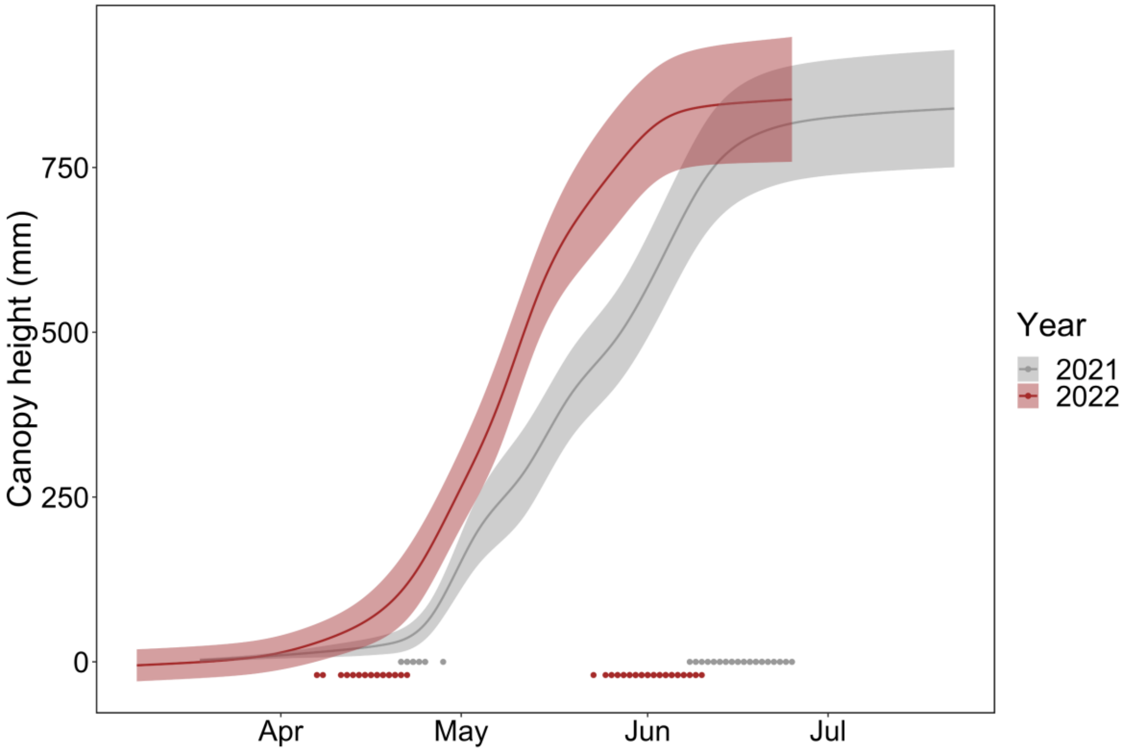
Temp. Related Traits

F8: Correlation Between 2021 and 2022



F8: Results and Discussion: Start of Stem Elongation in 2021 and 2022





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Higher prediction accuracy in 2022 compared with 2021

Conclusion

Aim: To use dense data of single season to gain as much information as possible about varietes with non-destructive methods

GP: Differences in prediction accuracies between traits and years

Improving trait extraction, modelling GxE interactions, or including environmental parameters could help to increase prediction accuracy

Genomic Prediction has the potential to speed up breeding process, e.g. with predicting start of stem elongation

Thank you!

Questions?
Feedback?
…

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Data 2021 and 2022

Number of genotypes / in GP / number of checks

346, 373 / 254 , 242 / 4, 3

Plot size:

1.5 m x 2 m

Drone: 28 m, 2.3 m/s,

Markers: 25 k snp array: most common markers in European wheat varieties, and additional markers from QTL studies

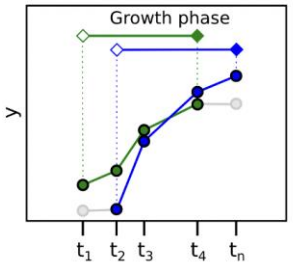
Heritability

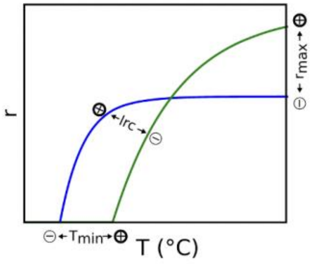
Amount of phenotypic variance that can be explained by the genotypic variance

$$H^2 = \frac{\sigma_g^2}{\sigma_P^2}$$

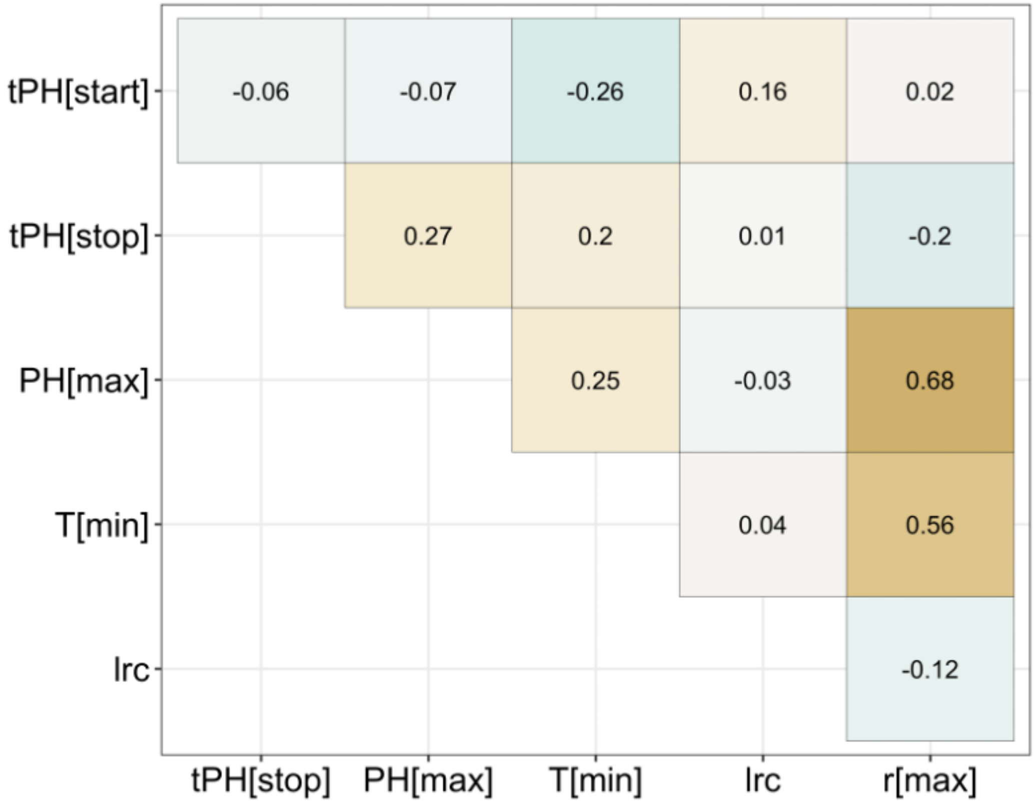
$$R = \frac{i\,\sigma_G\,h}{L}$$

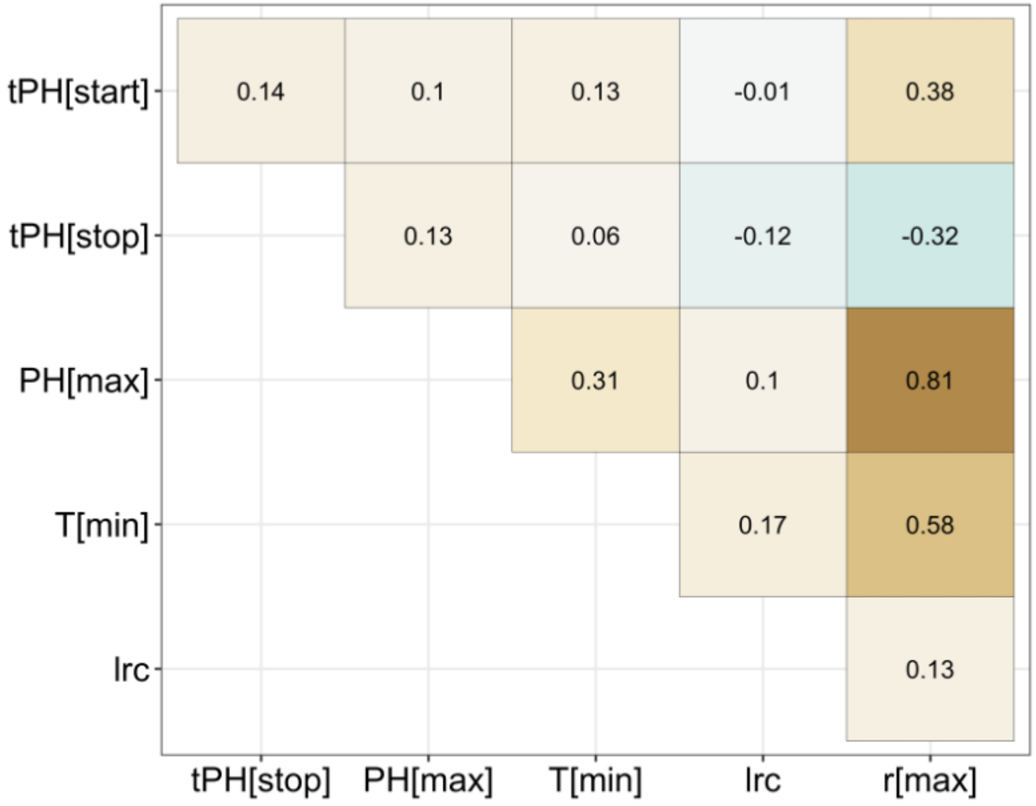
Height related traits		Temperature related traits	
Final canopy height	0.97	**Maximal growth rate**	0.43
End stem elongation	0.86	**Minimal temperature**	0.28
Start stem elongation	0.48	**Steepness response**	0.31





Genetic correlation F8



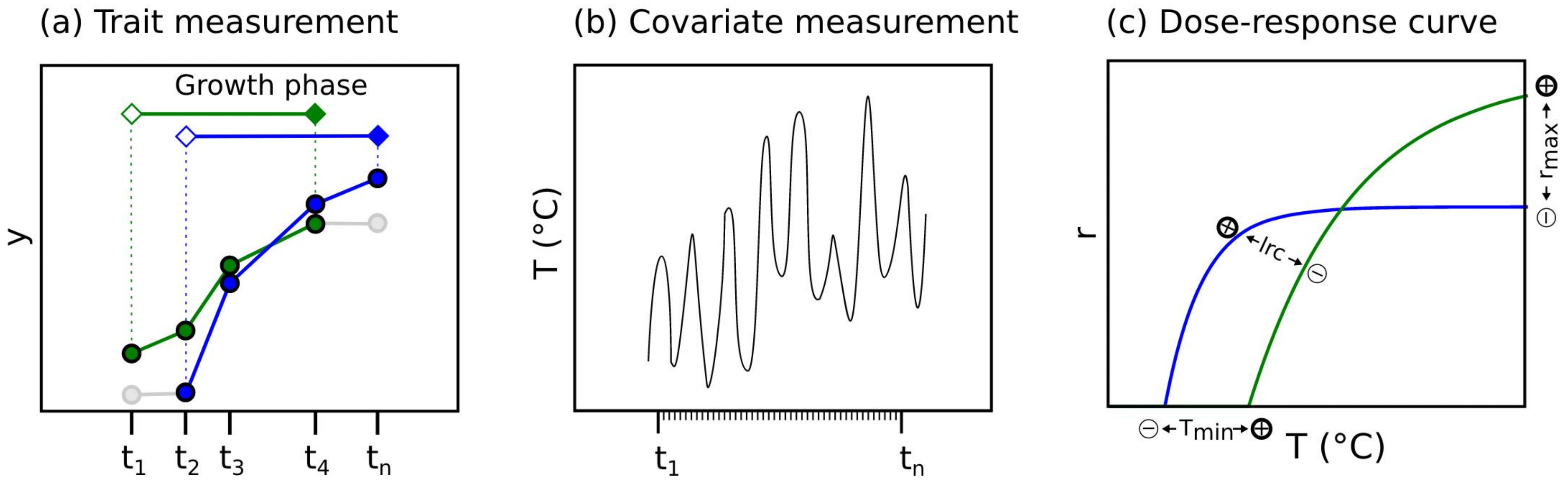


Modelling Temperature Response

$$r = r_{\max} * (1 - exp(-exp(s) * (T - T_{\min})))$$

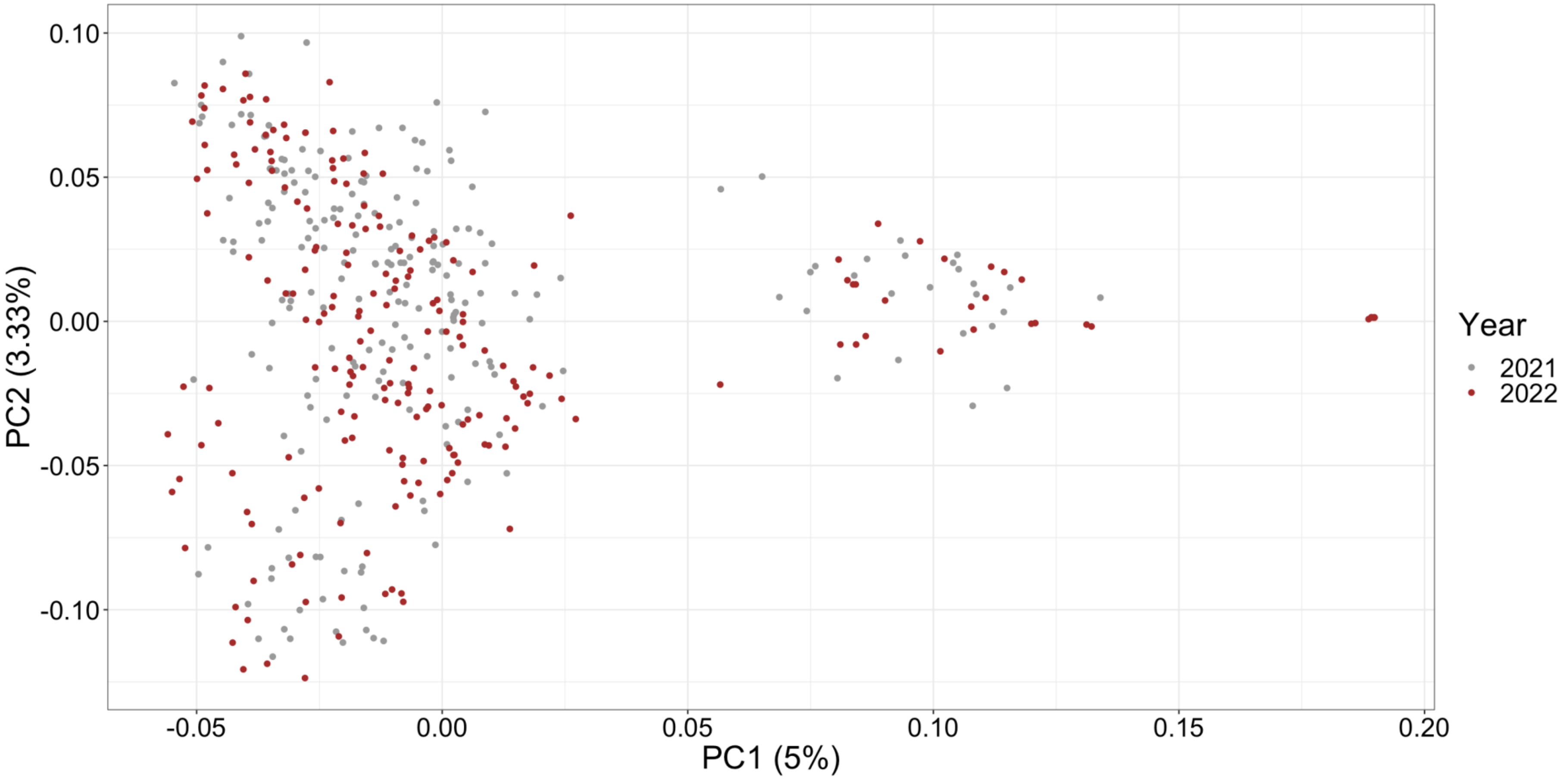
$$r_{\mathrm{asym}}(T) = \begin{cases} r, & r>0, \\ 0 & \text{otherwise} \end{cases}$$

$$y_t = \sum_{d=t_0}^{t} (\sum_{h=1}^{n_d} r(T_{dh}, \theta) * \Delta m_h),$$



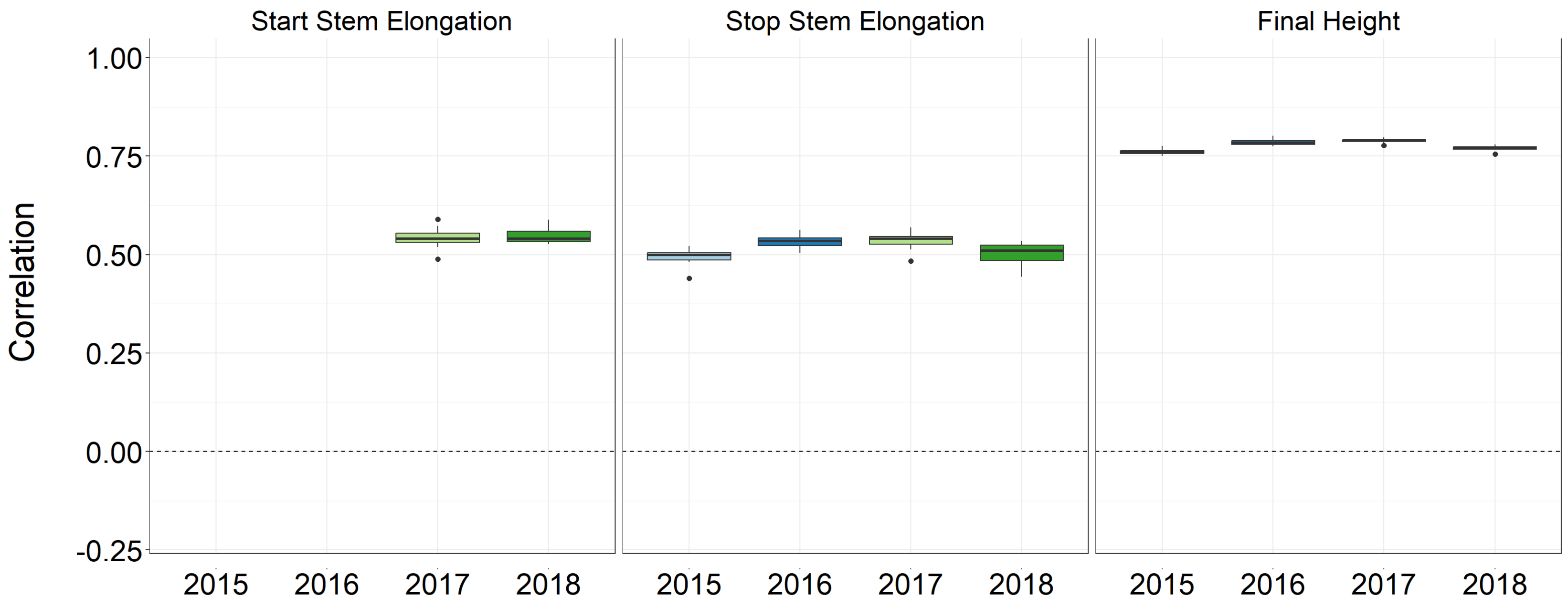
Lukas Roth, Hans-Peter Piepho, and Andreas Hund (2022). Phenomics data processing: extracting dose– response curve parameters from high-resolution temperature courses and repeated field-based wheat height measurements

Relationship

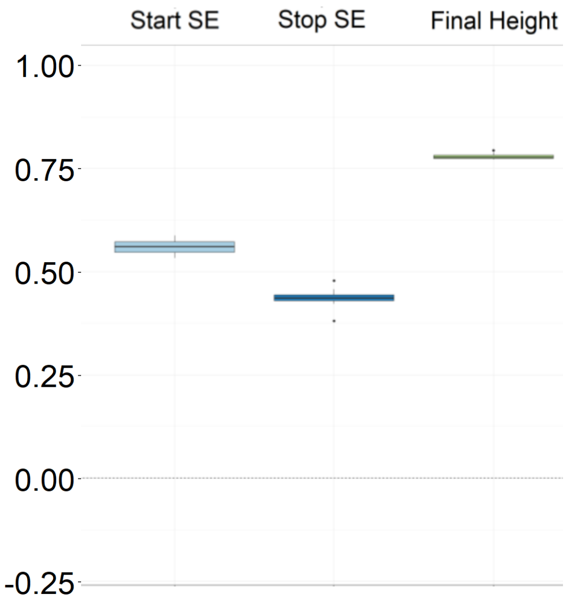


GABI: Year-wise and overall CV of Height-related Traits

Year-wise



Overall

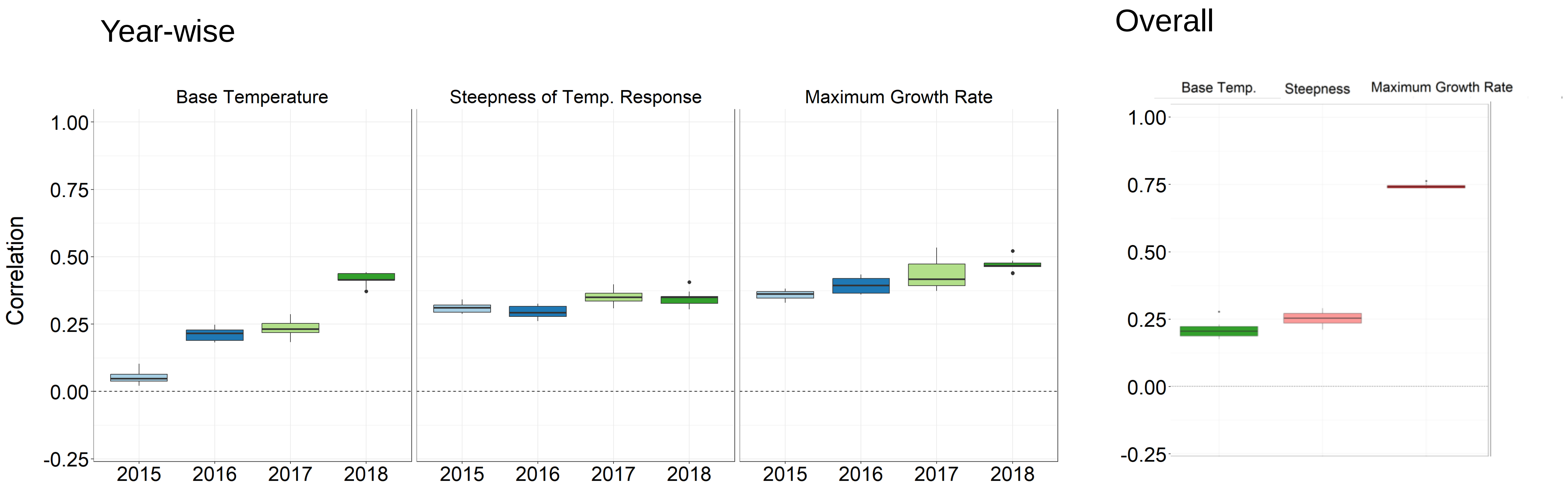


Overall genomic prediction accuray didn’t increase compared with year-wise prediction accuracy

Calculation of GDD

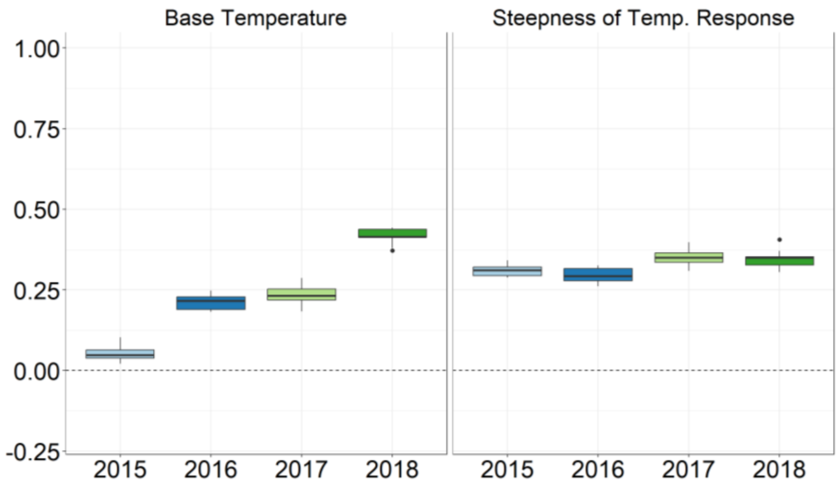
$$\mathrm{GDD(DAS)} = \sum_{d=1}^{\mathrm{DAS}} \sum_{h=1}^{24} \begin{cases} \dfrac{T_{d,h} - T_{\mathrm{base}}}{24}, & T_{d,h} > T_{\mathrm{base}}, \\ 0, & T_{d,h} \le T_{\mathrm{base}}, \end{cases}$$

GABI: Year-wise and overall CV of Temperature-related Traits

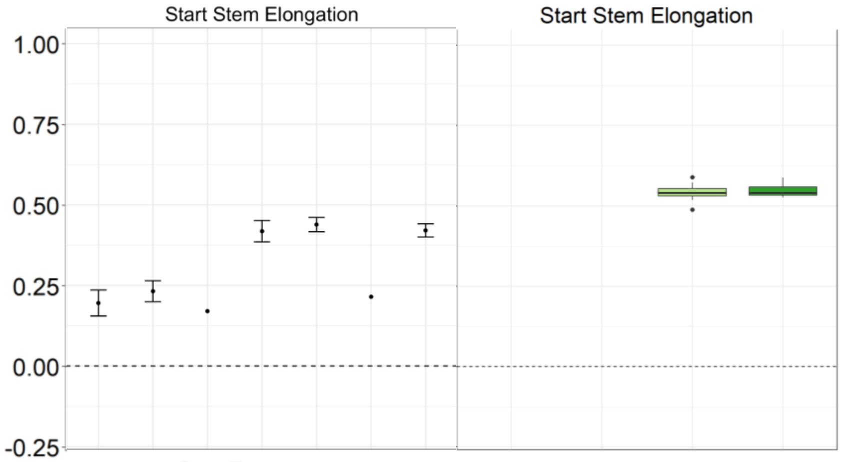


For maximum growth rate, overall genomic prediction accuray increased compared with year-wise prediction accuracy

Discussion and Conclusion



Still quite low prediction accuracies for temperature related traits



Higher prediction accuracy of start of stem elongation with GABI panel

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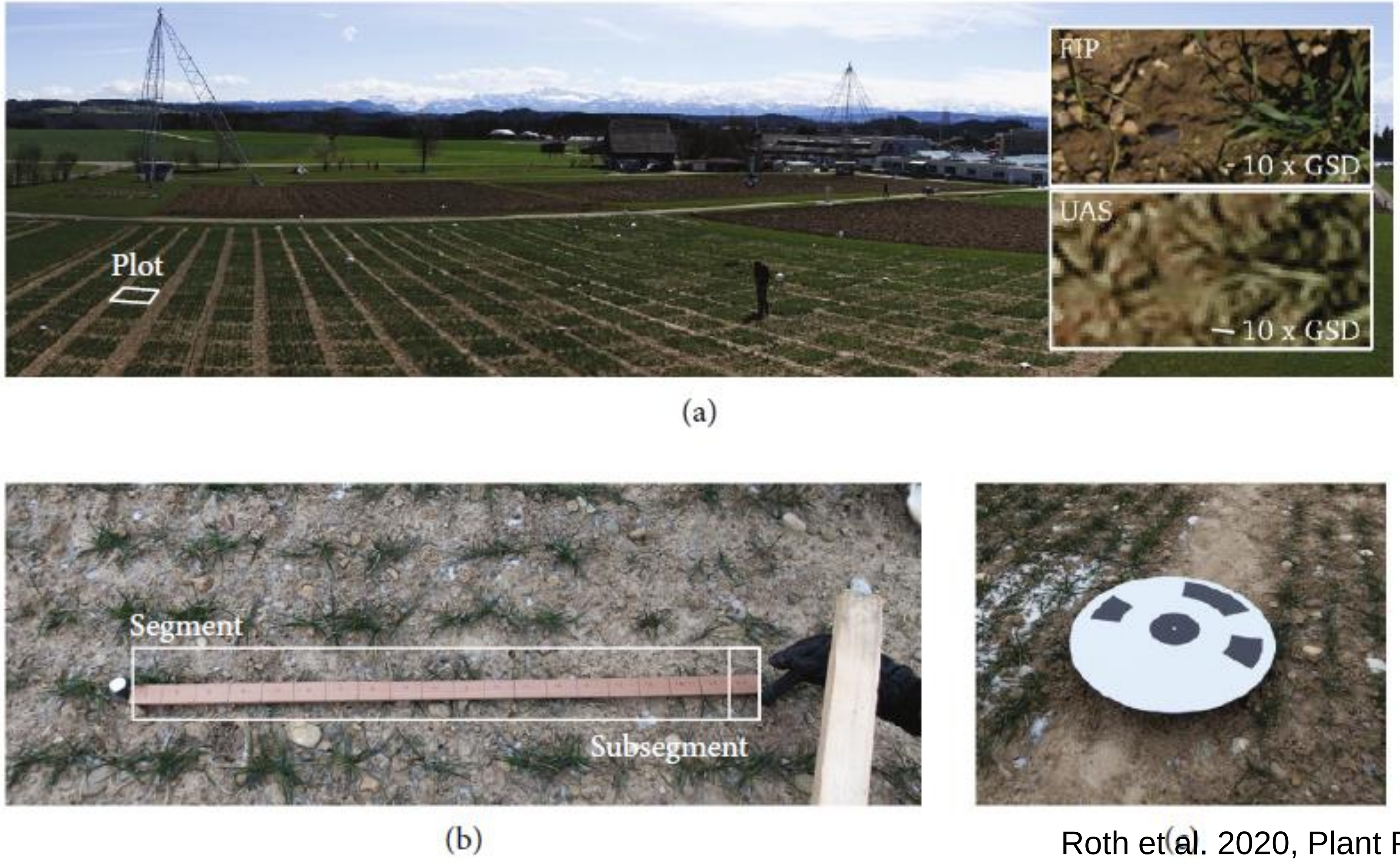
Crop Rotation

- Since 2012: winter wheat, soybean, buckwheat and maize

Example from RGB imaging at different scales



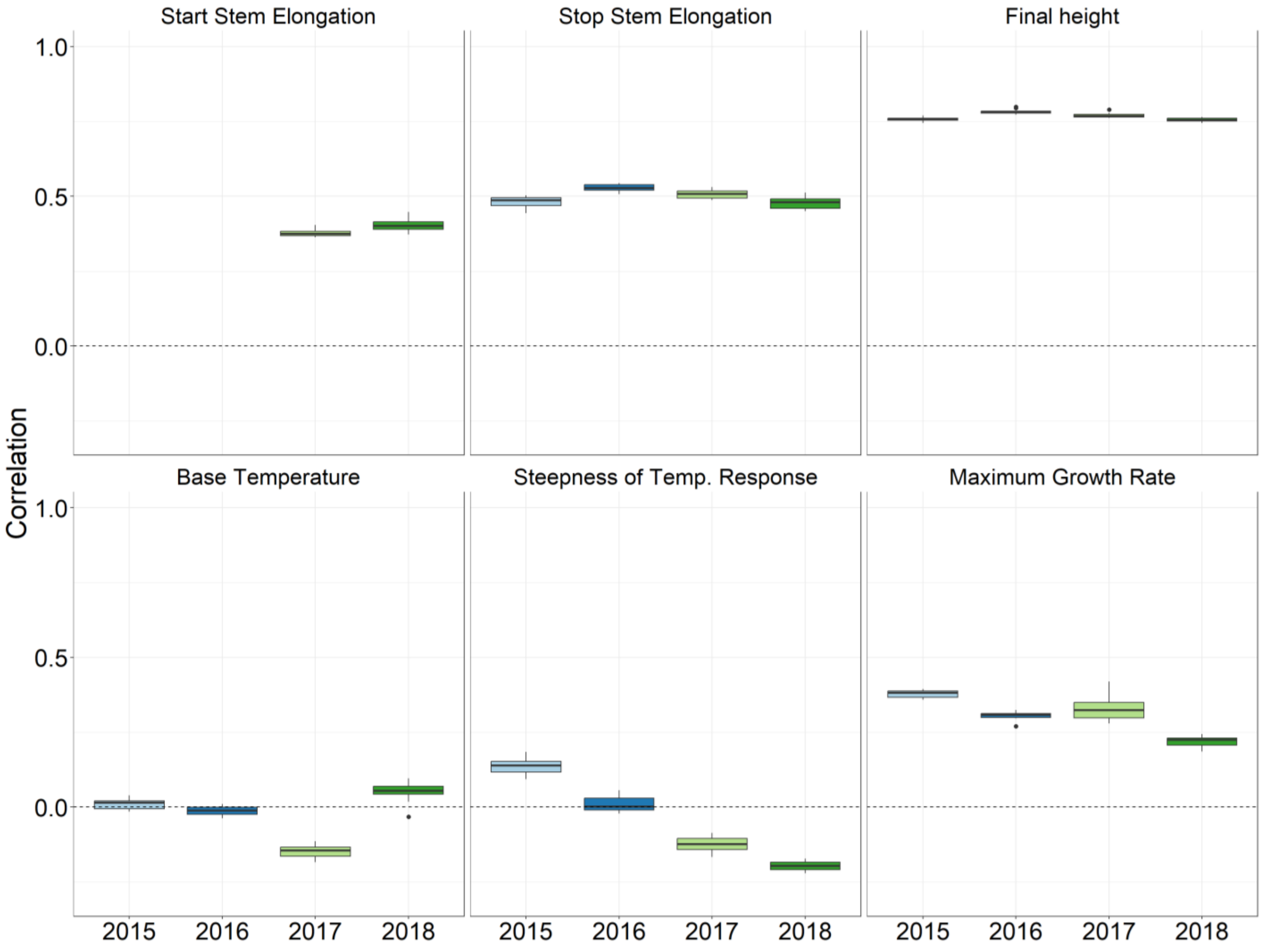
FIP dolly, 3m distance 0.6 mm GSD

UAS, 28 m altitude, 3 mm GSD

Ground control point

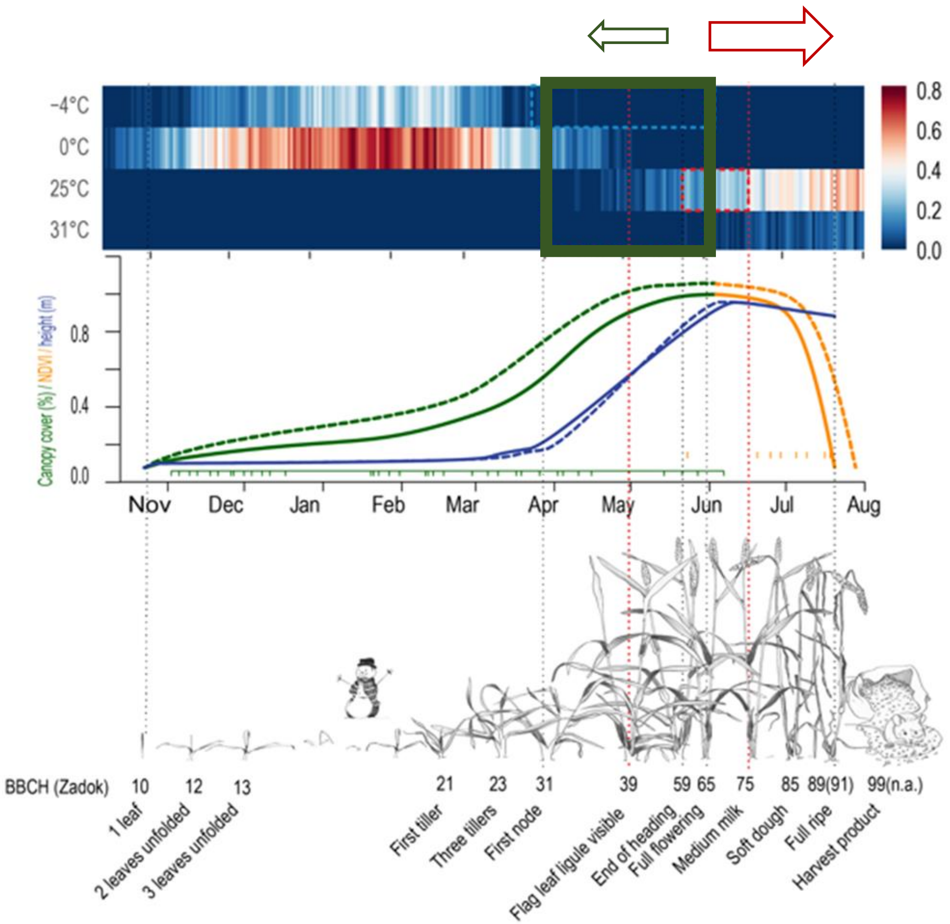
Roth et al. 2020, Plant Phenomics, DOI: 10.34133/2020/3729715

GABI: Prediction of unseen genotypes in unseen years



Prediction of unseen genotypes in an unseen environment

Challenge



Focus: Effect of climate change on wheat yield

Breeders aim at keeping sensitive phase «stress free»

Higher temperatures due to climate change will result in altered phenology and earlier/shorter «stress free» phase

- Escape: stay in «stress free» zone: shorter vegetation period and yield reduction
- Heat tolerance: later varieties with heat tolerance

Where is the balance?
How can our phenotypic and genomic prediction methods contribute to answer this question?

(John R Porter and Megan Gawith (1999) Temperatures and the growth and
w, adapted by Andreas Hund)

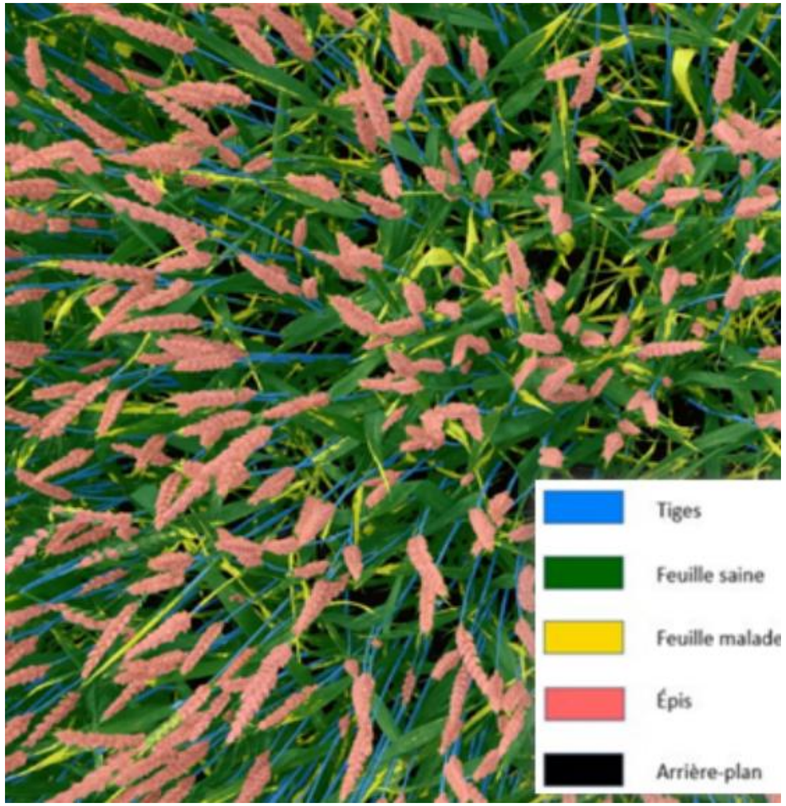
2.2 GlobalWheat

2.2 Global Wheat Dataset

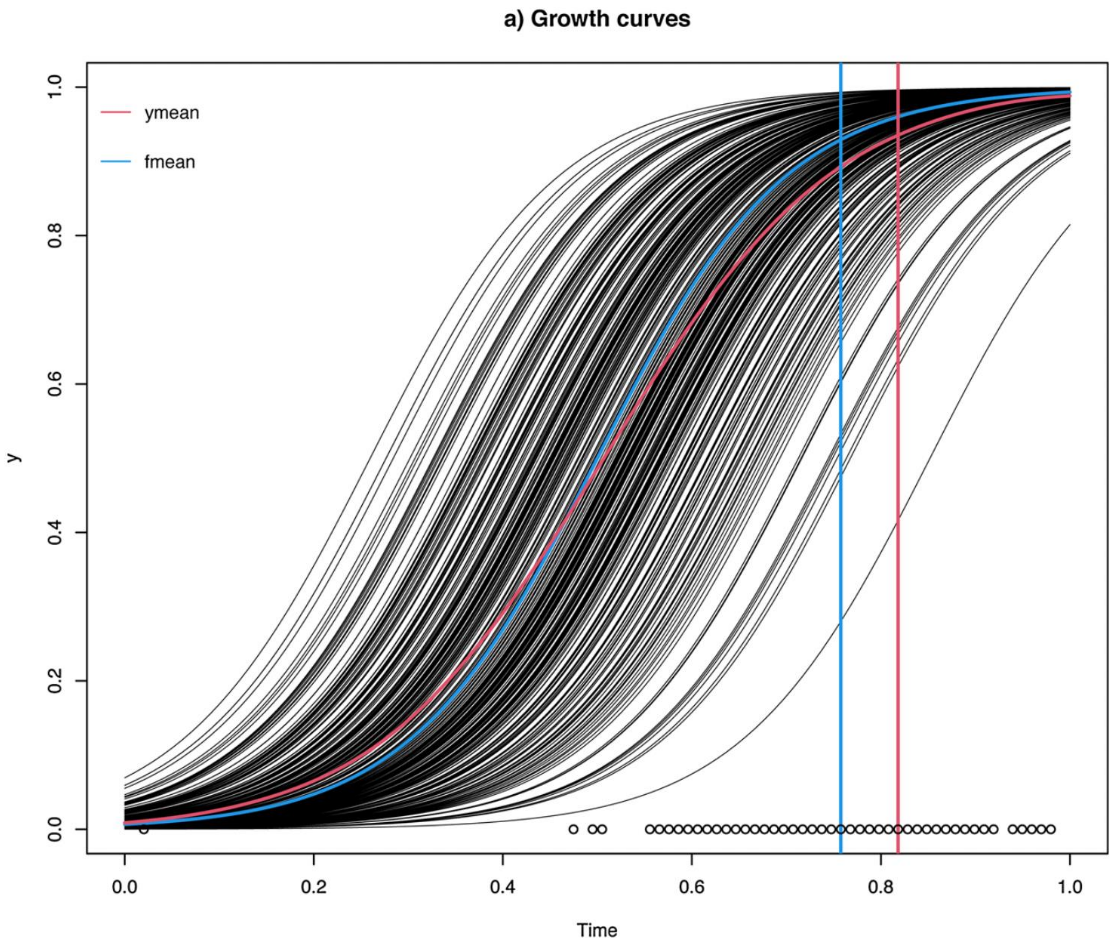
Segmentation:

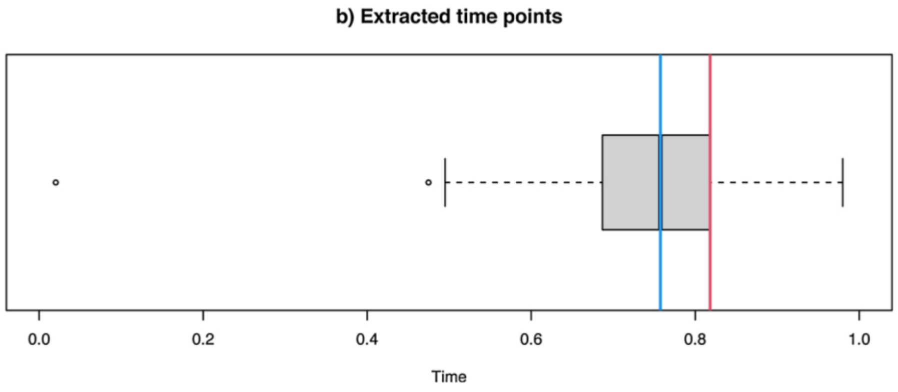
Define a dataset with most relevant features

- Spikes
- Stem
- Leaves
- Soil

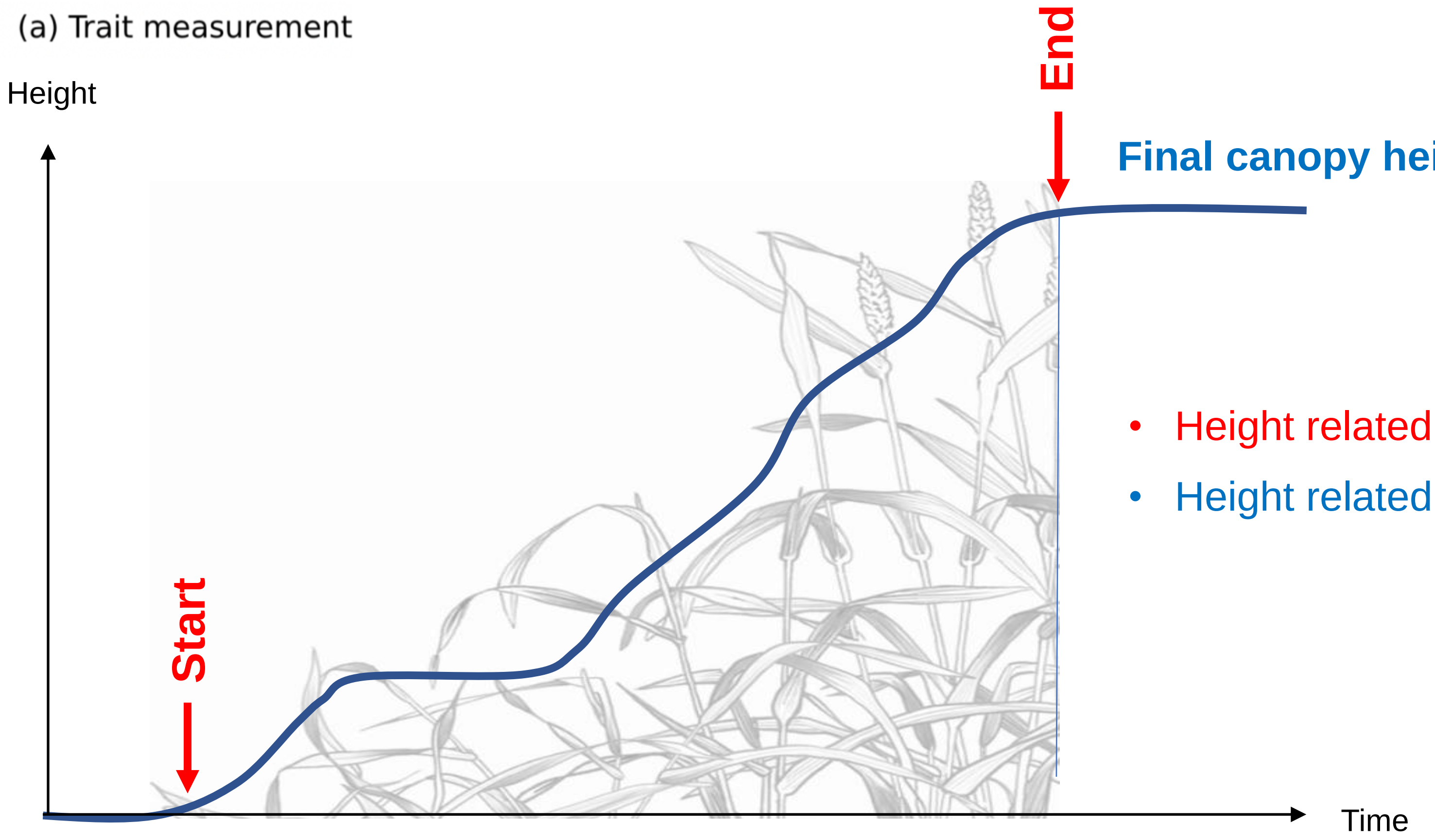


Spatial and temporal correction





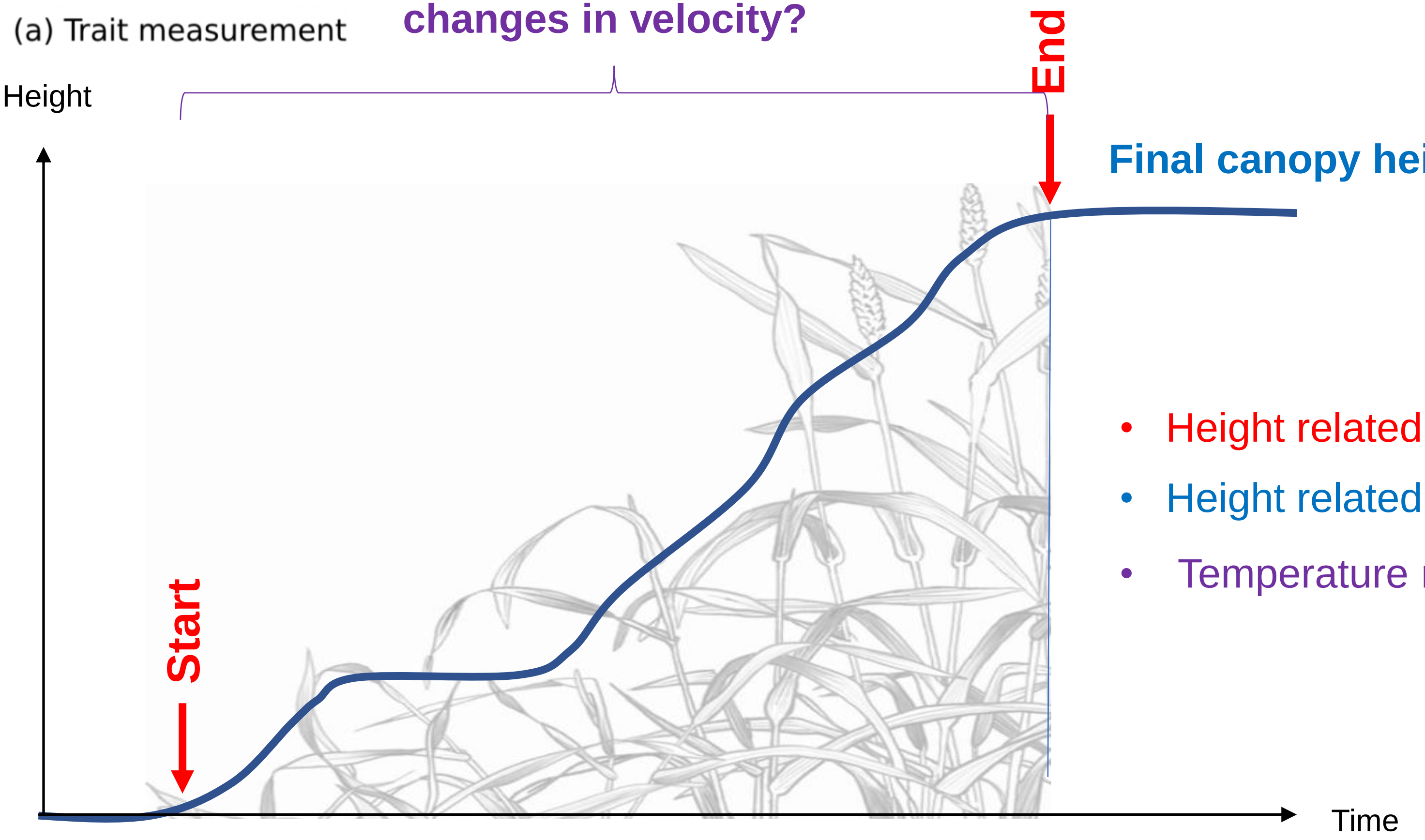
Traits



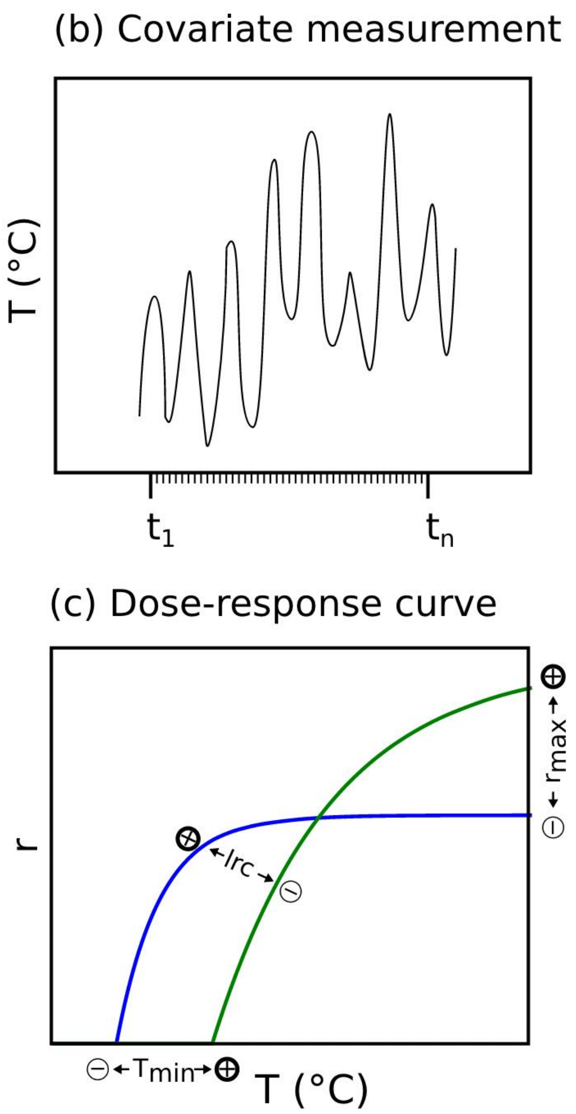
- Height related trait: Point of time
- Height related trait: Quantity

Lukas Roth et al. (2021) Phenomics data processing: A plot-level model for repeated measurements to extract the timing of key stages and quantities at defined time points, visualized by Andi Hund.

How well does temperature describe changes in velocity?



- Height related trait: Point of time
- Height related trait: Quantity
- Temperature related traits



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