Crop Modelling and Parameterisation

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Model Parameterisation Why?

Crop models are widely used for

- advising farm management and policy makers
- Research and hypothesis testing
- Defining directions for crop breeding (including climate change adaptation)

Predictions between different models and any particular model used by different expert users show large differences

Uncertainties due to

- Model structure (processes, functional forms)
- Input data (sampling errors, spatial and temporal variability, lack of data availability)
- Model parameters (calibration method)

Model Parameterisation

No standard approach!

- Complex mathematical model structure
- Nonlinearity of many processes
- Complex interactions of processes

- Many model parameters
- Model outputs generally difficult to link with existing calibration software
- Software with calibration algorithm might converge to local not global minimum
- Problem of equi-finality
- Various model outputs, one or multi-objective calibration?

Calibration Procedures – Current Practices

Study by Seidel et al. (2018)

- Various model platforms and models APSIM, DAISY, DSSAT, STICS

- Mainly calibrated for phenology, yield and biomass
- Additionally grain N, biomass N at harvest, in season measurements of LAI, soil moisture, soil N, in season biomass
- Median number of parameters was 6 (range 1 to 116)
- generally in stages (1st stage often phenology)
- Parameter choice based on model developers, or own choice (SA or expert opinion)
- Parameter value ranges generally based on values from literature or expert opinion

Seidel, S.J., Palosuo, T., Thorburn, P., Wallach, D., 2018. Towards improved calibration of crop models – Where are we now and where should we go? European Journal of Agronomy 94, 25-35.

Calibration Procedures – Current Practices

Survey by Seidel et al. (2018)

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- Parameter values estimated on
  - Goodness of fit (SSE, RMSE)
  - GLUE (software e.g. build into DSSAT): random sampling method within parameter space
  - Bayesian approach:

1. capturing available knowledge via the prior distribution
2. likelihood function based on information in the observed data
3. combining both the prior distribution and the likelihood function to obtain posterior distribution.

- Parameter uncertainty
  - confidence limits for each parameter
  - Distribution of possible parameter values
  - Use of parameter uncertainty to calculate uncertainty in model output?

Calibration Procedures – Current Practices

Survey by Seidel et al. (2018)

- Performance of calibrated model based on:
  - Goodness of fit with calibration dataset
  - Data splitting or using the entire dataset to represent the entire population?
  - Cross validation
  - Site/year/management combinations

Only 1% of survey respondents had no difficulties with calibration!

Seidel, S.J., Palosuo, T., Thorburn, P., Wallach, D., 2018. Towards improved calibration of crop models – Where are we now and where should we go? European Journal of Agronomy 94, 25-35.

Parameterisation Procedures

which of the numerous model parameters?

- Sensitivity Analysis (SA) : Identification of most influential parameters
- ➢ Local SA single parameter at a time
- ➢ Global SA – combined effect of multiple parameters
    - Main effect index and total effect index

- Computationally expensive
- Parameter influence dependent on environmental conditions and management
- Sensitivity of prior assumptions about parameter values

Sensitivity Analysis (SA)

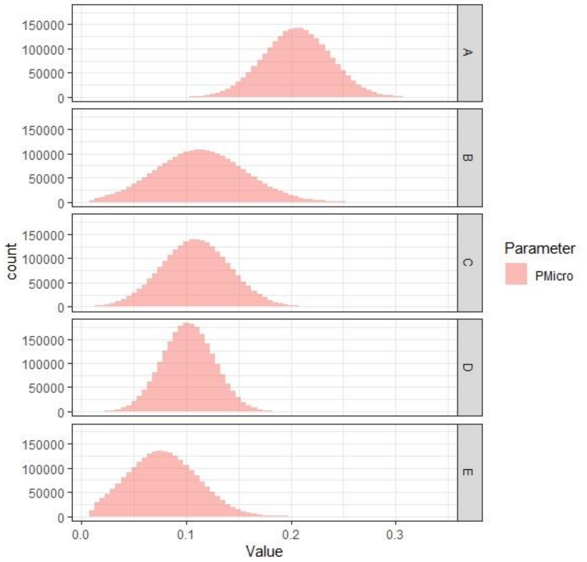
Identification of most influential parameters – effect on model output

Parameter selection

Parameter bounds

Parameter distribution

Parameter as Listed in APSIM-Sugar Model (*Description*)	Level	Code	Unit	Lower and Upper Bound
leaf_size (*Leaf area of the respective leaf*)	Leaf_size_no = 1	LS1	mm^2	500–2000
	Leaf_size_no = 14	LS2	mm^2	25,000–70,000
	Leaf_size_no = 20	LS3	mm^2	25,000–70,000
cane_fraction (*Fraction of accumulated biomass partitioned to cane*)		CF	gg^{-1}	0.65–0.80
sucrose_fraction_stalk (*Fraction of accumulated biomass partitioned to sucrose*)	Stress factor = 1	SF	gg^{-1}	0.50–0.70
sucrose_delay (*Sucrose accumulation delay*)		SD	gm^{-2}	0–600
min_sstem_sucrose (*Minimum stem biomass before partitioning to sucrose commences*)		MSS	gm^{-2}	450–1500
min_sstem_sucrose_redn (*reduction to minimum stem sucrose under stress*)		MSSR	gm^{-2}	0–20
tt_emerg_to_begcane (*Accumulated thermal time from emergence to beginning of cane*)		EB	°C day	1200–1900
tt_begcane_to_flowering (*Accumulated thermal time from beginning of cane to flowering*)		BF	°C day	5500–6500
tt_flowering_to_crop_end (*Accumulated thermal time from flowering to end of the crop*)		FC	°C day	1750–2250
green_leaf_no (*Maximum number of fully expanded green leaves*)		GLN	No.	9–14



Parameterisation of Crop Phenology

- many physiological processes depend on phenological stage.
- parameterisation of new crop varieties
- The best parameter values for one output might not be the same for another output?
- Which parameters? Degree days to each stage, photoperiod sensitivity, cardinal temperature?

- *Trial and error with goodness of fit* – mostly used procedure

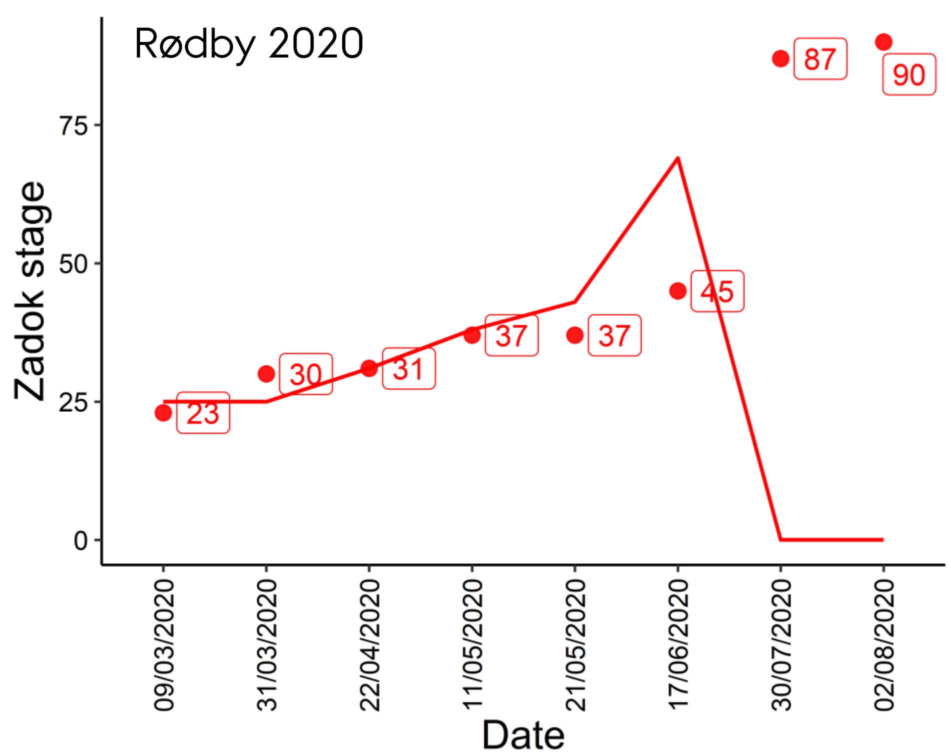
➢ Easier to do, than coupling crop models coupled with statistical software

➢ Time consuming
➢ Low chance of finding the true best-fit-parameters.
➢ No information on uncertainty of parameter estimation

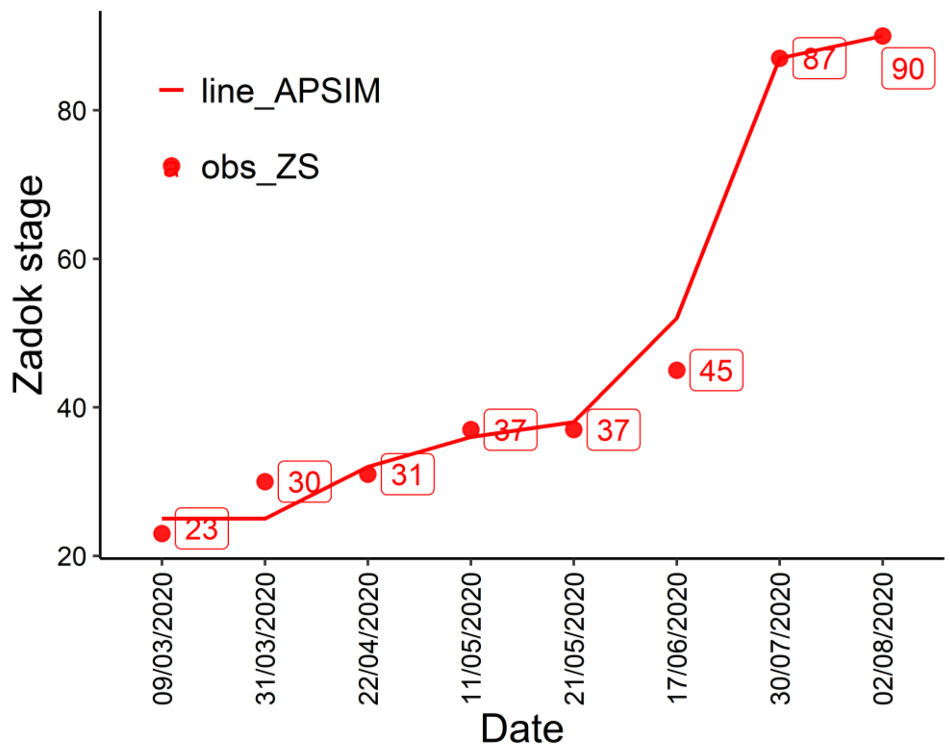
Example1: Parameterisation of Crop Phenology in APSIM Winter Wheat

TRIAL AND ERROR WITH GOODNESS OF FIT- 1 YEAR / 1 LOCATION

default parameters

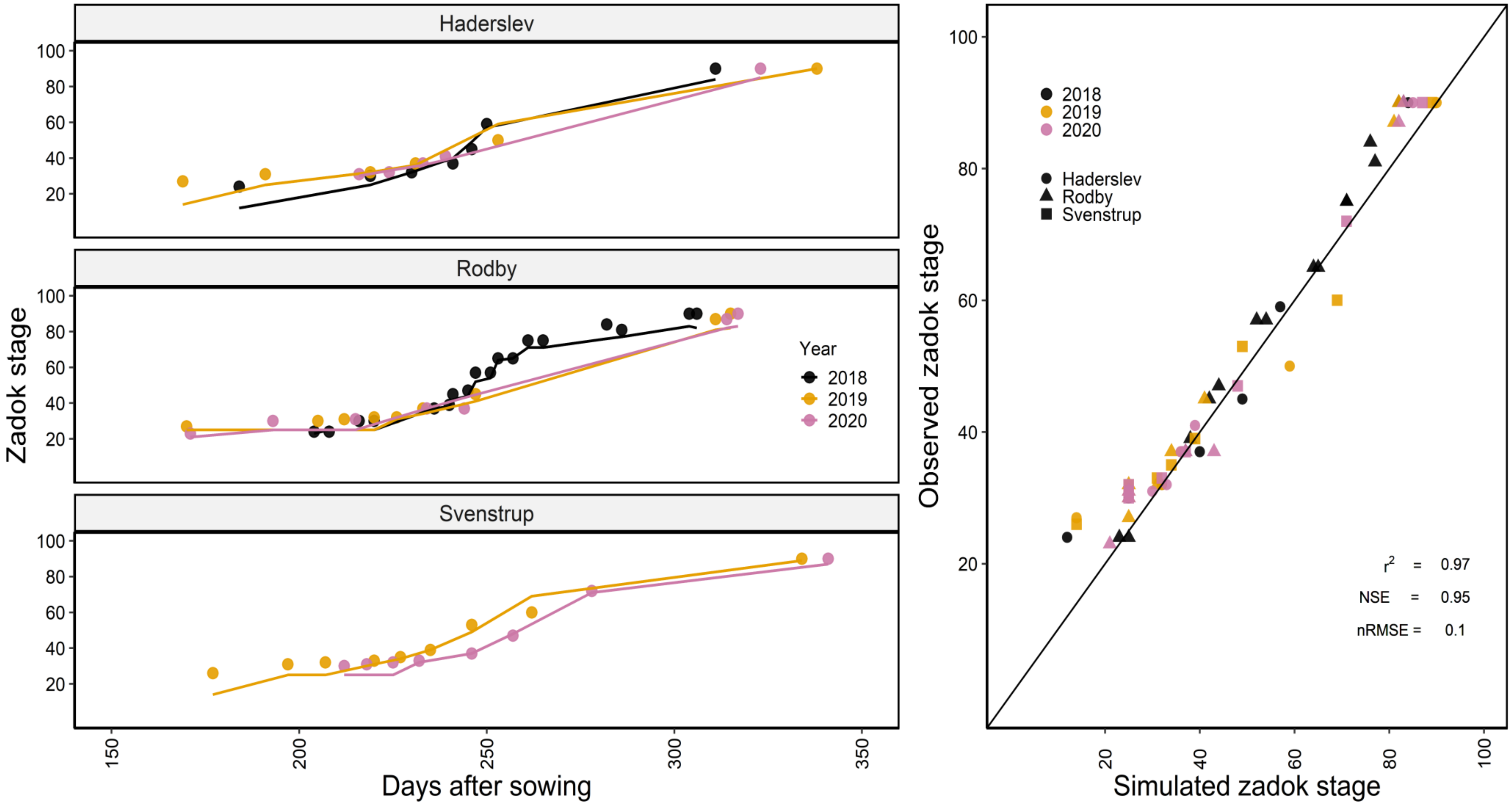


calibrated parameters



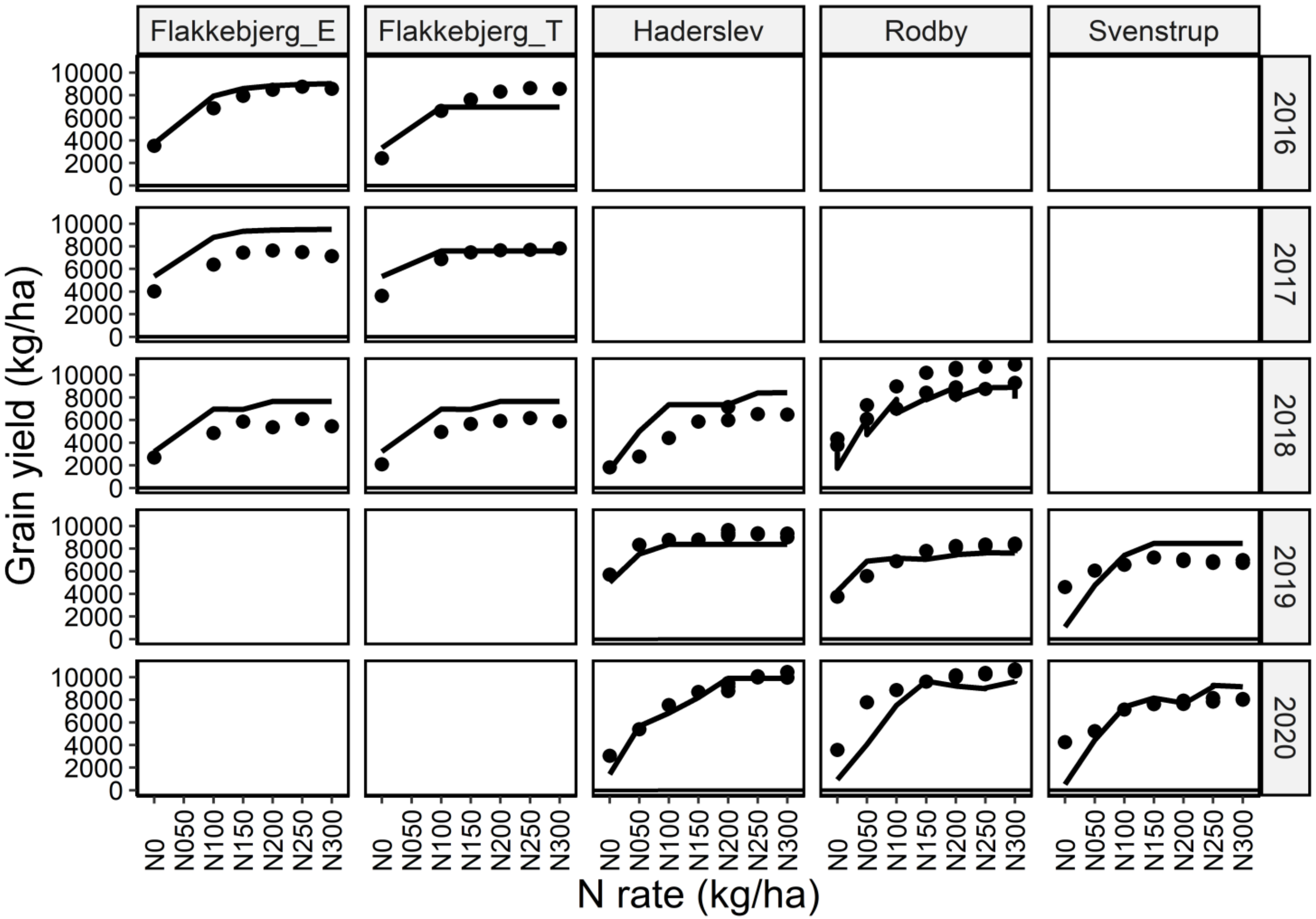
Example1: Parameterisation of Crop Phenology in APSIM Winter Wheat

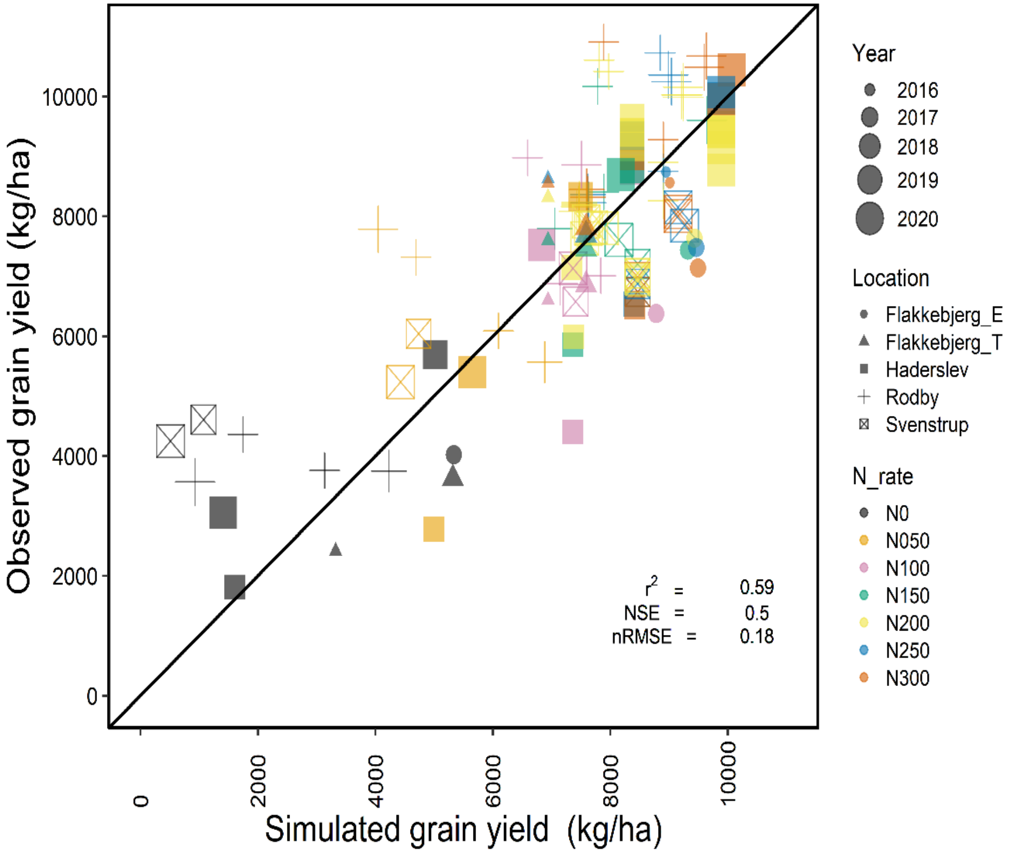
TRIAL AND ERROR WITH GOODNESS OF FIT- 3 **YEARS / 3 LOCATIONS**



Example1: Parameterisation of Grain Yield in APSIM Winter Wheat

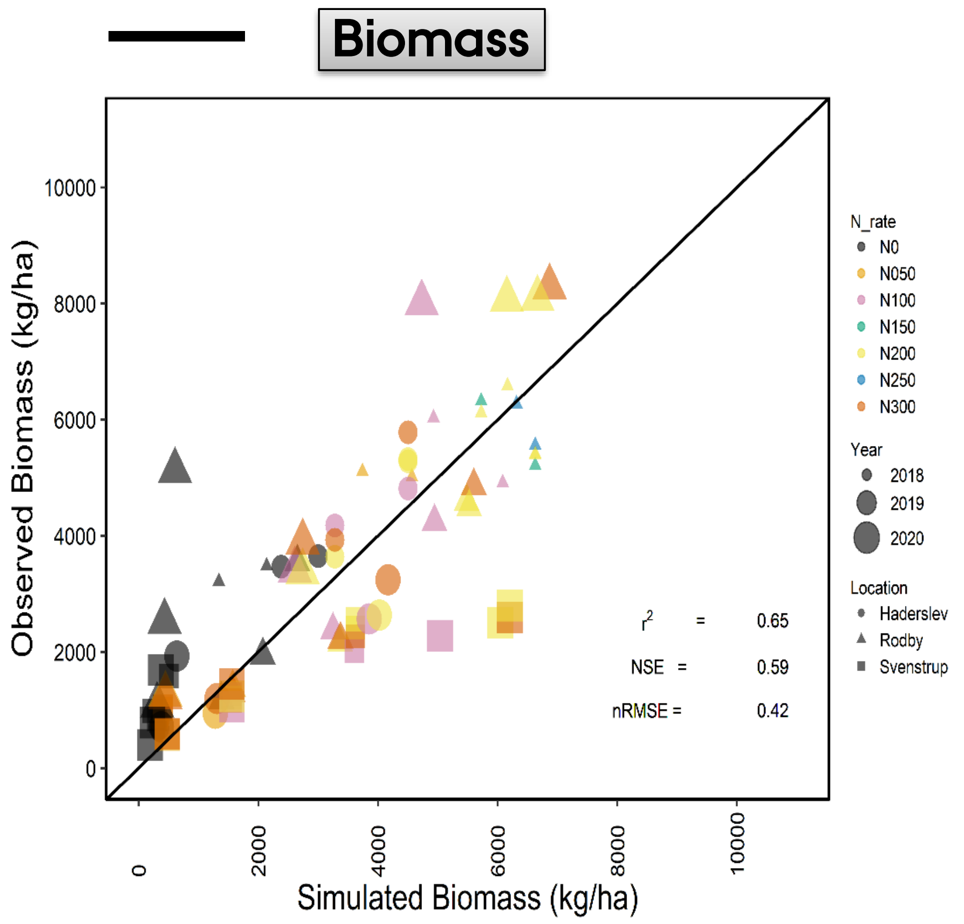
TRIAL AND ERROR WITH GOODNESS OF FIT- 5 YEARS / 4 LOCATIONS

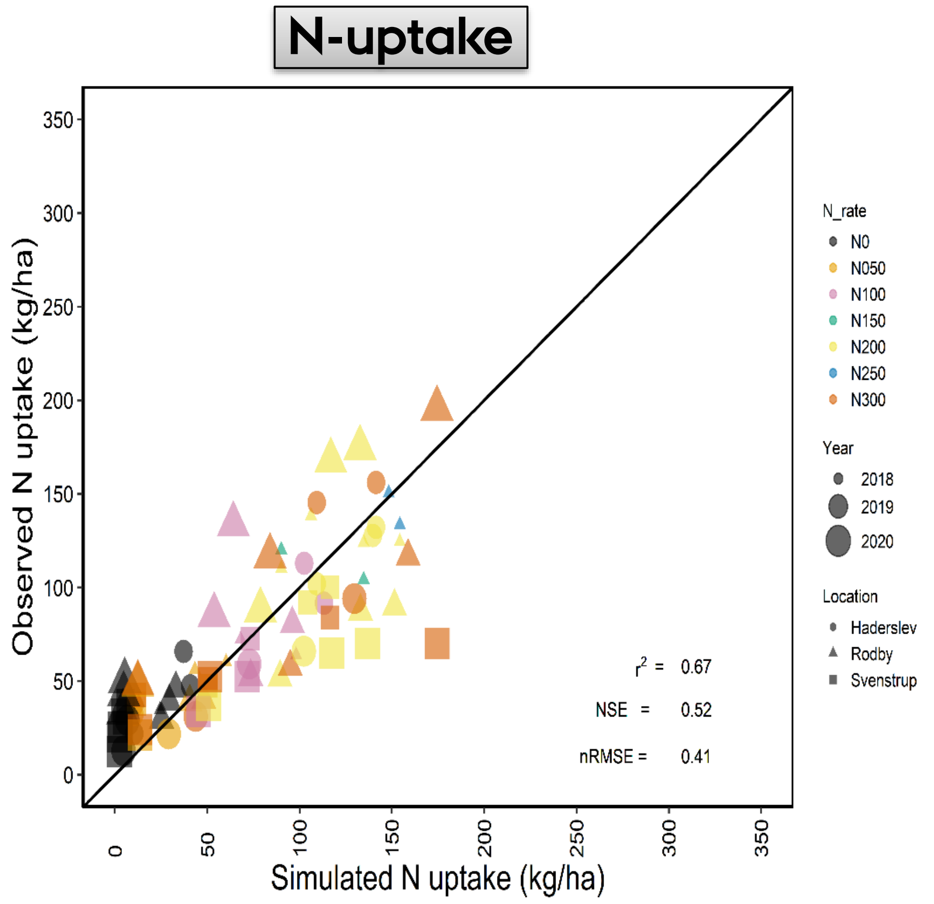




Example1: Parameterisation of Crop Biomass in APSIM Winter Wheat

TRIAL AND ERROR WITH GOODNESS OF FIT- 3 YEARS / 3 LOCATIONS



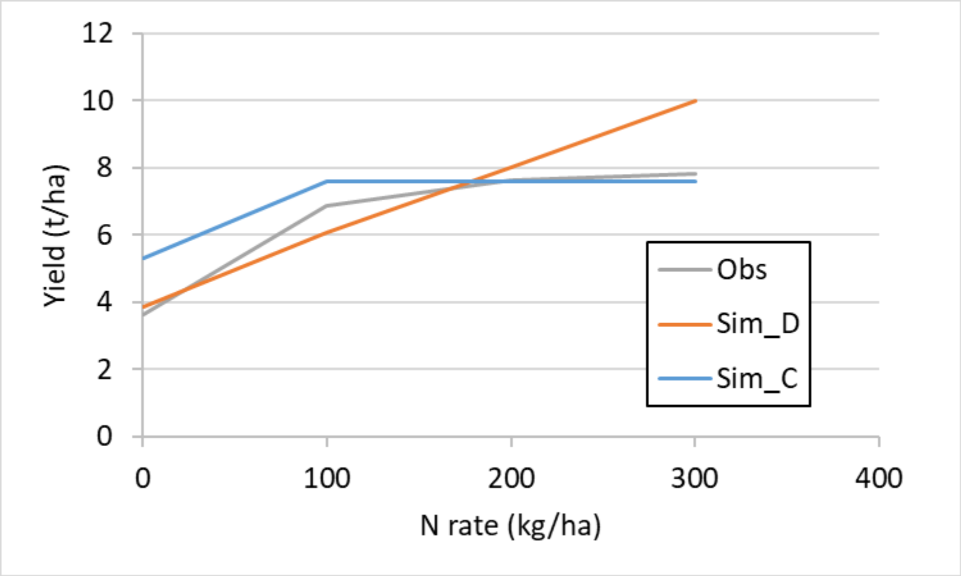


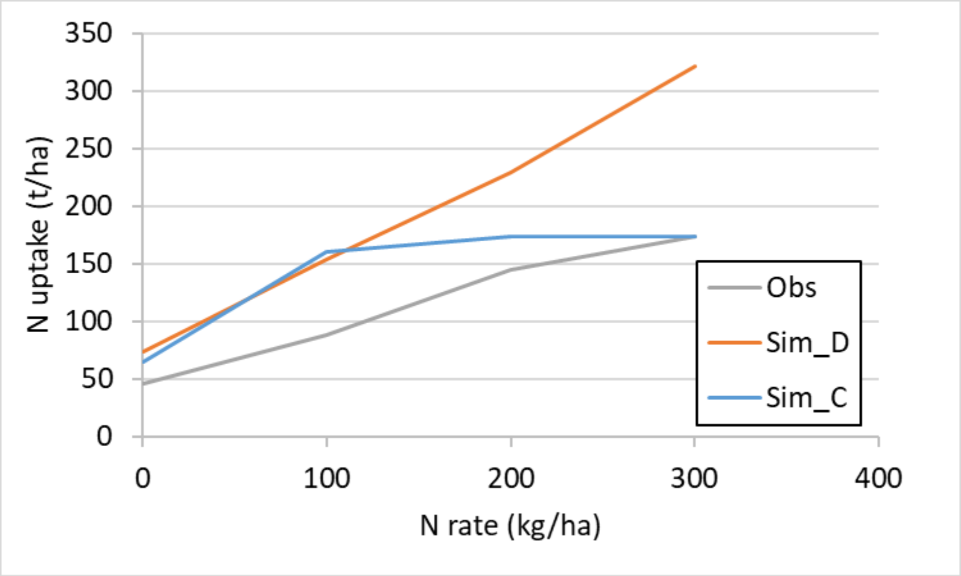
Example 1: Parameterisation of APSIM Winter Wheat

Key parameters	Description	Unit	Default values	Calibrated values
verns_sens	Phenology related	-	1.5	4.65
photop_sens	Phenology related	-	3	3.35
tt_end_of_juvenile	Phenology related	°Cd	400	490
tt_start_grain_fill	Phenology related	°Cd	545	1060
y_extinct_coef	Biomass accumulation	°Cd	0.50	0.47
y_sla_max	Biomass accumulation	$mm^2\ g^{-1}$	27000,22000	21000, 18000
grain_per_gram_stem	Grain yield related		25	33
potential_grain_growth_rate	Grain yield related	$g\ grain^{-1}\ day^{-1}$	0.001	0.011
SOMMiner_Toptimum	N mineralization	°C	22	25
y_n_conc_crit_leaf	N partitioning to leaf	fraction	0.0035-0.063	0.005-0.045
y_n_conc_max_leaf	N partitioning to leaf	fraction	0.005-0.07	0.035-0.06
y_n_conc_crit_stem	N partitioning to stem	fraction	0.0035-0.05	0.005-0.045
y_n_conc_max_stem	N partitioning to leaf	fraction	0.015-0.07	0.01-0.06
y_n_conc_crit_pod	N partitioning to pod	fraction	0.0035-0.05	0.005-0.045
y_n_conc_max_pod	N partitioning to leaf	fraction	0.015-0.07	0.01-0.06

Example1: Effect of Parameterisation of APSIM Winter Wheat

Yield and N uptake





Example 2: Parameterisation of Crop Phenology in APSIM Barley

factorial based parameterisation, 2 steps for different growth stage, 4 locations, 5 years

Kumar et al. (2021)

calibrated parameters

	Variety											
Parameter	**Alvari**	**Anneli**	**Aukusti**	**GN10063**	**Judit**	**Kaarle**	**Kannas**	**Rodhette**	**Severi**	**Vertti**	**Vilde**	**Vilgot**
Calibration 1_ AN												
photop_sens	1	1	0	0	0	1	0	1	1	0	0	0
vern_sens	0	0	1	0.5	1	0	0	0	0	0.5	0	0.5
tt_end_of_juvenile (°Cd)	300	300	200	200	200	300	300	300	300	200	300	300
tt_floral_initiation (°Cd)	320	320	300	320	300	320	320	320	300	320	320	300
tt_start_grain_fill (°Cd)												
RMSE (d)	1.3	0.7	0	1	0.4	0.7	0	0.7	2	0.8	0	0
Calibration 2_PM												
photop_sens	6	1	0	3	1	3	1	6	0	6	0	0
vern_sens	0	0	0.5	0	0	0	0	0	0.5	0	0.5	0.5
tt_end_of_juvenile (°Cd)	250	300	200	200	200	350	300	300	250	250	300	250
tt_floral_initiation (°Cd)	300	320	300	320	300	300	320	320	300	300	320	300
tt_start_grain_fill (°Cd)	525	525	575	625	575	550	575	550	575	525	500	575
RMSE (d)	4.5	3	2.2	7.5	2.5	8.6	8.2	8.5	4	6.7	6	3.5

- Barley varieties of different maturity bred for short growing seasons in high latitude

- Different thermal time requirements
  - ➢ important for cultivar selection
  - ➢ effect of climate change

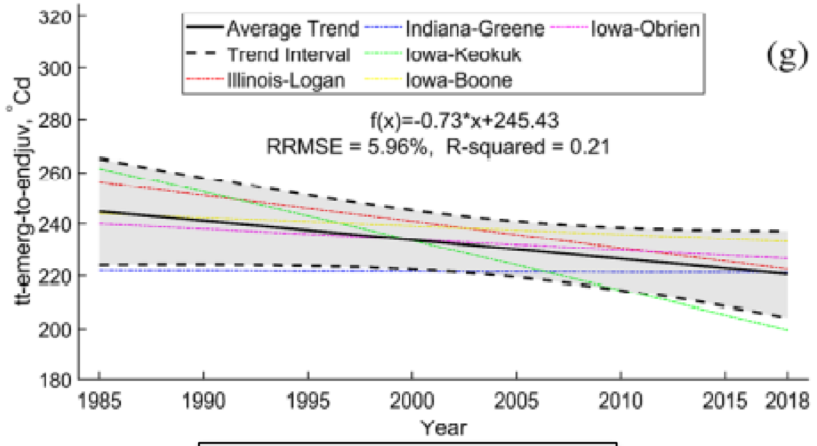
- What does this mean for future varieties, are we always one step behind the breeders?

Kumar, U., Morel, J., Bergkvist, G., Palosuo, T., Gustavsson, A.M., Peake, A., Brown, H., Ahmed, M., Parsons, D., 2021. Comparative analysis of phenology algorithms of the spring barley model in APSIM 7.9 and APSIM next generation: A case study for high latitudes. Plants 10, 1-24.

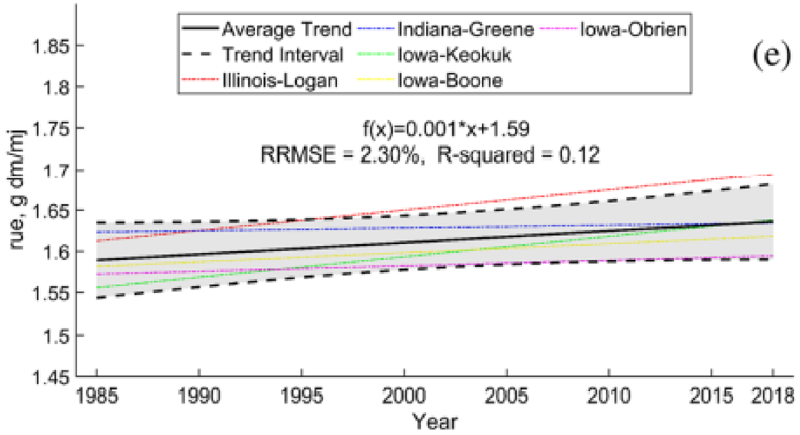
Example 3: Parameterisation of Maize Cultivars – Breeding Progress

Akhavizadegan *et al.* (2021)

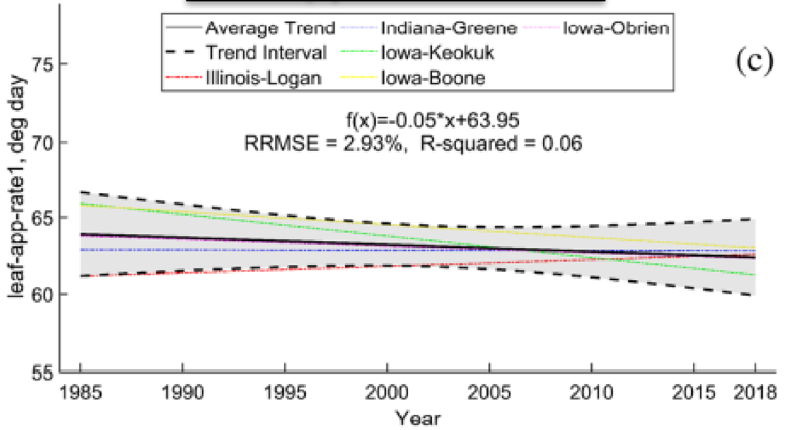
TT emergence to end of juvenile



RUE



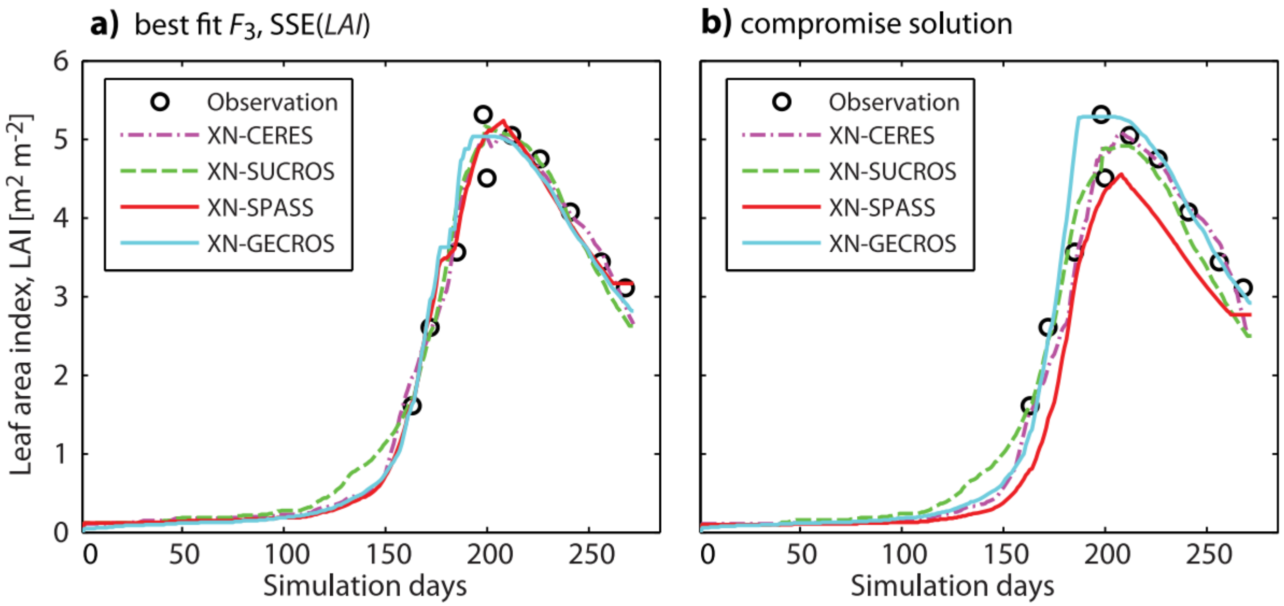
leaf appearance rate



Akhavizadegan, et al. (2021) *A time-dependent parameter estimation framework for crop modeling.* Scientific Reports, 11(1).

MULTIPLE OBJECTIVE CALIBRATION

Wöhling et al. (2013)



- to detect structural deficiencies of models
- observations on at least one state variable in the soil compartment (soil moisture), one variable describing plant development (LAI), and latent heat flux data (ETa) are required to accurately calibrate soil-plant models.

Wöhling, T., Gayler, S., Priesack, E., Ingwersen, J., Wizemann, H.D., Högy, P., Cuntz, M., Attinger, S., Wulfmeyer, V., Streck, T., 2013. Multiresponse, multiobjective calibration as a diagnostic tool to compare accuracy and structural limitations of five coupled soil-plant models and CLM3.5. Water Resources Research 49, 8200-8221.