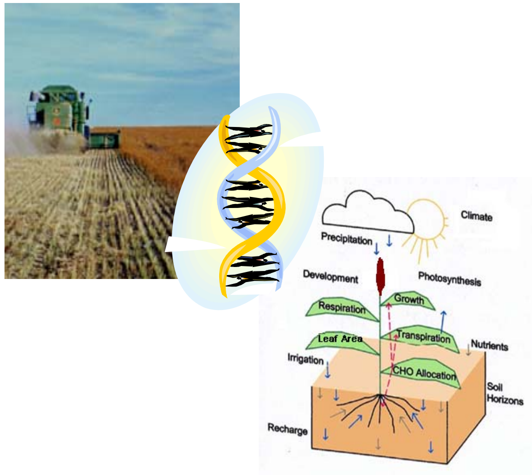
Physiological determinants framework for modelling crop growth and development

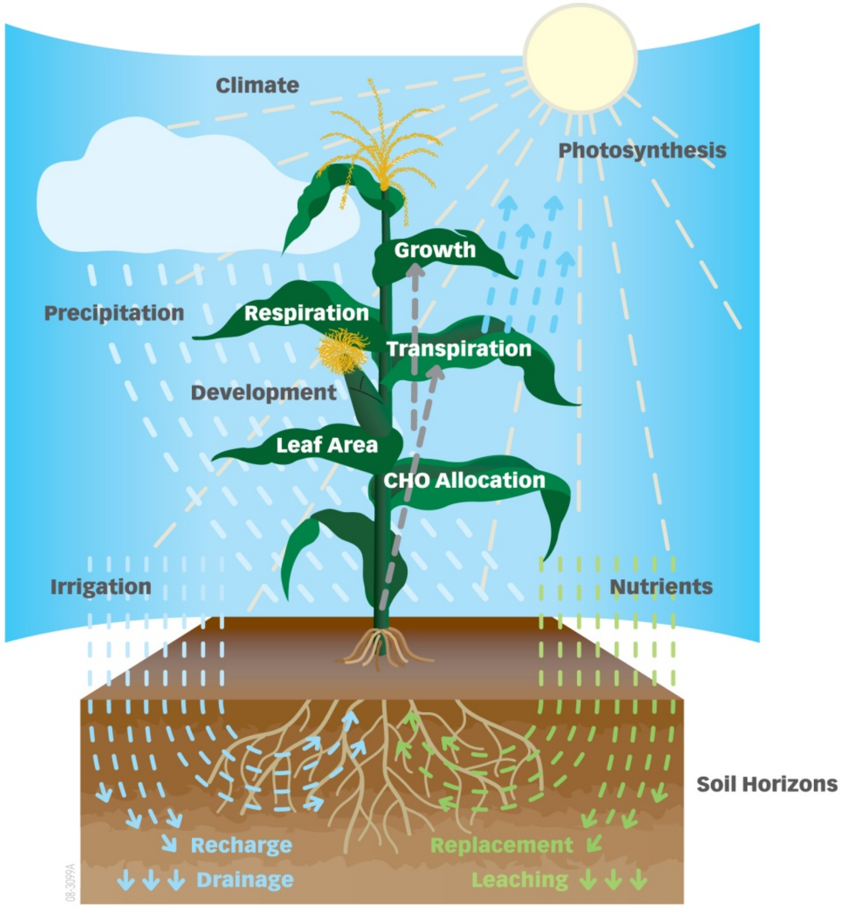


Graeme Hammer [and many others]

Centre for Plant Science
Queensland Alliance for Agriculture and Food Innovation
The University of Queensland

Working together with the
Queensland Government

Yield = Resource Capture • Resource Use Efficiency • Partitioning



Water Capture

Transpiration Efficiency

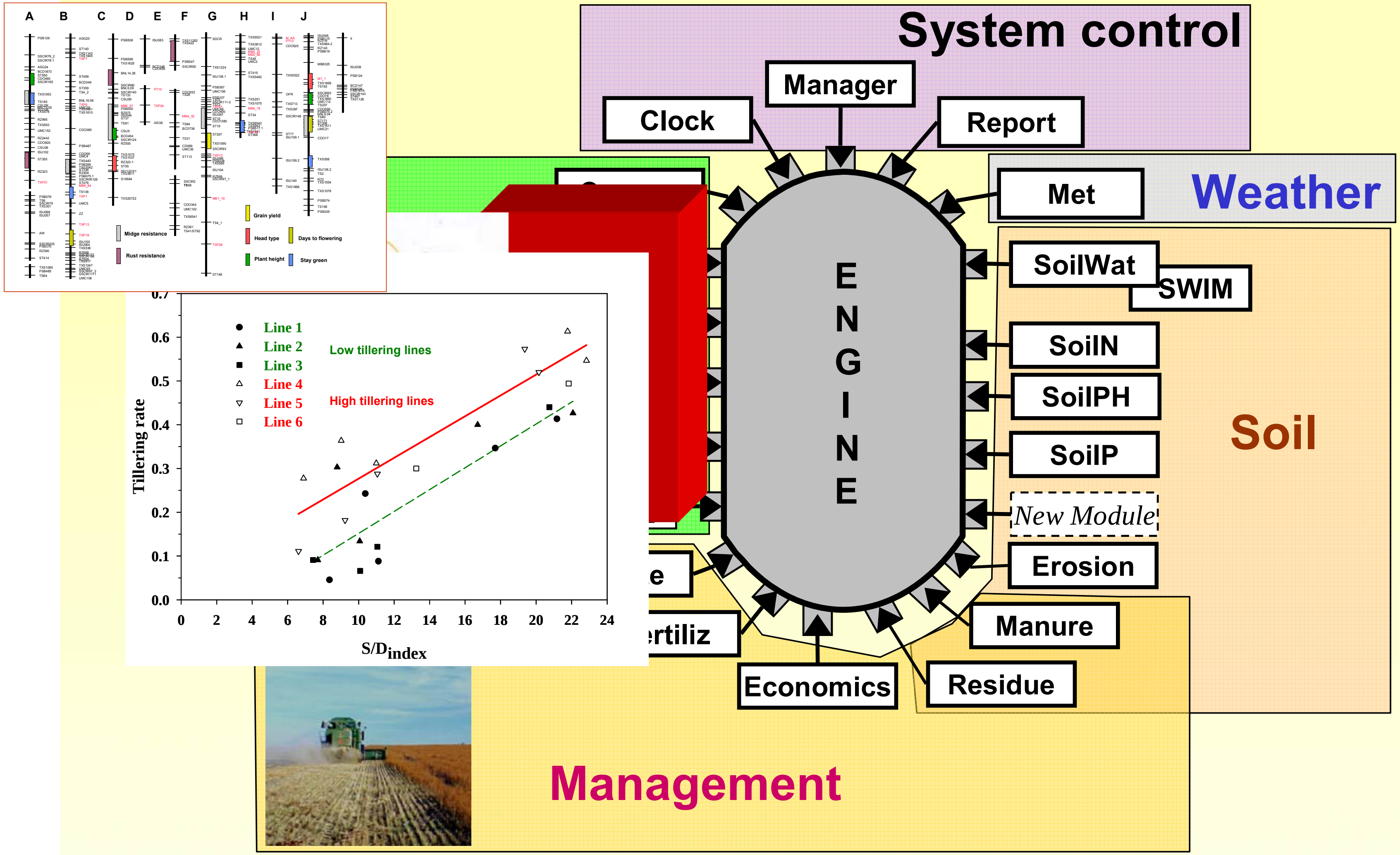
Water Status – critical period

Water use partitioning

Biomass partitioning

Yield = Genotype-by-Environment-by-Management Interactions

APSIM Modelling Platform & G*M*E



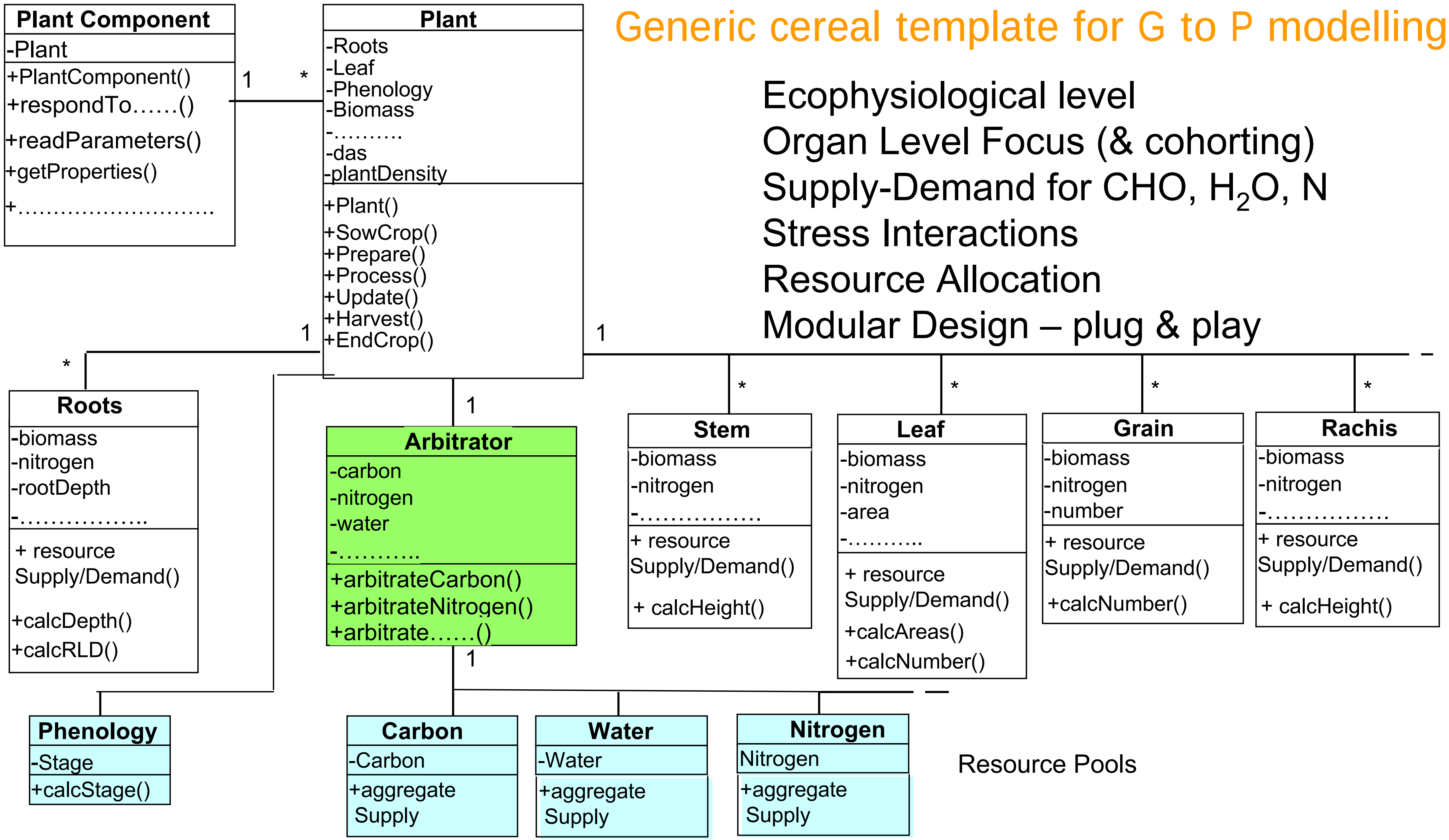
Wang et al (2002) *Eur. J. Agron* 18:121-140.

Keating et al (2003) *Eur. J. Agron* 18:267-288.

APSIM Modelling Platform & G*M*E

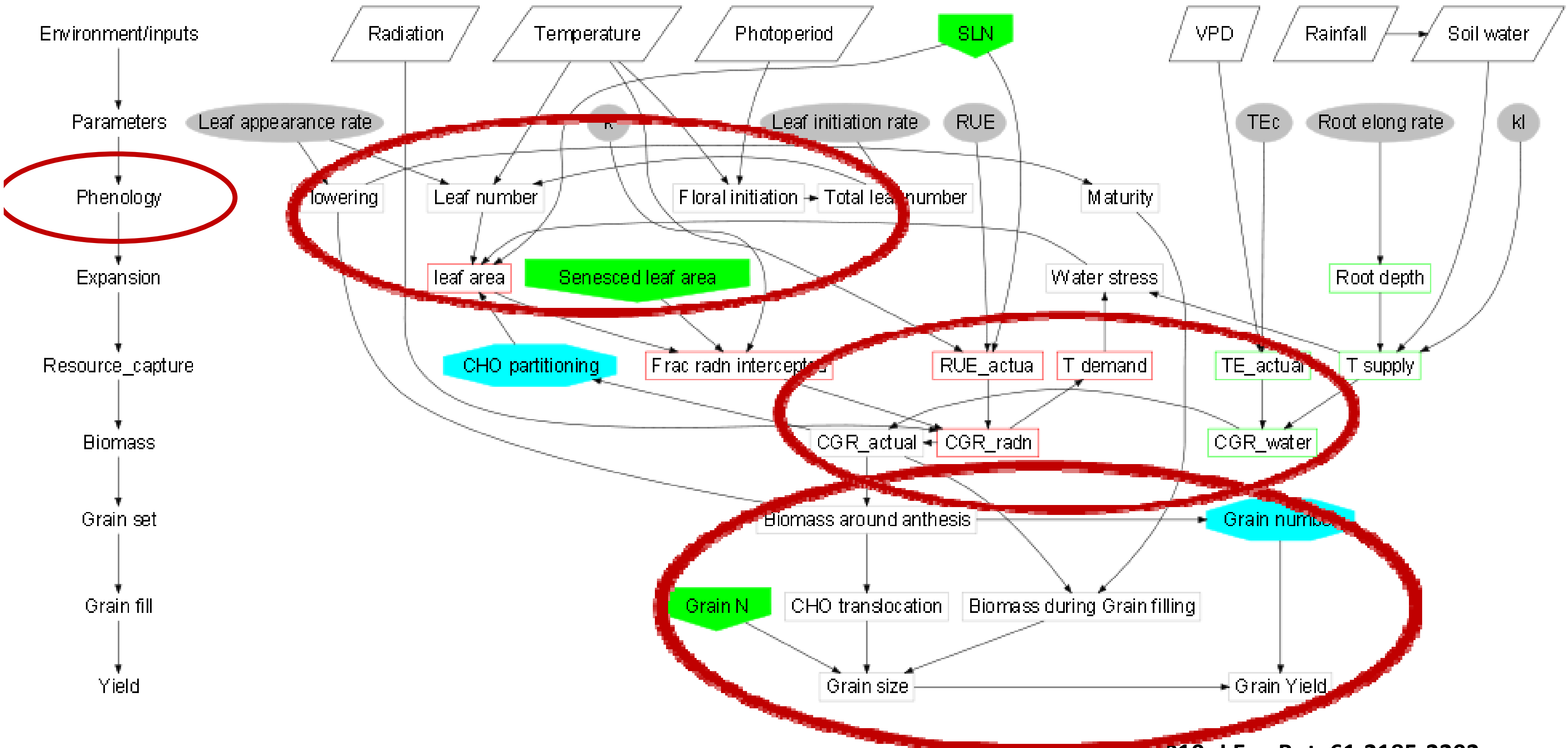
Generic cereal template for G to P modelling

Ecophysiological level
Organ Level Focus (& cohorting)
Supply-Demand for CHO, H_2O, N
Stress Interactions
Resource Allocation
Modular Design – plug & play



APSIM Cereal Crop Modelling Template

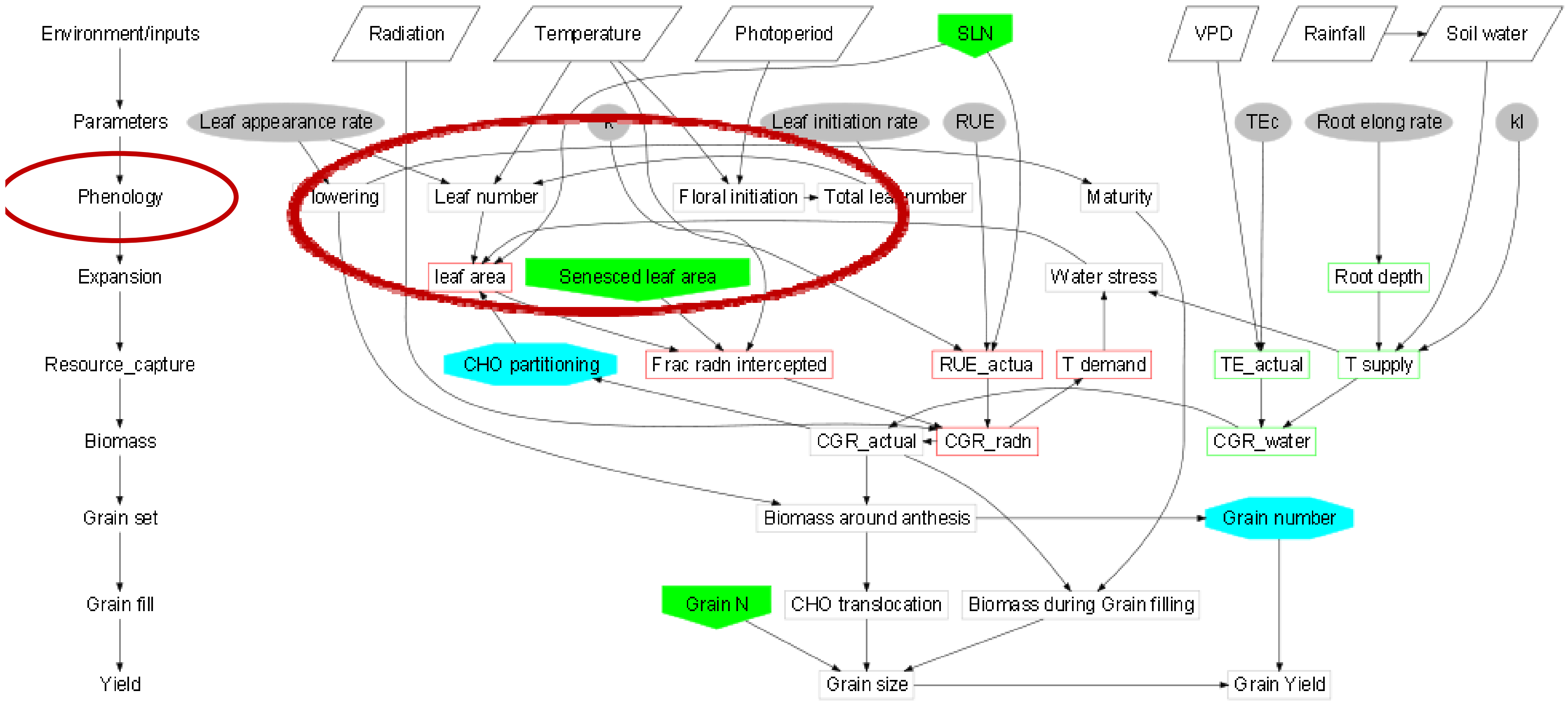
The dynamics of the tangled web of interactions and feedbacks - “functional physiology” design for trait G-to-P modelling



Hammer et al. 2010. J Exp Bot, 61:2185-2202

APSIM Cereal Crop Modelling Template

The dynamics of the tangled web of interactions and feedbacks - “functional physiology” design for trait G-to-P modelling



Hammer et al. 2010. J Exp Bot, 61:2185-2202

APSIM Cereal Crop Modelling Template

Phenology - Development Stages

Stage Code	Stage Name	Starting processes	Equivalent Zadok's
1	Sowing	Seed germination	0
2	Germination	Emergence, leaf initiation	5
3	Emergence	Vegetative growth (LAI, DM), water/N uptake	10
4	End of Juvenile Stage	Photoperiodism	10
5	Floral Initiation	Spikelet initiation	15
6	Flag Leaf	Active ear growth	40
7	Anthesis	Setting grain numbers	60
8	Start of Grain Filling	Active grain growth	71
9	End of Grain Filling	Maturity	87
10	Physiological Maturity	Grain moisture loss	90
11	Harvest Ripe		93
12	End Crop		100

APSIM Cereal Crop Modelling Template

Phenology (E-I) – temperature and photoperiod effects

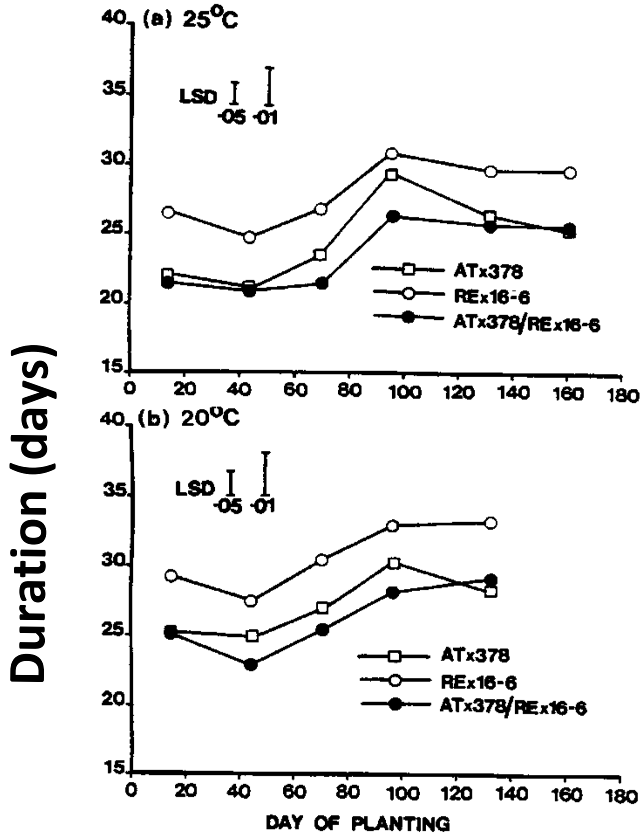
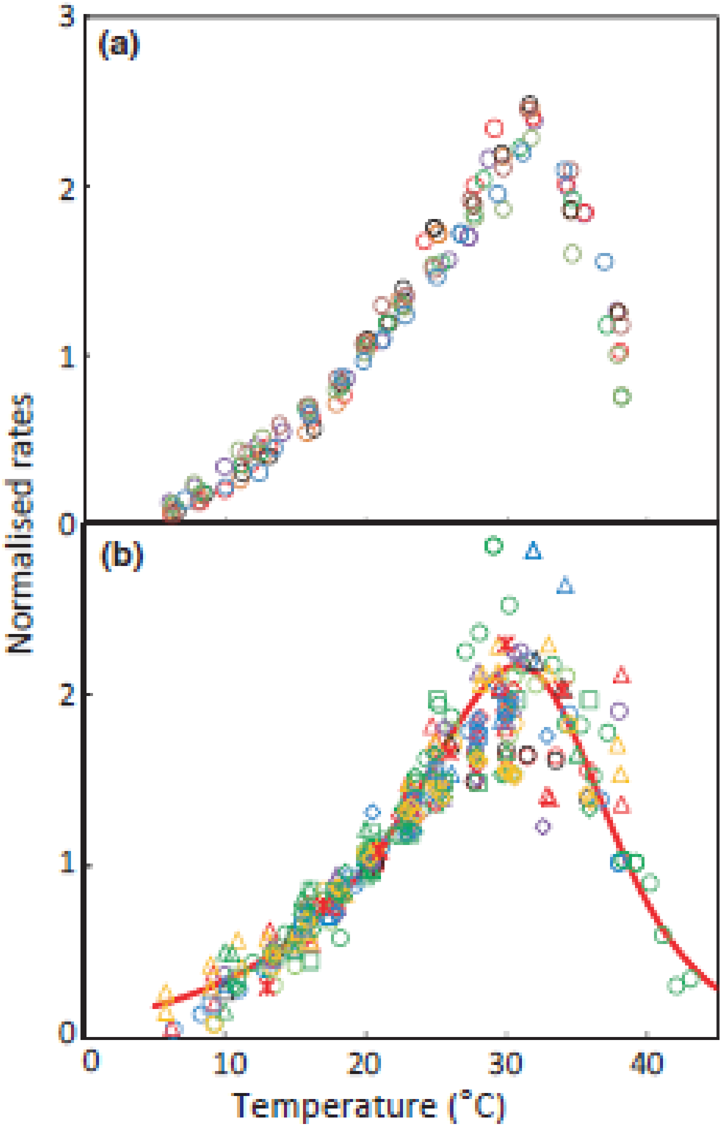


Fig. 2. Duration of GS1 at each planting date for three sorghum genotypes in each temperature treatment.

Duration Emergence to Initiation vs Sowing Time (PP) for Sorghum Grown at Two Temperatures

Hammer et al (1989) Crop Sci.

APSIM Cereal Crop Modelling Template



Temperature effects on development

Parent and Tardieu (2012)
New Phytologist

APSIM Cereal Crop Modelling Template

Phenology and Leaf Number

- Leaf Initn Rate = f(T)
- Total Leaf Number consequent on E-I (+ embryonic)

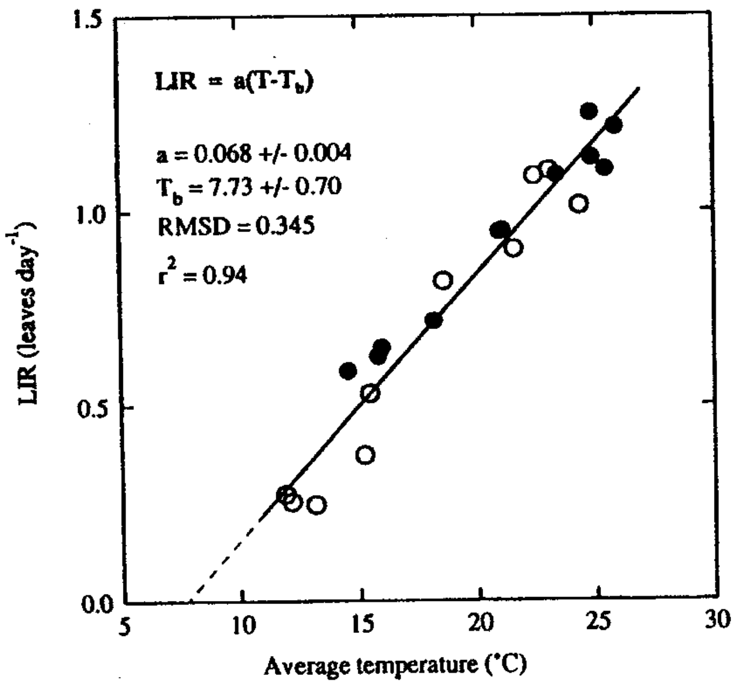
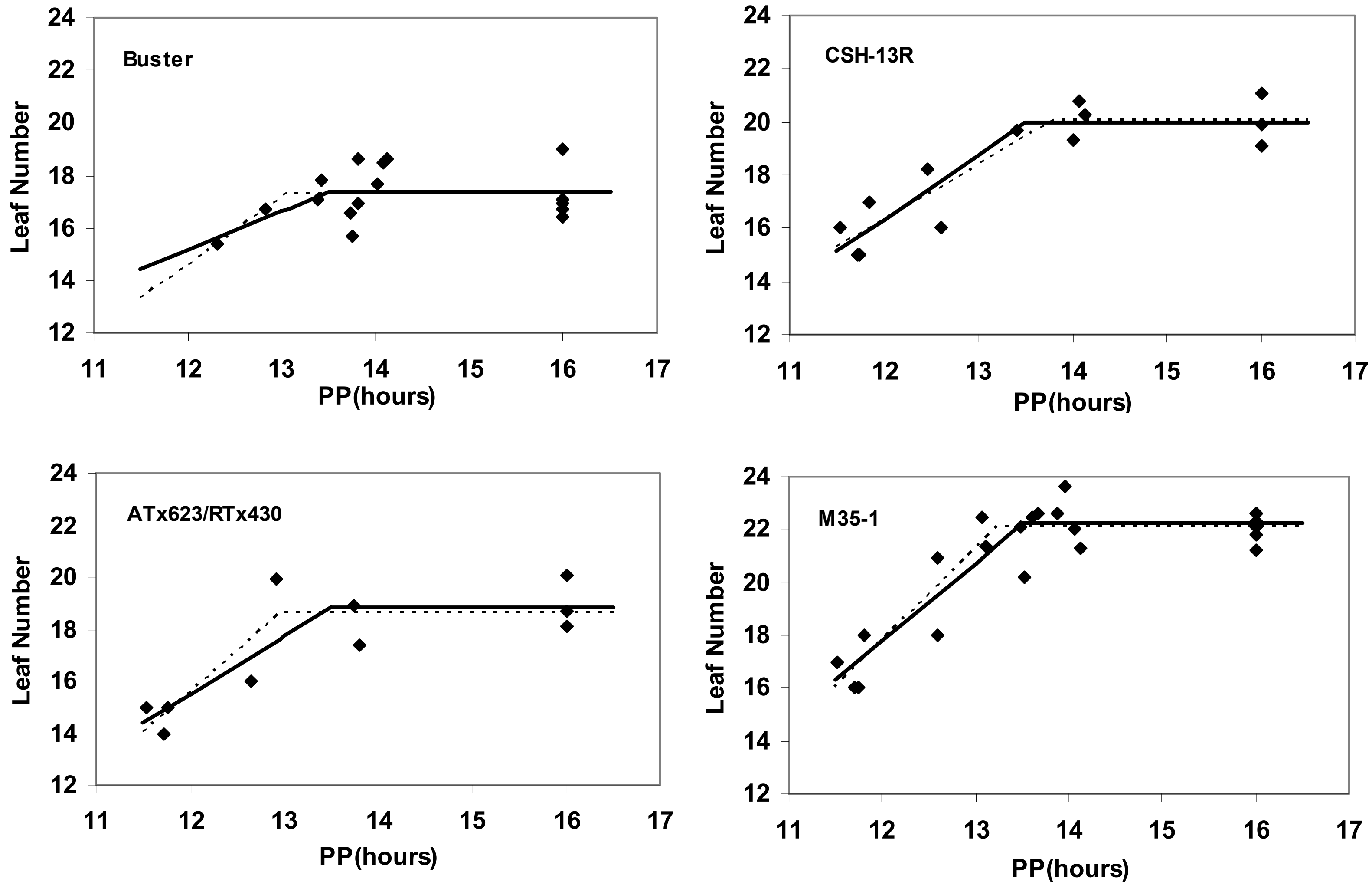


Fig. 3. Average leaf initiation rate (LIR) versus average temperature from emergence to head visible for a series of monthly plantings of Sunfola68-2 at Toowoomba (○) and Biloela (●). Source: Goyne et al. (1977, 1982); Goyne, unpublished data).

APSIM Cereal Crop Modelling Template

Phenology and Leaf Number



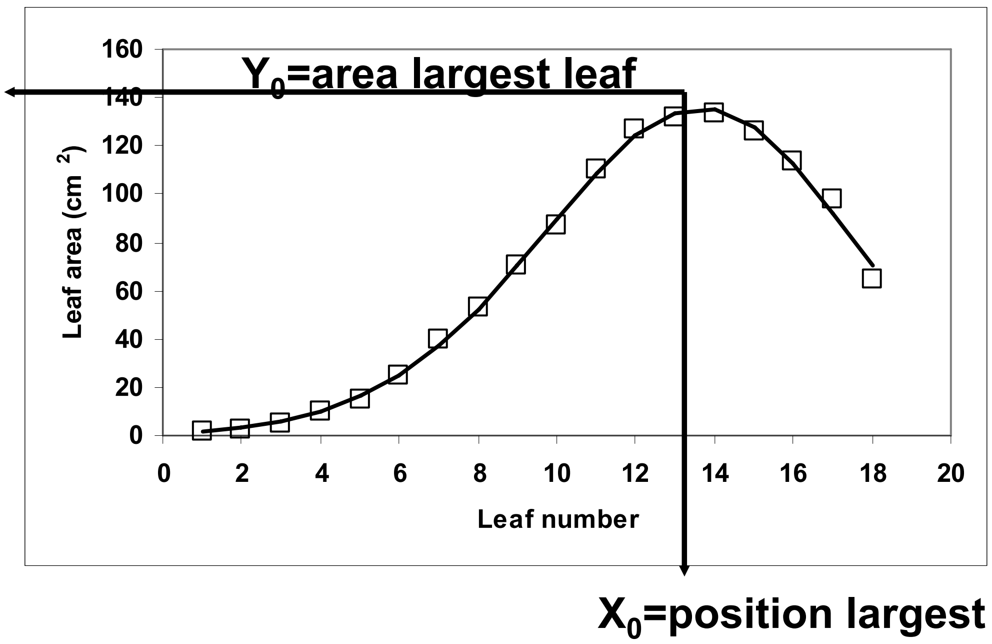
Ravi Kumar et al (2010) Field Crops Res.

APSIM Cereal Crop Modelling Template

Canopy LAI

- Leaf area production driven by T and constrained by H_2O and N
- SLA a consequence within bounds (Tardieu et al., 1999)
- Individual leaf size approach

$$Y=Y_0 \exp(a(X-X_0)^2+b(X-X_0)^3)$$



- All coefficients relate to TLN
- Examples for –

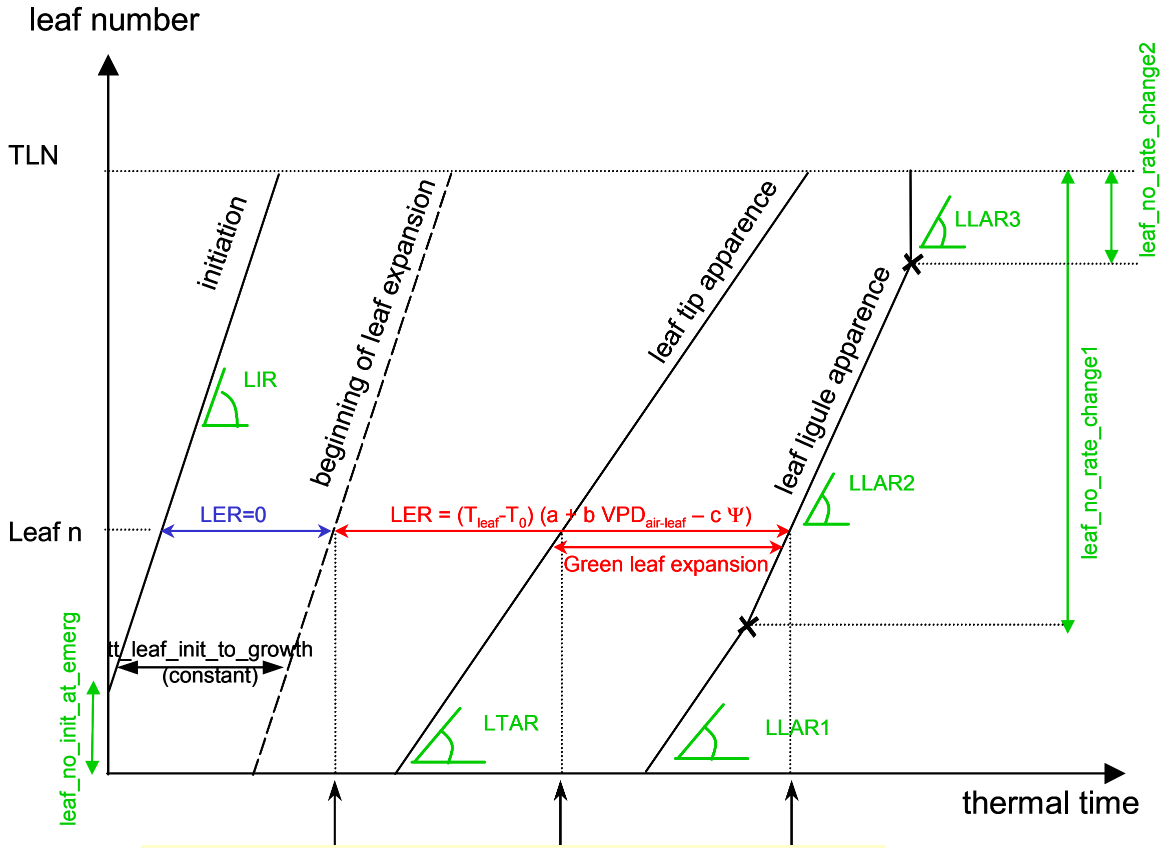
  maize (Carberry, Birch)

  millet (van Oosterom)

  sorghum (Carberry)

APSIM Cereal Crop Modelling Template

Canopy LAI – integrating leaf growth model

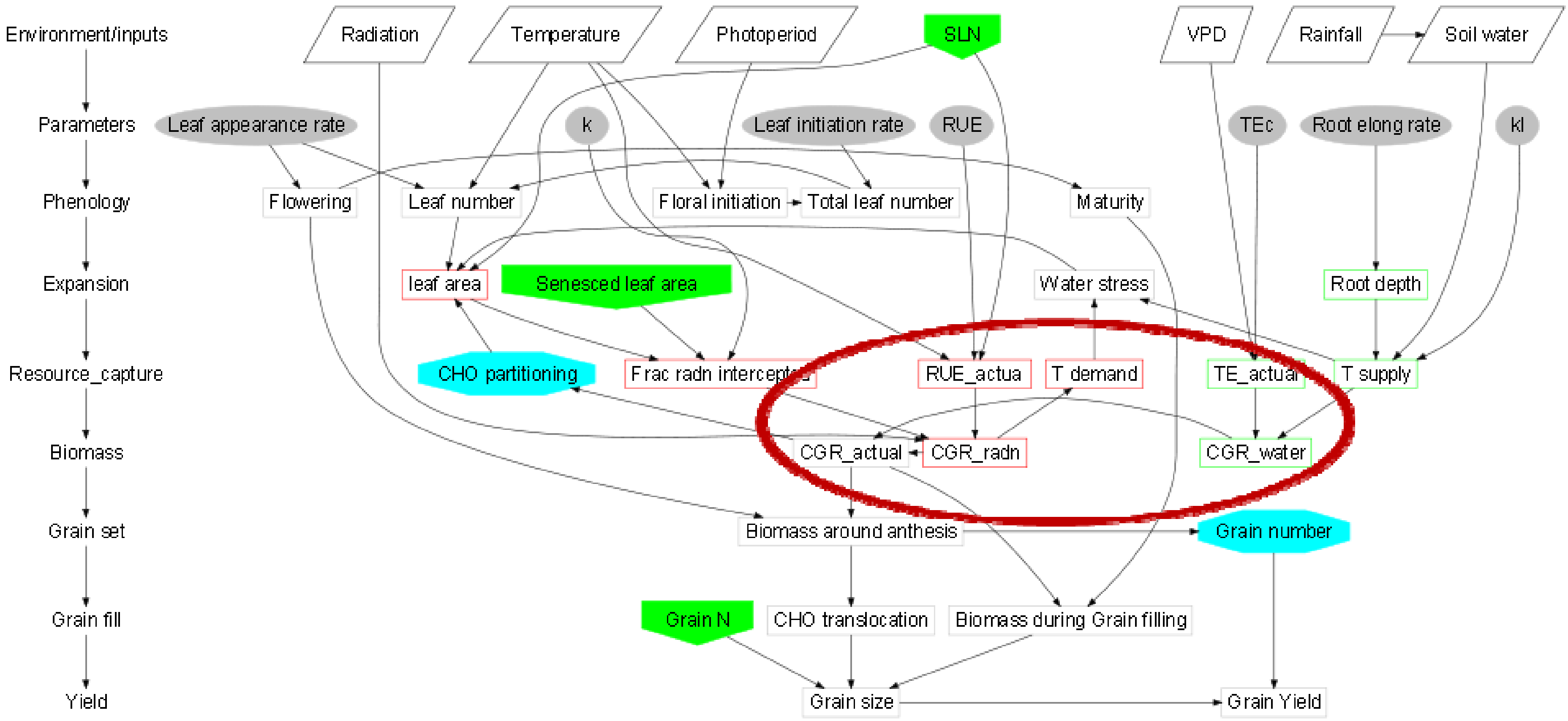


Integrating the individual leaf expansion model in the crop simulation model APSIM (scale integration).

Chenu et al (2008) PCE

APSIM Cereal Crop Modelling Template

The dynamics of the tangled web of interactions and feedbacks - “functional physiology”



Hammer et al. 2010. J Exp Bot, 61:2185-2202

APSIM Cereal Crop Modelling Template

Crop Growth Rate - Δ Biomass

- Resource capture (water or light) approach
- Implicitly incorporates N effects

$$\Delta \text{ biomass} = \min(IR*RUE, T_s*TE)$$

Light limited: $T_{supply} > T_{demand}$

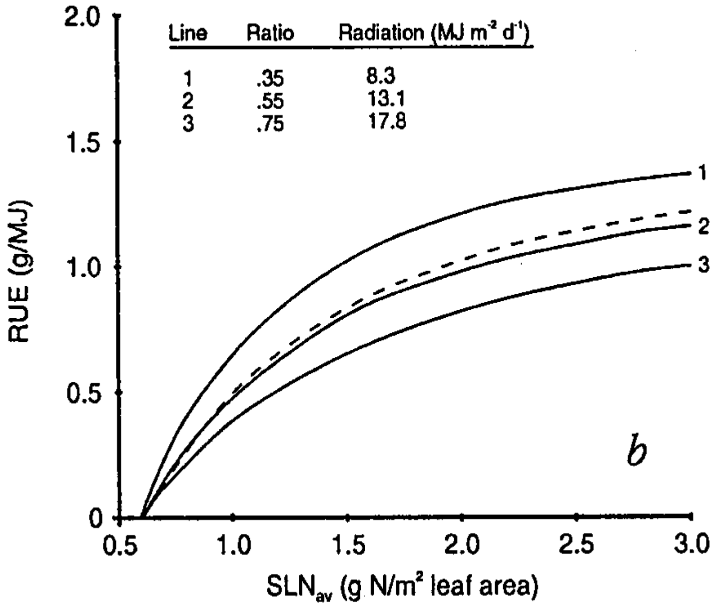
Water limited: $T_{supply} < T_{demand}$

- Based on stomatal regulation as trade-off between CO_2 gain and H_2O loss (Farquhar model)

APSIM Cereal Crop Modelling Template

Δ Biomass – Light Limited

- Δ Biomass = IR * RUE
- RUE and k can be linked to leaf and canopy attributes



RUE = f(SLN and TRATIO)

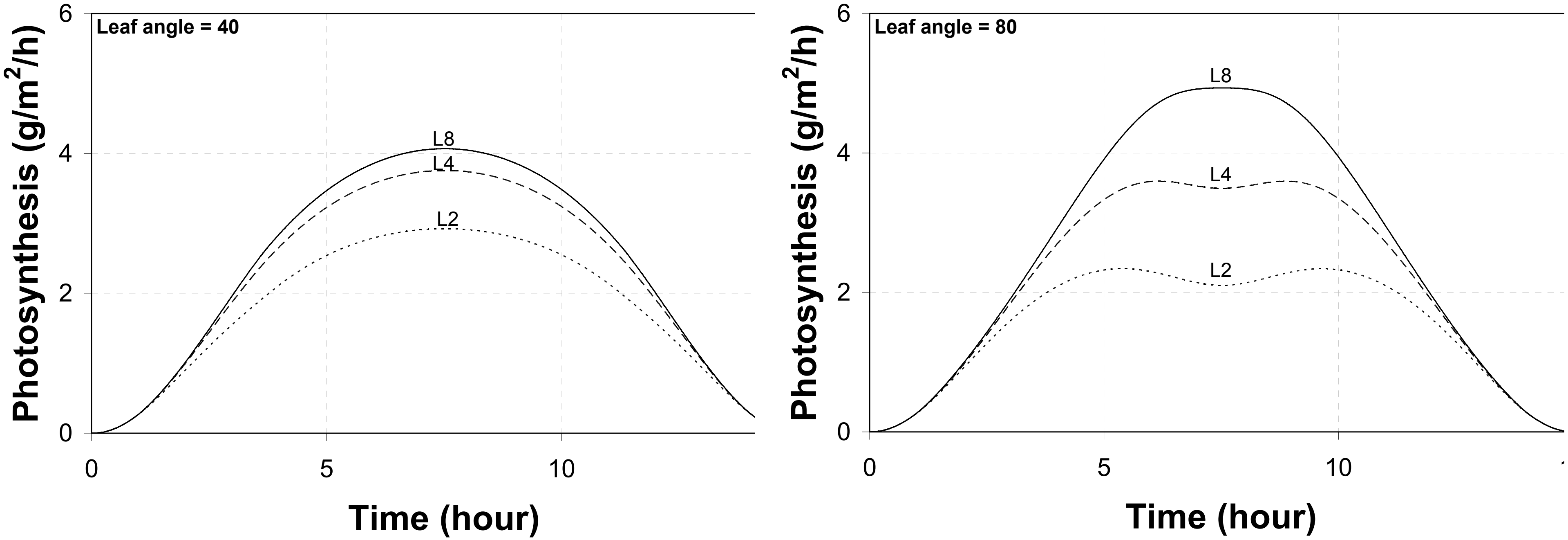
Sinclair and Horie (1989) Crop Sci.

Hammer and Wright (1994) Aust. J. Agric. Res.

- T_d = (IR * RUE)/(TE_c/vpd) TE_c = 9 Pa
- T_d = f(R*vpd) (conductance*gradient)

Δ Biomass – Canopy Photosynthesis Approach

- Light limited Δ Biomass and T_d derived from full layered diurnal canopy photosynthesis model

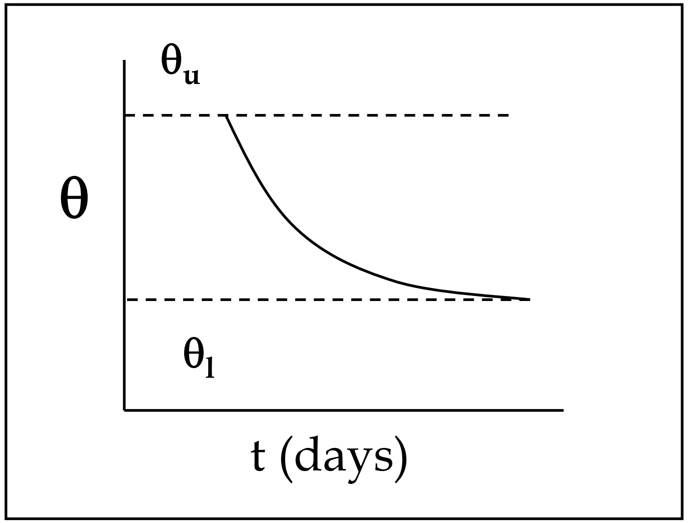


Hammer et al (2009)

APSIM Cereal Crop Modelling Template

Δ Biomass – Water Limited

- Δ Biomass = T_s * TE
- TE = TE_c/vpd where TE_c is intrinsic transpiration efficiency (9Pa for sorghum and maize)
- T_s is ability of roots to extract water from soil
- T_s = f(soil θ, root exploration, uptake rate)



For each soil layer i

$\theta_i = (\theta_u - \theta_l)\, e^{-kl*t}$

where kl = decay constant

$d\theta_i/dt = -kl\ \theta_i$

$T_s = \Sigma\, d\theta_i/dt$

Tanner and Sinclair (1983), Monteith (1986), Passioura (1983)

Water Supply (T_s)

- Water capture by roots $\theta_i = (\theta_u - \theta_l)\, e^{-kl^*t}$ $d\theta_i/dt = -kl\,\theta_i$

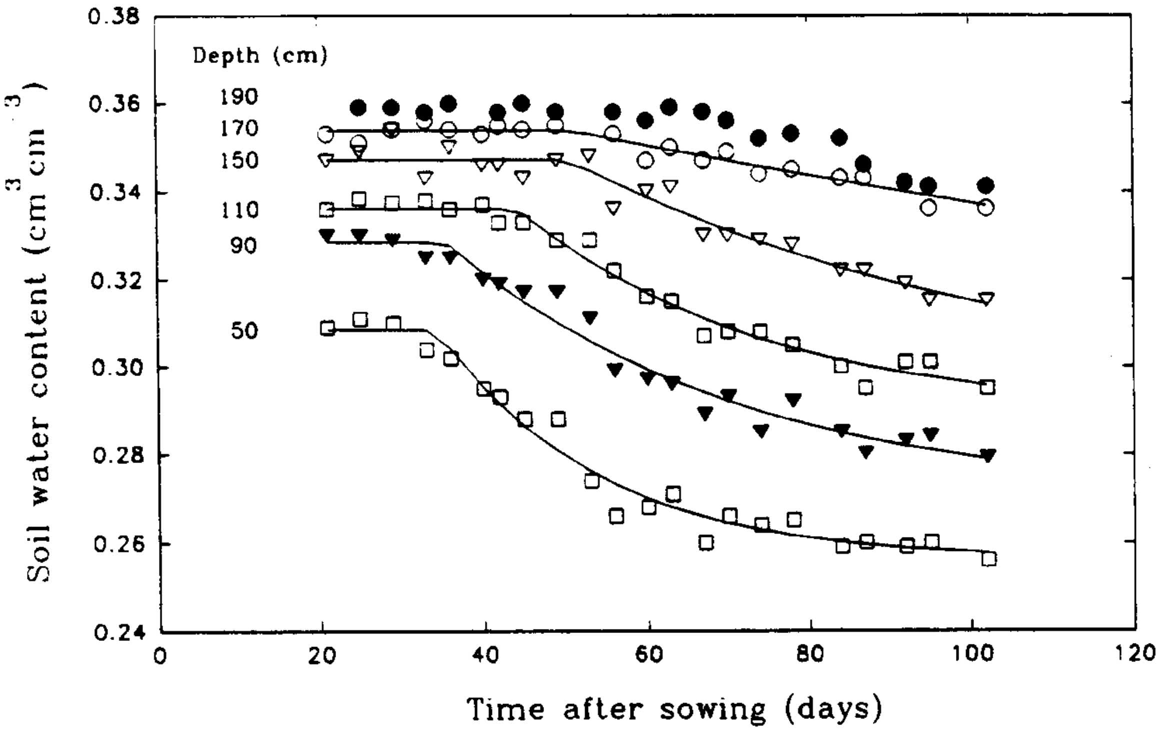


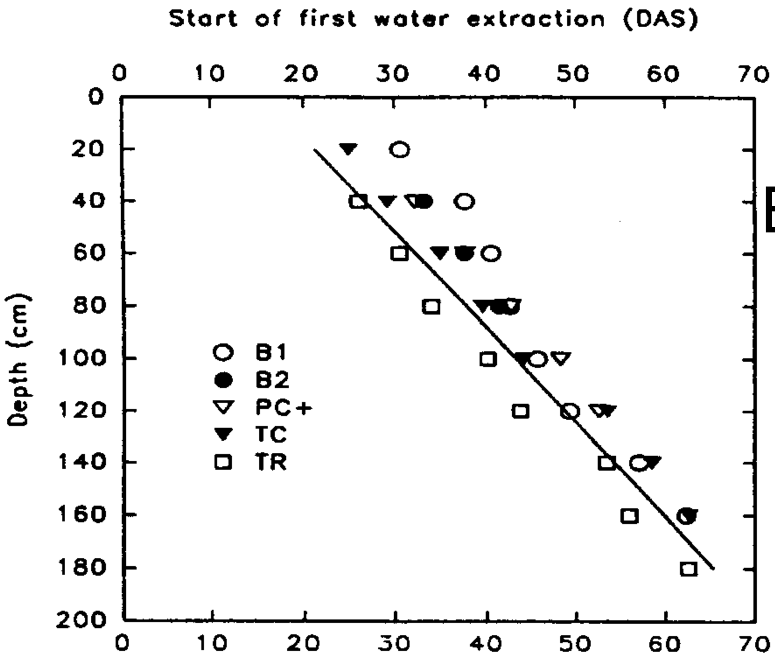
Fig. 1. The water extraction pattern and fitted curves for selected layers measured from one access tube of the +tillers treatment of Experiment 3. A curve was not fitted to the data at 190 cm.

Robertson et al (1993) Field Crops Res.

APSIM Cereal Crop Modelling Template

Roots

- Focus on water capture – kl and EFV



Estimating kl & EFV

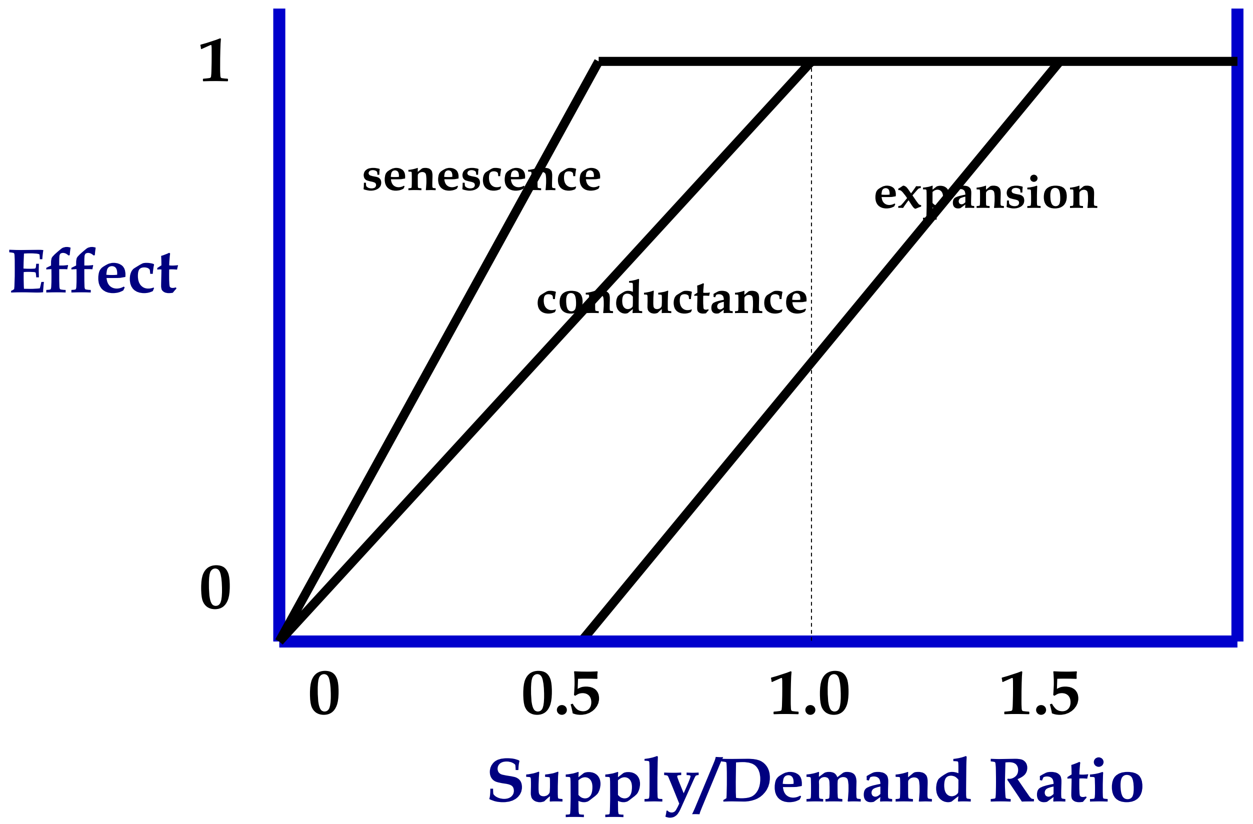
Fig. 5. Start of soil water extraction in a soil layer (t_c) versus depth of the layer for each soil type. The solid line is the potential depth of the extraction front (EF) determined from the combined regression for the two sites most limiting in $MAWC_{20}$ (TC and TR). The solid line describes an EFV of 3.62 cm day^{-1} and a t_0 of 15.7 DAS ($R^2=0.94$).

Meinke et al (1993) Field Crops Res.

APSIM Cereal Crop Modelling Template

Plant Water Status and Canopy LAI

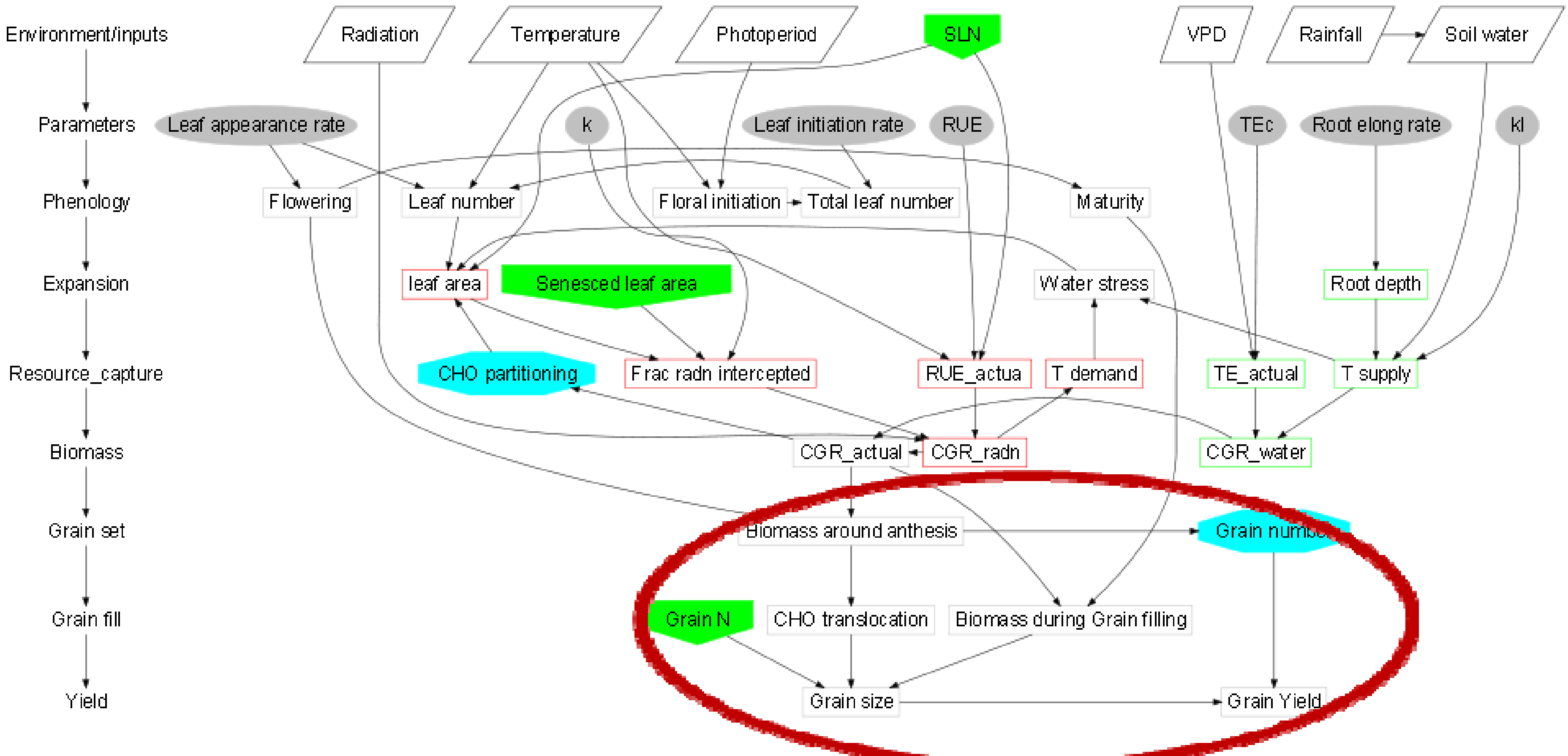
- T_s/T_d is indicator of plant water status
- Crop responses triggered (without modelling hormones)



Hammer et al (2001) Aust. Sorg. Conf.

APSIM Cereal Crop Modelling Template

The dynamics of the tangled web of interactions and feedbacks - “functional physiology”

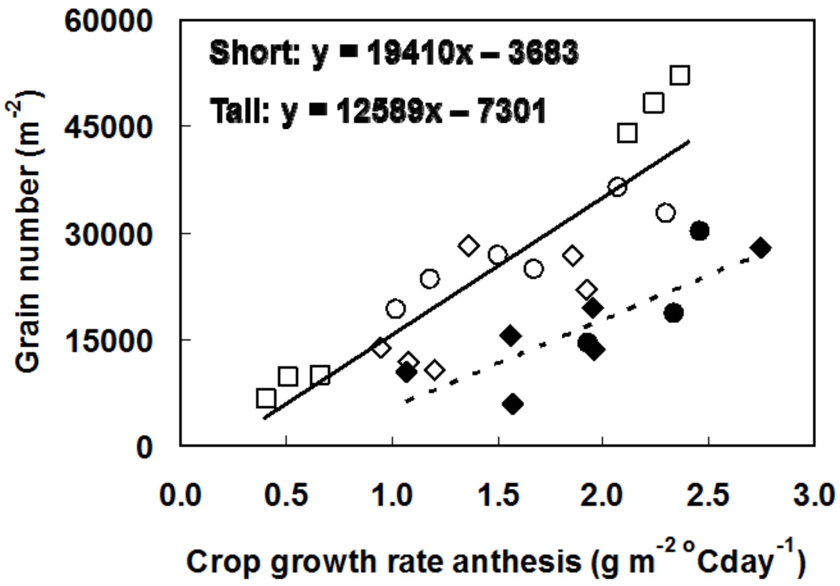


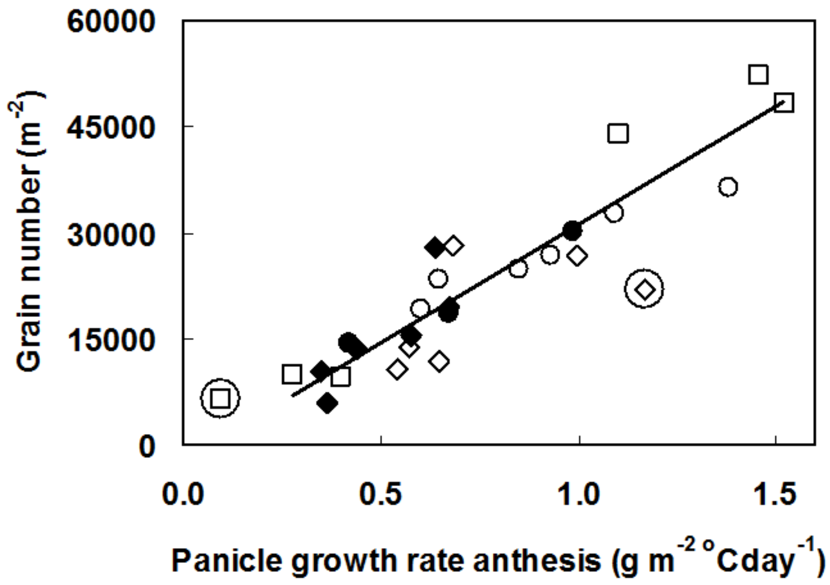
Hammer et al. 2010. J Exp Bot, 61:2185-2202

APSIM Cereal Crop Modelling Template

Grain Number

- Grain Number = f(Growth at A)
- Implicitly accounts for competing sinks and stresses



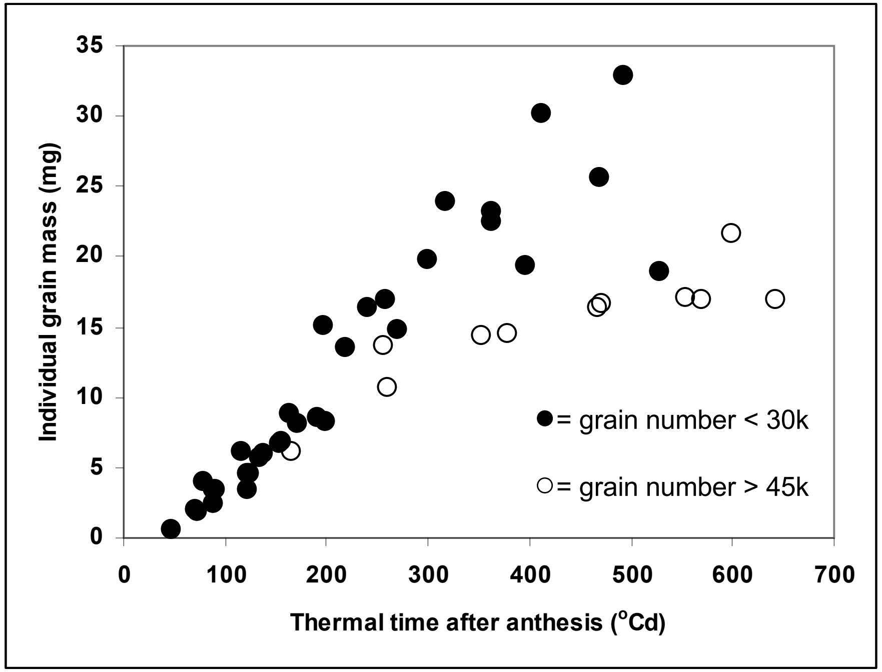


Van Oosterom and Hammer (2005) Field Crops Res.

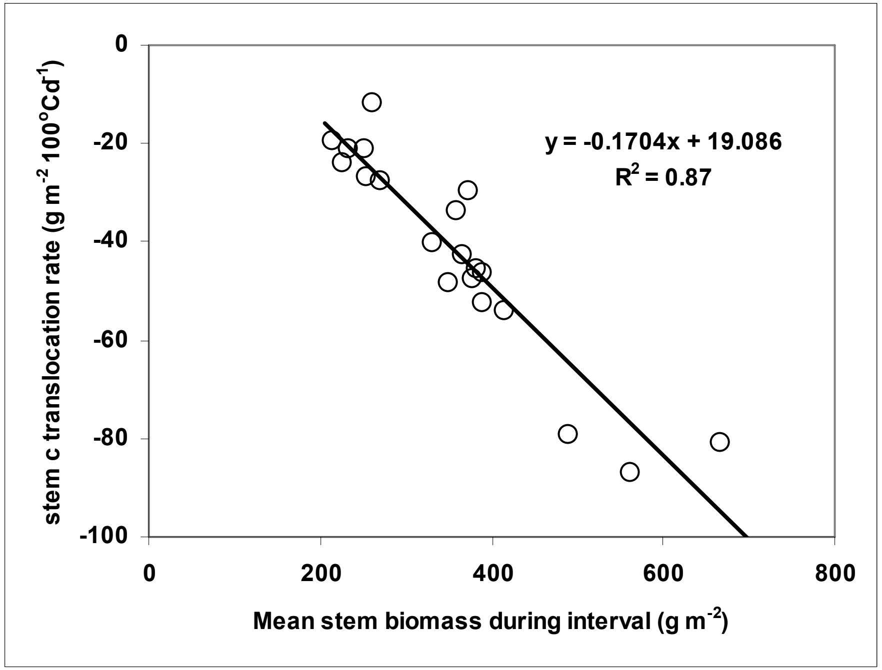
APSIM Cereal Crop Modelling Template

Grain Size - Retranslocation

- Potential dynamic supply-demand framework for C



Demand – potential grain growth rate



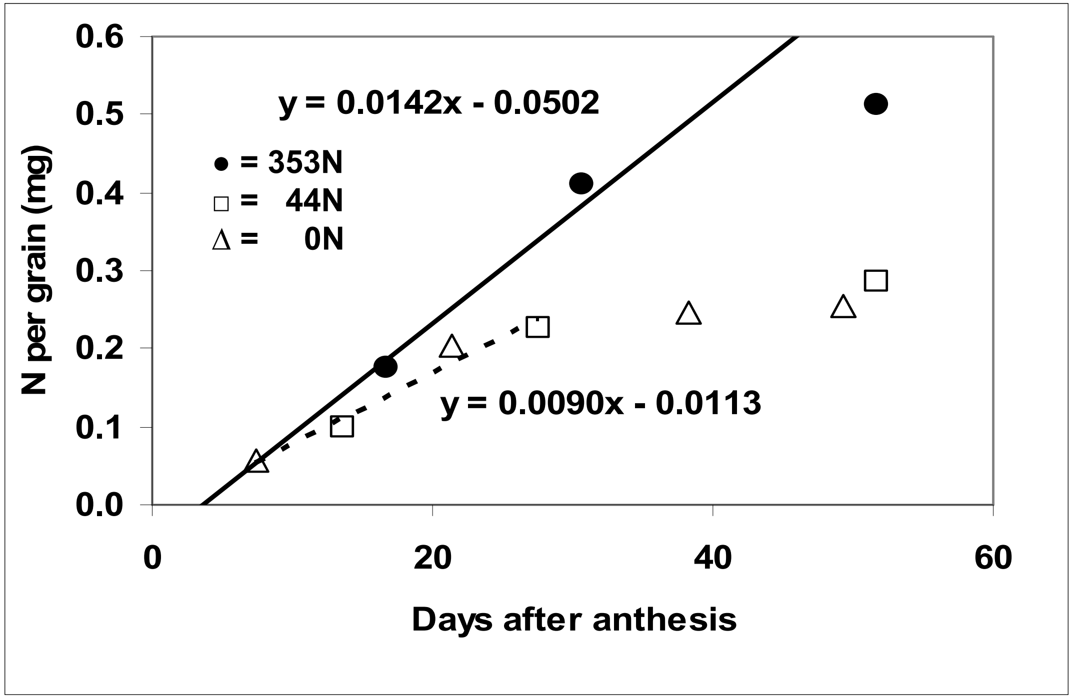
Supply – current assimilation plus stem retranslocation

Sorghum Data – van Oosterom

APSIM Cereal Crop Modelling Template

Grain N

- Dynamic supply-demand framework for N



Demand - potential N per grain (sorghum)

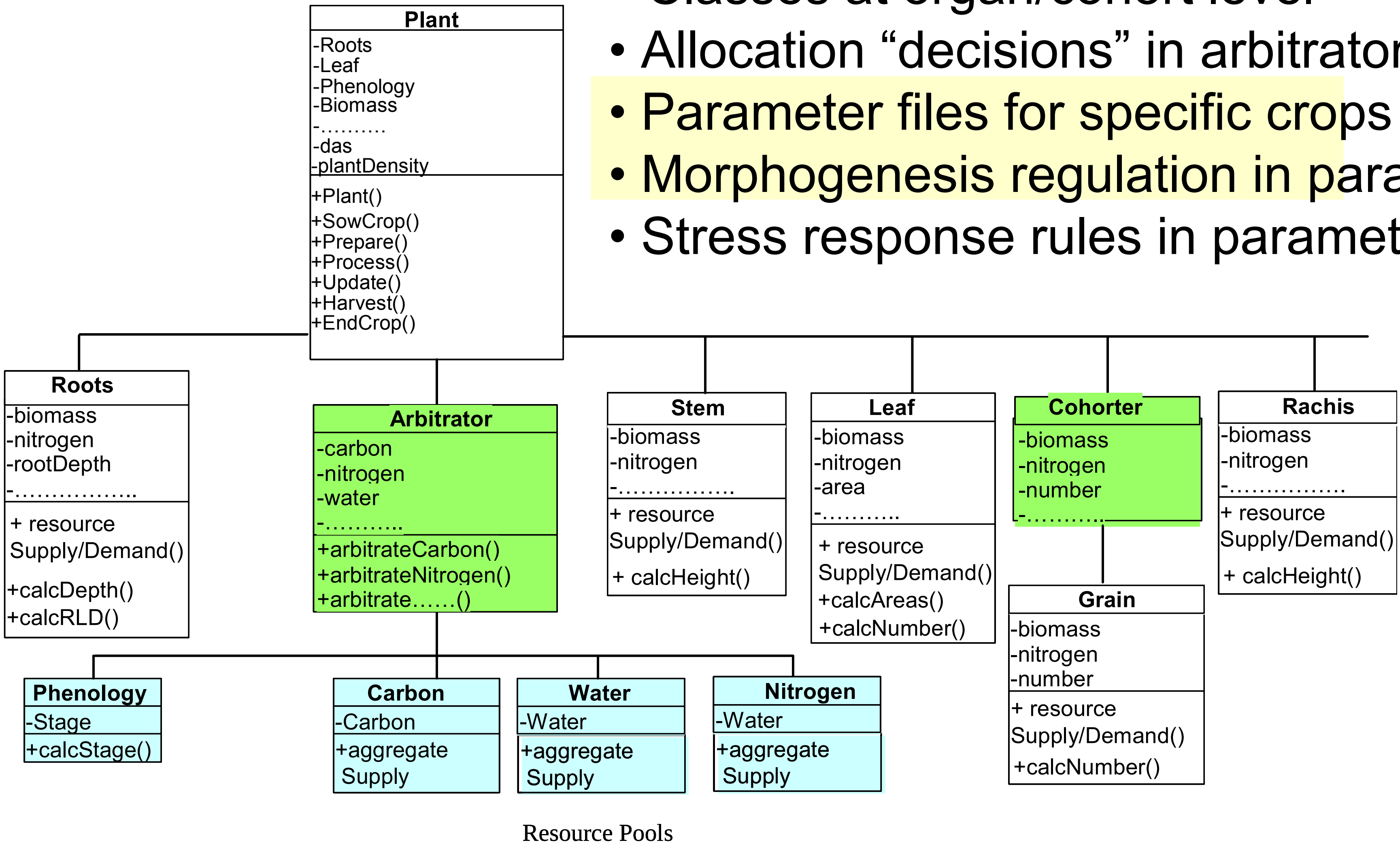
- influenced by Grain Number

Van Oosterom et al (2010) Field Crops Res.

APSIM Cereal Crop Modelling Template

Object Design of Modular Plant System Model

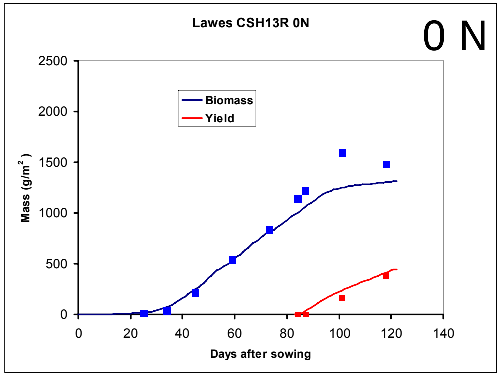
- Classes at organ/cohort level
- Allocation “decisions” in arbitrator
- Parameter files for specific crops
- Morphogenesis regulation in params
- Stress response rules in parameters

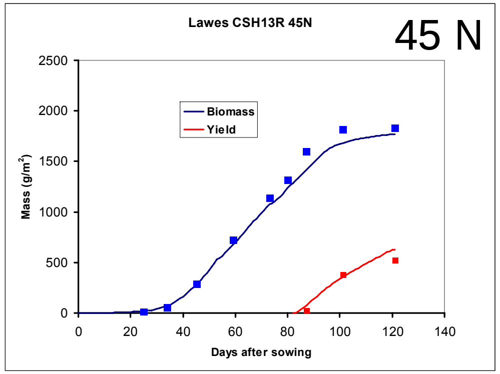


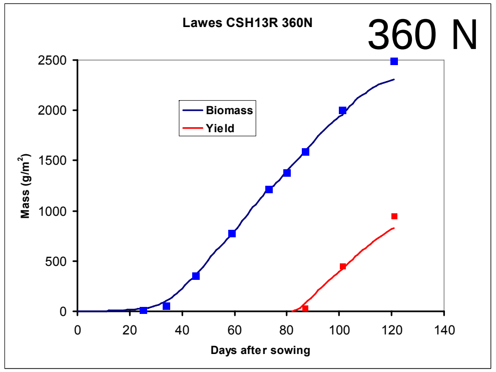
Implementation for Sorghum

- Model Testing
  - Simulation of N rate experiment – Gatton CSH13R (LE21)

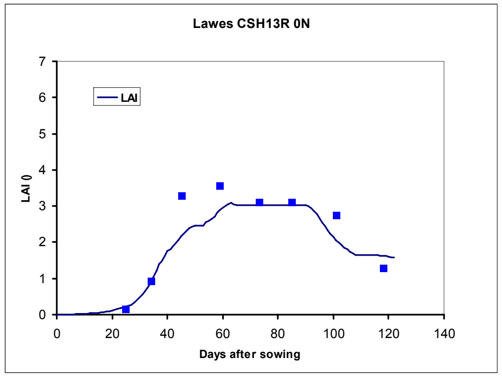
Biomass g m^{-2}

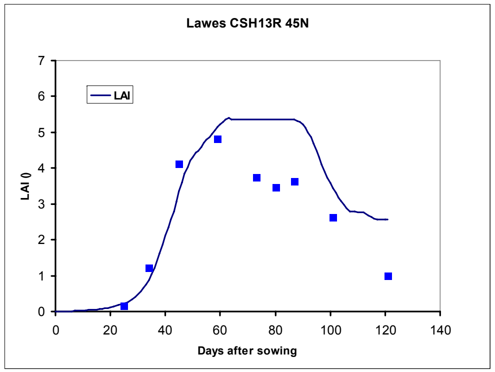


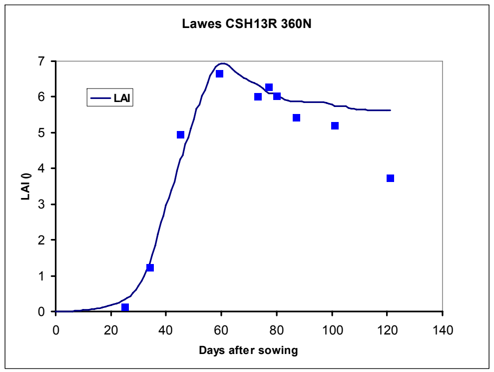




LAI



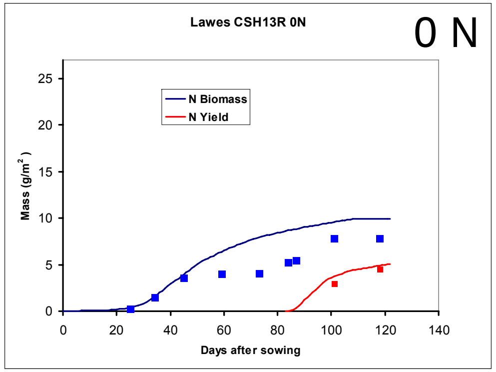


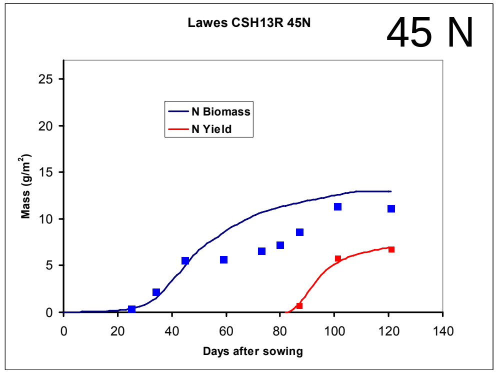


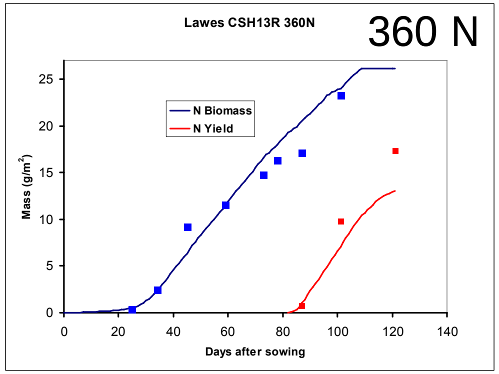
Implementation for Sorghum

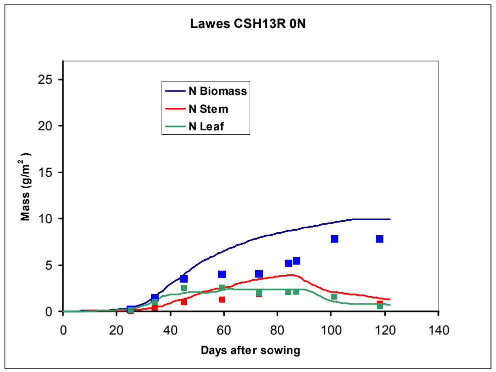
- Model Testing
  - Simulation of N rate experiment – Gatton CSH13R (LE21)

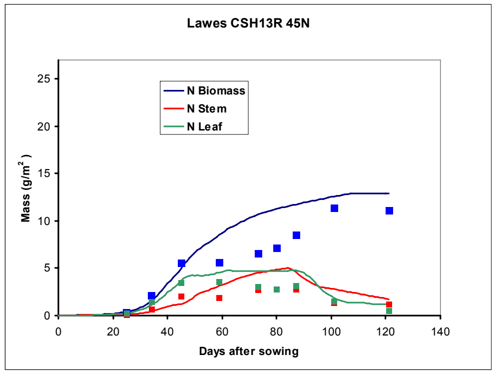
N Mass g m^{-2} (by organ)

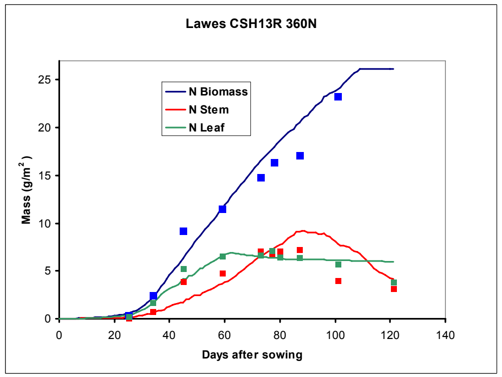








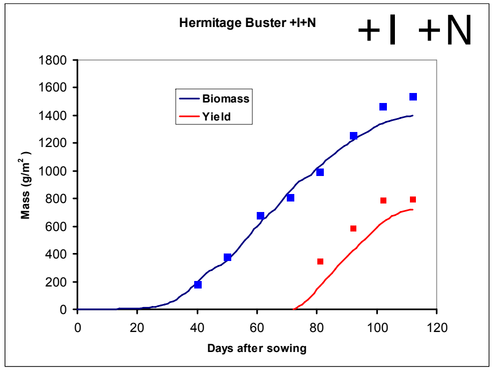


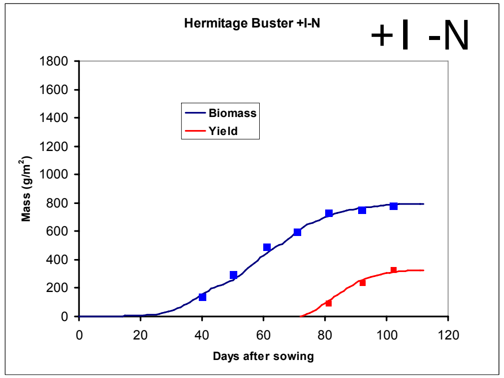


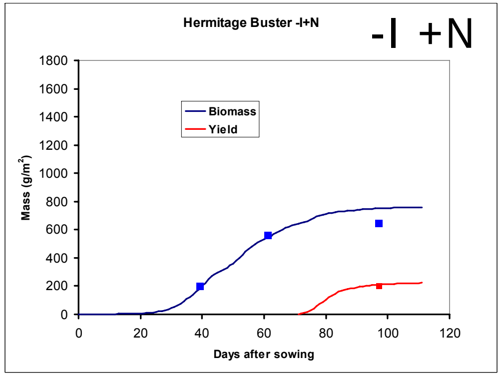
Implementation for Sorghum

- Model Testing
  - Simulation of IxN experiment – Warwick Buster (HE5-7)

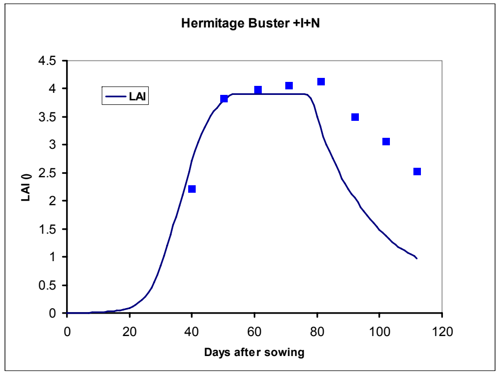
Biomass g m^{-2}

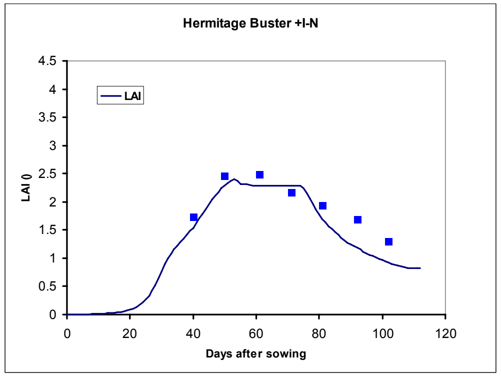


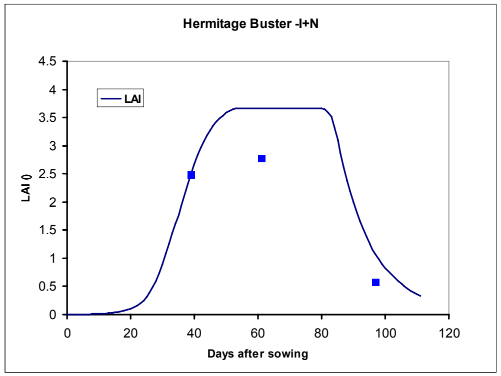




LAI







Implementation for Sorghum

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  - Simulation of IxN experiment – Warwick Buster (HE5-7)

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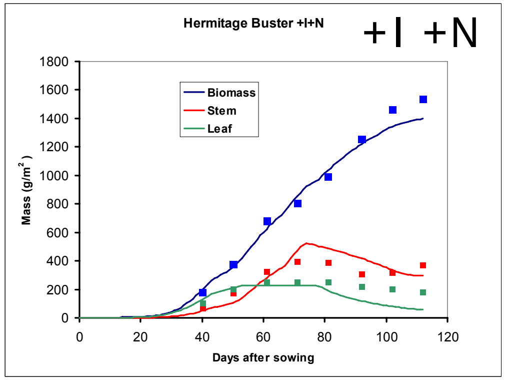
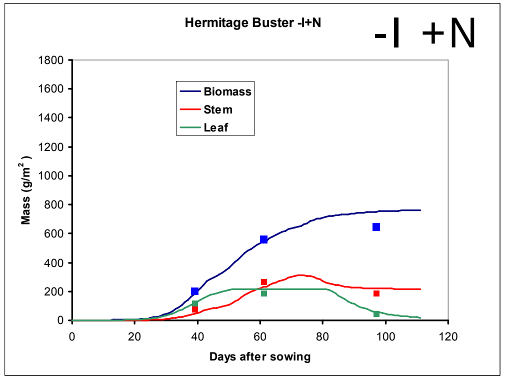
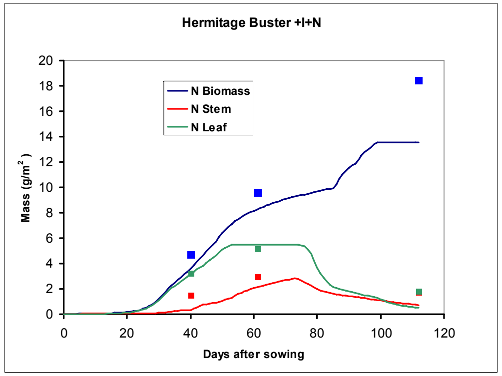
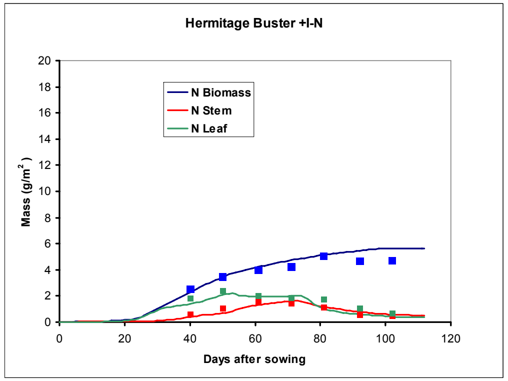
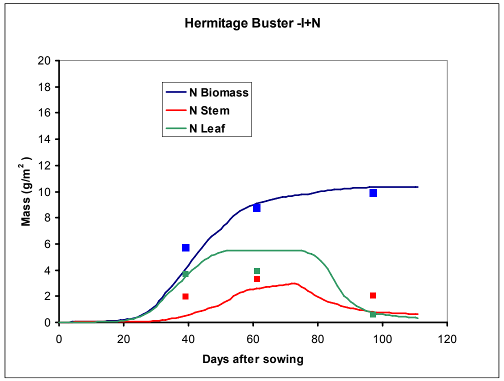




N Mass g m^{-2} (by organ)

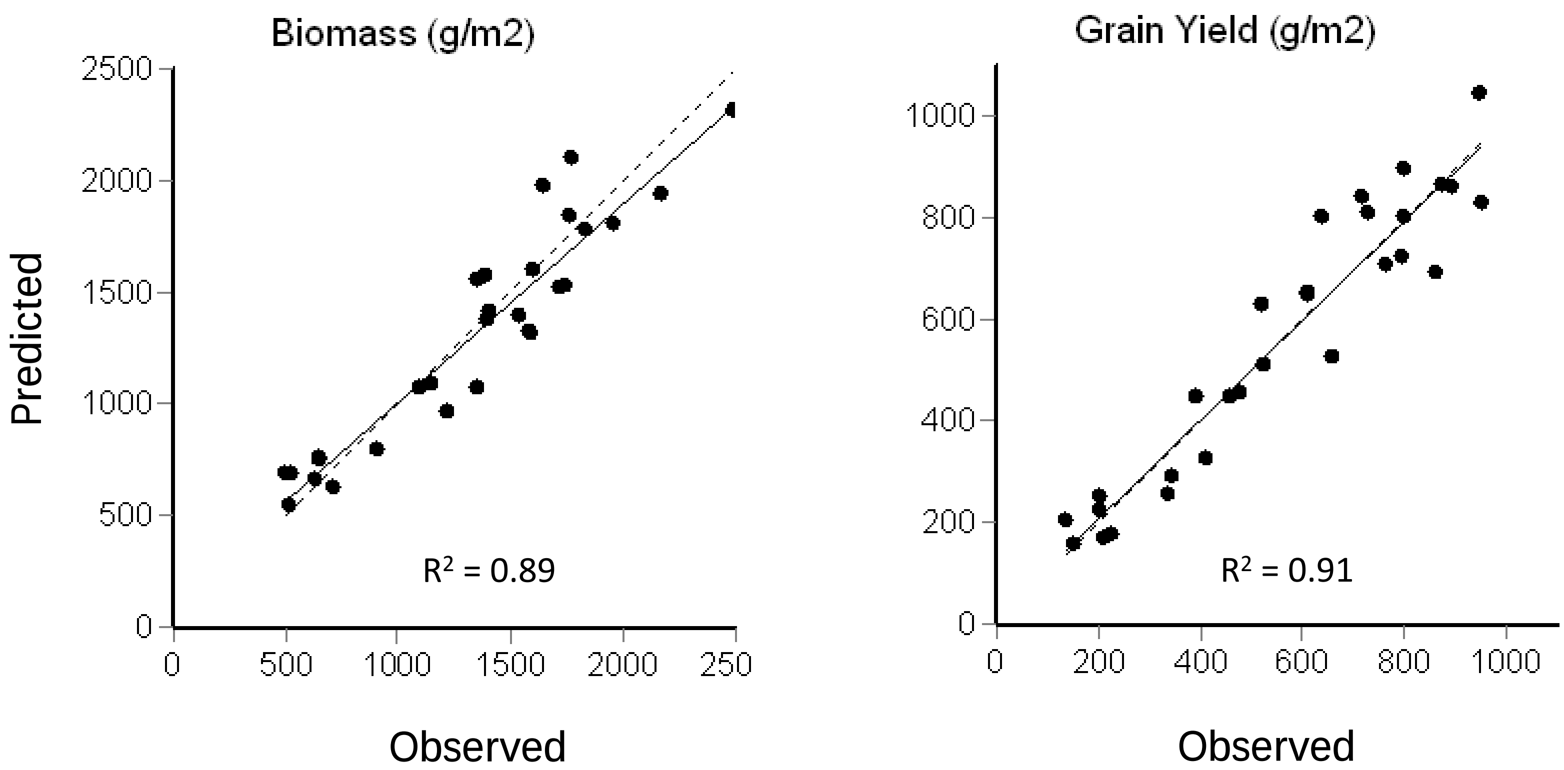






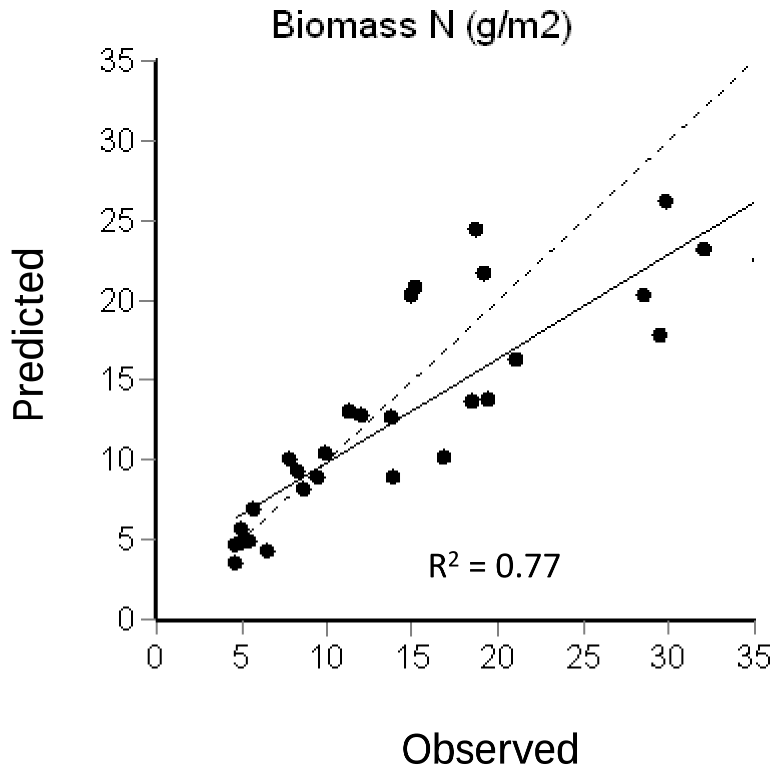
Implementation for Sorghum

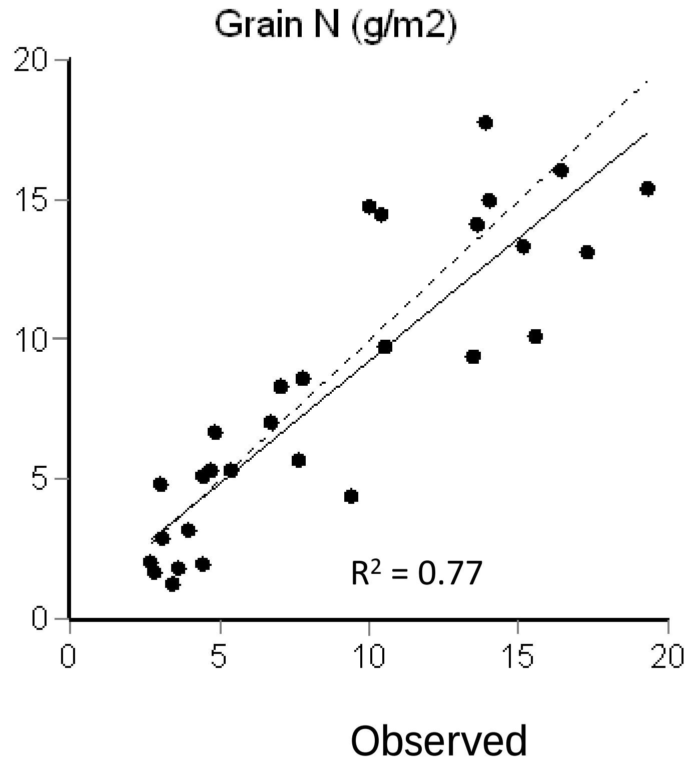
- Model Testing
  - Predicted vs Observed for all experiments (H_2O, N, cultivar)



Implementation for Sorghum

- Model Testing
  - Observed vs Predicted for all experiments (H_2O, N, cultivar)





Linking Role of Modelling

- Environmental characterisation
- Complex trait dissection
- Linking coefficients with genetics
- Identifying targets for high throughput
- Simulating adaptation and trait value

Connecting genetics to physiology