Generation
Cultivating Plant Diversity for resource poor

Short term responses of leaf growth rate to water deficit scale up to whole-plant and crop levels

An integrated modelling approach in maize

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THE UNIVERSITY OF QUEENSLAND

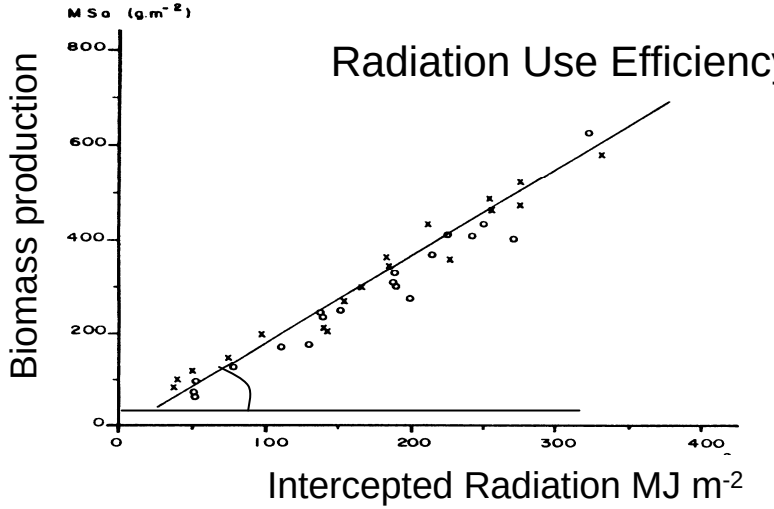
CSIRO

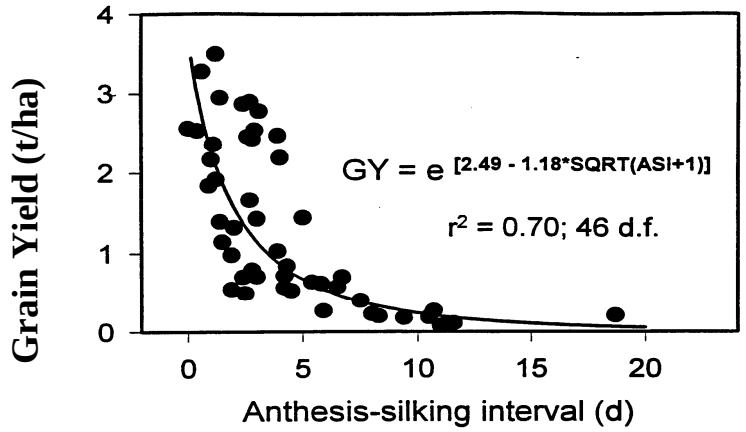
APSRU

Under drought, considering traits affecting yield via:

- Leaf growth
for light interception

- Reproductive growth (ASI)

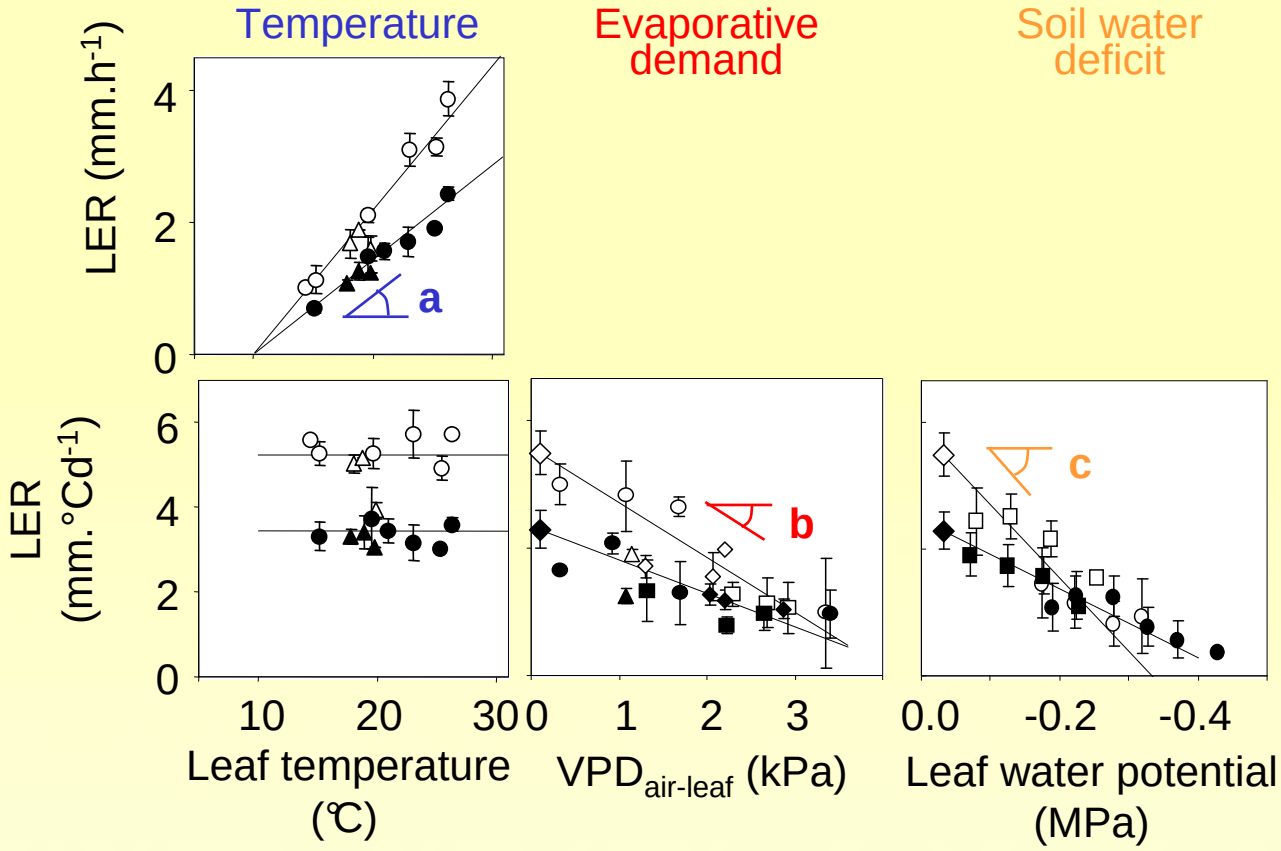




Bolaños et al, 1993 Chapman & Edmeades, 1999

Leaf growth
in response to drought conditions

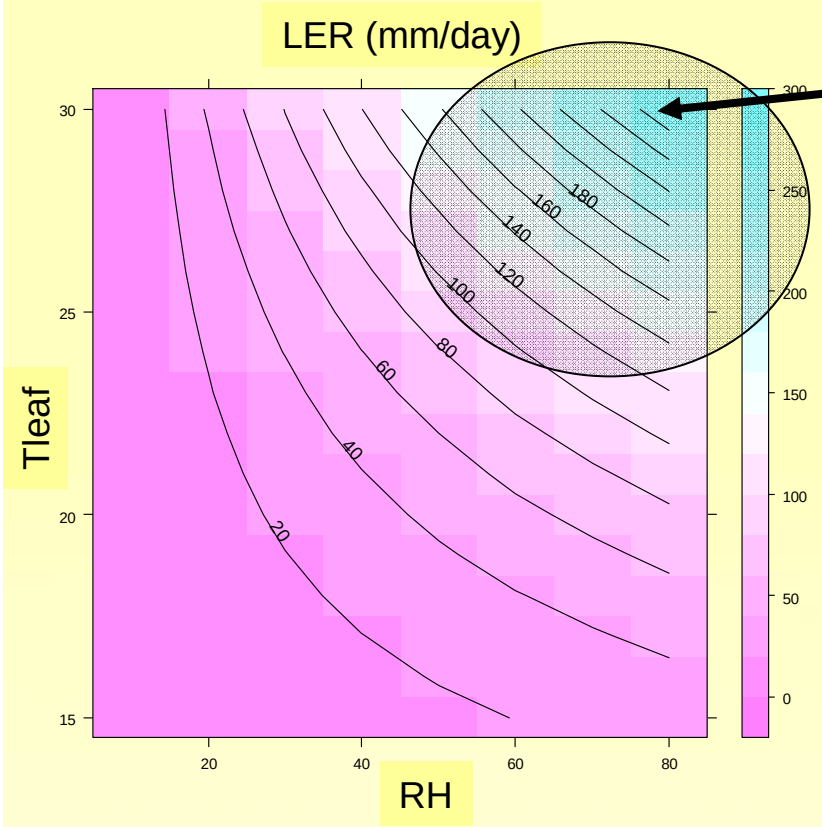
Leaf expansion in maize under drought conditions
Response to temperature and soil and air water deficits



For each genotype: $LER = dl/dt = (T-T_0)(a + b\ VPD_{air\text{-}leaf} + c\ \Psi)$

Reymond et al. 2003 Plant Phy

LER landscape for a ‘base’ genotype



‘base’ genotype:

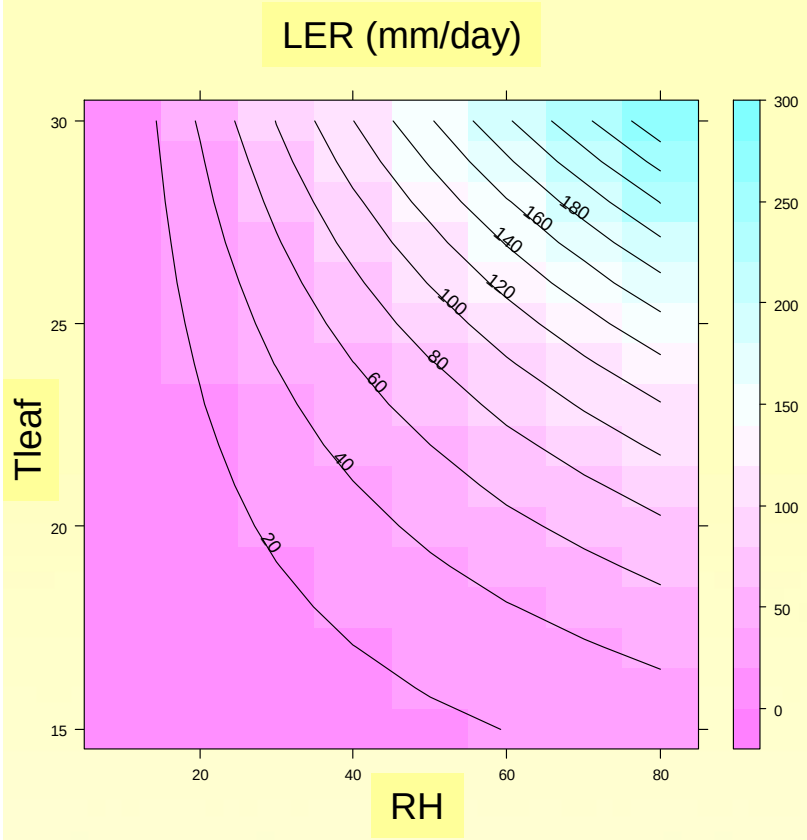
a = 4.8 mm ℃d^{-1}

b = -1 mm ℃d^{-1} kPa^{-1}

c = 6 mm ℃d^{-1} MPa^{-1} Tbase = 10℃

$$LER = (T-T_0)\,(a - bVPD_{fa} - c\,\Psi)$$

LER landscape for a ‘base’ genotype



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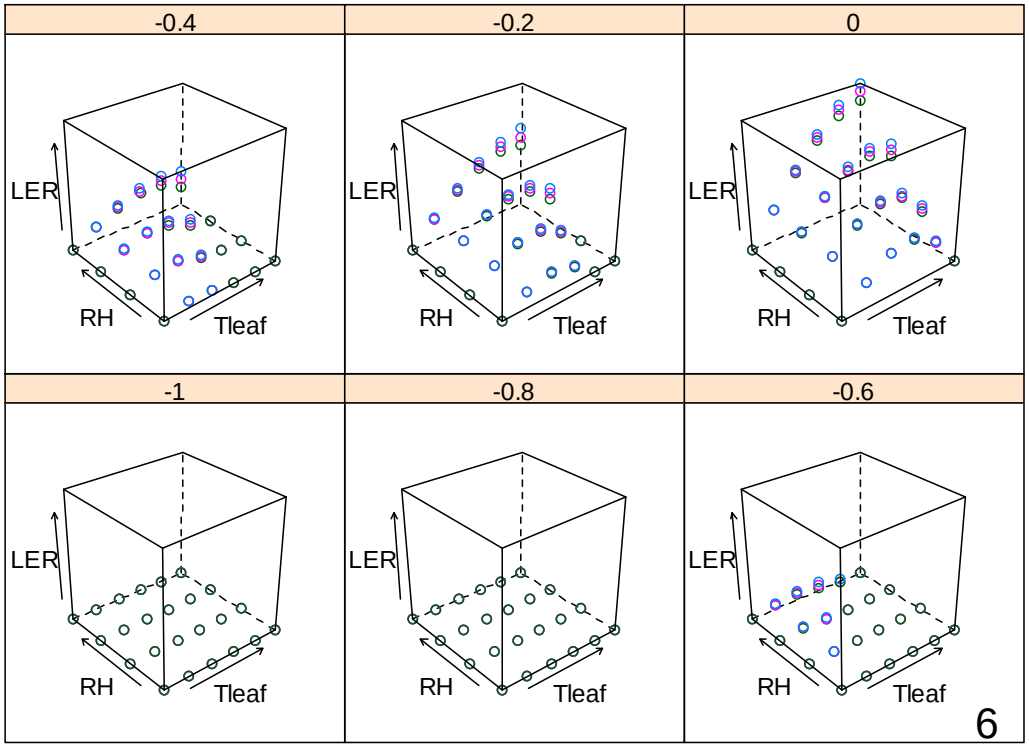
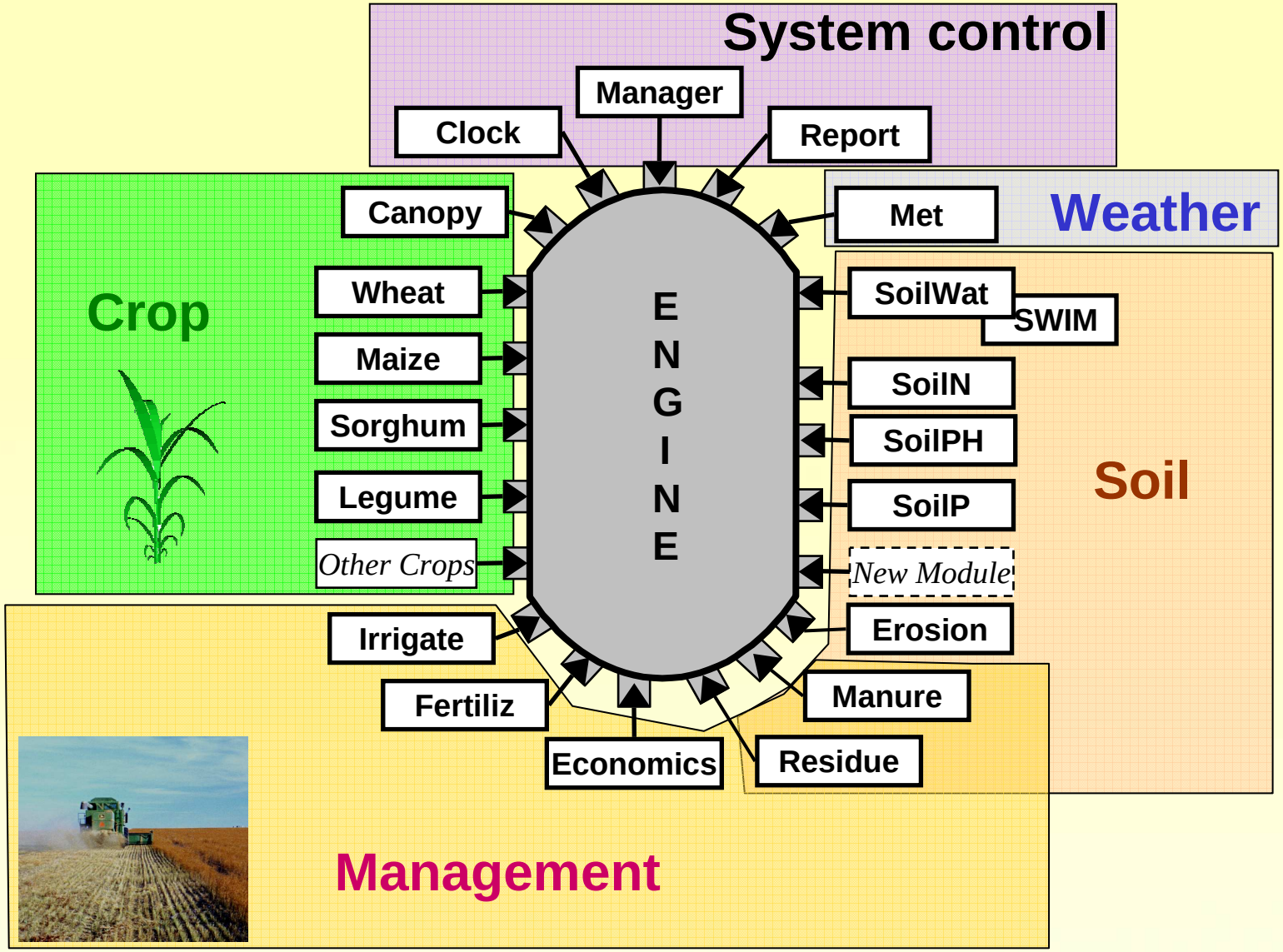
$$LER = (T-T_0)\,(a - bVPD_{fa} - c\,\Psi)$$

Variation of LER with temperature, RH at different soil water potentials

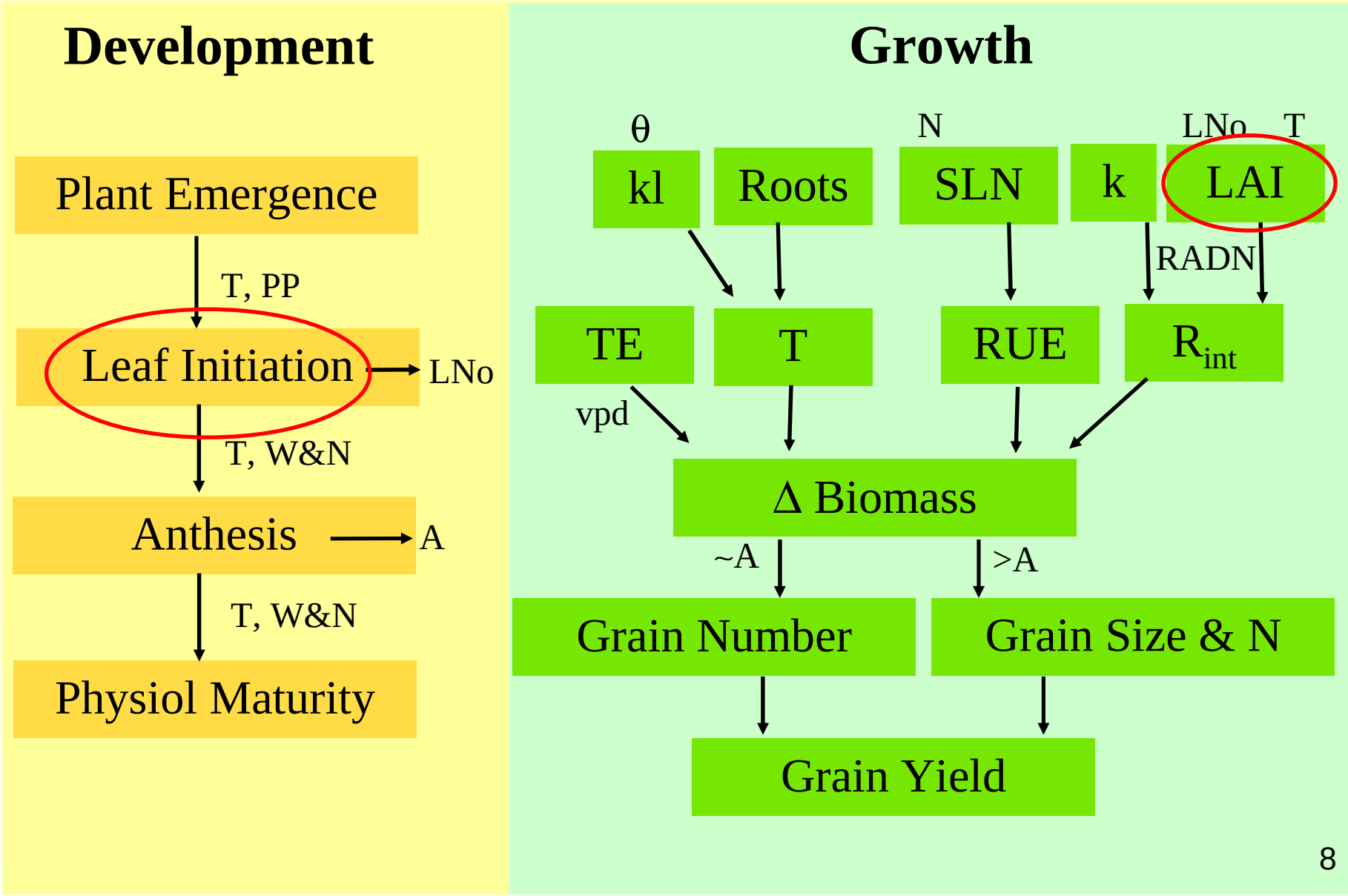


APSIM

A modular crop model



A general cropping system simulation for plant development



Experimental design

Exp.	Location	Sowing date	Treatment	Radiation	Rain	Temperature	$VPD_{air\text{-}meristem}$
				(MJ m^{-2})	(mm)	(°C)	(kPa)
GR92ap	Grignon, North of France	April 27,1992	control	21.1	62	15.6	1.098
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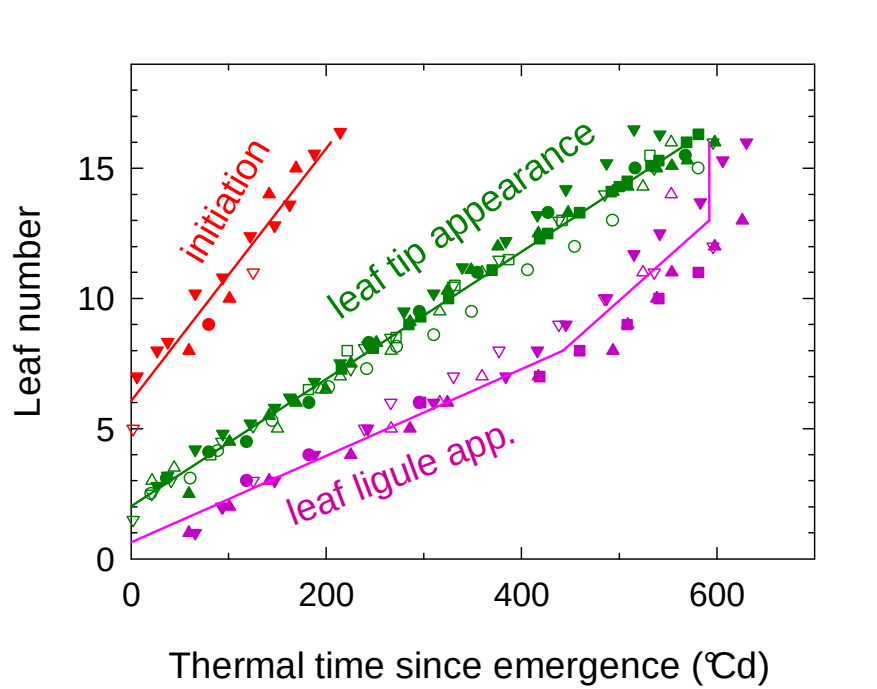
MA98ma	Mauguio, South of France	May 20, 1998	control	23	47	21.1	1.7

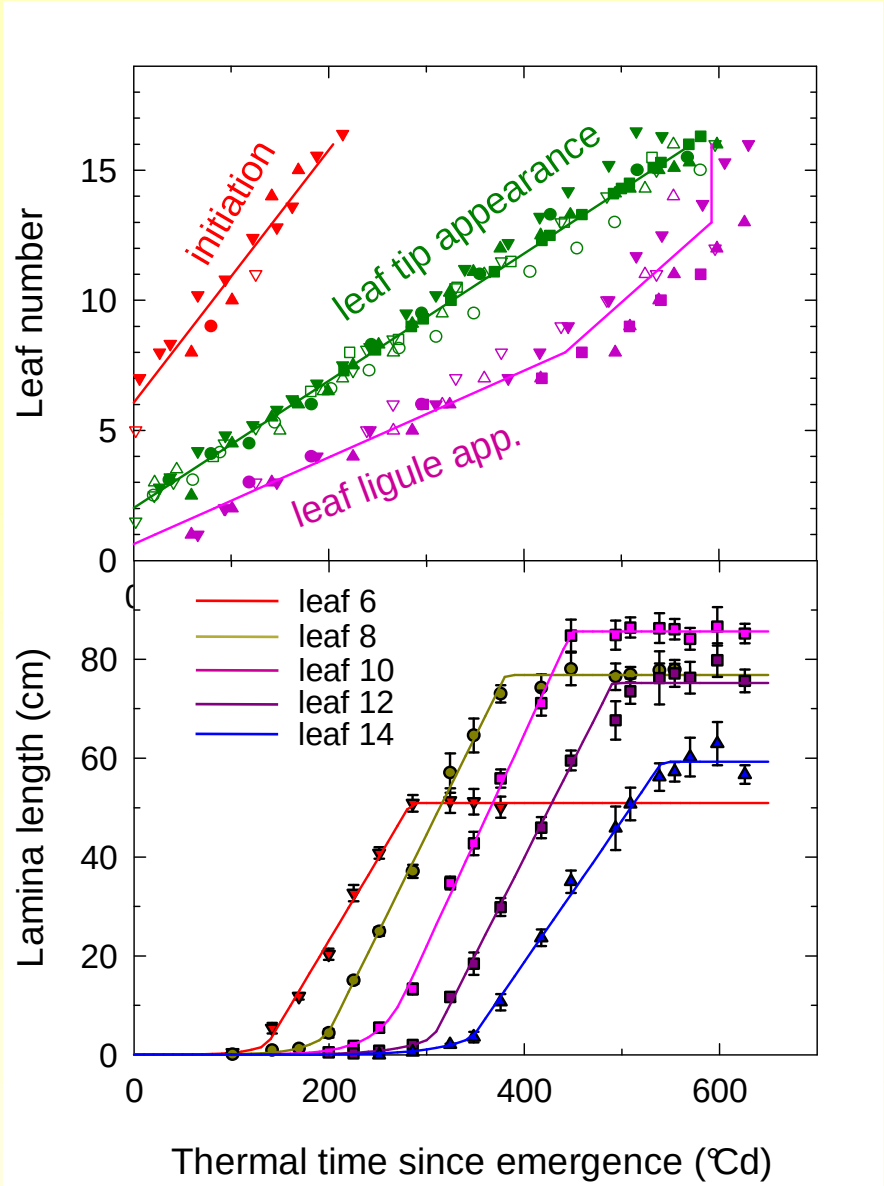
- 11 field situations: well-water / water-deficit
- Measurement:
  - leaf elongation since initiation
  - rate of leaf initiation, appearance and end of elongation
  - final leaf number

Developmental leaf model



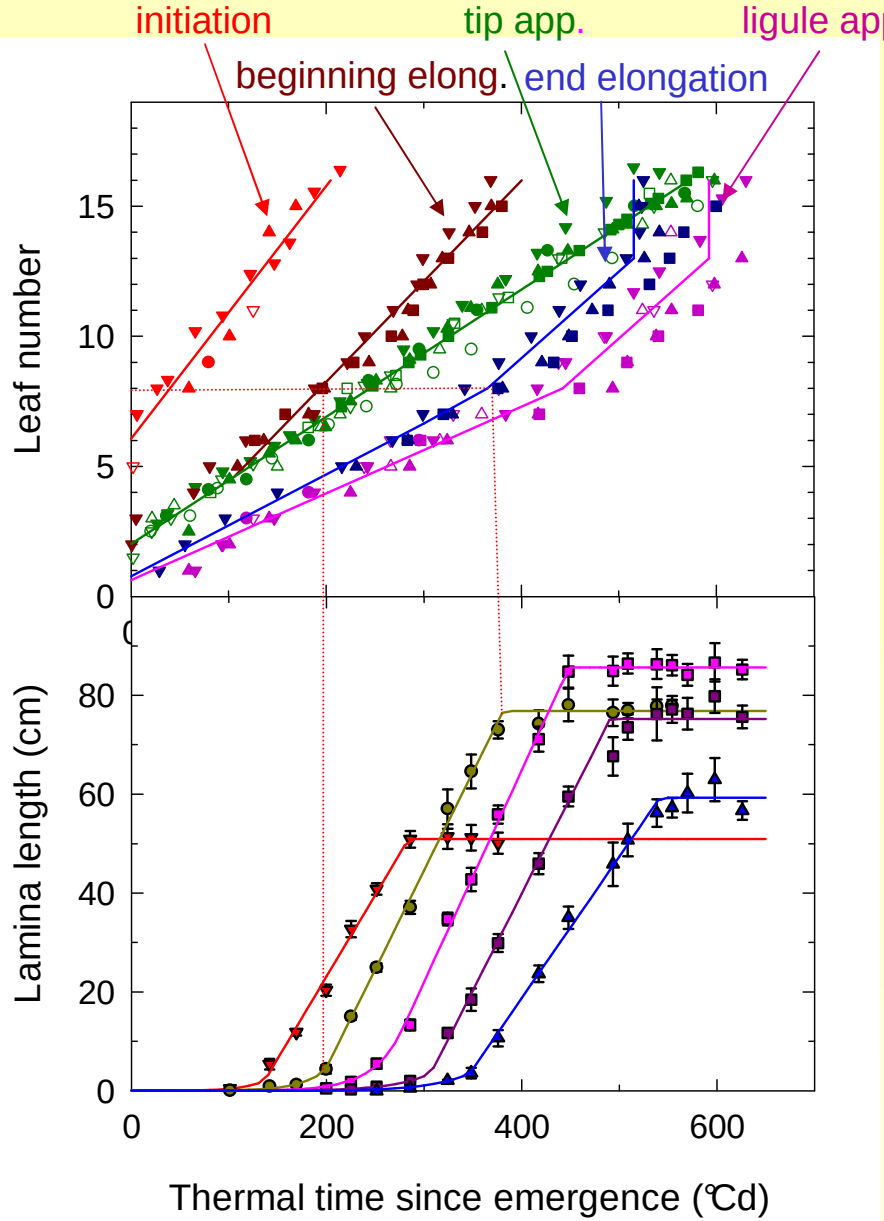
- Stable patterns over a large range of environmental conditions provide a time frame for leaf development

Developmental leaf model



- Stable patterns over a large range of environmental conditions provide a time frame for leaf development
- Leaf elongation is characterized by
- an exponential period followed by
- a linear period of elongation

Developmental leaf model



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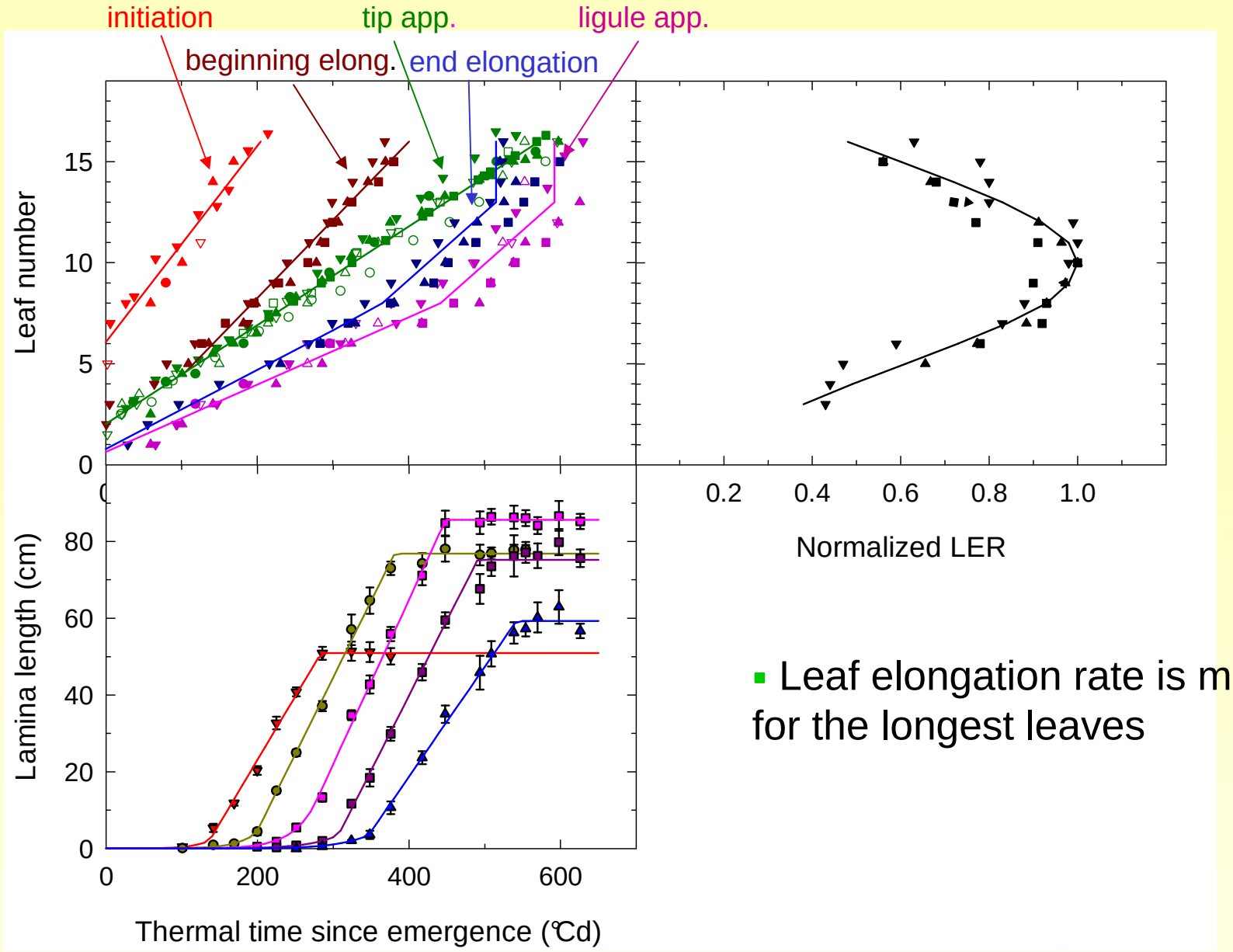
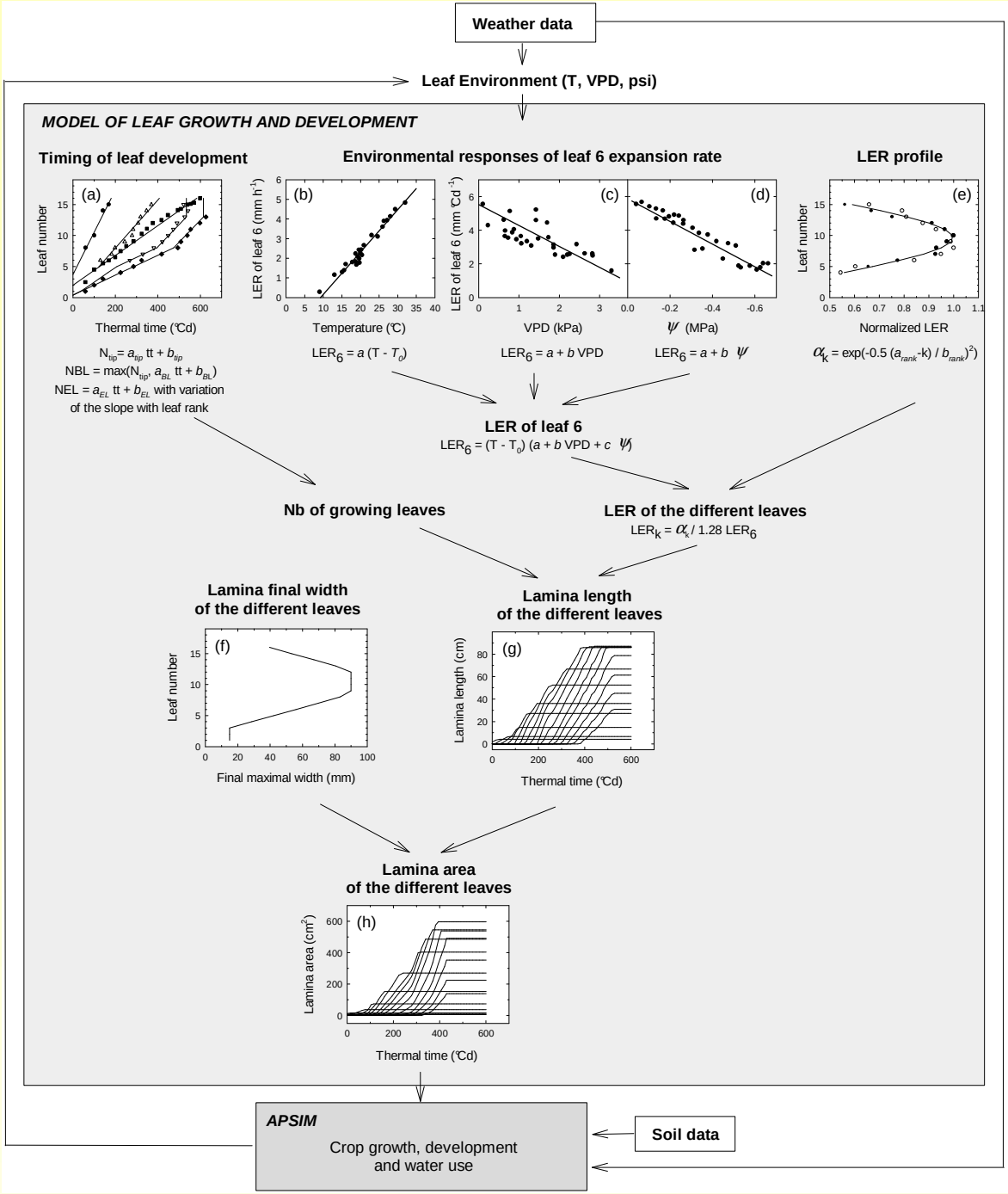
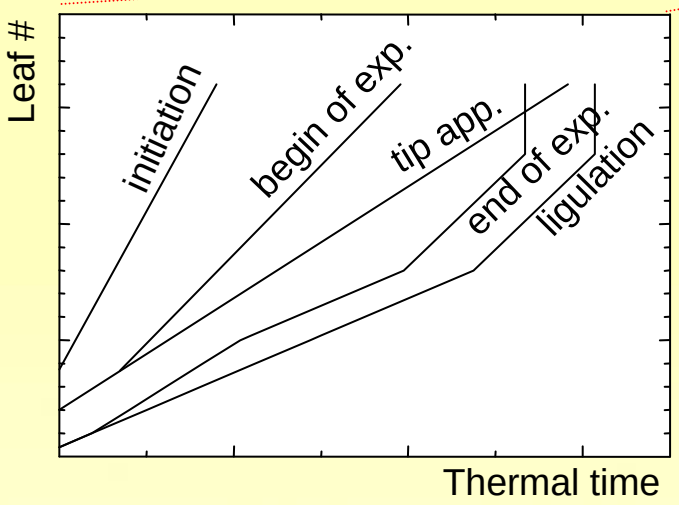


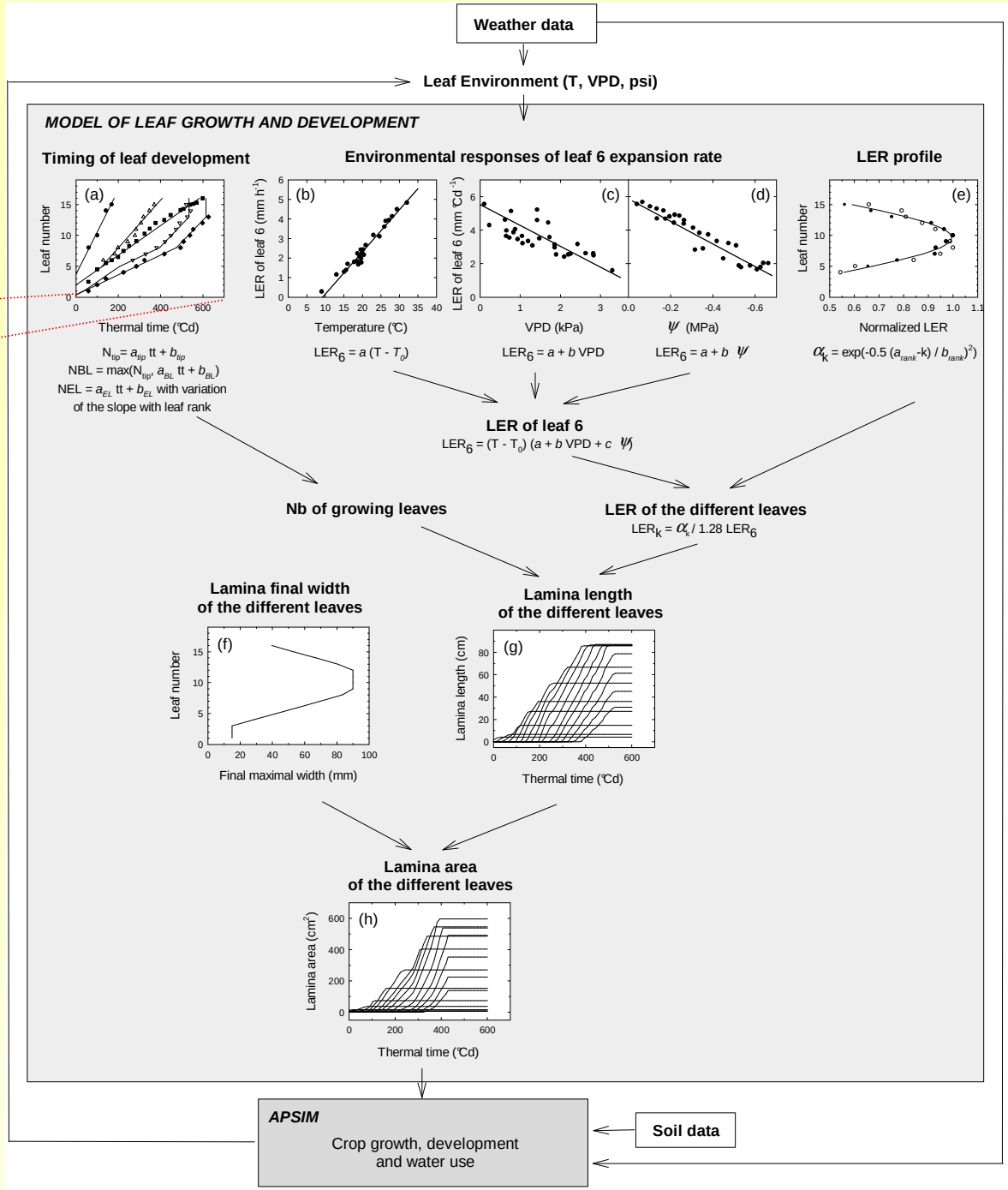
- Leaf elongation rate is maximum for the longest leaves

Model functionning



Model functionning

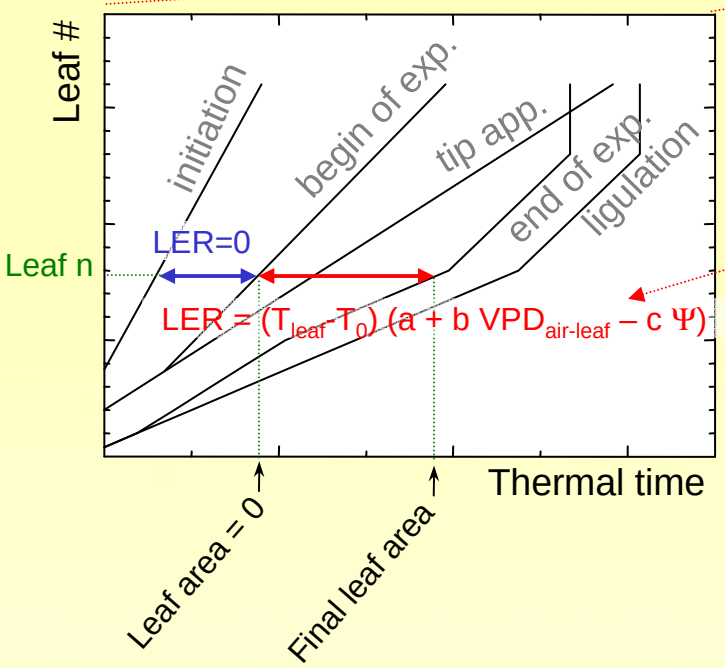




Hypothesis:

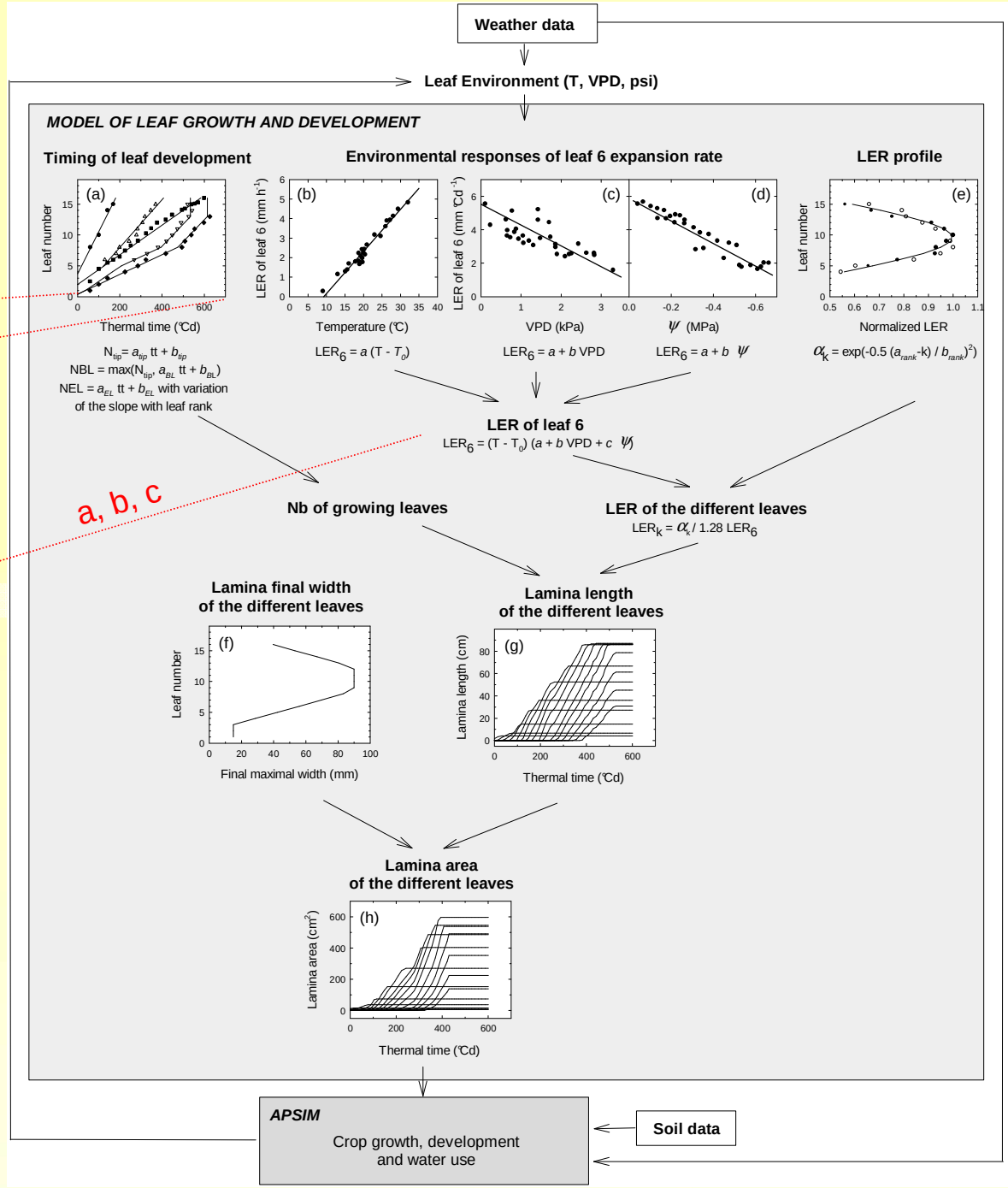
the phenology is not affected by the water deficit *i.e.* same period of expansion (beginning and duration)

Model functionning

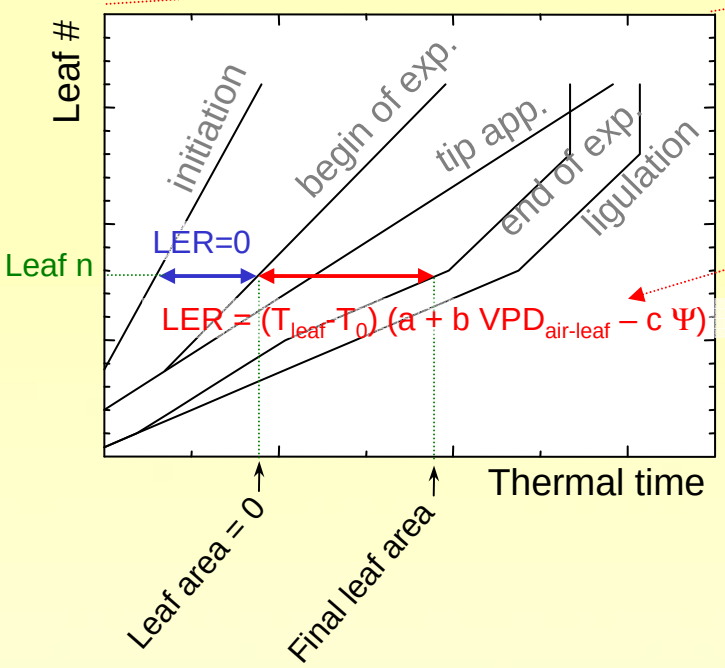


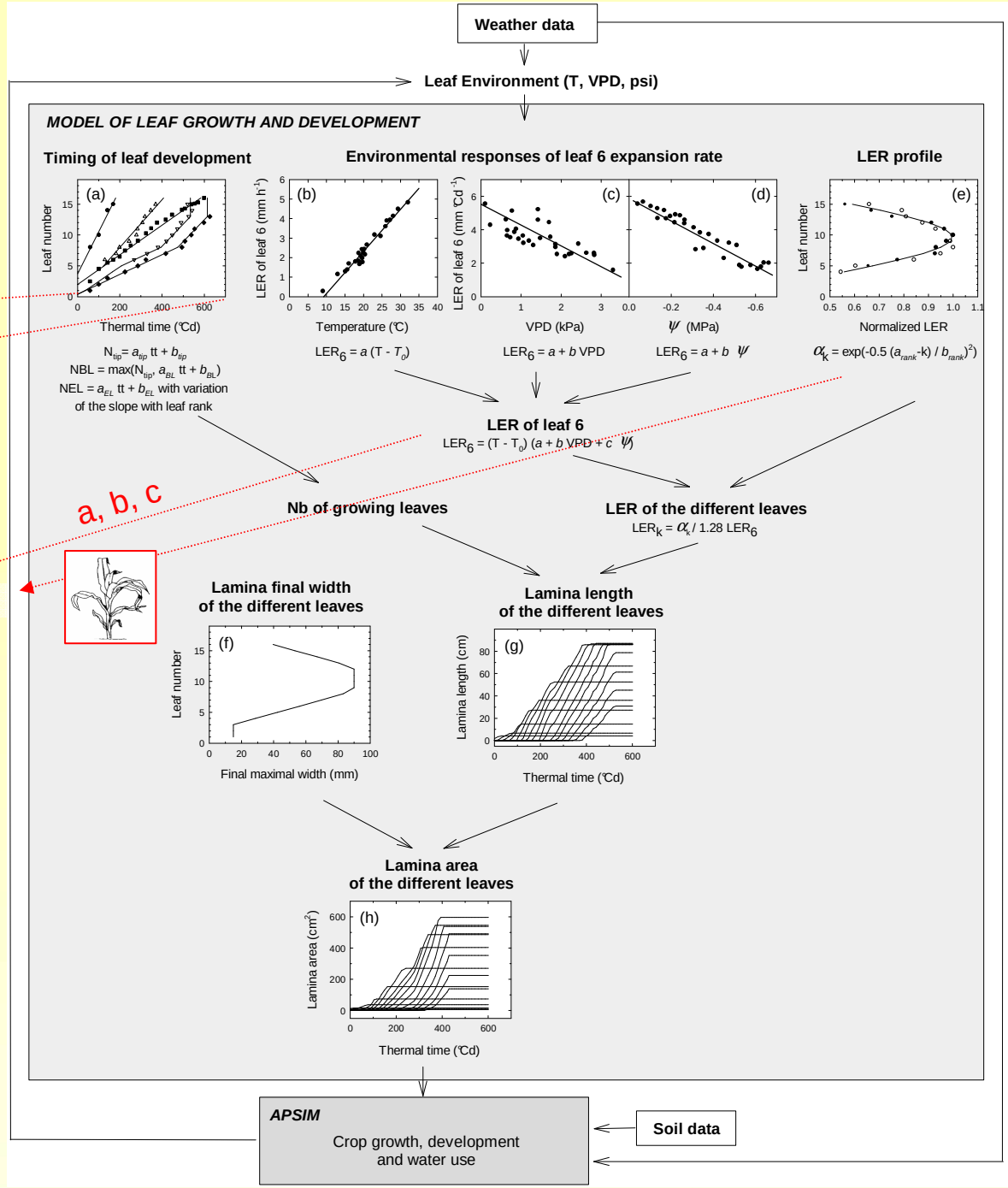
Hypothesis:

- the expansion during the exponential phase is not affected by the water deficit
- water deficit affect the LER to the same extend whether the leaf is hidden in the whorl or visible



Model functionning

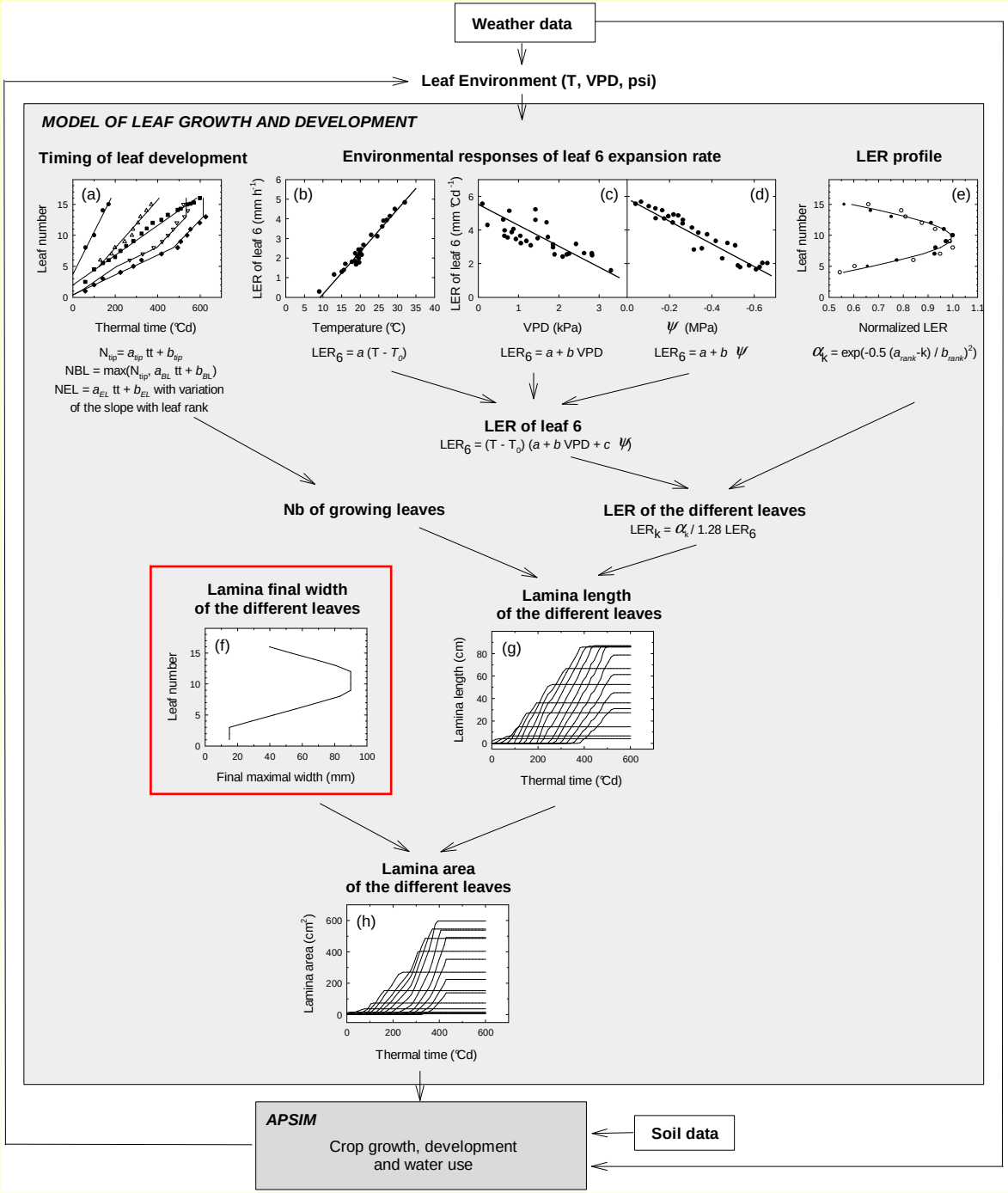




Hypothesis:

LER is modified by a factor depending on leaf rank,
i.e. the 3 parameters (a, b, c) are all modified to the same extent by leaf rank.

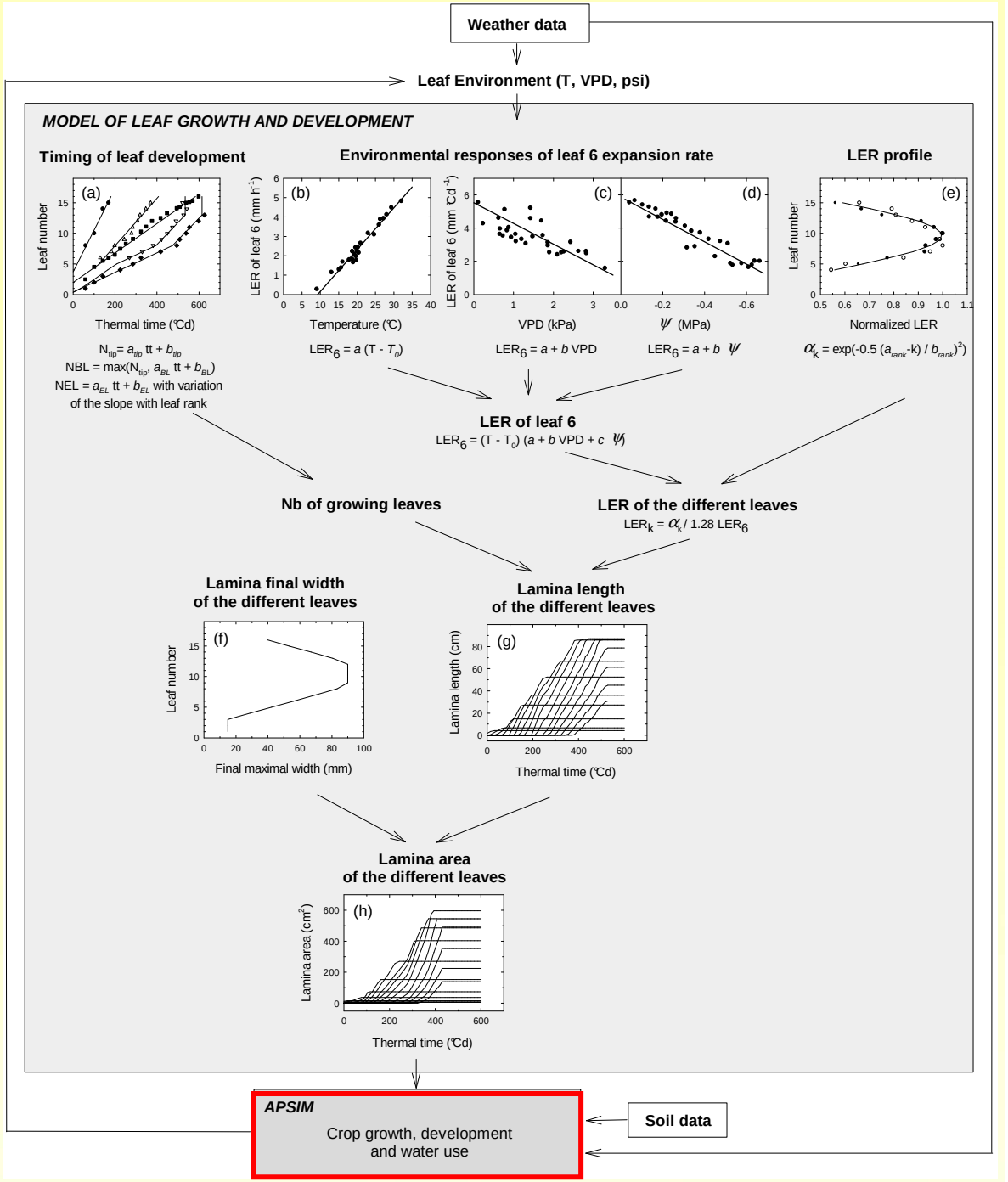
Model functionning



Hypothesis:

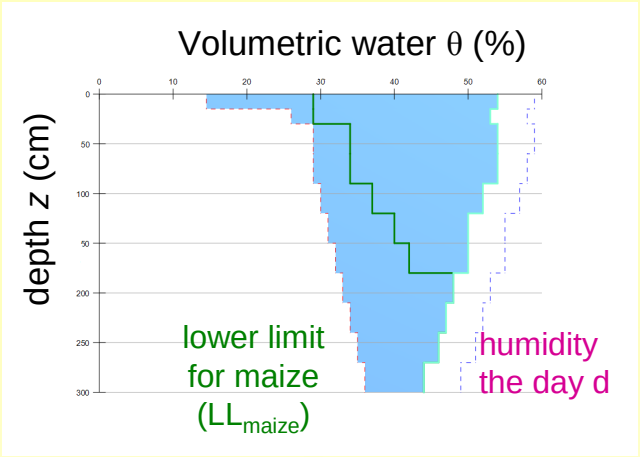
leaf width is not affected by environment

Model functionning

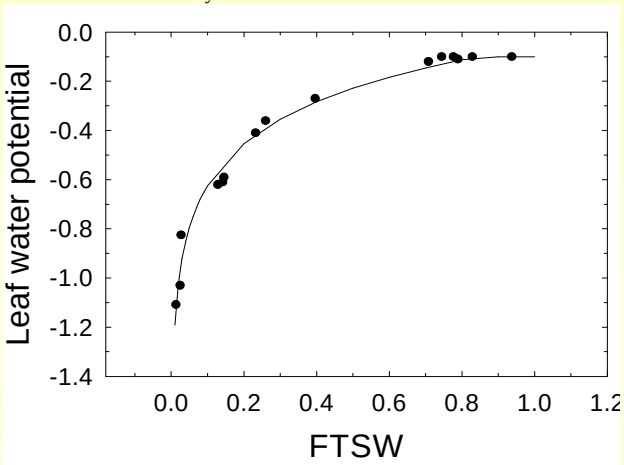


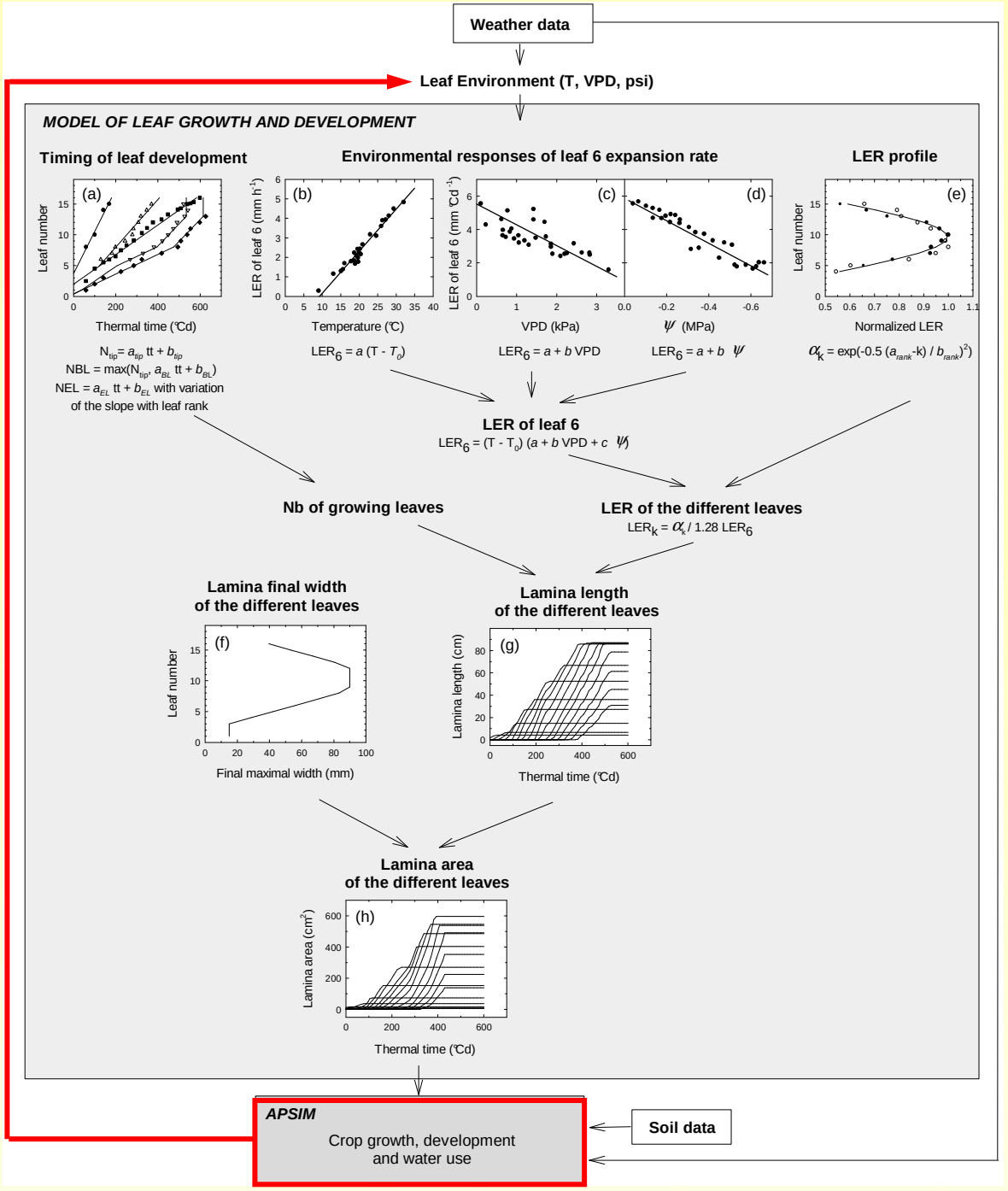
Model functionning

Calculation of predawn leaf water potential: $\Psi = f(\theta)$



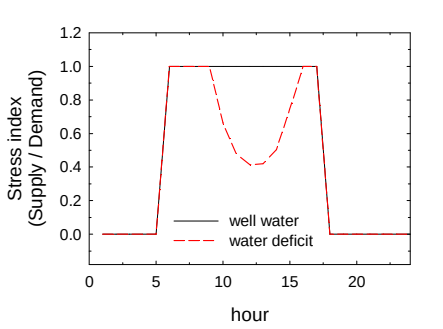
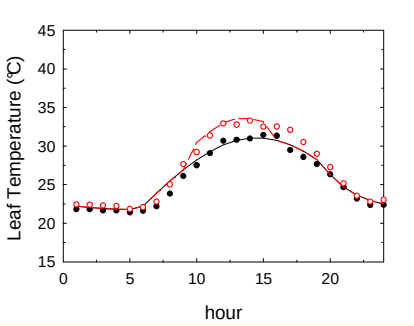
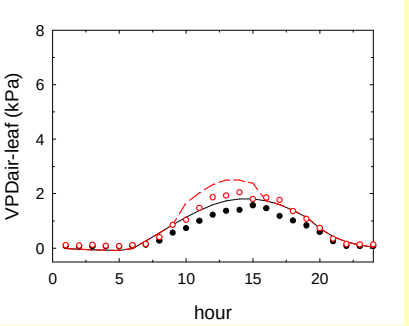
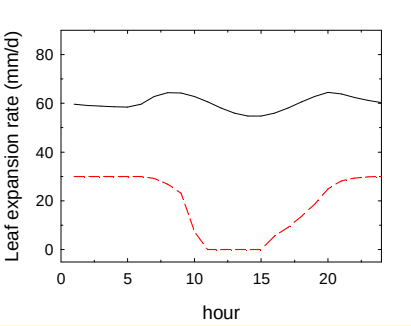
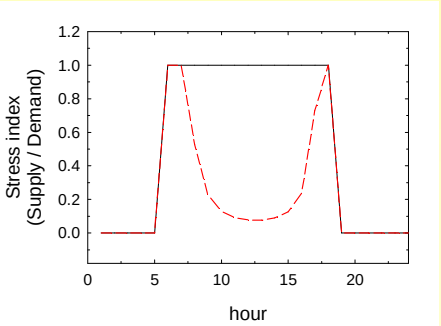
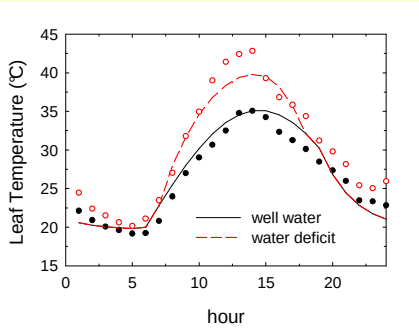
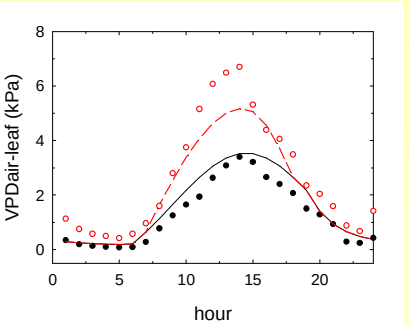
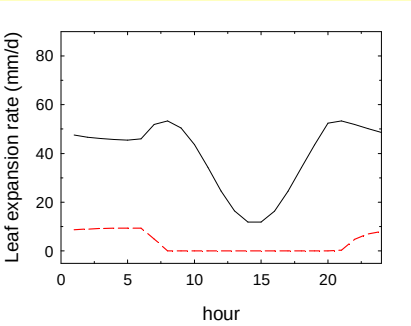
$$FTSW = \frac{\sum_{layer} (\theta_t - LL_{maize})\, z_{layer}}{\sum_{layer} (\theta_{upper.limit} - LL_{maize})\, z_{layer}}$$





Test of the model

Simulation of the weather variables

	Stress index	Leaf temperature	$VPD_{air\text{-}leaf}$	LER
low VPD				
high VPD				

Daily weather data ($T_{air\ min}$, $T_{air\ max}$, radiation) are interpolated to simulate environmental variables (T_{leaf}, $VPD_{leaf\text{-}air}$…) at a hourly time step

⇨ Estimation of Leaf Expansion Rate (LER) responding to instantaneous environmental stress

Test of the leaf model

Exp.	Location	Sowing date	Treatment	Radiation	Rain	Temperature	$VPD_{air\text{-}meristem}$
				($MJ\ m^{-2}$)	(mm)	(°C)	(kPa)
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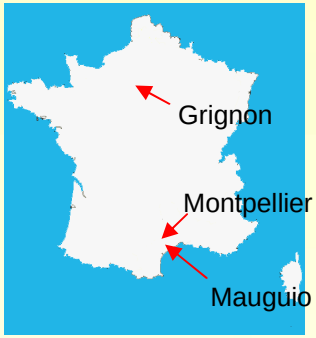
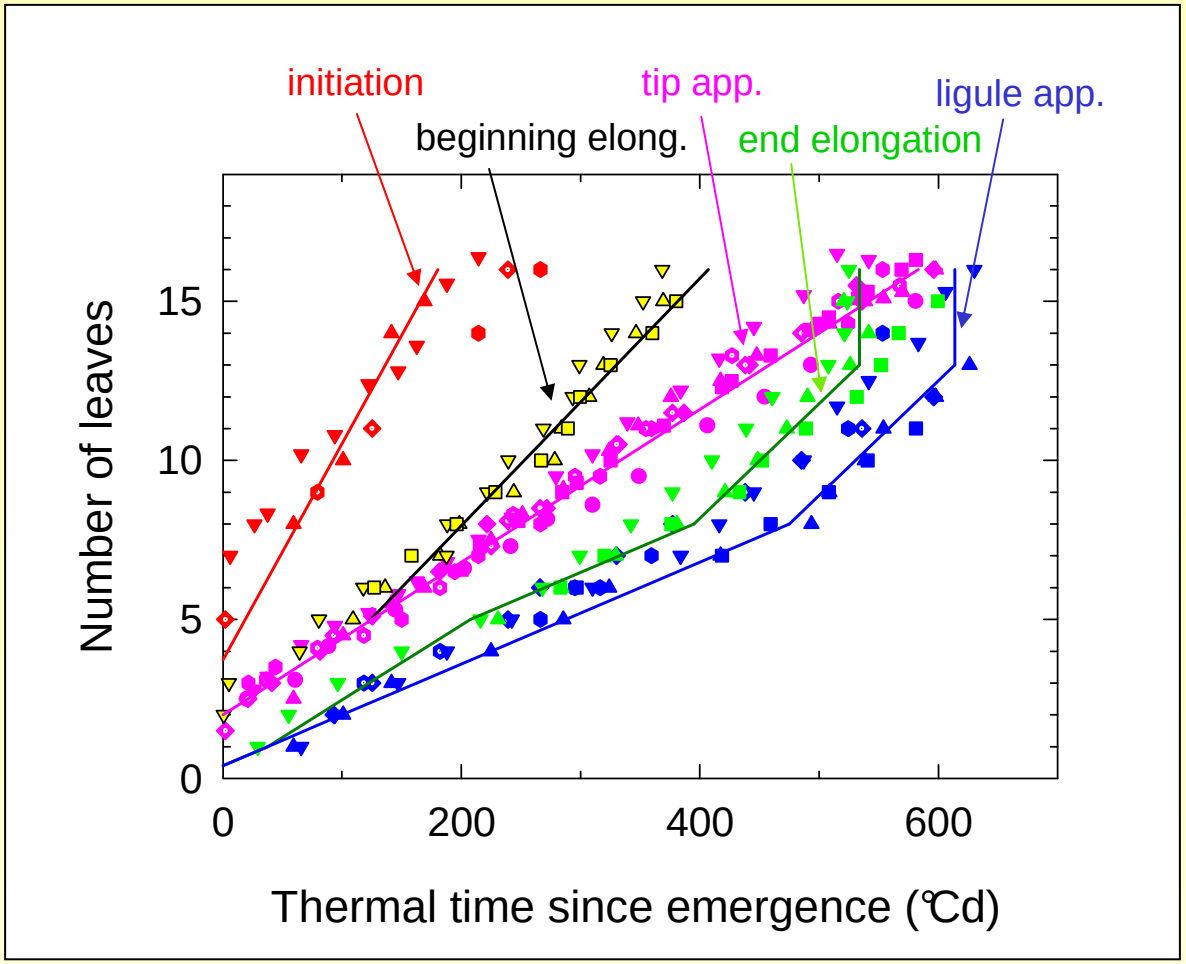
- 1 situation => Parametrisation of the model
- 11 situations => Test of the model



Test of the model

- Major leaf development stages -

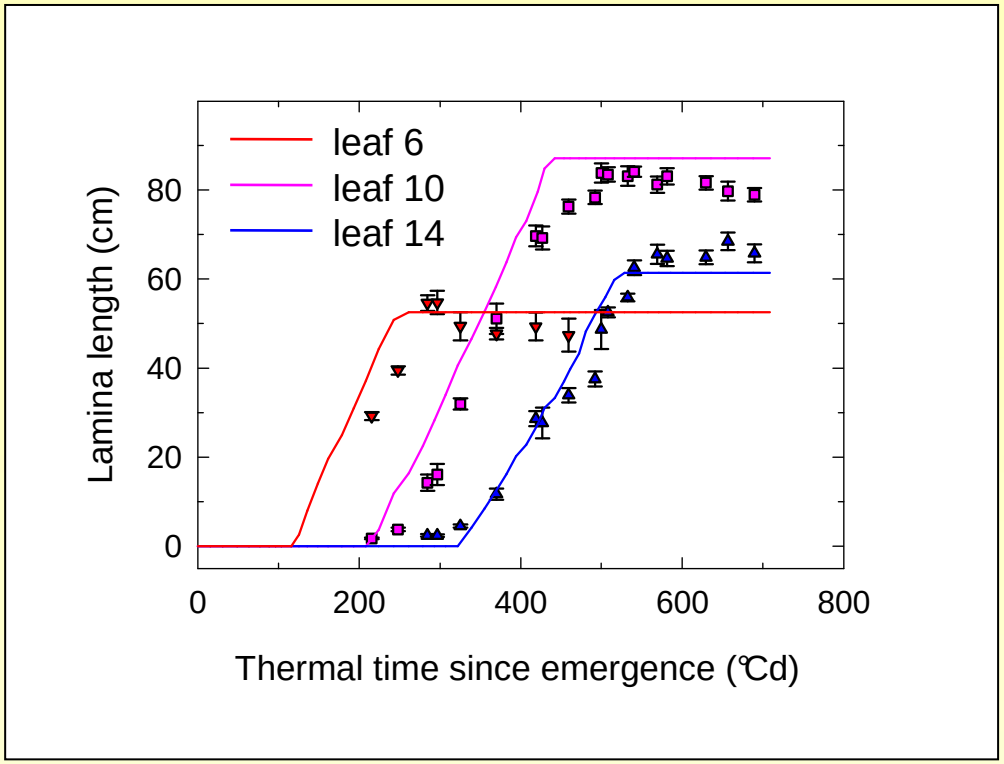


Data: all experiments (very few data with water deficit)

1 symbole = 1 experiment

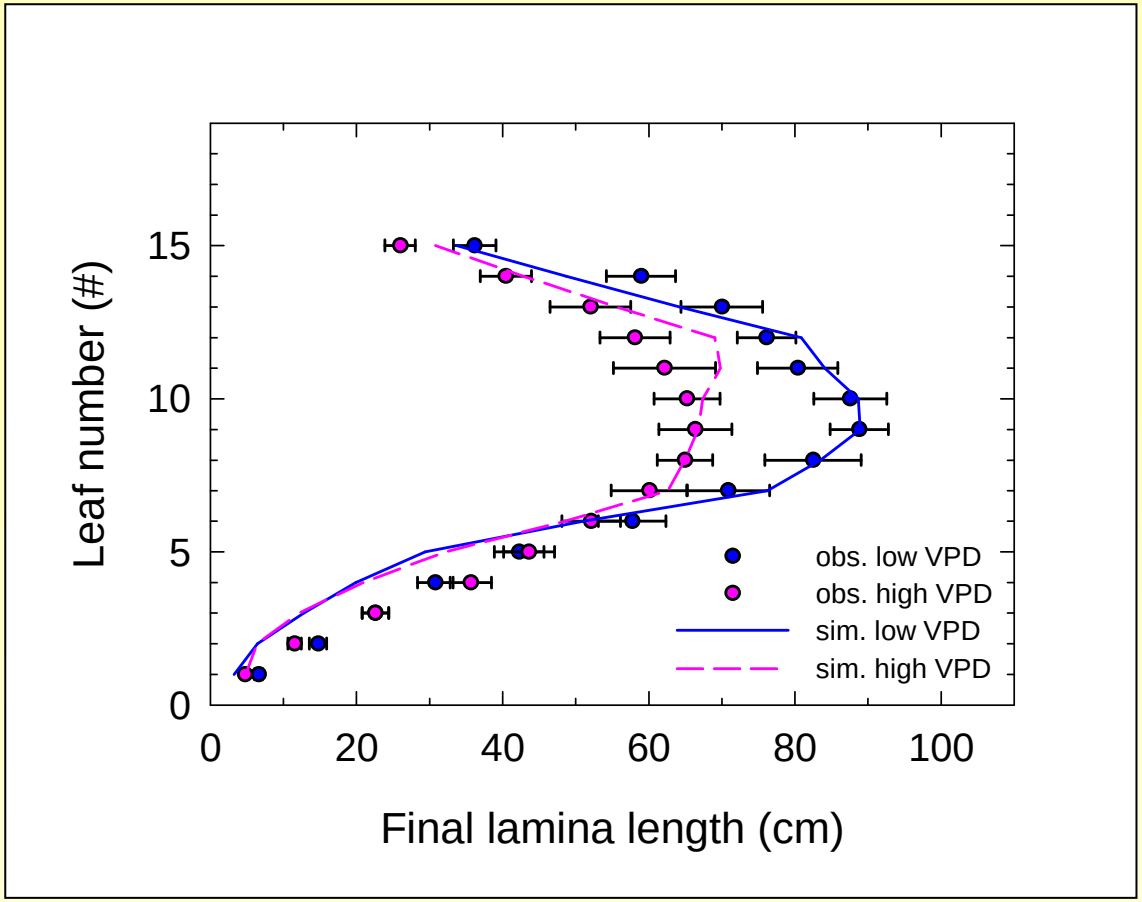
Test of the model

- Evolution of leaf elongation -



Test of the model

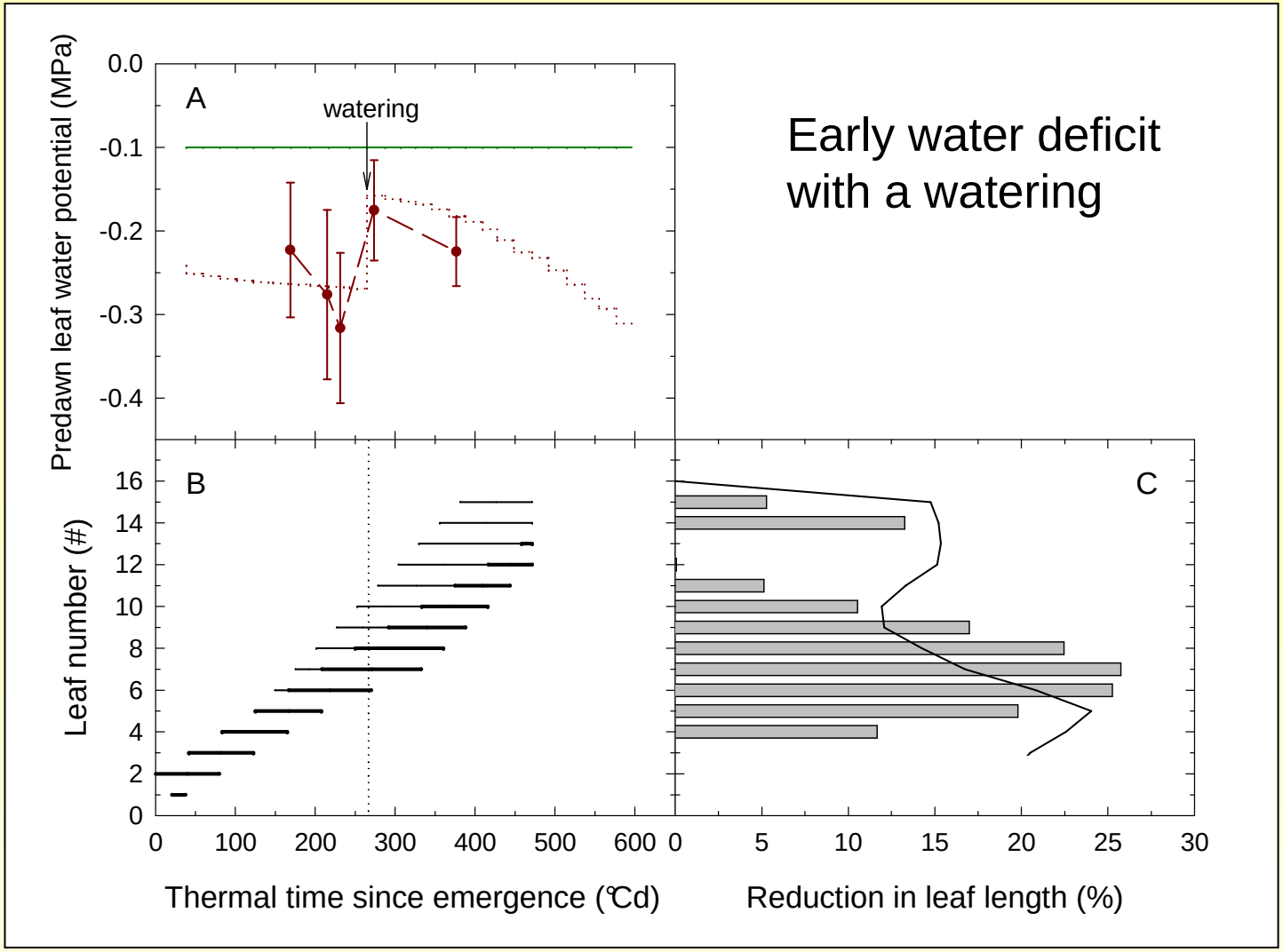
- Effect of high and low VPD environment -



Data: GR92WW (VPD = 1.1 kPa) & MP94WW (VPD = 2.6 kPa)

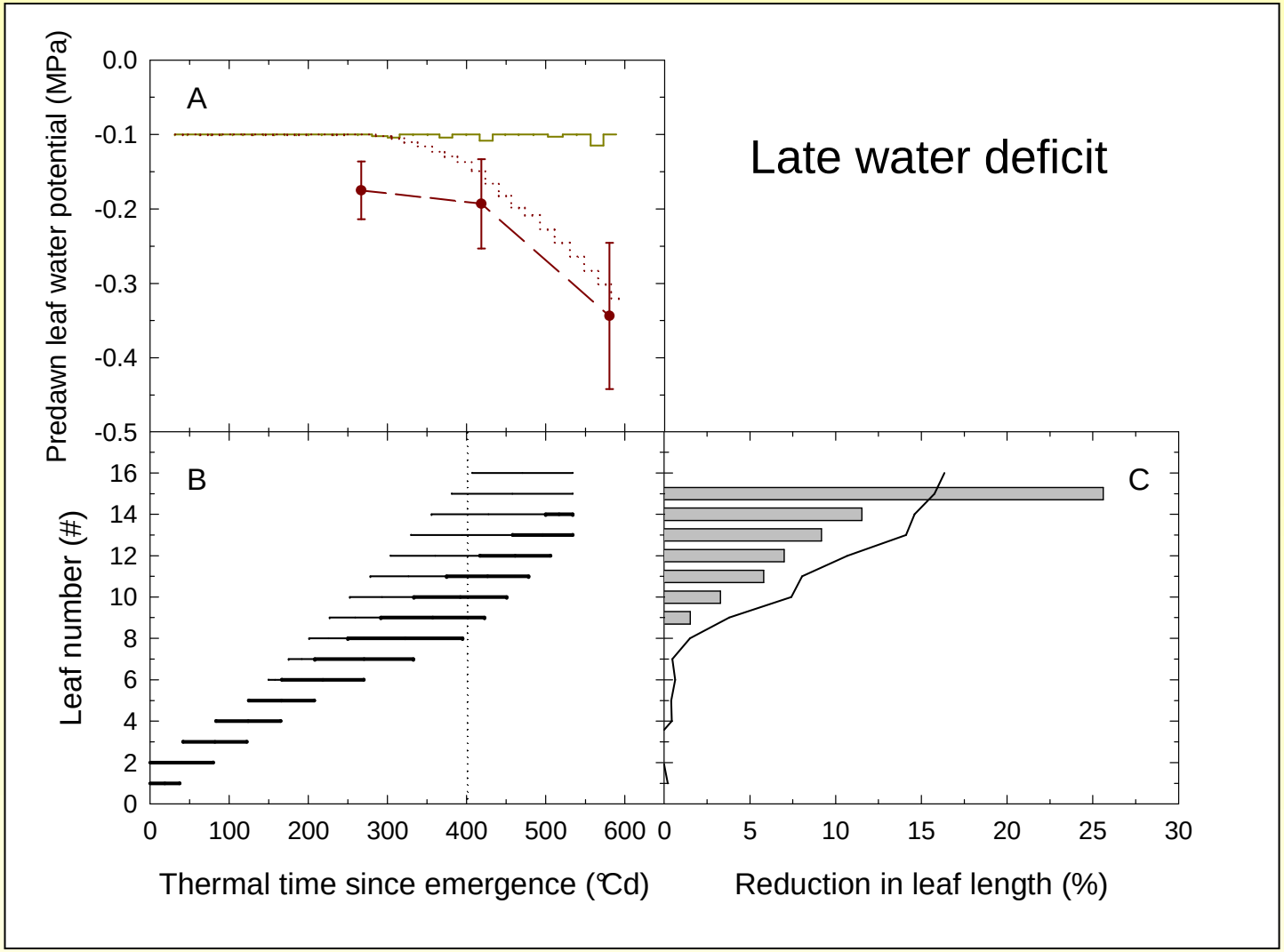
Test of the model

- Effect of water deficit -



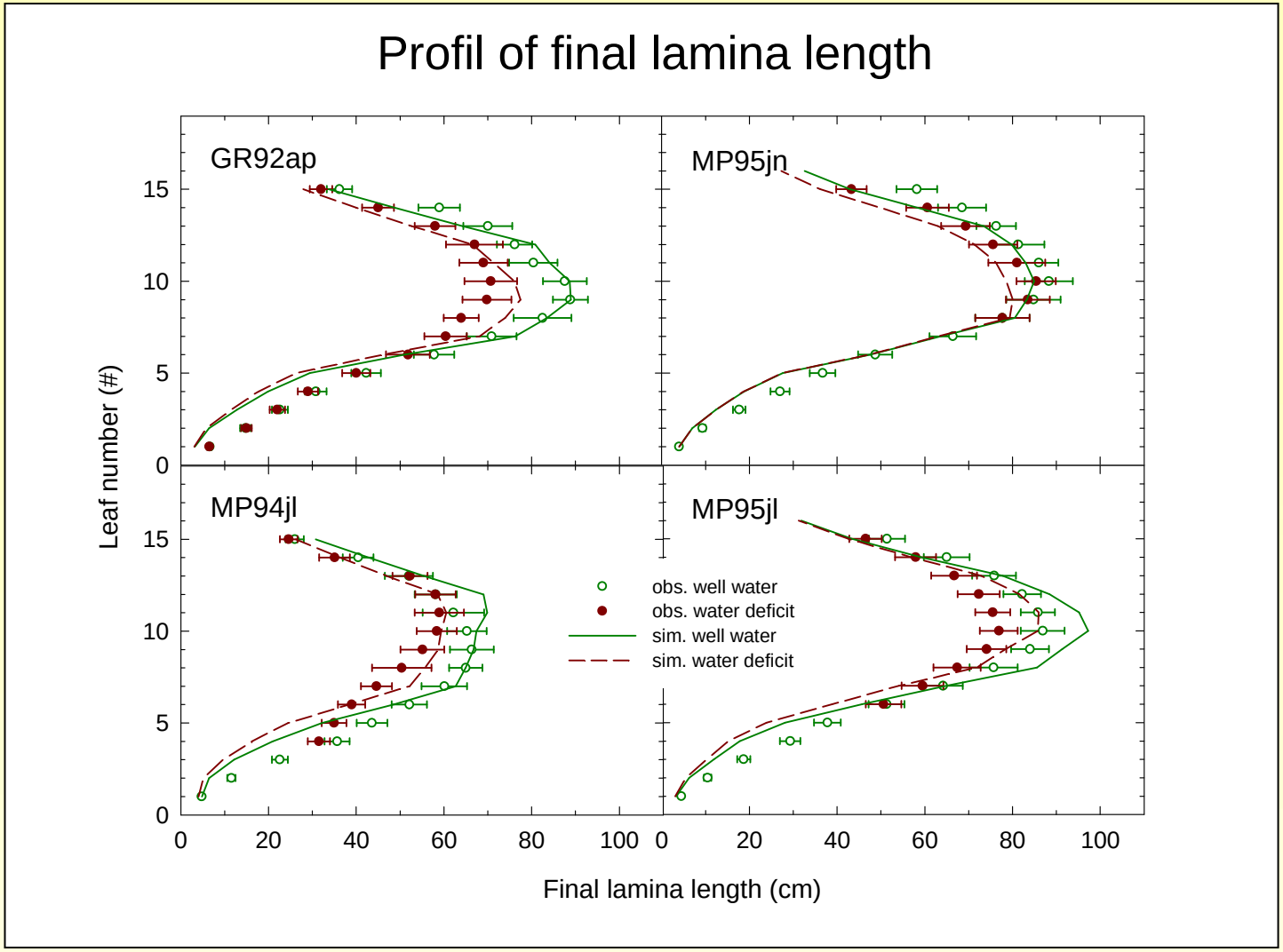
Test of the model

- Effect of water deficit -



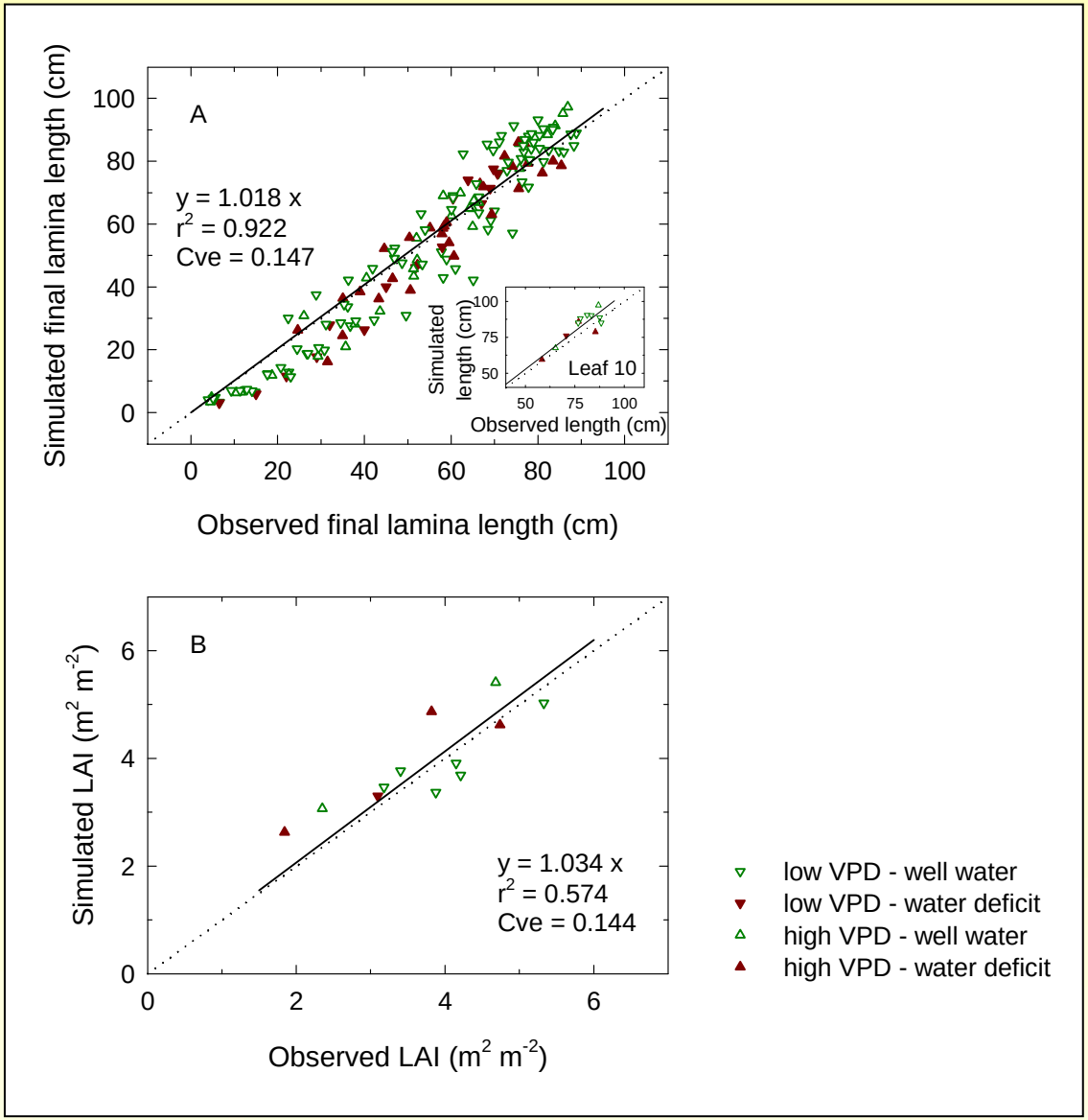
Test of the model

- Effect of water deficit -



Test of the model

- Overview -



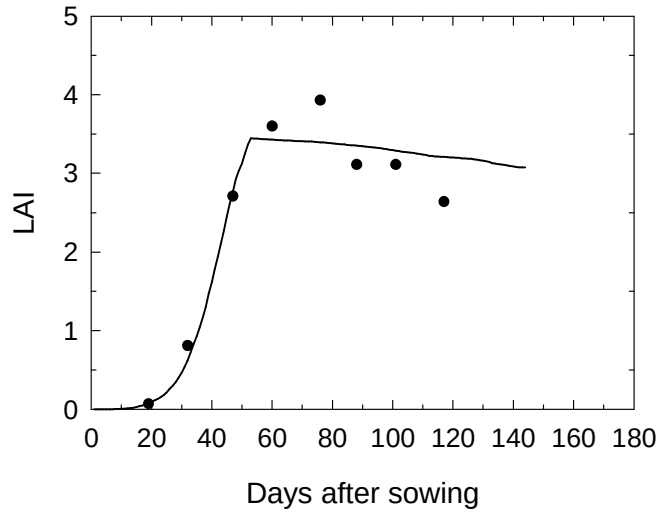
Integrated test of the model using field data

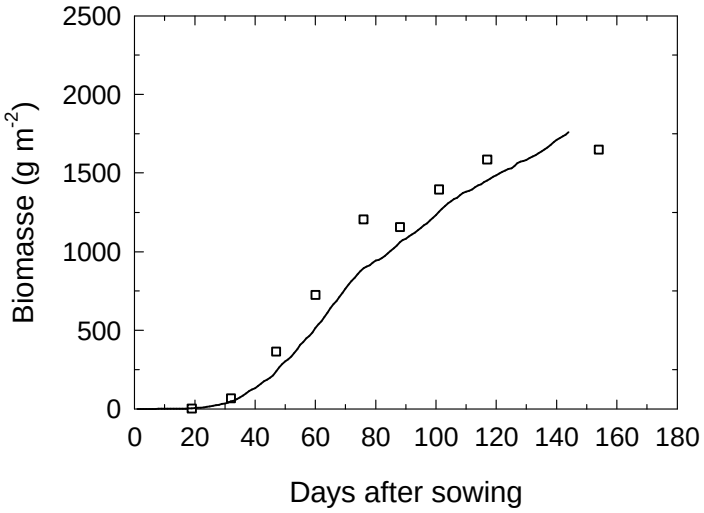
Integrated test of the model

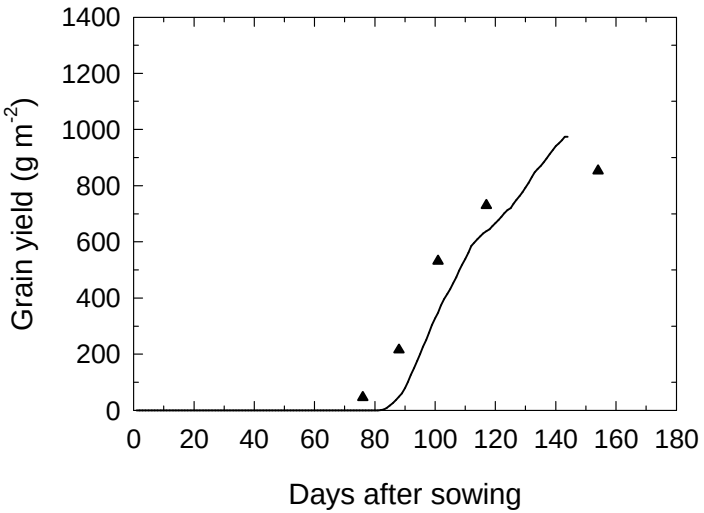
- **3 field experiments in Gatton (Australia)**
- **Pacific HyCorn53 (sub-tropical hybrid)**
  higher early vigour than Déa (old European hybrid)

Exp.	Location	Sowing date	Treatment	Radiation	Rain	Temperature	$VPD_{air\text{-}meristem}$
				(MJ m^{-2})	(mm)	(°C)	(kPa)
Exp 1	Gatton, Australia	February 19, 1999	well-water	16.6	106	23.4	1.36
Exp 2	Gatton, Australia	September 16, 1999	well-water	10.4	156	20.1	1.278
Exp 3	Gatton, Australia	January 4, 2001	well-water	21.6	204	25.6	1.71

Integrated test of the model





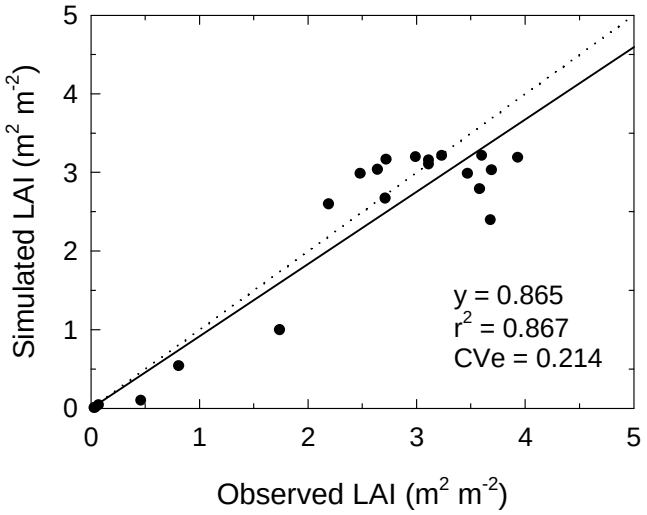


Effect on LAI, biomass, yield

Experiment 1

(Gatton, Australia)

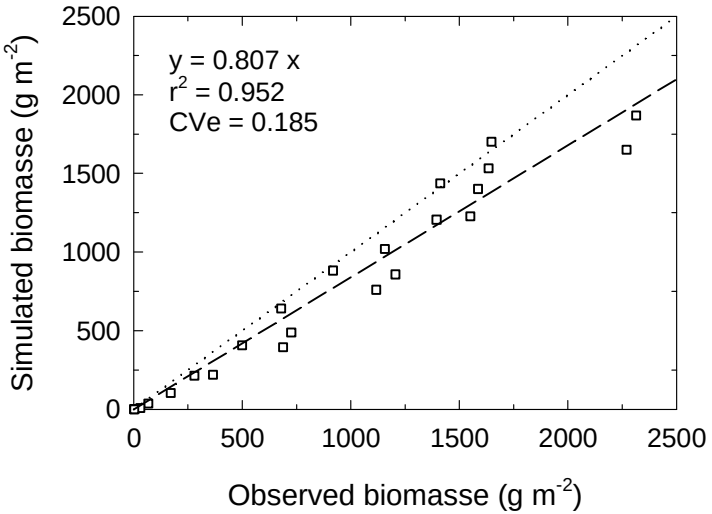
Integrated test of the model

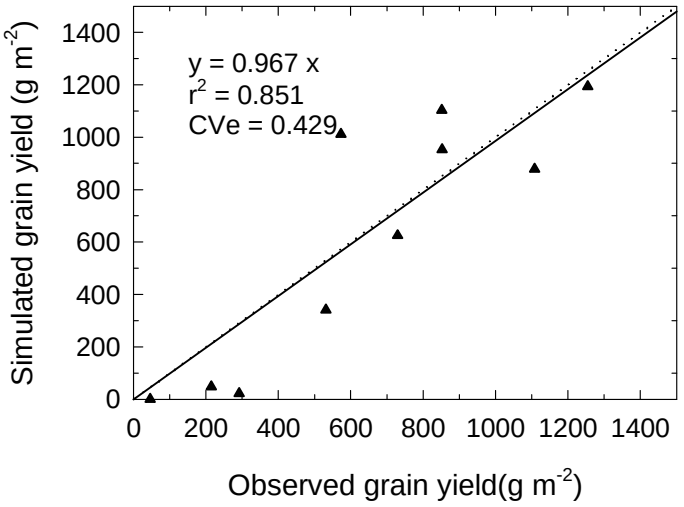


Effect on LAI, biomass, yield

Experiment 1, 2 & 3

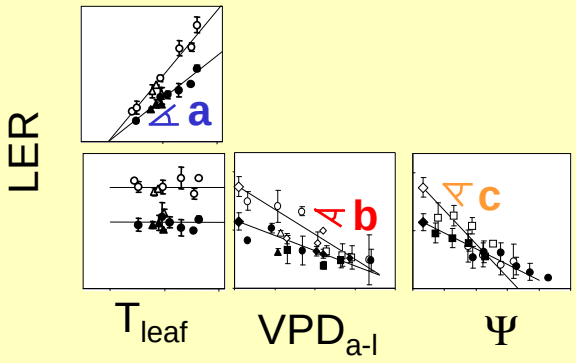
(Gatton, Australia)

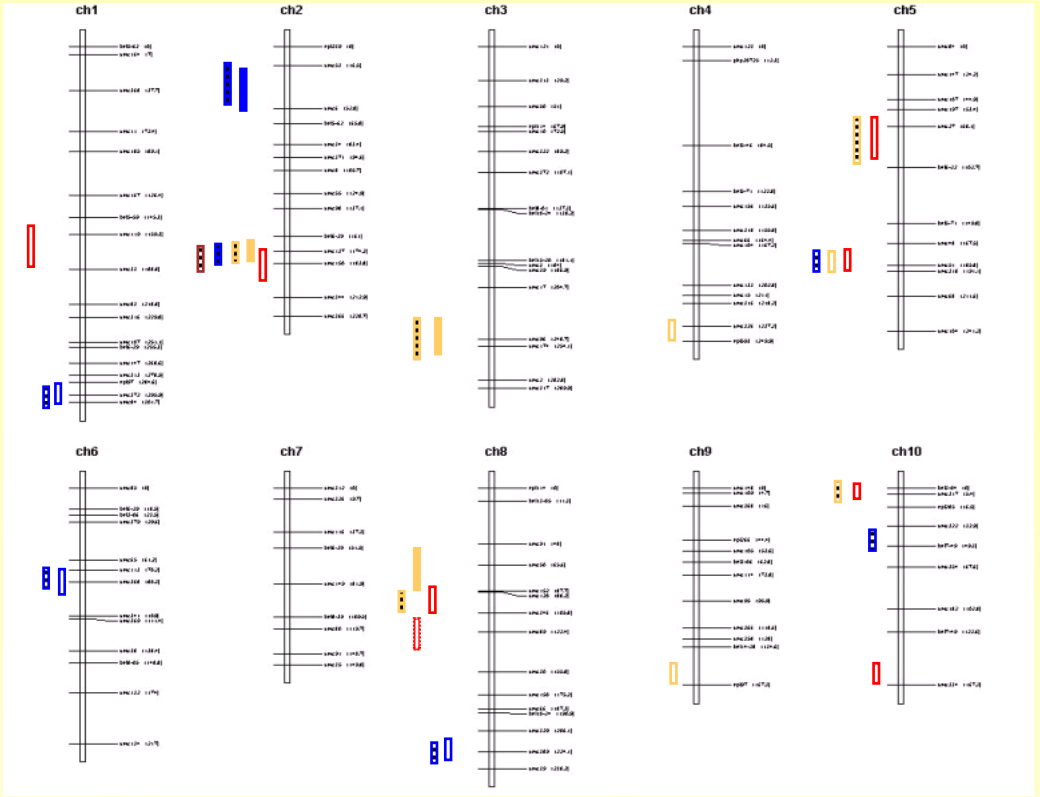




Influence of QTL on leaf development

Leaf expansion in maize under drought conditions
QTL related to environment responses



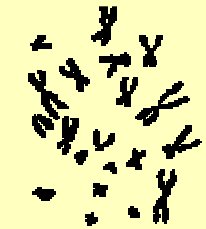


Welcker et al. 2007

$$LER = dl/dt = (T-T_0)(a + b\ VPD_{air\text{-}leaf} + c\ \Psi)$$

$$a = \bar{a} + \Sigma\ \alpha\ QTL \qquad b = \bar{b} + \Sigma\ \beta\ QTL \qquad c = \bar{c} + \Sigma\ \gamma\ QTL$$

Modelling influence of QTL on leaf development



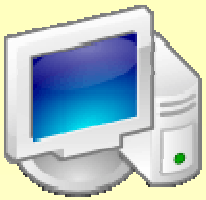
alleles of the QTLs

a, b, c

T_{leaf}, $VPD_{air-leaf}$, Ψ

Ta, Rn, HR, rain

$LER = (T-T_0)(a+bVPD+c\Psi)$



Leaf growth

Simulation of QTL impact in different scenarii

- **Simulation of virtual genotypes**

- Genotypes characterised from their leaf elongation rate variables (a, b & c)
- Estimation of a, b & c from the 5 major QTL identified for each variable (Welcker et al. 2007)

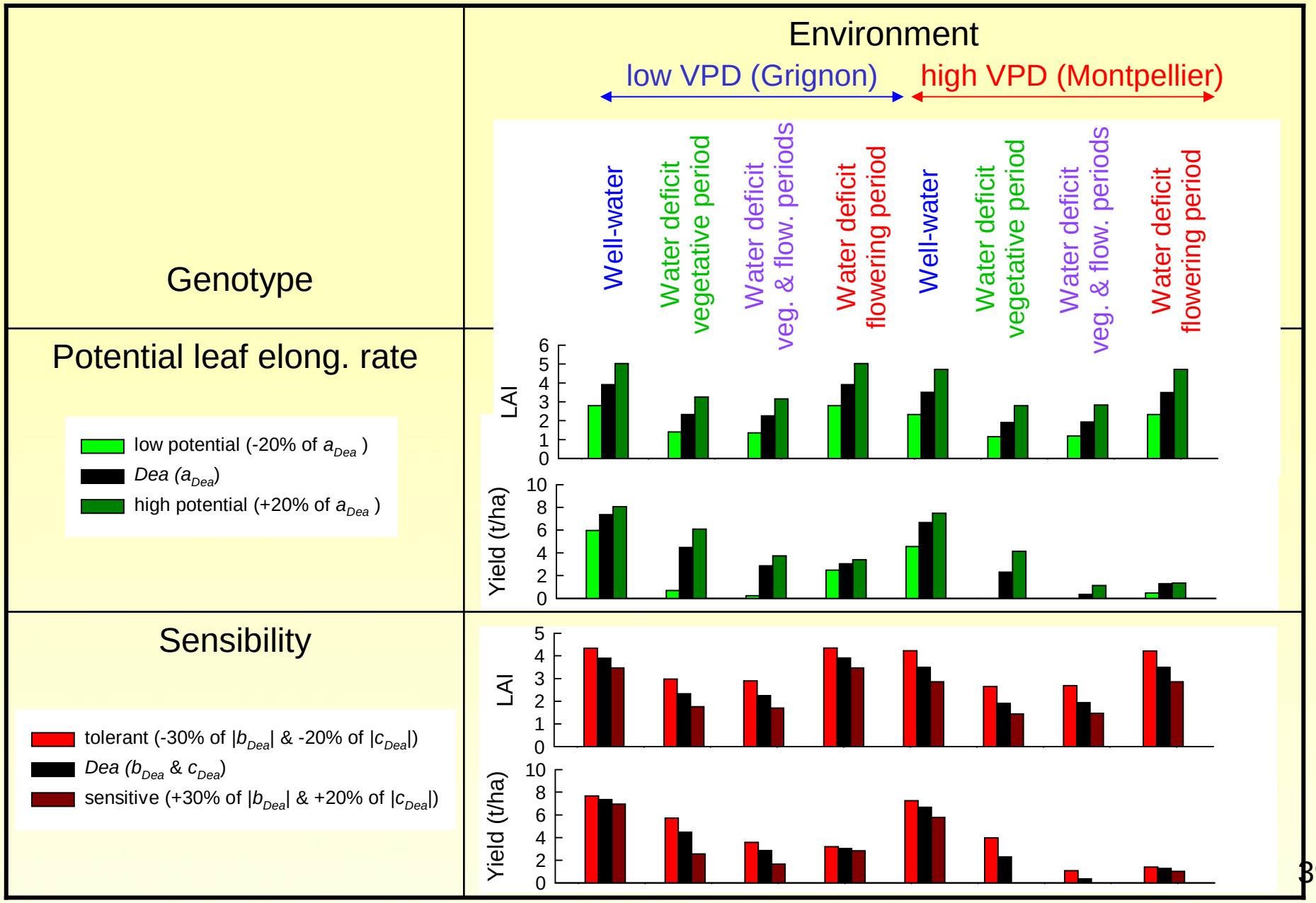
- Generation of genotypes with
  . high/low leaf elongation rate
  . high sensitivity/tolerance to VPD and water deficit

- **Environments**

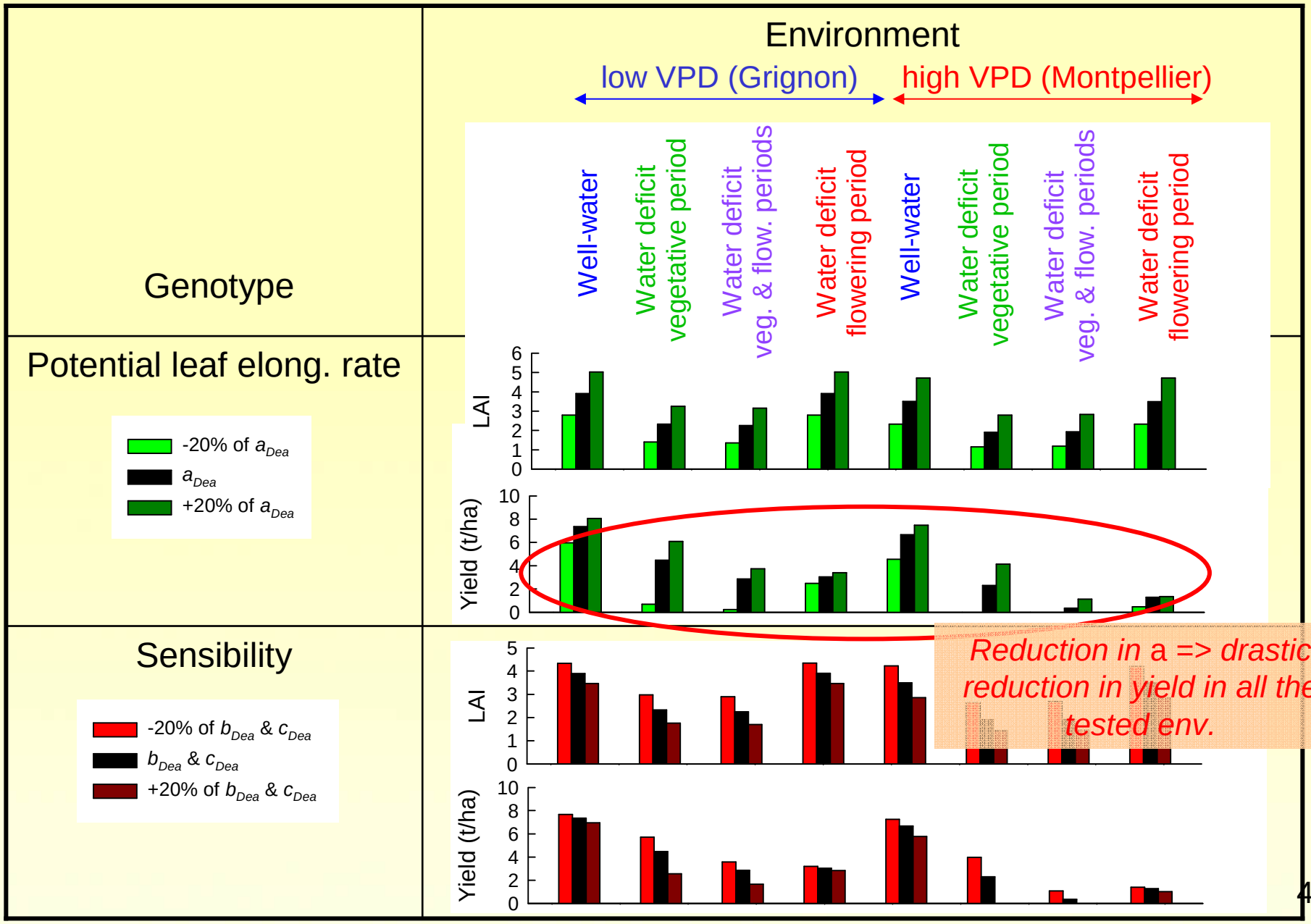
- High/low evaporative demand (Grignon/Montpellier)
- Water deficit during the vegetative / vegetative & flowering / flow. periods

graphe FTSW

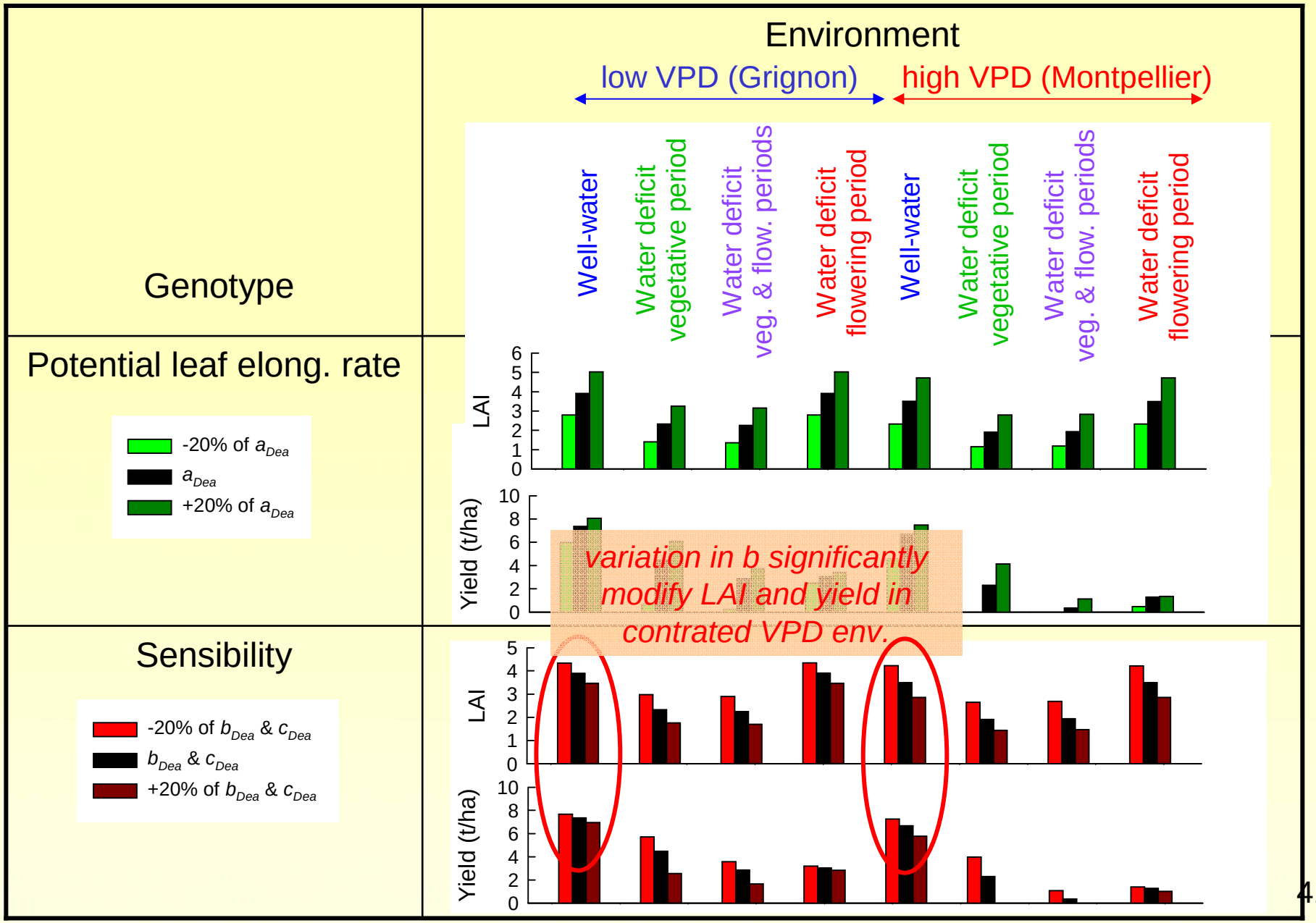
Influence of QTL on leaf development



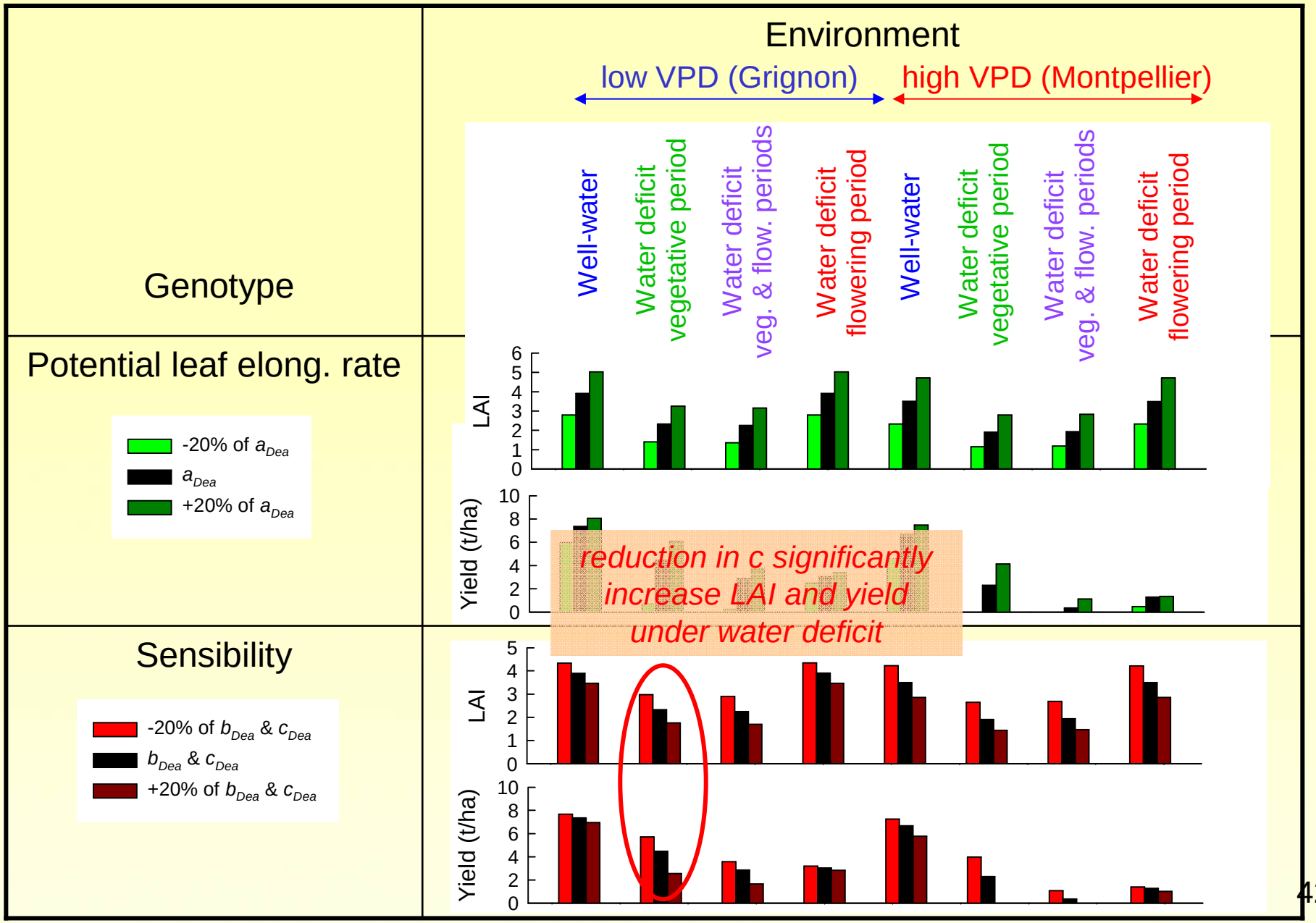
Influence of QTL on leaf development



Influence of QTL on leaf development



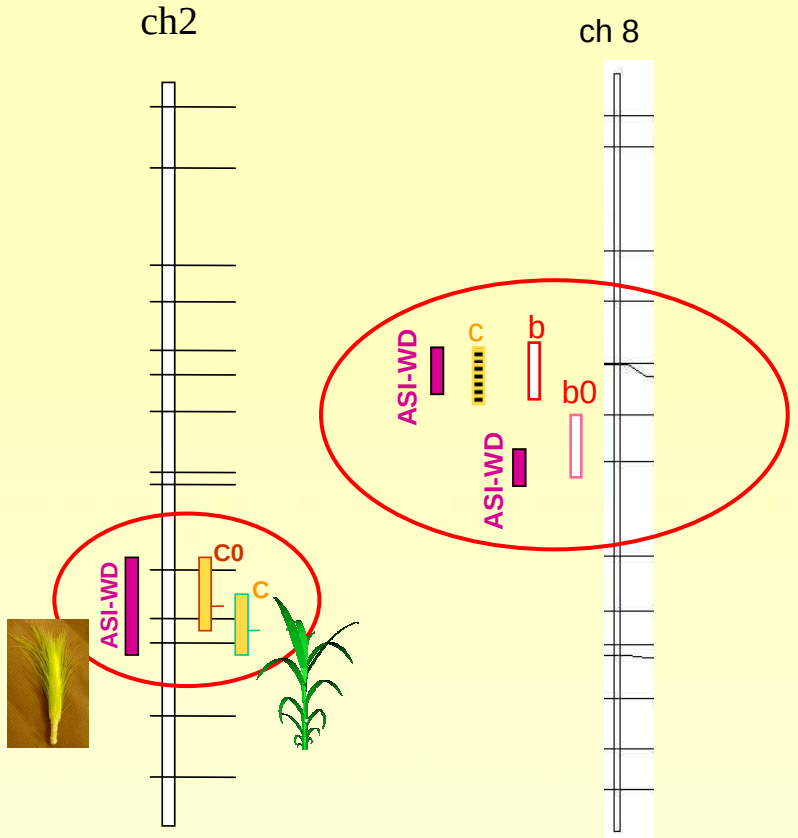
Influence of QTL on leaf development



Influence of QTL
on reproductive development

Reproductive development

- Common QTLs for ASI and the response of leaf elongation under water deficit

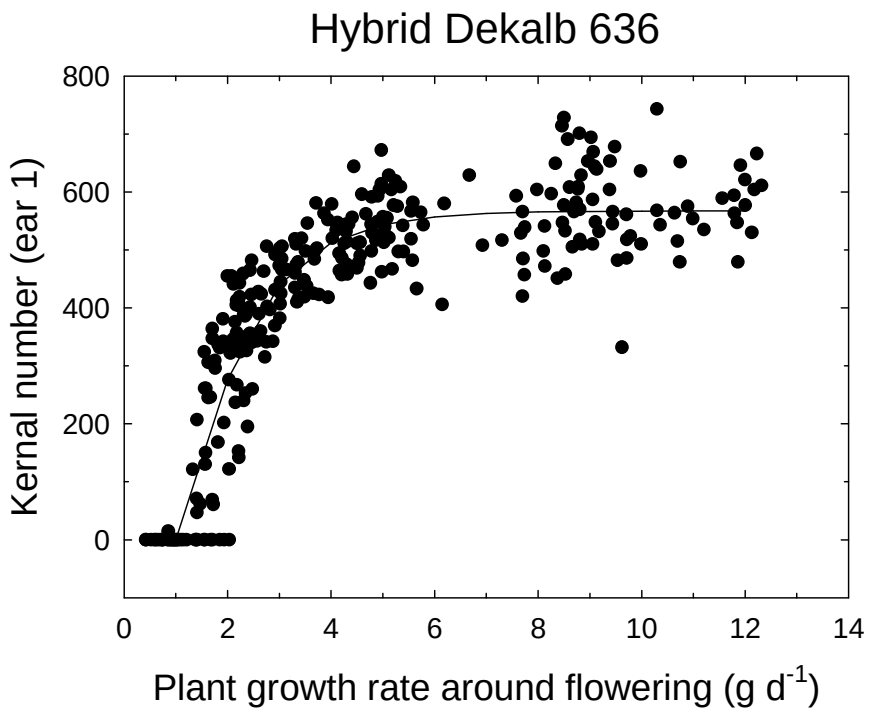


⇨ Effect of the QTLs of ASI integrated in APSIM.

Welcker et al. 2007

Reproductive development

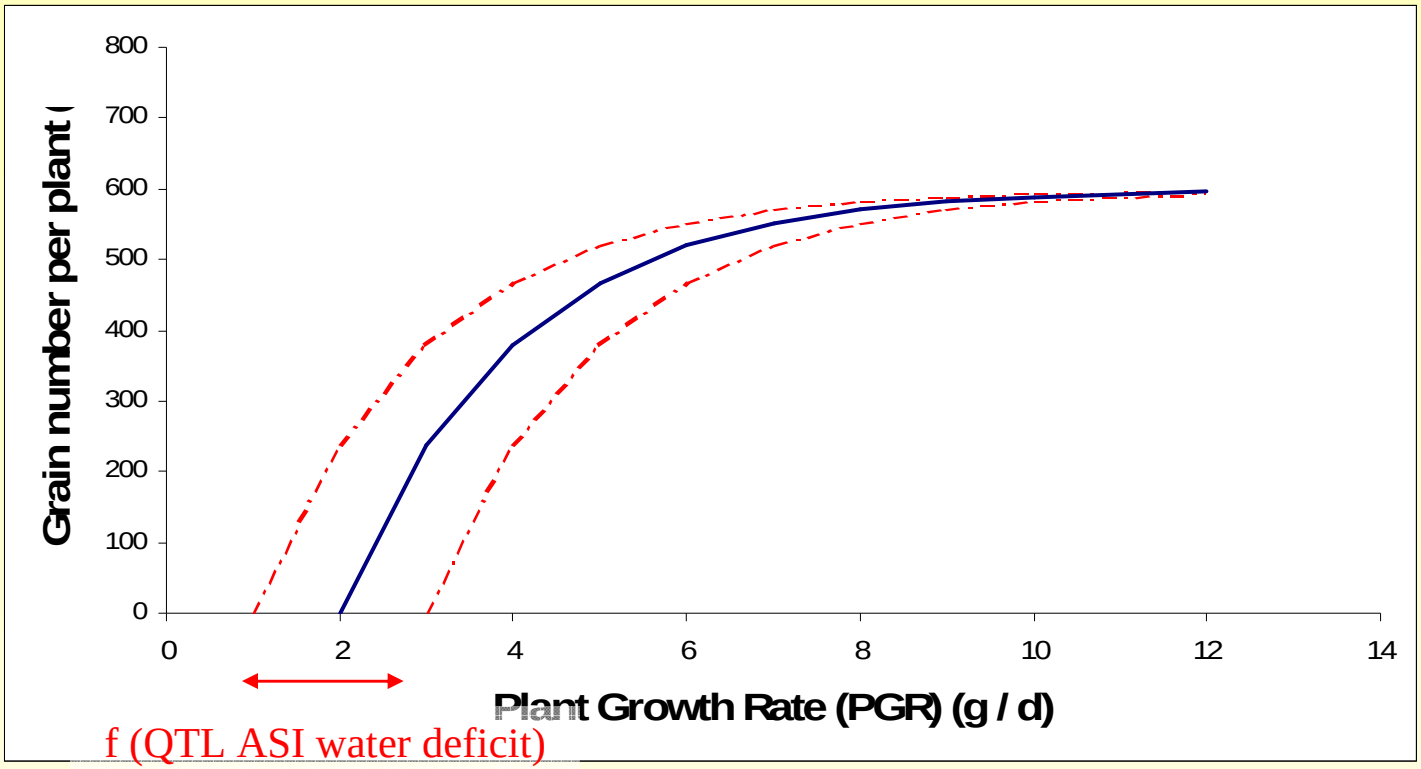
- **Estimation of grain number**



Andrade et al. 1999

Reproductive development

- Estimation of grain number in APSIM
- **Genetic variability for drought treatments**



Influence of QTL on leaf & silk development

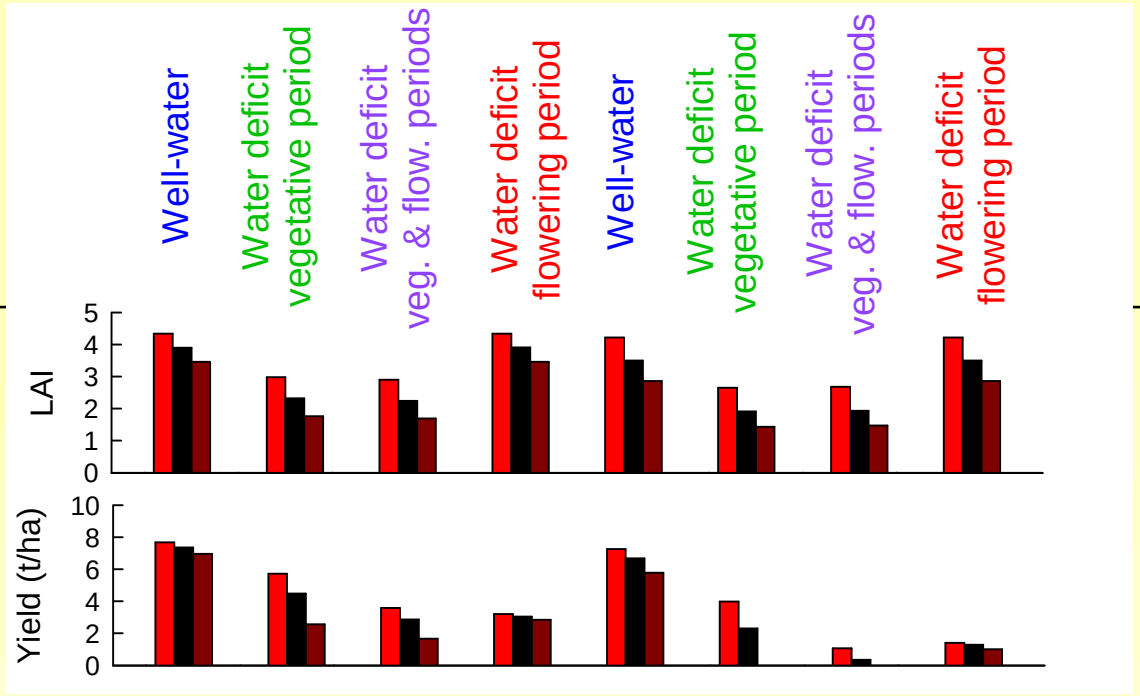
Genotype

Environment

low VPD (Grignon) — high VPD (Montpellier)

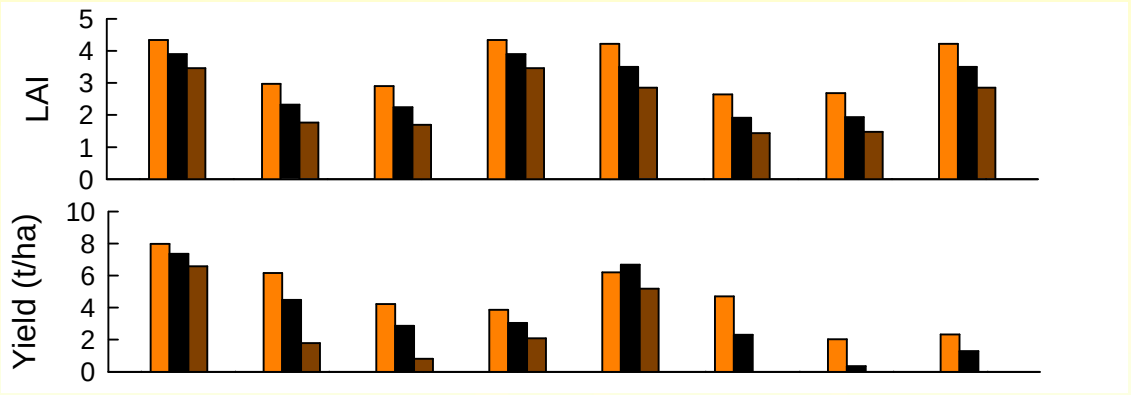
Sensibility of **leaf** elong. rate

- tolerant (-30% of $|b_{Dea}|$ & -20% of $|c_{Dea}|$)
- *Dea* (b_{Dea} & c_{Dea})
- sensitive (+30% of $|b_{Dea}|$ & +20% of $|c_{Dea}|$)

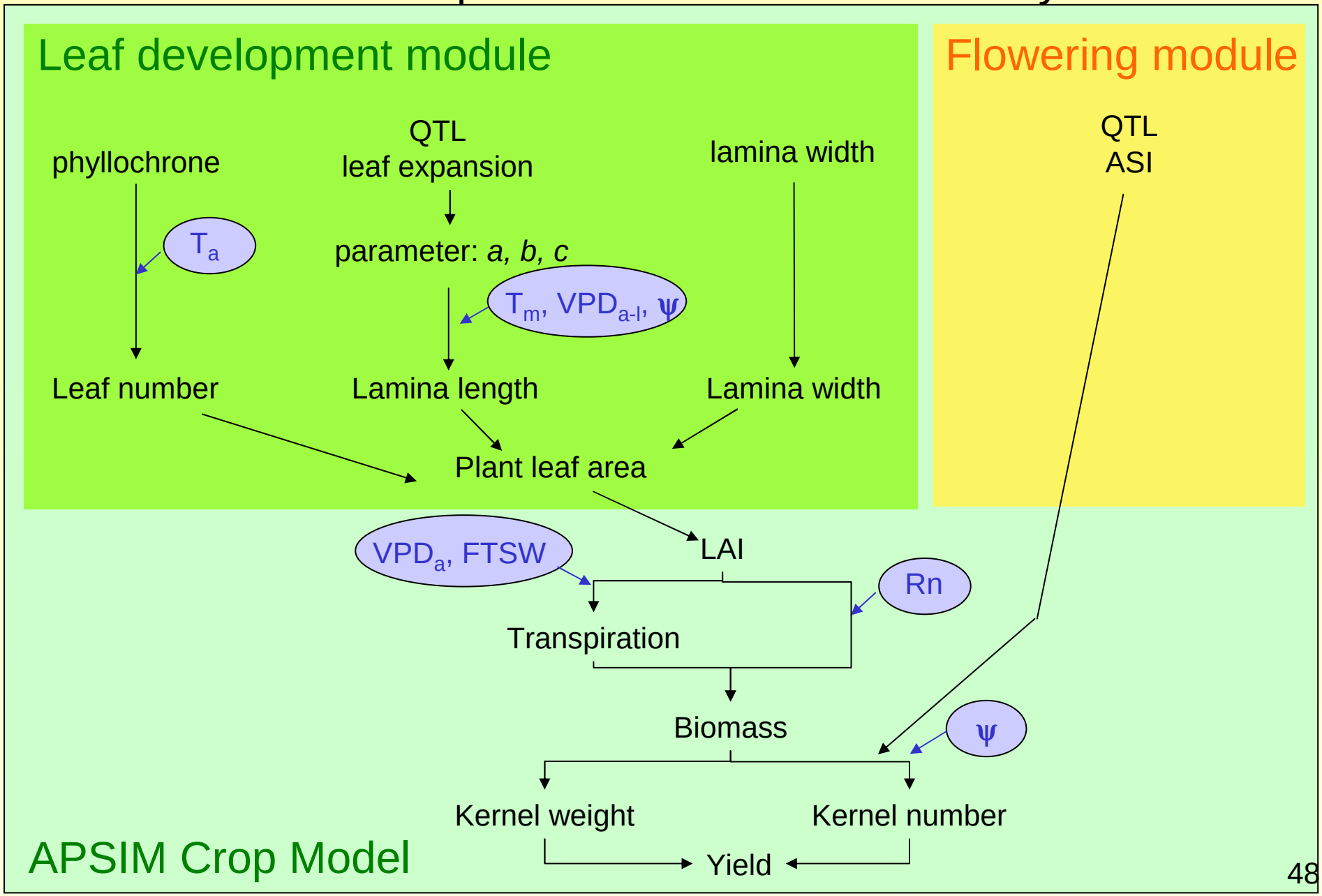


Sensibility of **leaf & silk** elong. rate

- tolerant (-30% of $|b_{Dea}|$ & -20% of $|c_{Dea}|$ & PGR_{base} low)
- *Dea* (b_{Dea} & c_{Dea})
- sensitive (+30% of $|b_{Dea}|$ & +20% of $|c_{Dea}|$ & $PGRba_{base}$ high)



Integrating QTL information on leaf and silk growth response into a crop simulation model - Summary



Summary - Perspectives

- **Leaf development**

- Observation: QTL found for the response of leaf expansion rate to temperature, evaporative demand, soil water deficit

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- Correct simulations:

. for leaf expansion in contrasted French environments with or without water deficit,

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Summary - Perspectives

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- Observation: QTL found for the response of leaf expansion rate to temperature, evaporative demand, soil water deficit

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- Integration of the QTL impact in APSIM

Summary - Perspectives

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- Observation: Common QTL for the growth parameters of leaf and silk, in well watered and water deficit conditions

Summary - Perspectives

- **Leaf development**
- **Reproductive development**

- Observation: Common QTLs for the growth parameters of leaf and silk, in well watered and water deficit conditions

- Integration in APSIM to test the effect of the QTL of ASI under different drought scenarios (Mexico data, virtual situations)

Model of maize leaf and silk elongation (INRA)

F. Tardieu
C. Welcker
M. Reymond
O. Turc
W. Sadok
A. Fuad-Hassan
Ph. Naudin
B. Boussuge
H. Ben-Haj-Salah
C Paysant
C Thonat

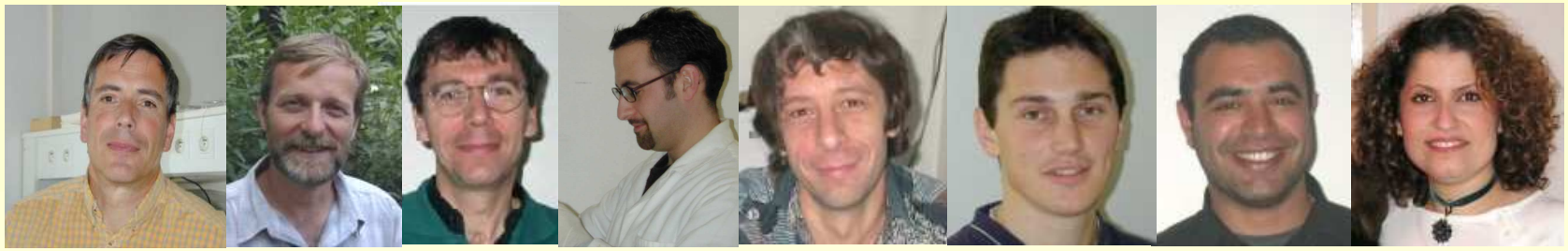
Generation
Cultivating Plant Diversity for resource poor

APSIM modelisation

G.L. Hammer (UQ)
S.C. Chapman (CSIRO)
G. McLean (QDPI&F)

Mexican data

JM Ribaut (Cimmyt)



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