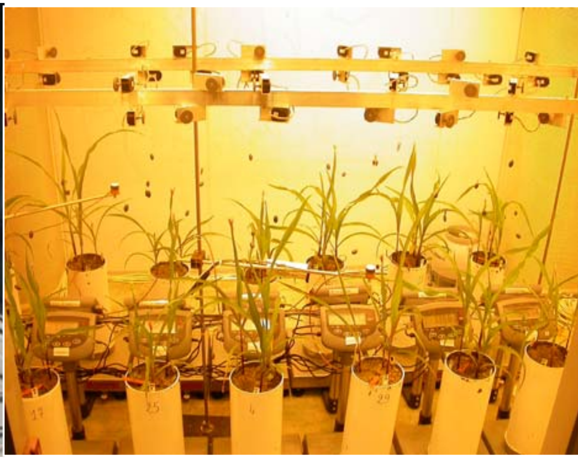
Modelling the GE interaction

Which models for what ?

C Welker, O. Turc, F. Tardieu



lepse Montpellier

Laboratoire d'Ecophysiologie des Plantes Sous Stress Environnementaux

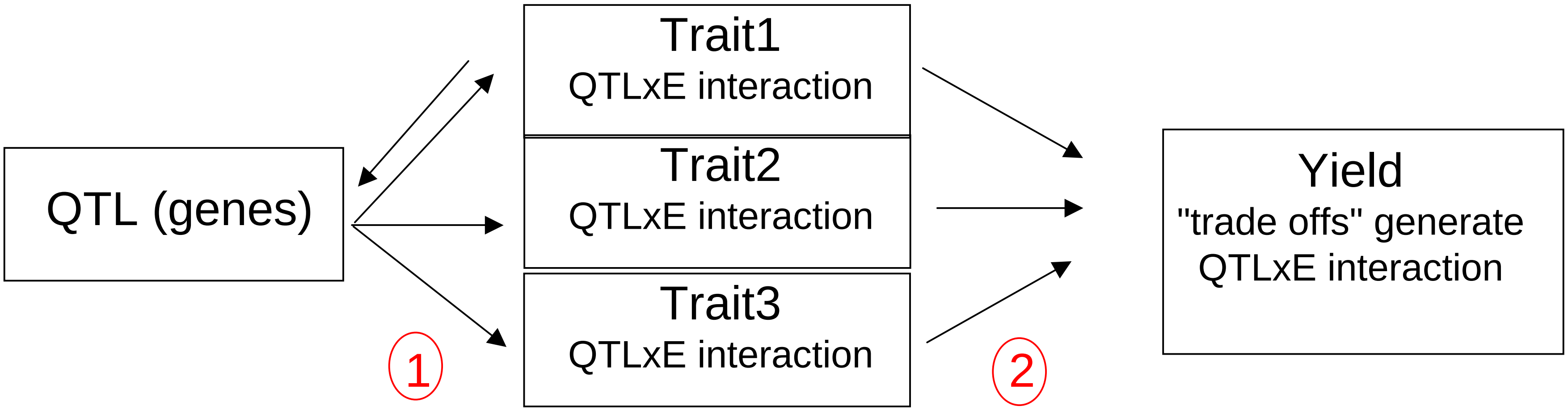
INRA

GENOPLANTE

Generation

Which model (s) ?

2 types of modelling activities :



2 : C. Messina's and M Cooper's presentations, 1 hypothetical

1 : how to identify QTLs across environments ?

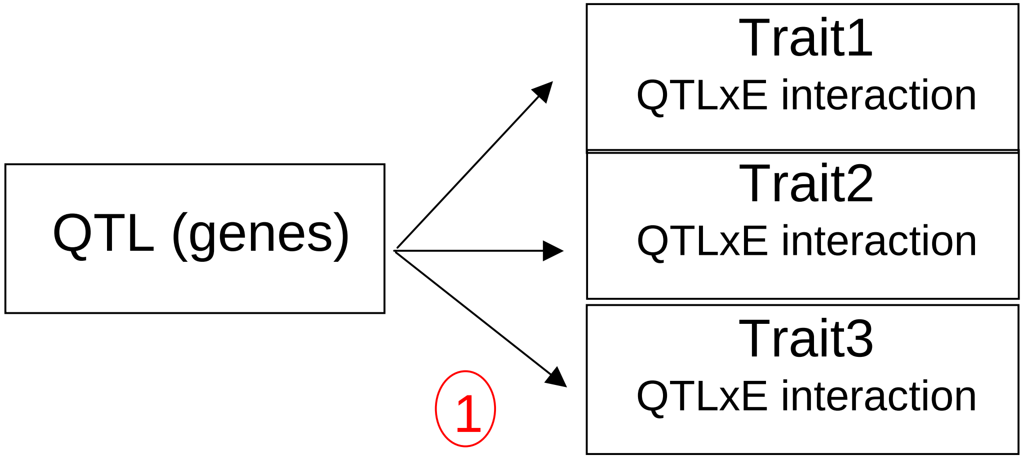
- Network of experiments (Van Eeuwijk et al. 2005)
- Can modelling help, and how ?

GCP project : link 1 and 2 with two different modelling approaches

1 : GCP project 15, my presentation

2 : GCP project WPM, Karine Chenu (weight the importance of QTLs of growth)

Which model (s) ?



Model : express the phenotype in such a way that it encapsulates the GxE

Trait = f(V1, V2, V3 , a1, a2, a3)

V, environmental variables, a parameters (should not change)

Photosynthesis = f(light,initial slope, plateau)

genotypic constants

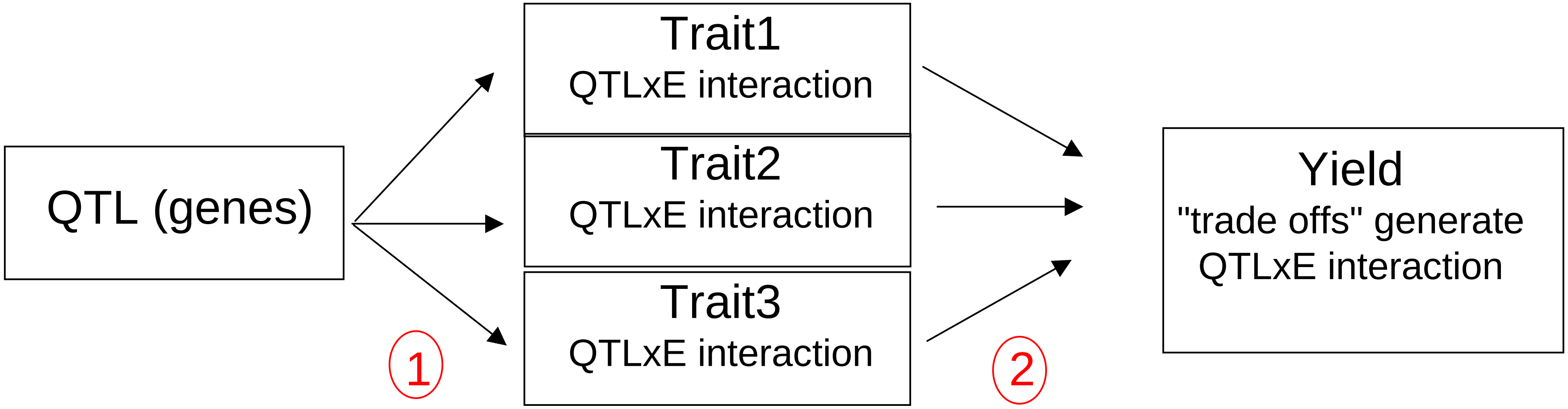
↓

genetic analysis

↓

simulated phenotypes

Which model (s) ?



Can the models in 1 and 2 be the same ?

- Yes : **Fit a "preexisting, conceptual model" on data**,
  extract parameters + genetic analysis
  (Quillot et al. 2003, Yin et al. 2004, Luquet et al 2006)

- No : **Build "ad hoc" models which fit data with very few parameters**
  . genetic analysis of parameters
  . the physiology / genetics come after this analysis
  (Reymond et al. 2003, Welcker et al 2007, Sadok et al. 2007)

Which model ?

1. Fit a "pre-existing, conceptual model" on data,
   extract parameters + genetic analysis

2. Build "ad hoc" models which fit data with very few parameters
   . genetic analysis of parameters
   . the physiology / genetics come after this analysis

Do 1 and 2 really differ ?

1 : I believe in my model, I can build genetic analyses on it

2 : I don't, we do not know enough of the mechanisms to build a theory for the genetic variability of responses to environment

Which model ?

1. Fit a "pre-existing, conceptual model" on data,
   extract parameters + genetic analysis

2. Build "ad hoc" models which fit data with very few parameters
   . genetic analysis of parameters
   . the physiology / genetics come after this analysis

Do 1 and 2 really differ ?

1st part :

Our experience with process-driven models

Test candidate mechanisms / equations for leaf growth:

"fill the graveyard of mechanisms"

C availability ? ABA ? Cell wall properties? Hydraulics ?

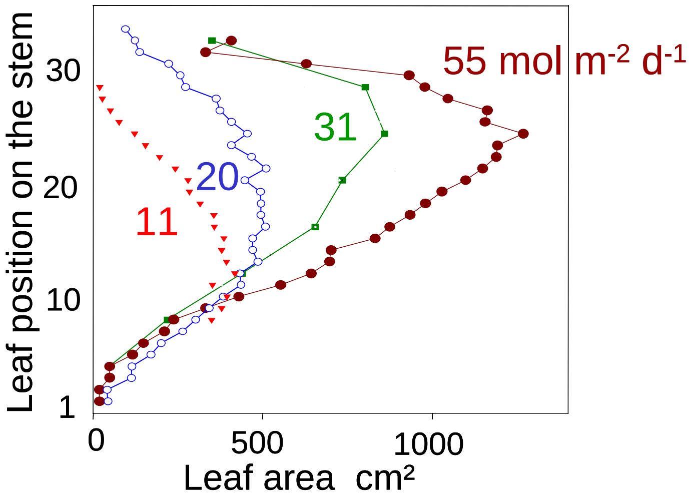
2nd part :

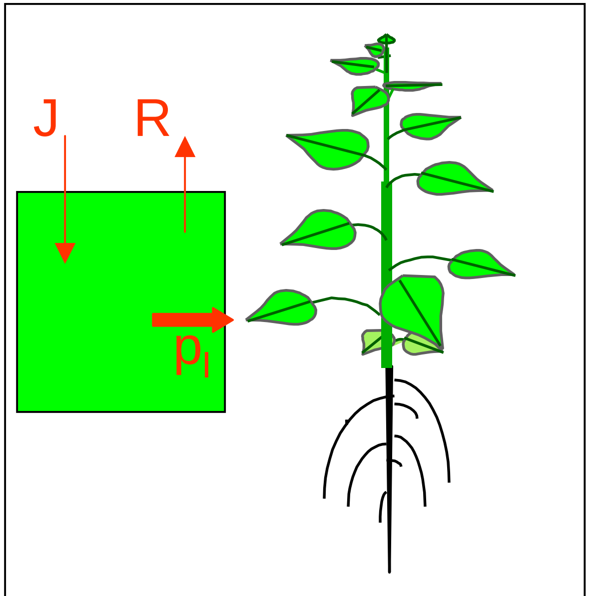
Genetic analysis using an "hypothesis free" model.

Testing candidate mechanisms /equations for leaf growth

A model based on carbon availability ?

Increase in leaf area	=	Carbon gain	*	% C to leaves	*	Leaf area per unit mass C
$\Delta A / \Delta t$	=	$(J - R)$	*	p_l	*	SLA

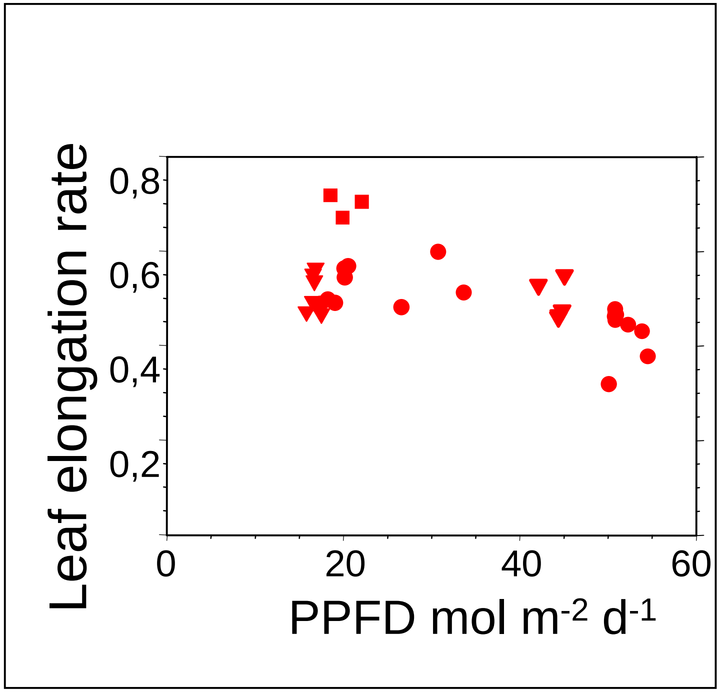




Testing candidate mechanisms /equations for leaf growth

Maize (all monocots ?) : No effect of C availability

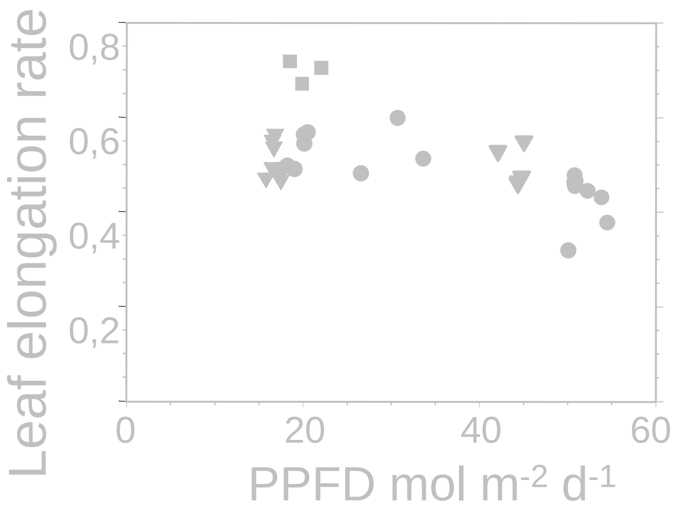
Does light availability increase the leaf growth rate ?



Tardieu et al. 1999

Maize (all monocots) : No effect of C availability

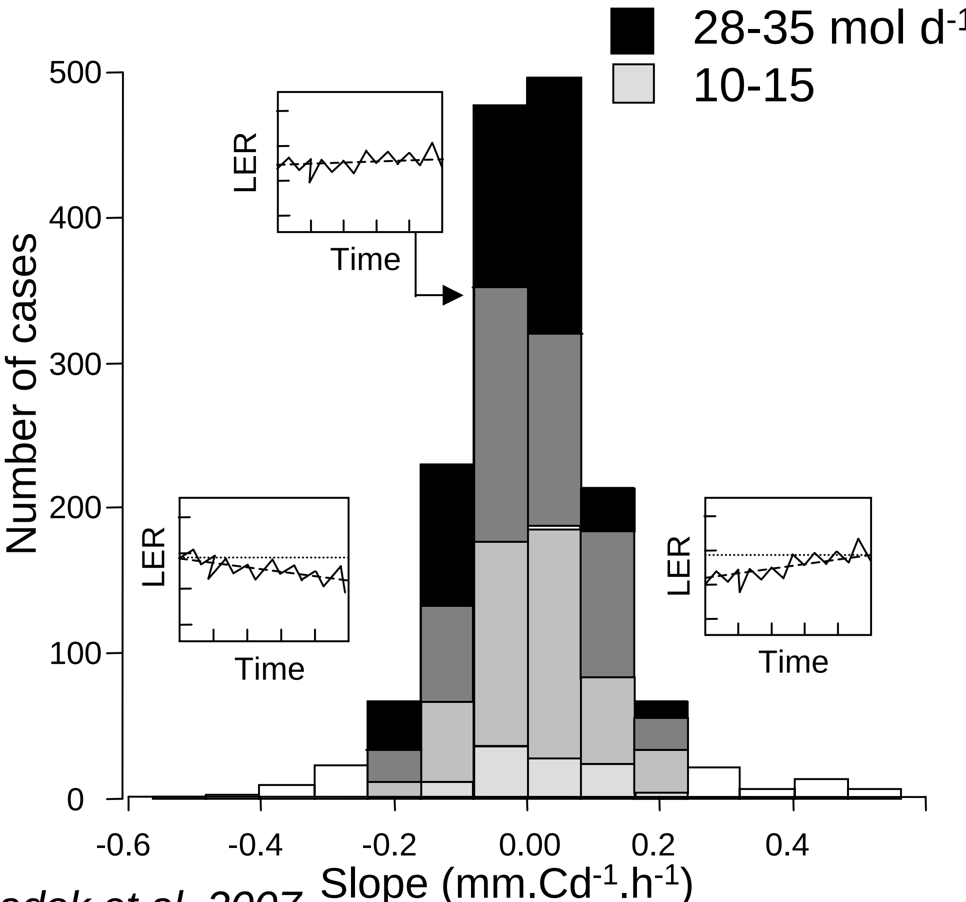
Does light availability increase the leaf growth rate ?



Tardieu et al. 1999

A decline during the night if light is not sufficient ?

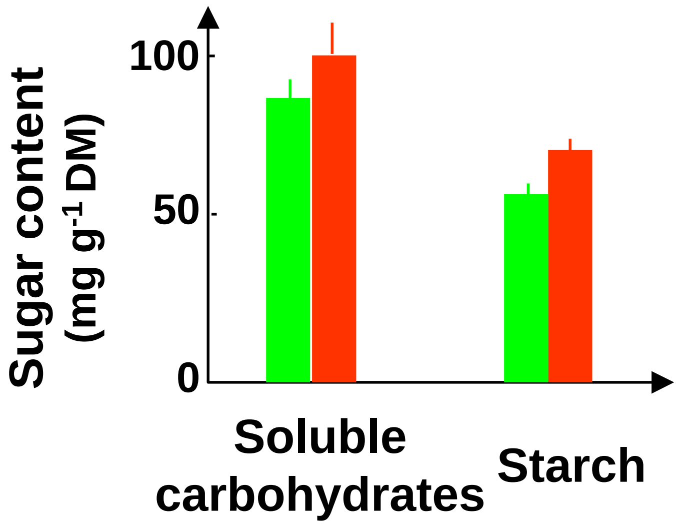
A GxE interaction ?



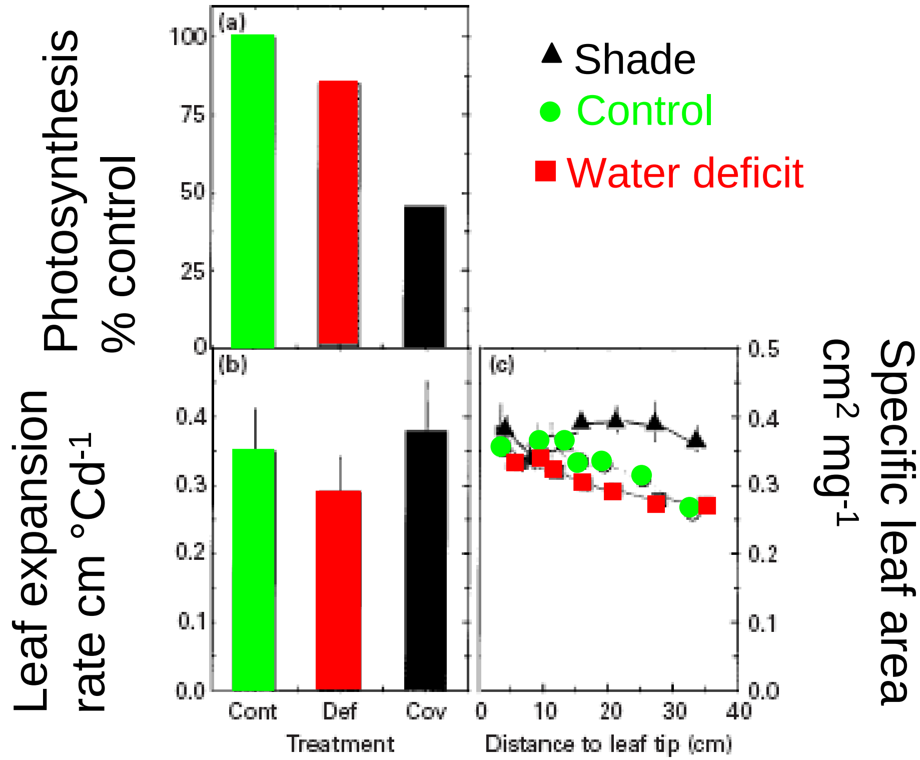
Sadok et al. 2007

Maize (all monocots) : No effect of C availability

Adjusted on specific leaf area and sugar content.



Leaves "heavier" in deficit, "lighter in shade



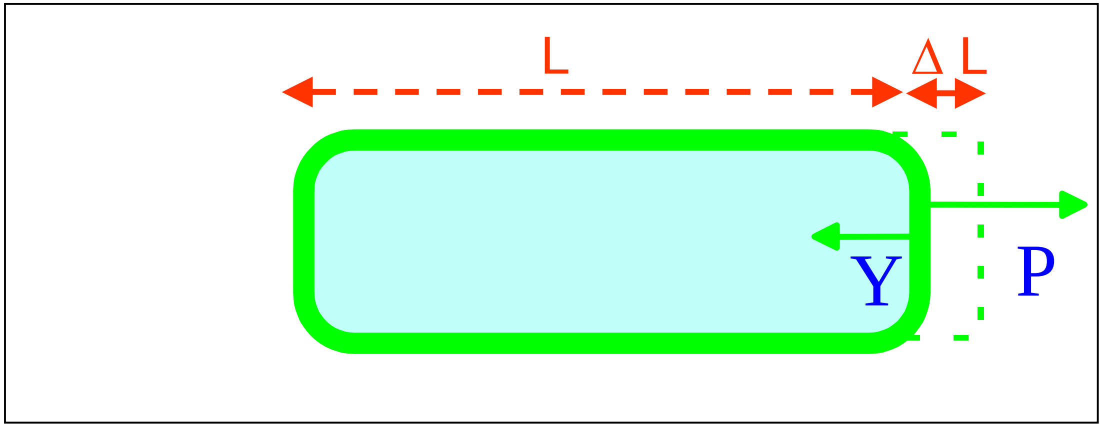
Tardieu et al. 1999

Testing candidate mechanisms/equations for leaf growth

Cell wall extensibility ?

Increase in leaf area (rel)	=	Tissue extensibility	*	Turgor - threshold turgor
$\Delta A / A \Delta t$	=	ϕ	*	$(P - Y)$

expansins : family of genes which facilitate wall expansion
"molecular grease"
Cosgrove 2005

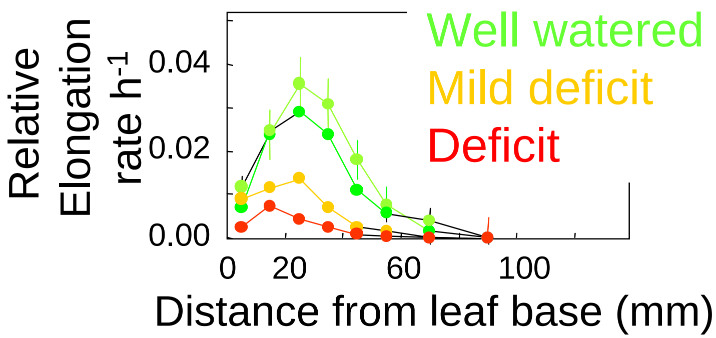


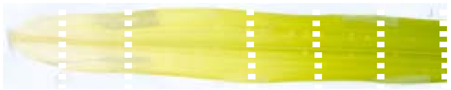
Testing candidate mechanisms/equations for leaf growth

Expansins ?

Do expansins account for the changes in elongation rate with water deficit ?

33 expansins
19 expressed in growth zones
5 good candidates





Muller et al. 2007 Plant Phy 143, 278

Testing candidate mechanisms/equations for leaf growth

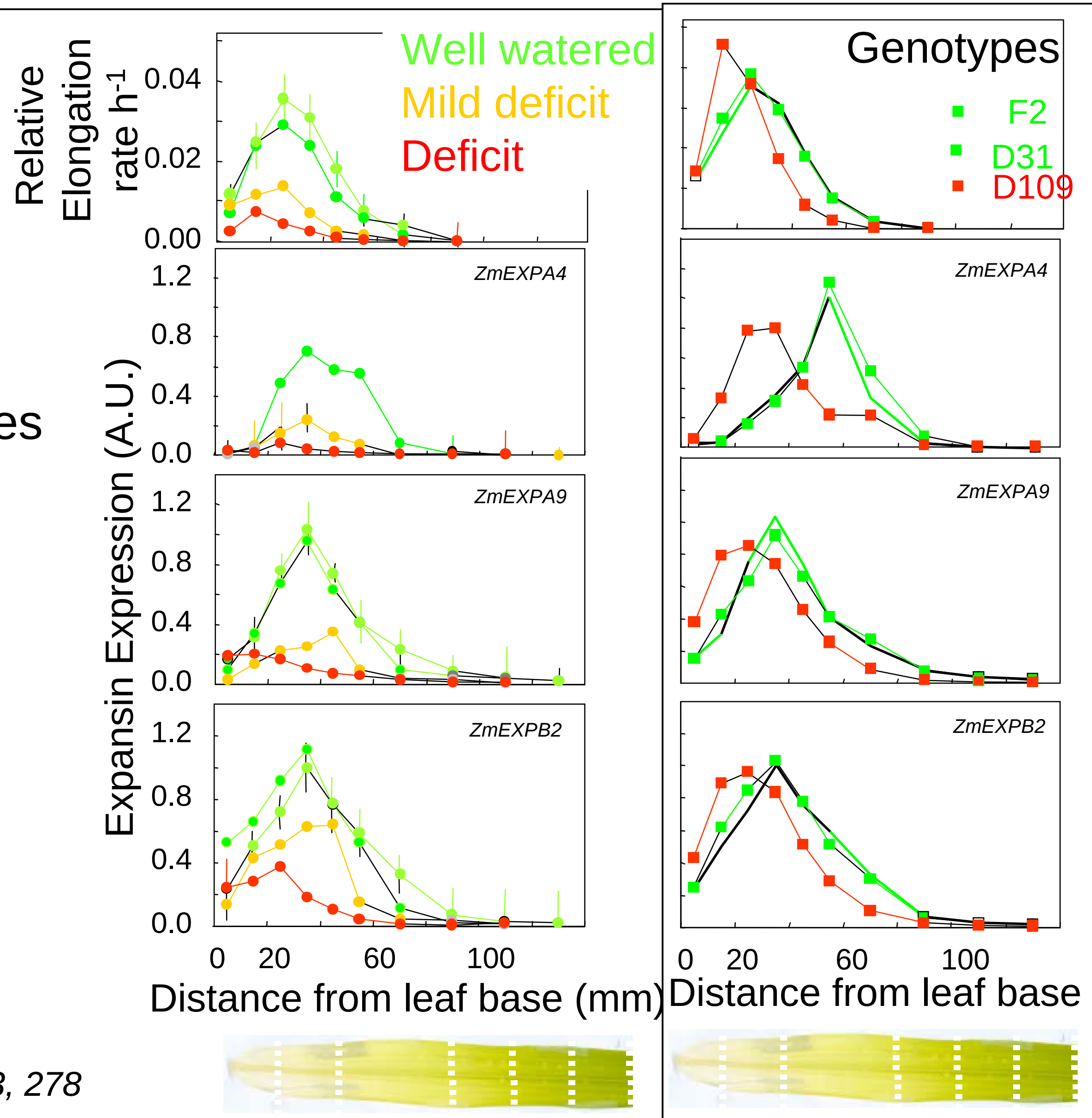
Expansins ?

3 expansins account for differences in growth rate due to water deficit

... and for genotypic differences

... and for leaf aging...

Causes ?
Consequences ?
Who follows who ?



Muller et al. 2007 Plant Phy 143, 278

Testing candidate mechanisms/equations for leaf growth

ABA ? $\Delta A / A \Delta t = a [ABA]_{xyl} + \text{hydraulic effect}$

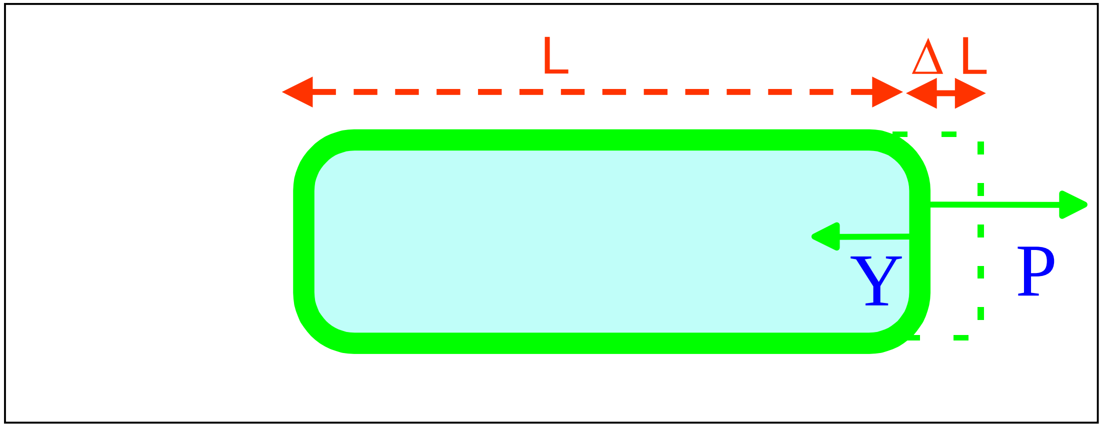
Over/under expressors of the NCED gene

"raw phenotype" : no effect on leaf growth *(Voisin et al. 2006 PCE)*

Testing candidate mechanisms/equations for leaf growth

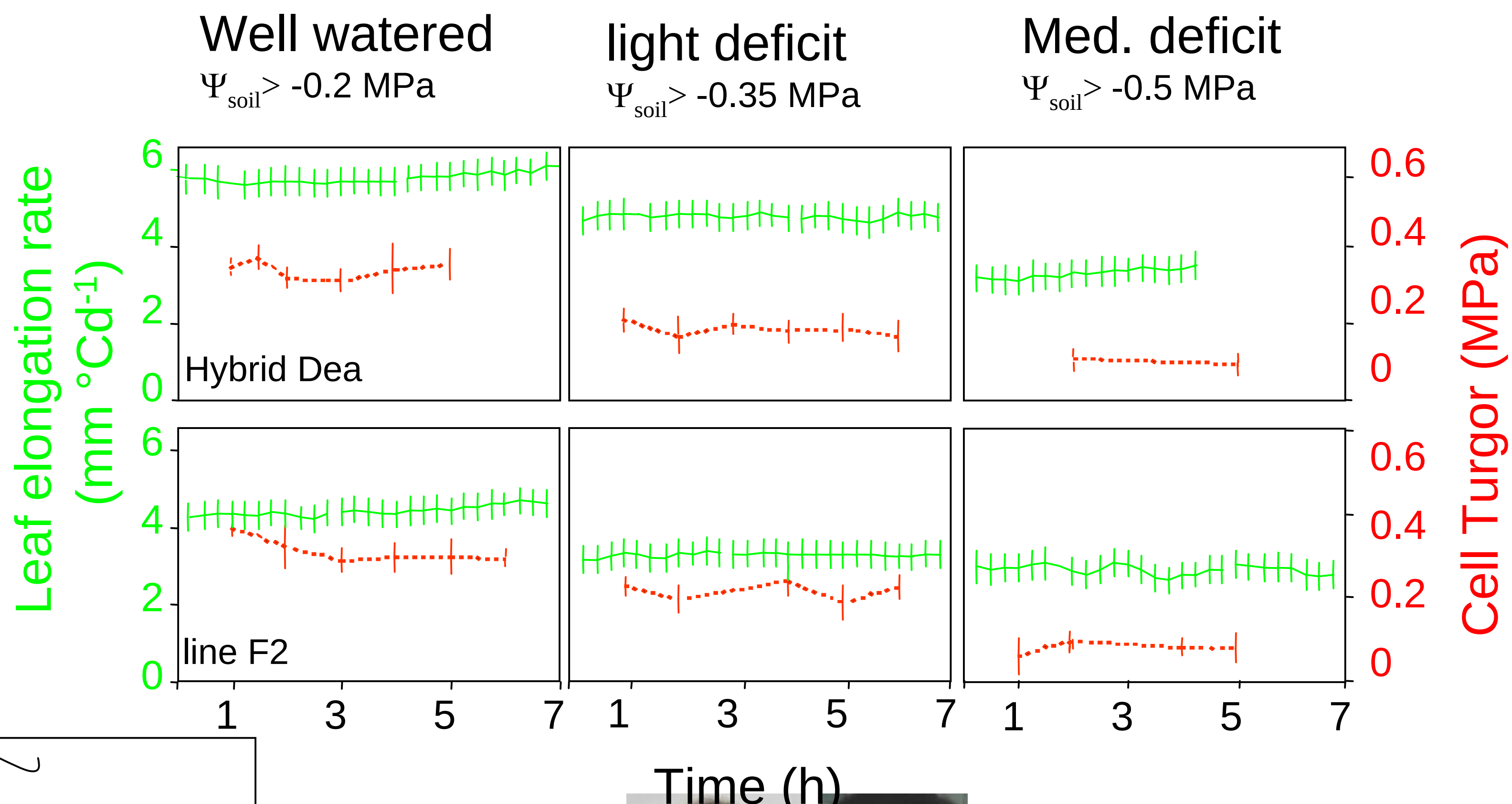
Hydraulics ?

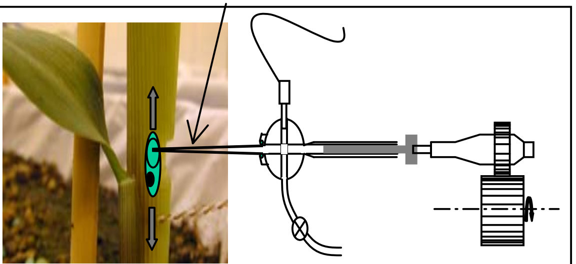
Increase in leaf area (rel)	=	Tissue extensibility	*	Turgor - threshold turgor
$\Delta A / A \Delta t$	=	ϕ	*	$(P - Y)$



Testing candidate mechanisms/equations for leaf growth

Hydraulics : Changes in elongation rate accounted for by turgor





Bou chabke, Tardieu Simonneau

Testing candidate mechanisms/equations for leaf growth

1. Fit a "pre-existing, conceptual model" on data, extract parameters + genetic analysis

2. Build "ad hoc" models which fit data with very few parameters
   . genetic analysis of parameters
   . the physiology / genetics come after this analysis

- A big graveyard of models and hypotheses which would account for genetic variability of responses of leaf growth
<u>Although each hypothesis could generate a reasonable model</u>
    C availability, ABA, cell wall properties via expansins, cell division rate

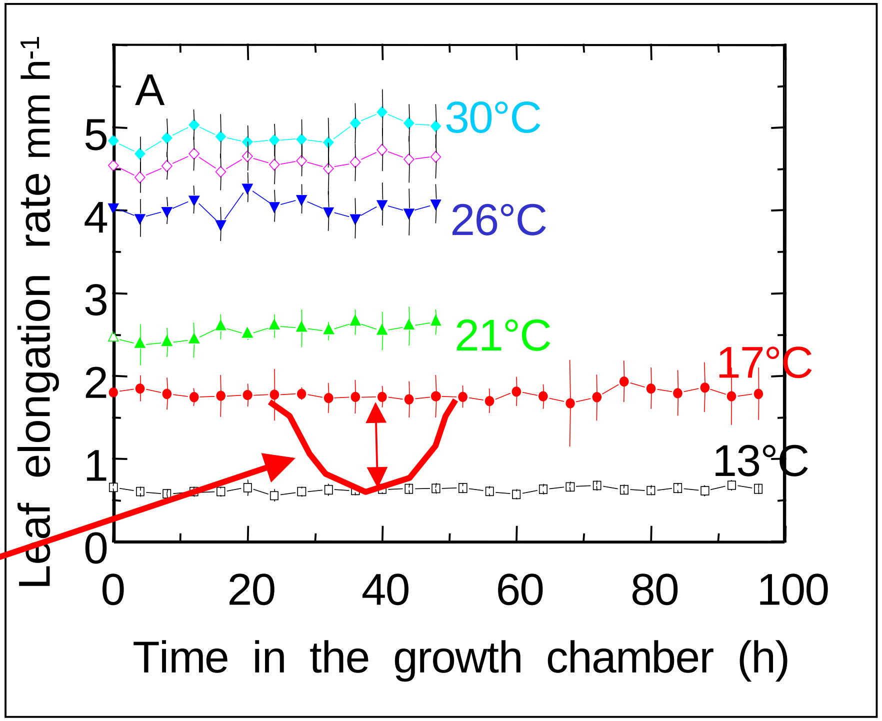
- Hydraulics seem to resist... a dynamic model
  but too many parameters for genetics

A simpler, "hypothesis free" model for genetics :
identify "identity card' of genotypes : stable characteristics

A "phenotypic" model of growth

Monocots : possibility to follow with a 15 minutes definition :

- leaf expansion rate
- transpiration
- micrometeorological conditions



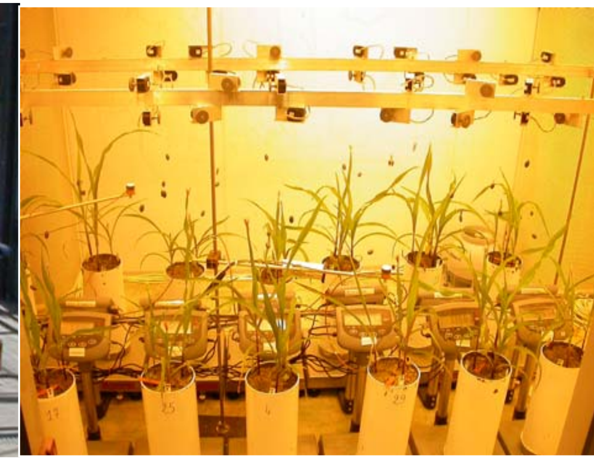
Elongation rate is stable
in stable environmental conditions
Ben Haj Salah and Tardieu 1995 Plant Phy

The effect of environmental conditions can be assessed by the difference observed value - expected value at the same temperature

A "phenotypic" model of growth

Phenotyping platform

380 plants



40 plants

meristem
temperature

Soil water status
transpiration rate

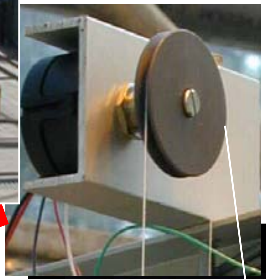
data logger

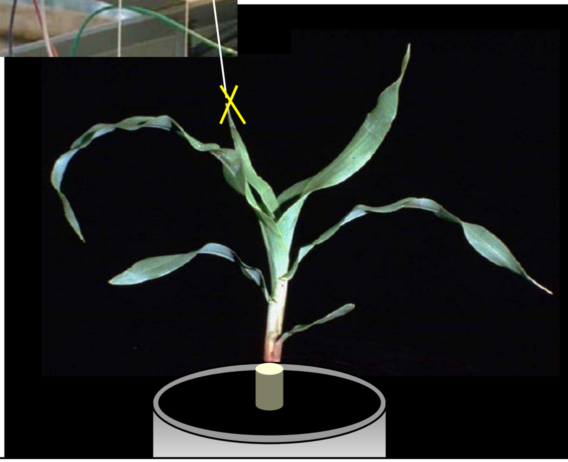
evaporative
demand

light

A "phenotypic" model of growth

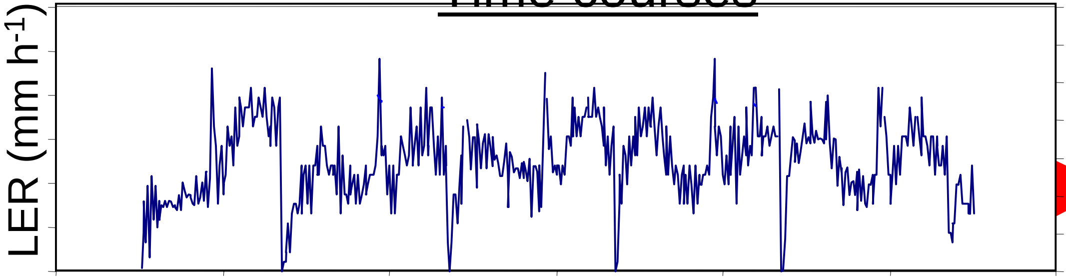
Phenotyping platform





Data loggers

Time courses



Data base

1000s of time courses :

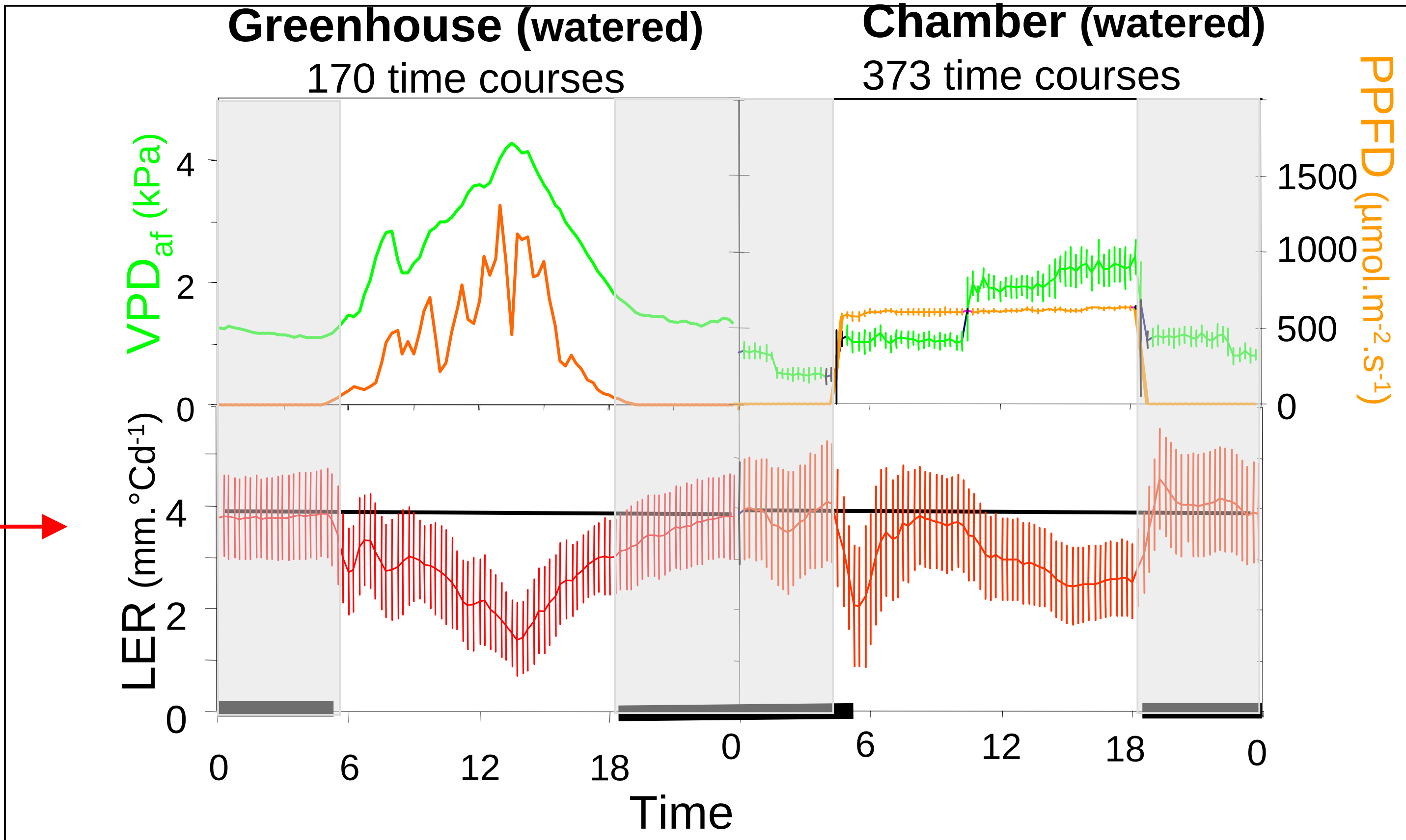
growth + env conditions

+ transpiration + phenology.

A "phenotypic" model of growth

- Rates <u>per unit thermal time</u> : stable with time during the night

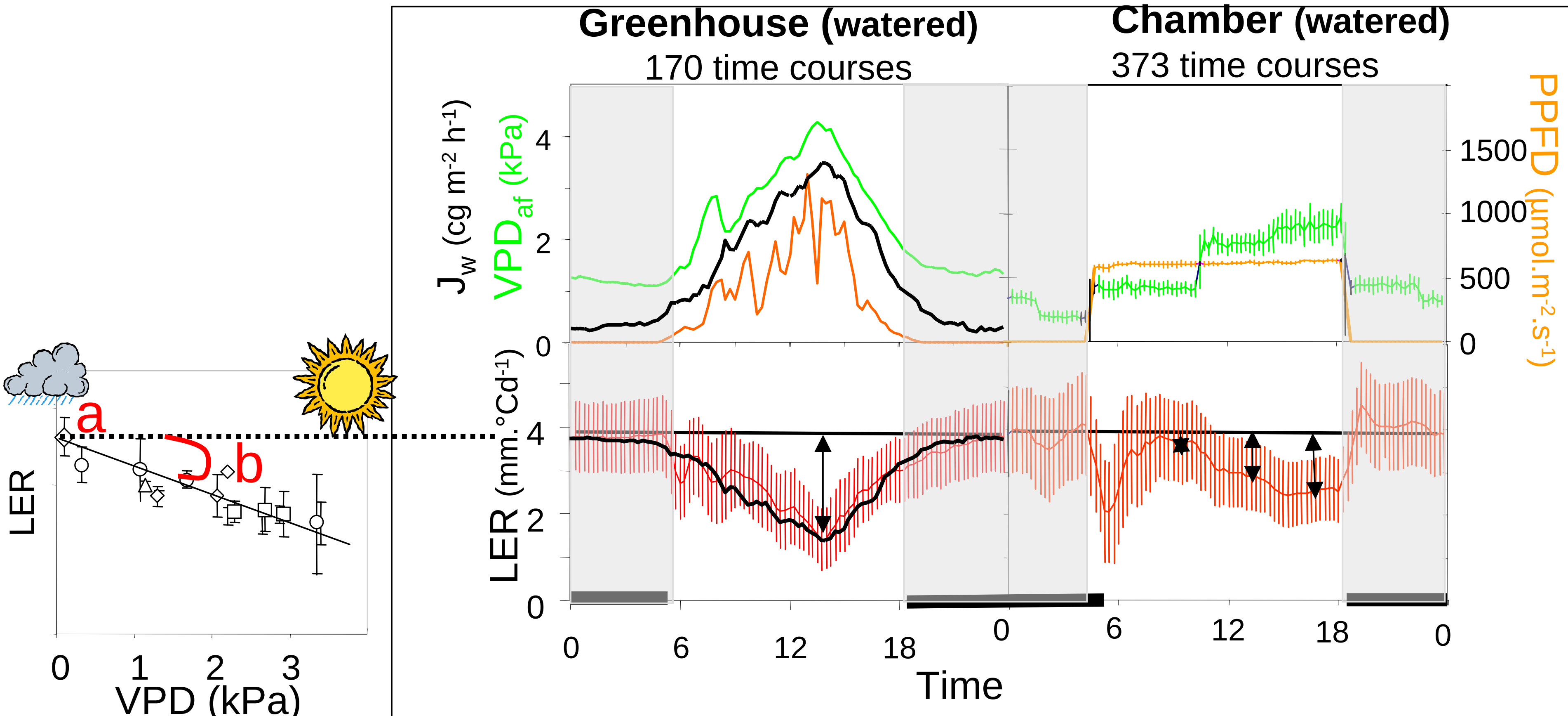
$dL/dt_t = a$ →



Sadok et al. 2007 PCE **30**, 135–146

A "phenotypic" model of growth

- Rates <u>per unit thermal time</u> : stable with time during the night
- Rates (day) decrease with evaporative demand, rapid transitions
- Elongation rate follows transpiration rate (LER_{th} = a -b J_w)



Sadok et al. 2007 PCE **30**, 135–146

A "phenotypic" model of growth

apparently accounted by the superposition of two kinetics :

“Rapid”
Alternation due to
evaporative demand "hydraulic"

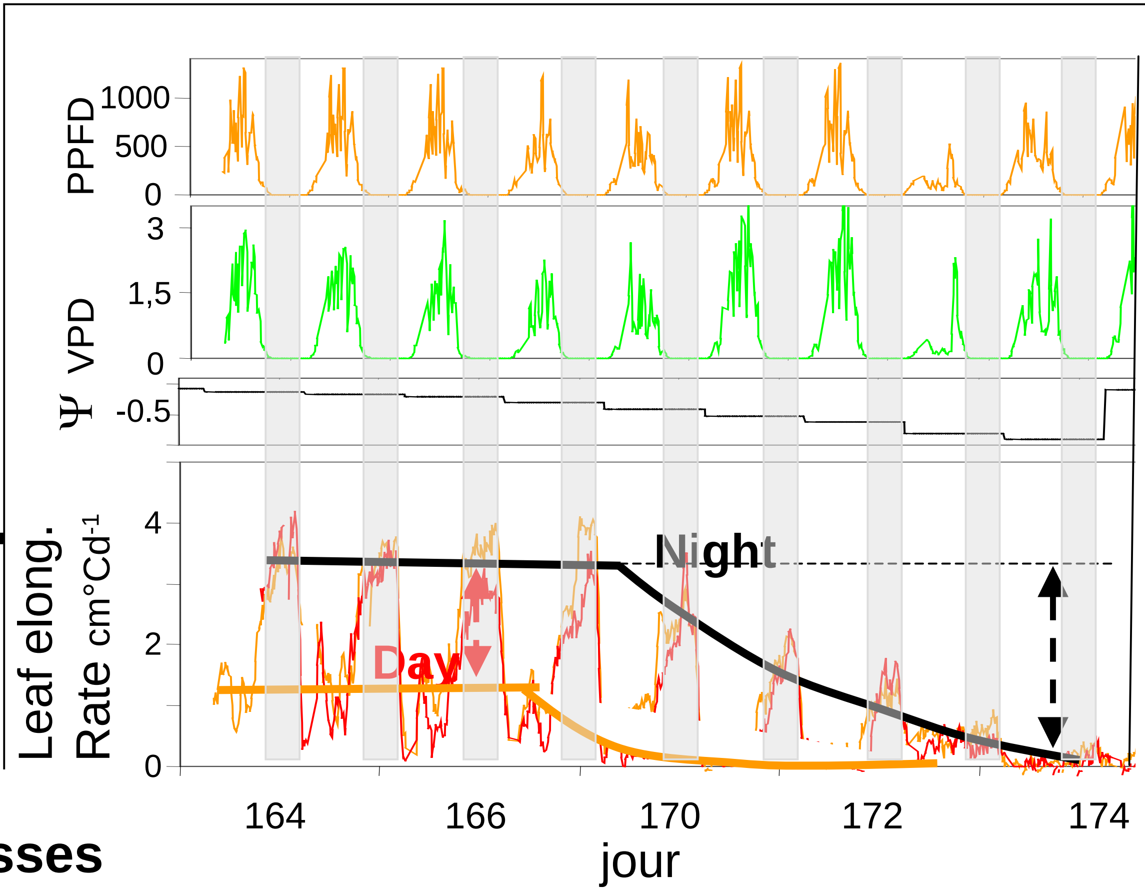
$dl/dt = (T-T_0)(a-bVPD_{la})$

“Slow”
Decline of night values
"cell walls, cell cycle, message"

$dl/dt = (T-T_0)(a-c\ \Psi)$

Time course modelled by the sum of slow and rapid processes

$dl/dt = (T-T_0)(a-bVPD_{la} -c\ \Psi)$

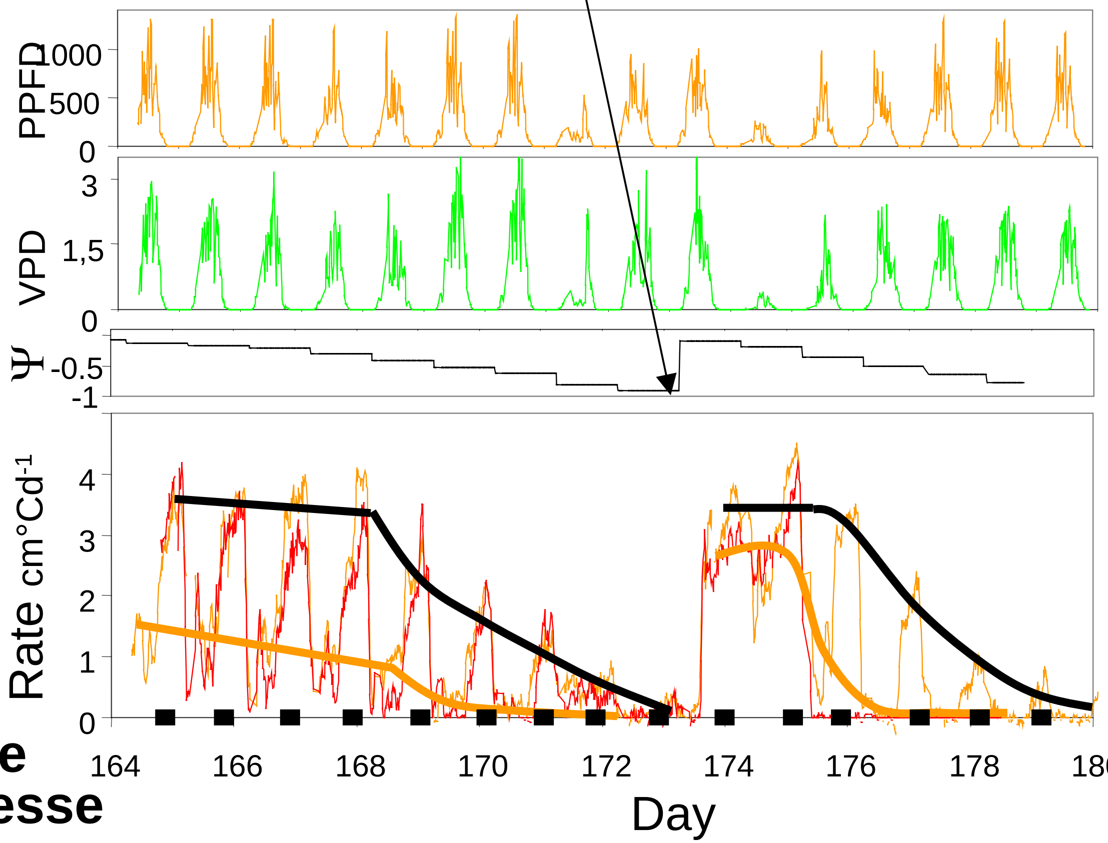


Leaf elongation rate for a 10-d period with water deficit

Ben Haj Salah and Tardieu 1997 Plant Phy 114, 893
Reymond et al 2003 Plant Phy 131, 664

A "phenotypic" model of growth

full recovery in 1 h !



Time course modelled by the sum of slow and rapid processe

$dl/dt = (T-T_0)(a-bVPD_{fa} -c\ \Psi)$

A "phenotypic" model of growth

- Rates (day) decrease with evaporative demand, rapid transitions

- Effect of soil water deficit : superposition of two kinetics ?

$$dl/dt = (T-T_0)(\ a - b\ VPD_{la} - c\ \Psi)$$

intrinsic growth rate of the genotype

sensitivity to evapor. demand "rapid, hydraulic"

sensitivity to soil water deficit "slow, messages"

Ben Haj Salah and Tardieu 1997 Plant Phy 114, 893- , Reymond et al 2003 Plant Phy 131, 664-,
Sadok et al 2007 PCE 30, 135–

Genetic analysis of model parameters

$$dl/dt = (T-T_0)(a - b\, VPD_{la} - c\, \Psi)$$

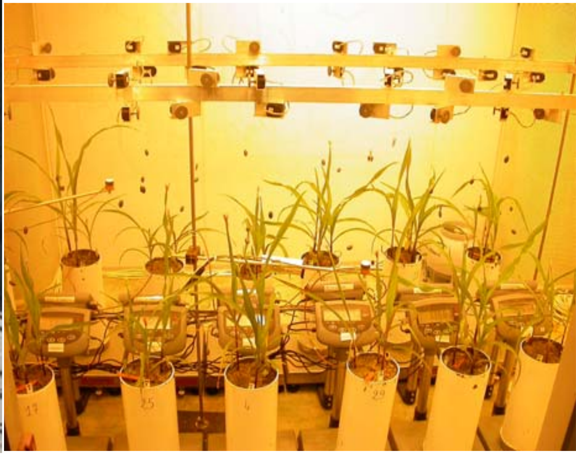
a: intrinsic growth rate of the genotype

b: sensitivity to evapor. demand

c: sensitivity to soil water deficit

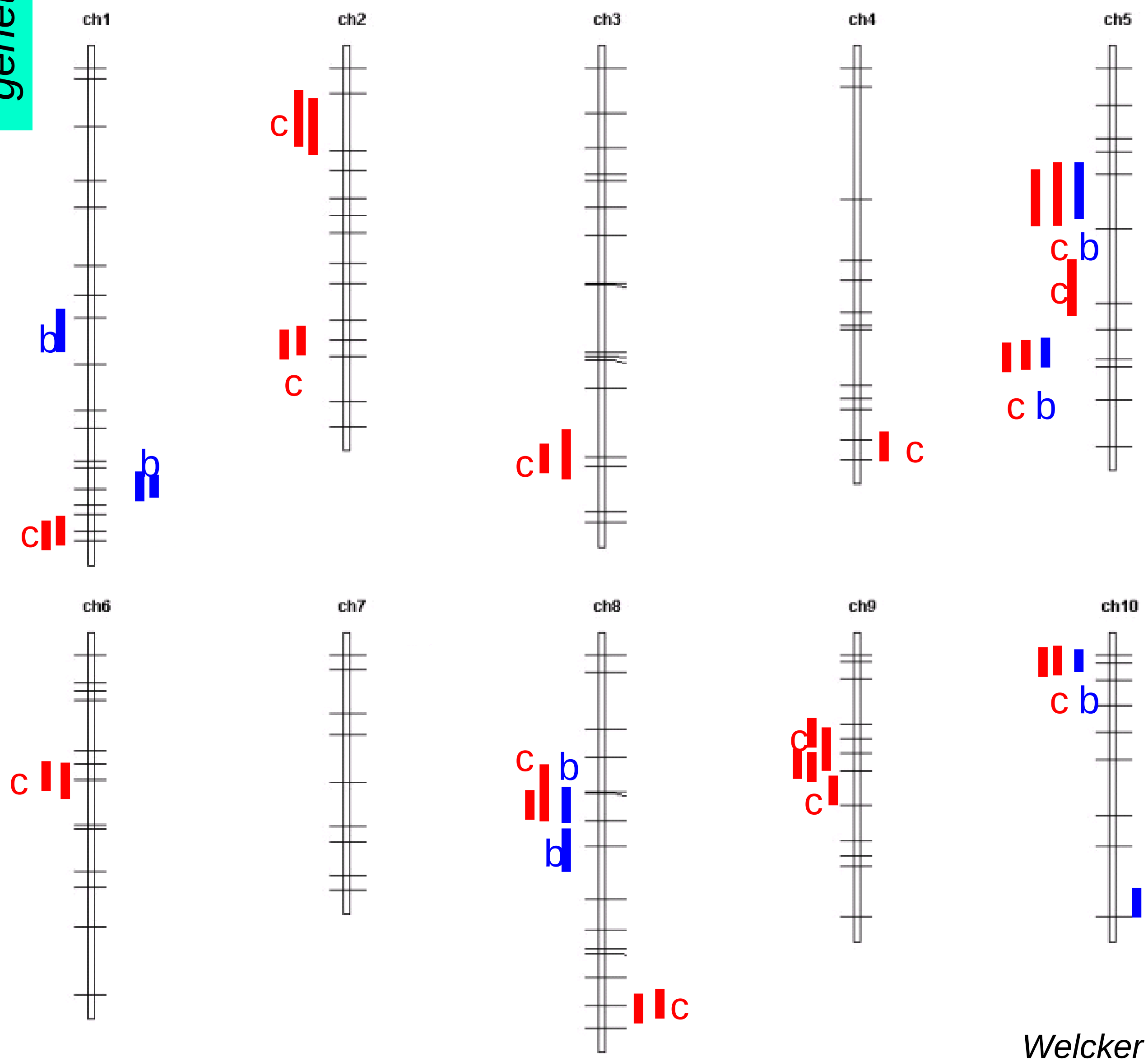
3 mapping populations :

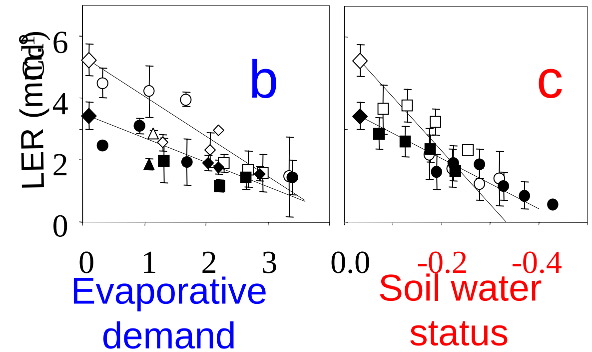
- European F-2 x Io (tolerant) 6 experiments Field / greenhouse
- European F-2 x F252 4 experiments greenhouse / growth chamber
- Tropical P1 (tolerant) x P2 6 experiments greenhouse / growth chamber



genetic analysis

QTLs of responses tend to be common for evaporative demand (b) and soil water status (c)





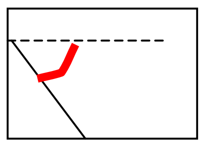
Pop. P1xP2
(tropical)
2 years
greenhouse +
chamber
h^2 = 0.7 - 0.8

Welcker et al. 2007 J. Exp Bot 58, 339

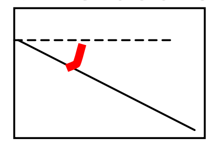
QTLs of responses to evaporative demand affect the rate of morning decrease in elongation rate

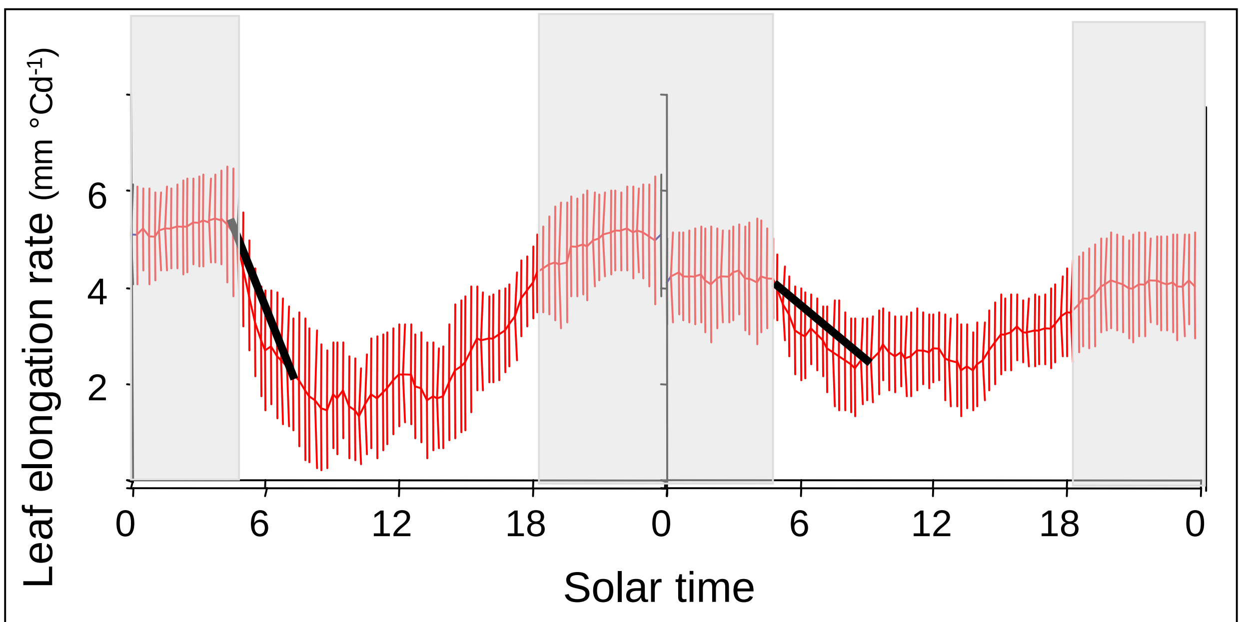
Alleles for response to evaporative demand :

Steep
(60 time courses)



Flat
(59 time courses)





W. Sadok)

Sadok et al 2007 PCE 30, 135–

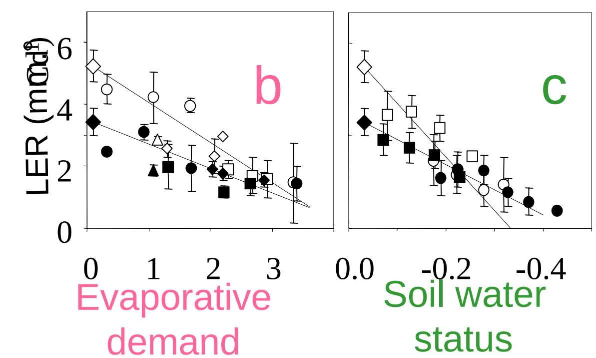
genetic analysis

Common QTLs in 3 mapping populations : 7 "hot" zones

7 loci tested in 3 populations of insertion lines :

- CML 444 in F252
- Gaspe in B73 (Tuberosa)
- Biogemma lines

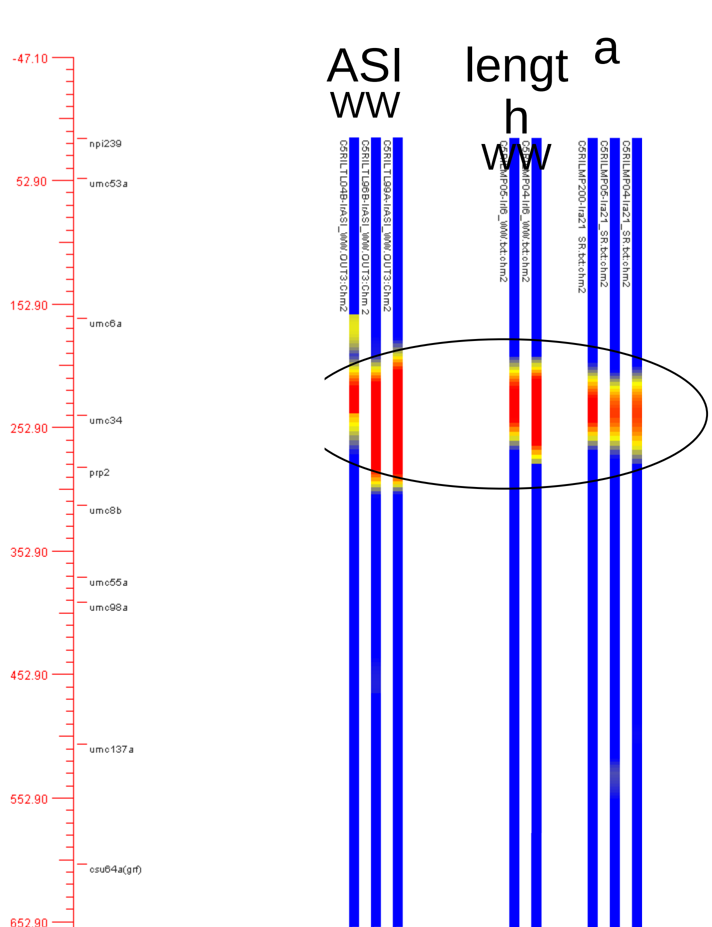
QTL	why?	evaporative demand	water deficit
*sler*1	b	*	*
*sler*2	c		*
*sler*3	b	**	*
*sler*4	b,c	*	***
*sler*5	b,c	*	*
*sler*6	b,c	*	*
*sler*7	c	*	*



C. Welcker

- **Zones are now reasonably sure**
- **Allelic effect are common to evaporative demand and soil water status.**

Applicable to silks ?



Chrom
2

Common QTLs for ASI well watered and plateau leaf elongation rate

ASI : 3 experiments
in the field

Leaves :
model parameters

Welcker et al. 2007
J. Exp Bot

Applicable to silks ?

Chrom 2

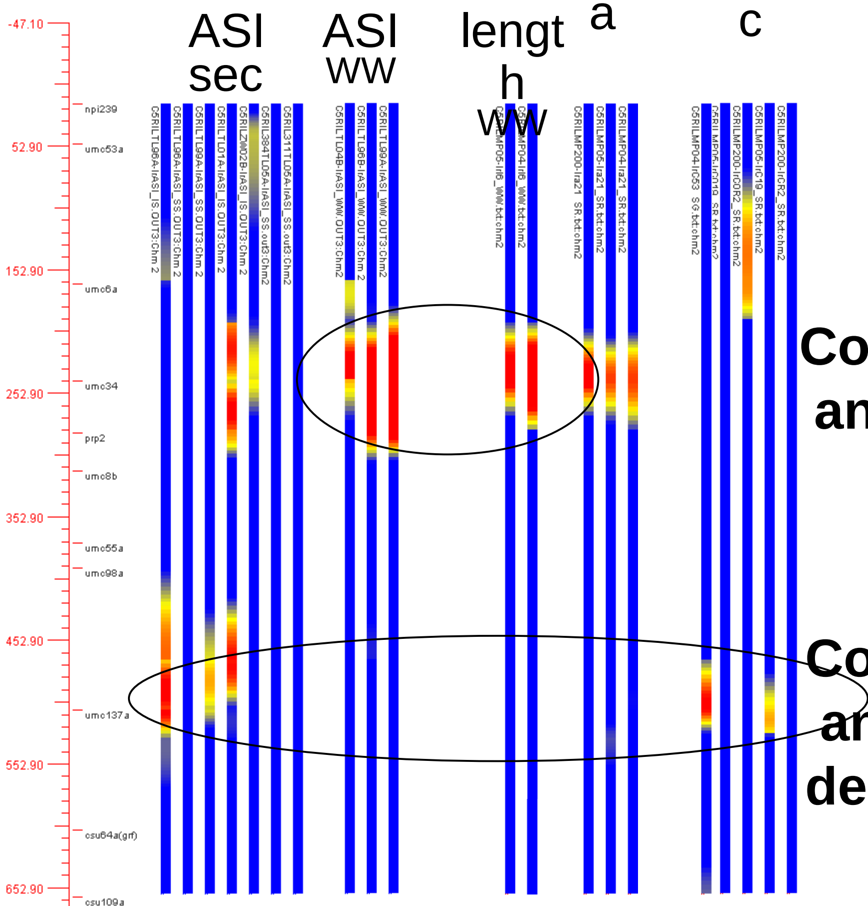
ASI sec

ASI ww

length ww

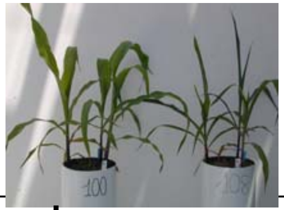
a

c



Common QTLs for ASI well watered and plateau leaf elongation rate

Common QTLs for ASI stressed and response to soil water deficit



ASI : 3 experiments in the field

Leaves : model parameters

Welcker et al. 2007 J. Exp Bot

Conclusion

1 Modelling the GxE interaction : "mechanistic" or "phenotypic" models ?

We should look for mechanistic BUT

- we are not sure of mechanisms (best bets change...)

- if parameters are analysed genetically, should be independent and of reduced number...

"Phenotypic" models more efficient and allow a posteriori mechanistic analyses

Need more phenotyping effort :
"identity card" with phenotyping platforms

2 Rapid responses and hydraulic processes predominant ?

3 How does it translate to whole plant and yield (Karine)

Model of maize leaf elongation rate

C. Welcker
M. Reymond
Ph. Naudin
B. Boussuge
W. Sadok
N. Hilgert (Montpellier)

QTL analysis

The sames +
A Charcosset (INRA-Le Moulon)
JM Ribaut (Cimmyt)

Hydraulics

O. Bouchabke
Th Simonneau
C. Ehlert
Ch Maurel (Montpellier)

ABA and growth

E. Redondo (Biogemma)
F. Chaumont (Louvain)
B. Parent

Silk elongation rate

O. Turc
A. Fuad-Hassan

Whole plant modelling

K. Chenu
G. Hammer U. Queensland
S. Chapman CSIRO

INRA
Institut National de la Recherche Agronomique

Generation
Cultivating Plant Diversity for resource poor

GENOPLANTE