Un Fruit Virtuel pour prédire la croissance et la qualité

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Fruit Virtuel

- Né dans les années 90s pour modéliser la qualité d'un fruit

- **Taille, teneur en MS**
- **Qualité gustative**

Concentrations en sucres (saccharose, glucose, fructose, sorbitol)

Concentrations en acides (malique et citrique)

- Valeur santé

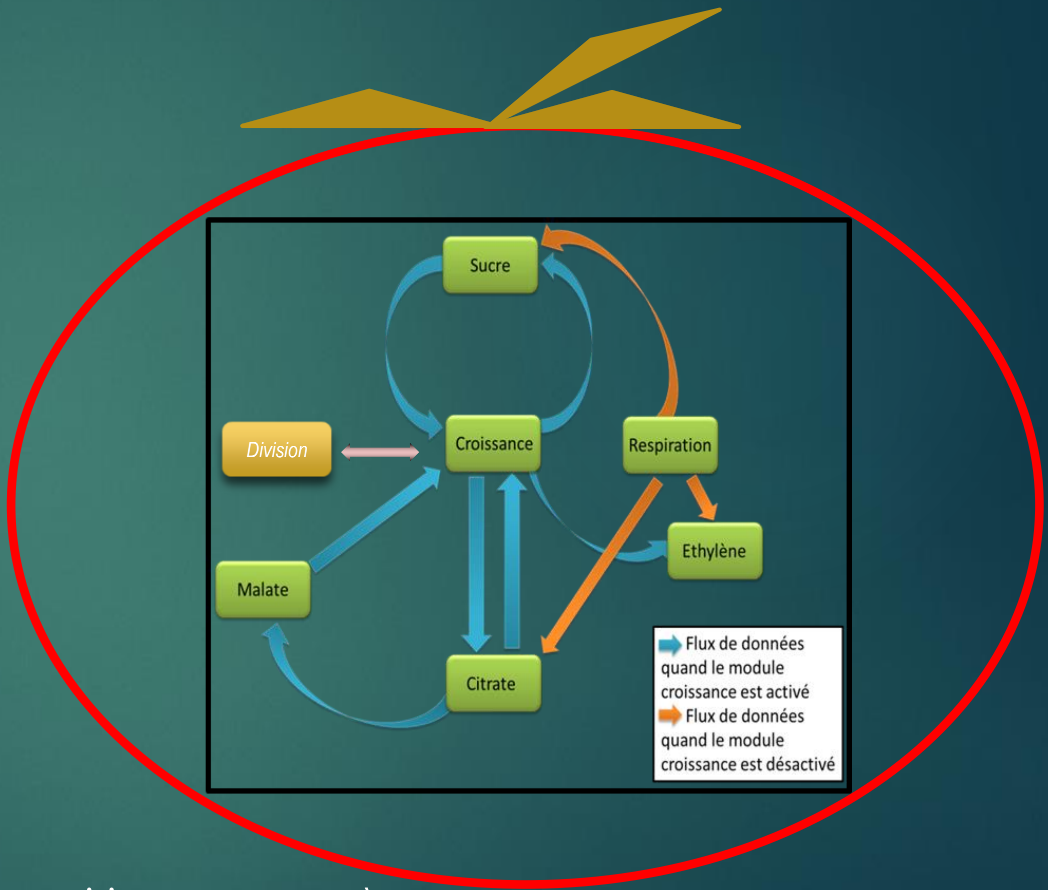
(caroténoïdes, vit. C)

- Texture

- **Application à plusieurs**
- **Espèces:**
- **tomate, pêche, raisin,**
- **Mangue, banane**

Fruit Virtuel: structure générale

- Plusieurs modules <-> processus physiologiques
  - Autonomes or en interaction
  - Activables au choix
- Interaction avec l'environnement



- Description modulable
  - Selon les espèces (pêche, tomate, raisin, mangue,…)
  - Selon les question scientifiques
  - Selon les informations biologiques disponibles

Interaction avec l'environnement

- via la plante
  - Concentration en sucres dans le phloème
  - Potentiel hydrique

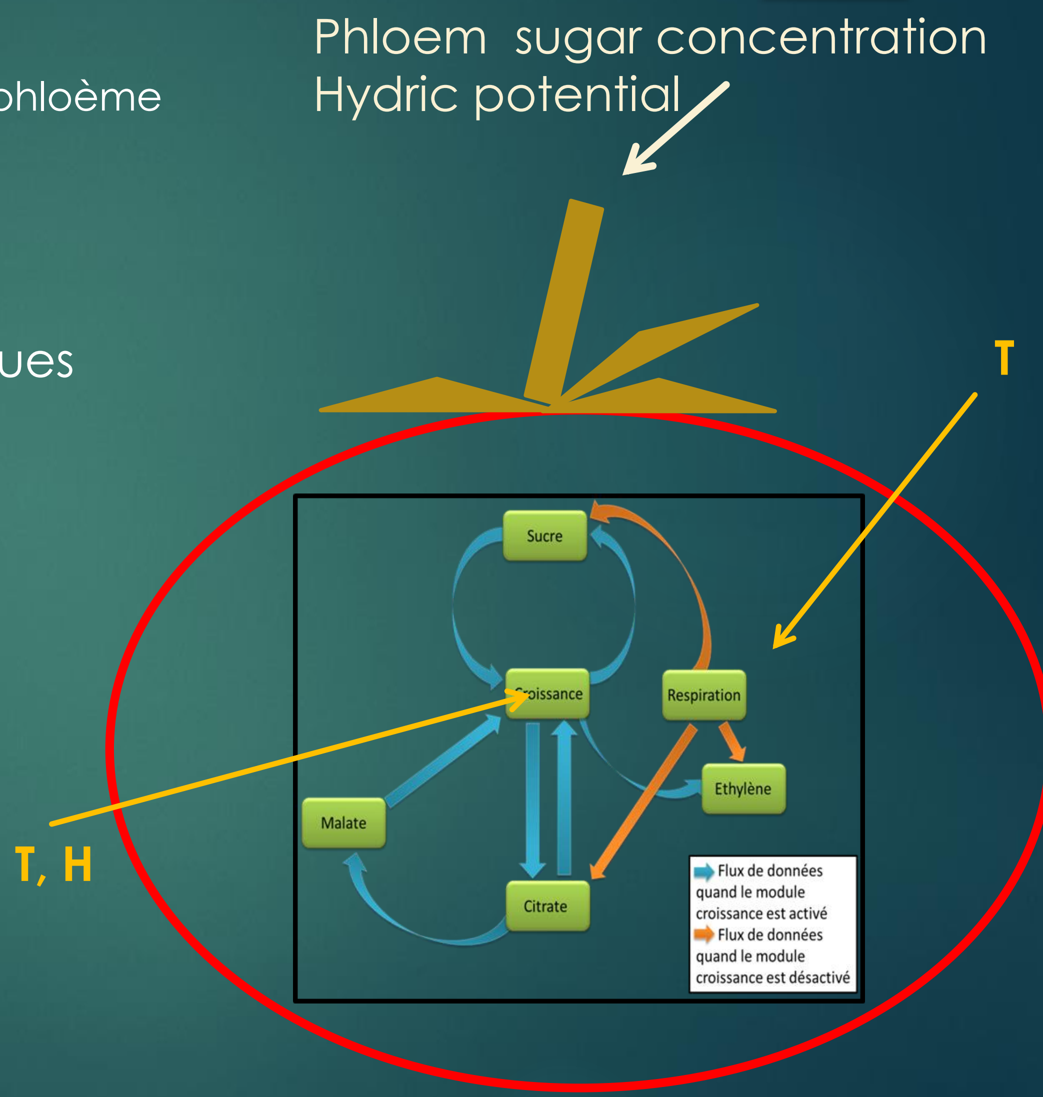
- via quelques processus spécifiques
  - Transpiration du fruit:

$$T_f = \alpha(T)\, \rho\, A_f (H_f - H_a)$$

  - Respiration du fruit:

$$R_f = q_g \, {}^{ds}/_{dt} + q_m(T) s$$

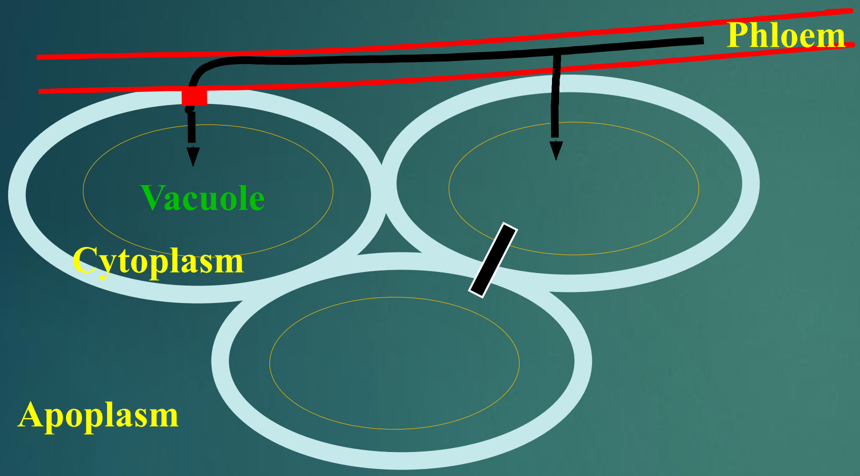
$$q_m = q_{m(20)} Q_{10}{}^{(T-20)/10}$$



Croissance

Modelling

Carbon transport in fruit



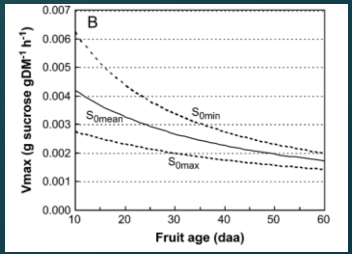
dMS/dt = FluxS – Rf + (Phot)

FluxS = sugar unloading flux
Rf= respiration of the fruit
Phot=photosynthesis

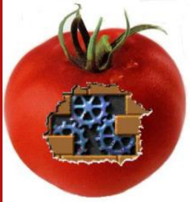
$$FluxS = \overbrace{\frac{s \times v_m \times C_{phl}}{(K_M + C_{phl}) \times IF}}^{Active \quad transport} + \overbrace{(1-\sigma_p) C_s Flux_{phl}}^{Mass \quad flow} + \overbrace{A_p p_s (C_{phl} - C_{fruit})}^{Passive \quad diffusion}$$

σ_p solute reflection coefficient of the membrane
p_s = permeability to sugars
C sugar concentration, IF inhibition factor
Ap exchange area

Phénologie dans *Vm/IF*



Fruit volume expansion



$$dV/dt = (F_x + F_p - T_f)$$

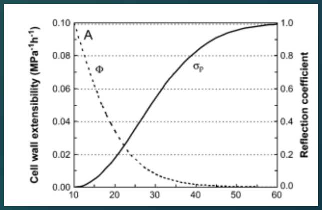
F_x = Xylemic flow = $A_x \, L_x \, (\psi_{xyl} - \psi_f)$

F_p = Phloemic flow = $A_p \, L_p \, (P_p - P_f - \sigma_p (\pi_p - \pi_f))$

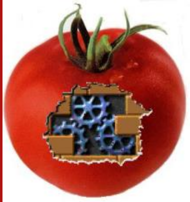
T_f = Transpiration = $Surf \; a \; \rho \; (H_f - H_a)$

Water flux ⇨ From high to low water potential (ψ)
From high to low turgor pressure (P)
From low to high osmotic pressure (π)
From high to low relative humidity (H)

Phénologie dans Lx, Lp, σ_p et ρ



Irreversible PLASTIC variations in volume



$$dV/dt = (F_x + F_p - T_f)$$

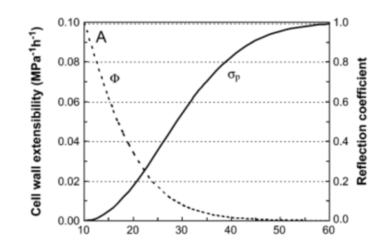
Lockhart equation (1965)

$$dV/dt = \phi \,.\, V \,.\, (P_f - Y)$$

ϕ = plasticity

⇓

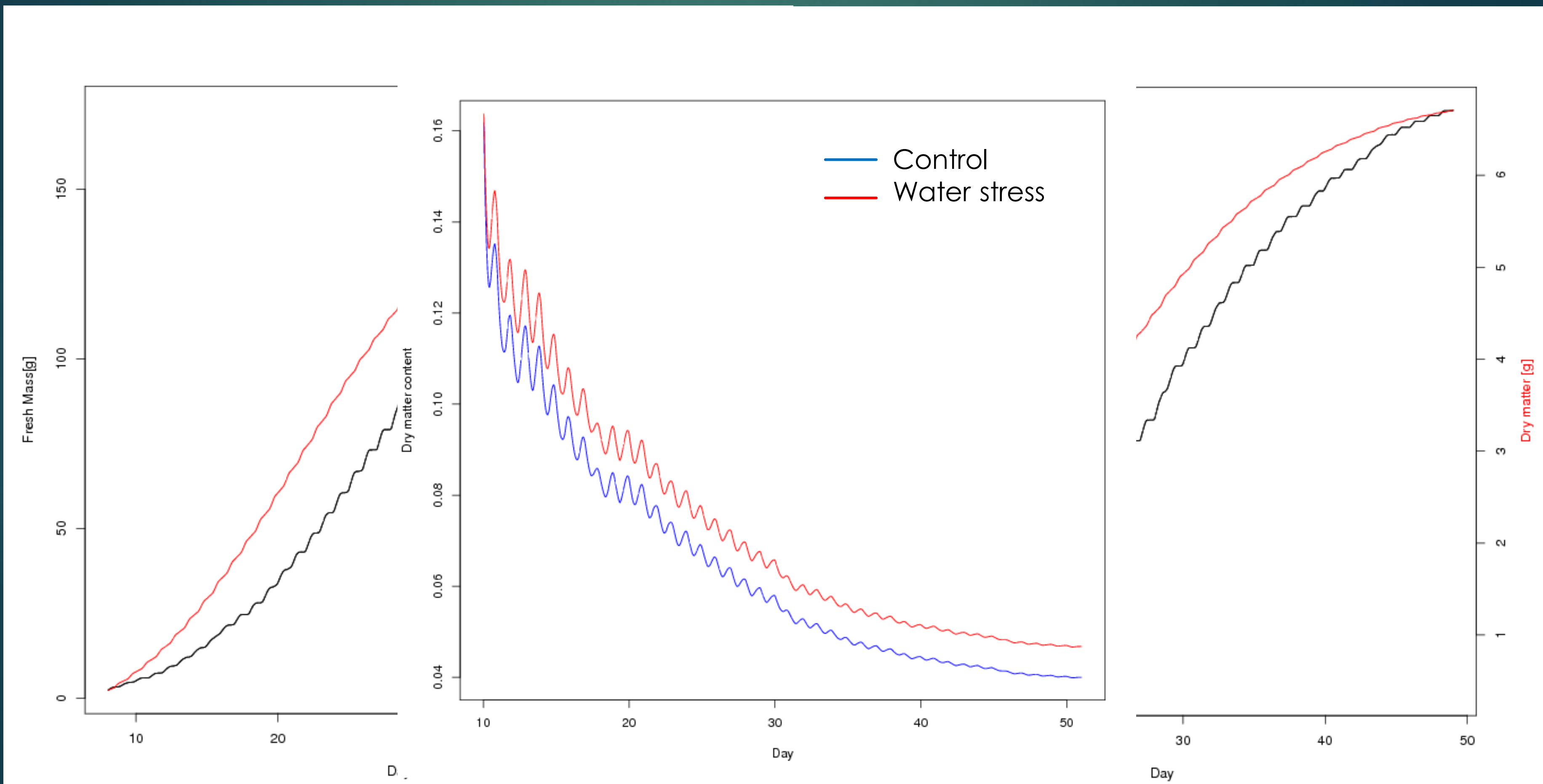
Fruit turgor pressure



Phénologie dans ϕ et Y

Etude des effets de stress hydrique

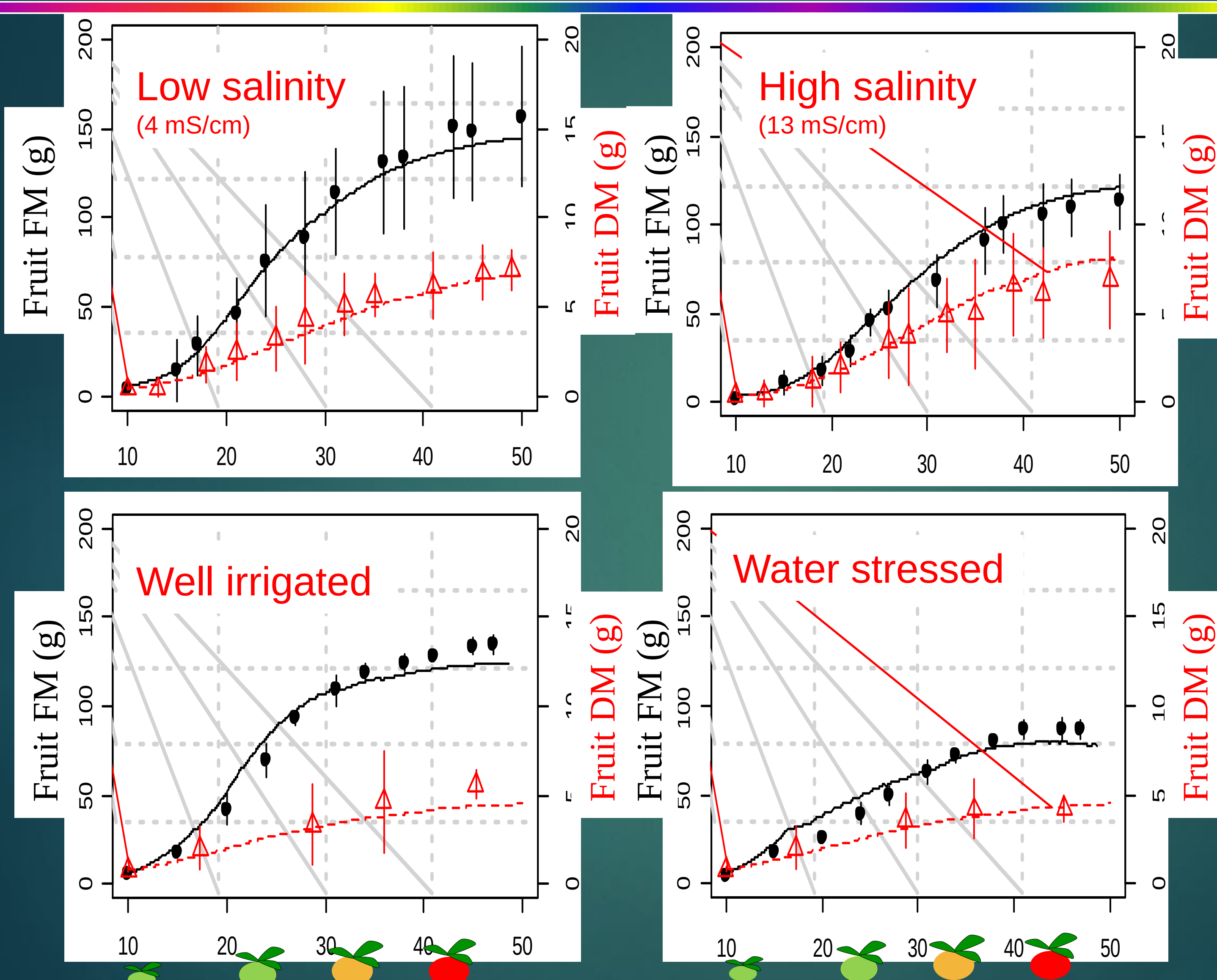
- Stress hydrique : Potentiel hydrique -1 bar (Tomate)



Réduction de la masse fraiche et sèche du fruit

Augmentation de la teneur en matière sèche

Etude des effets de stress hydrique

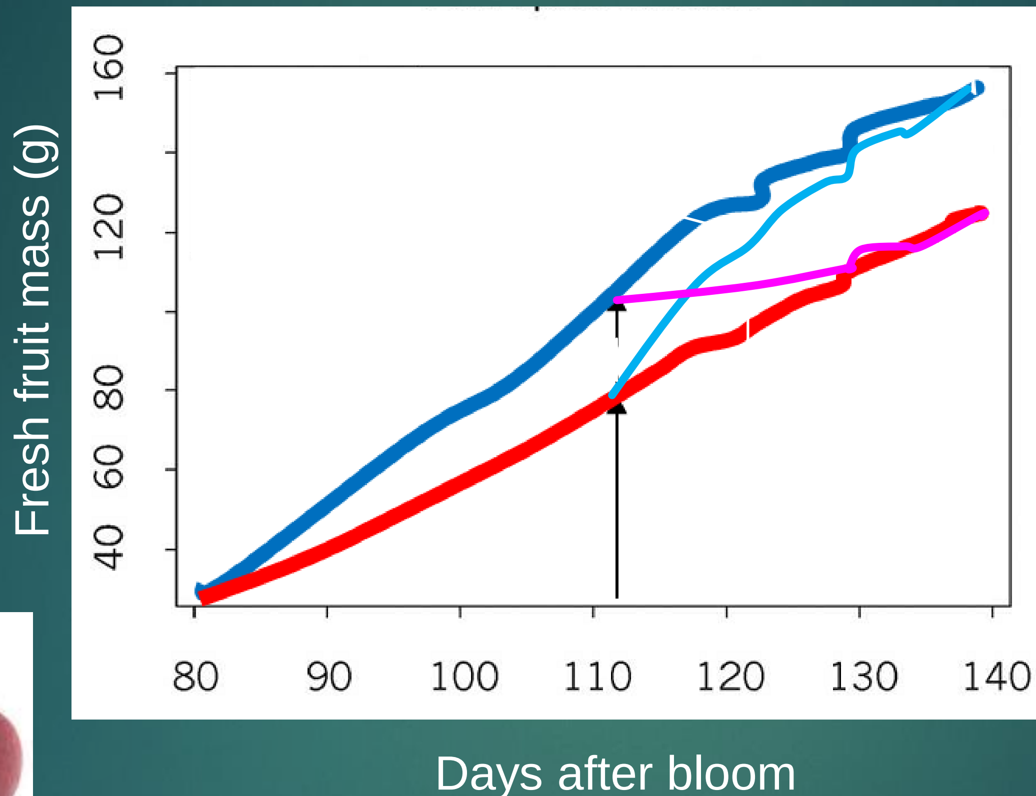


Fruit age (DAA)

Tomate

Model capacity to simulate the effect of salinity and water stress on fruit growth

The virtual fruit is able to reproduce complex behaviors



Memory effect:
A water stressed fruit grows quicker if it has been acclimated to the stress

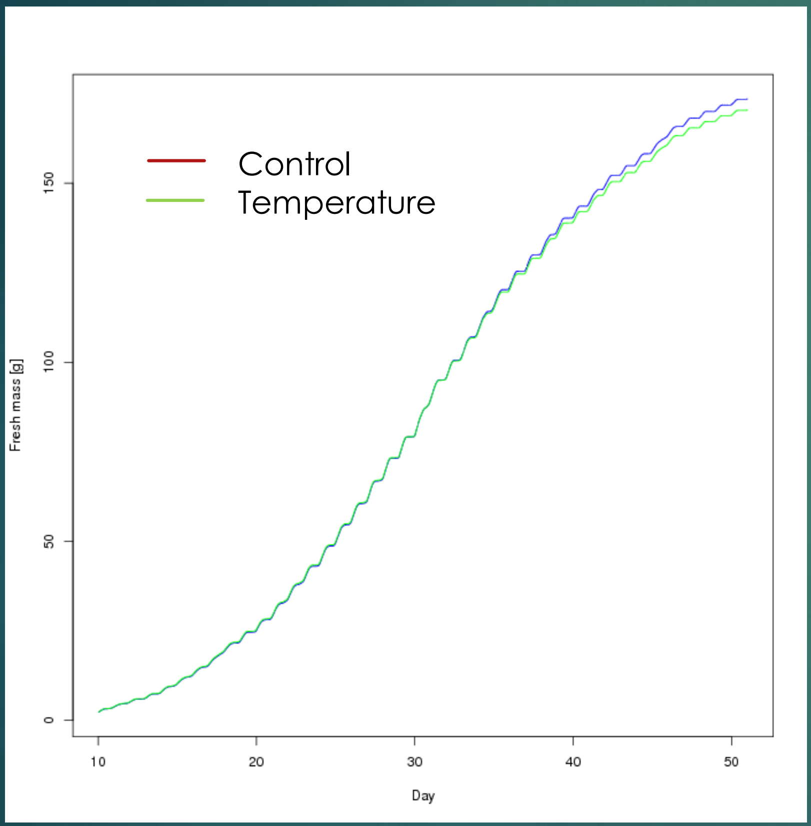
Compensatory growth:
a water stressed fruit grows quicker when well irrigated

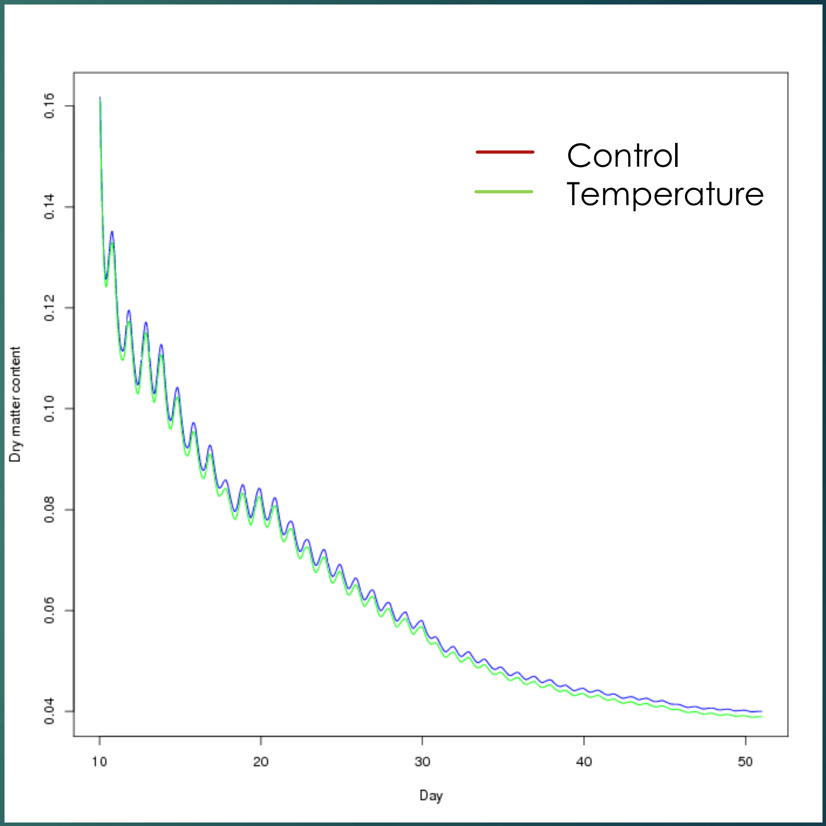
Pêche

Etude des effets de stress thermique

Etude des effets de stress thermique

- température du fruit + 6 °C (Tomate)





Faible effet de la température dans le modèle

Prise en compte partielle des effets température/stress hydrique

Piste pour amélioration du module « croissance » du Fruit Virtuel

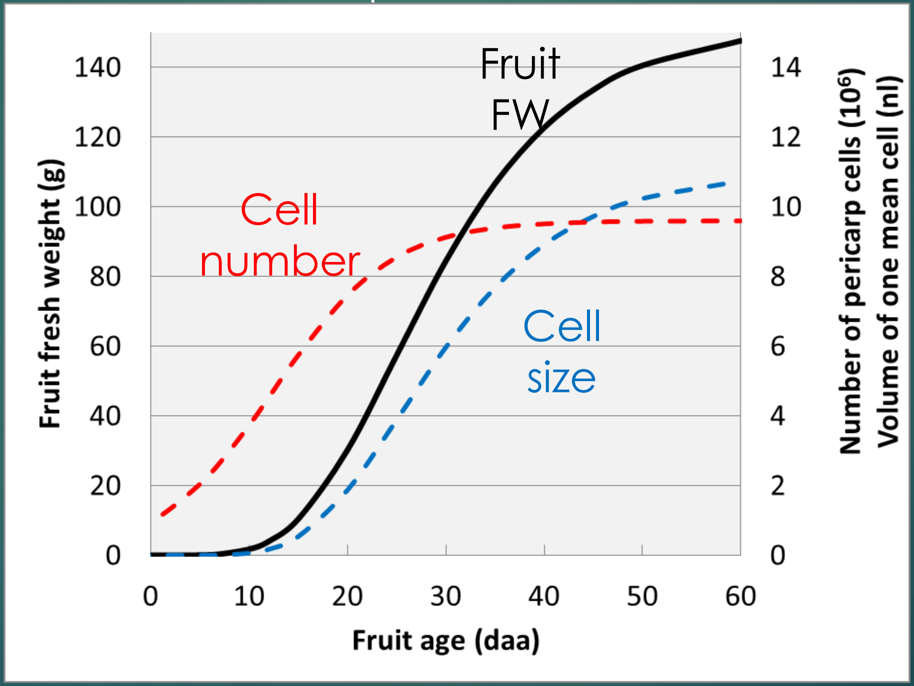
- Effet temperature sur la viscosité sève, le métabolisme,

la respiration (faible Q10 dans nos simu tomate)

- Effet de la temperature sur la division cellulaire et l'endoreduplication
- Connexion avec la plante

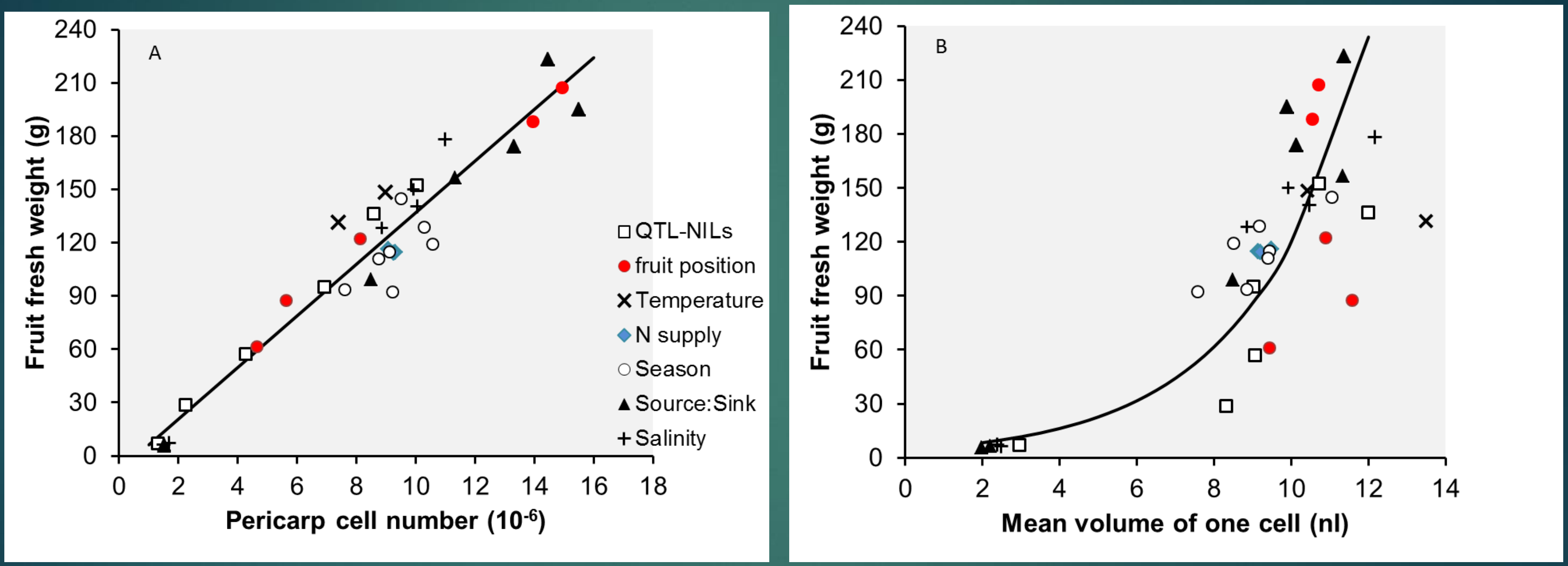
Final fruit size emerges from interactions among several processes during fruit development

Cell division
Cell expansion
Ripening



The relative contributions of division and expansion processes to fruit growth can be easily illustrated

Relationships between final fruit size and cell number or mean cell size for different genotypes and environments



Cell expansion is responsible for the fruit volume increase, but final fruit size is highly correlated to the number of cells

Effet de la temperature sur nombre de cellules

Plusieurs effet de la température sur les processus cellulaires sont reporté dans la littérature

Sur division:

- Reduced cell duration division phase and increased number of cell layers at high temperature has been reported in tomato fruit (Bertin et al. 2005, Fanwoua et al 2012)
- Division rates are shown to increase with temperature in maize (Parent et al. 2010)

Sur endoreduplication:

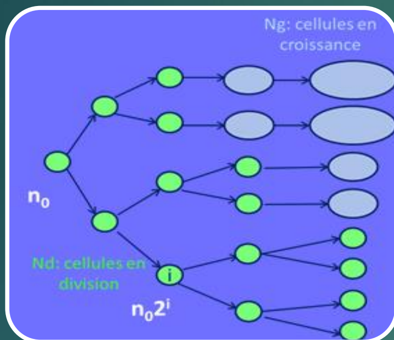
- Low temperature is reported to delay entry into endoreduplication in orchid flower (Gendreau, Hofte, Grandjean, Brown, & Traas, 1998) and slightly reduce the final endoreduplication level in tomato fruit and maize seed (Bertin, 2005, Engelen-Eigles et al. 2001)

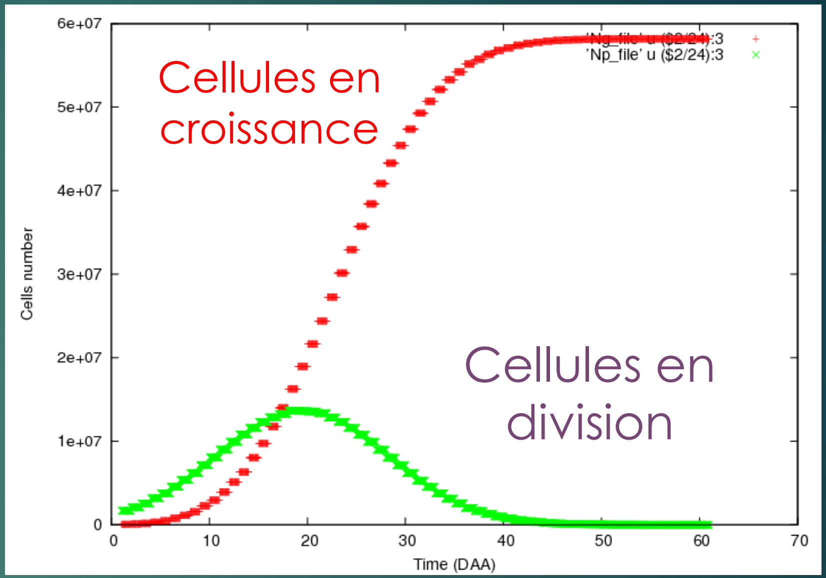
Interaction avec pratiques possible!!

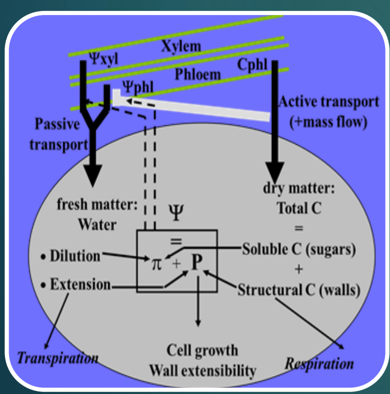
- The onset of cell expansion is advanced at high temperature in tomato but the resulting effect on final cell size may depend on fruit load (Bertin 2005, Fanwoua et al 2012)
- Increased fruit load reduces meristem cells number (Baldet et al.)

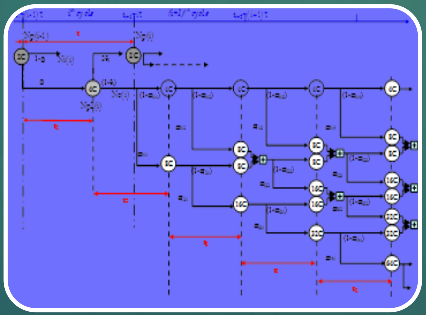
Vers un modèle intégré division-croissance-endoreduplication

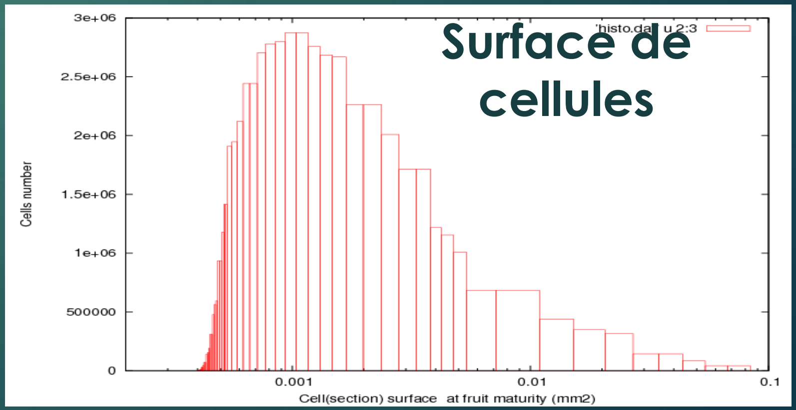
Modélisation couplée des processus de division cellulaire, d'endoréduplication et de croissance





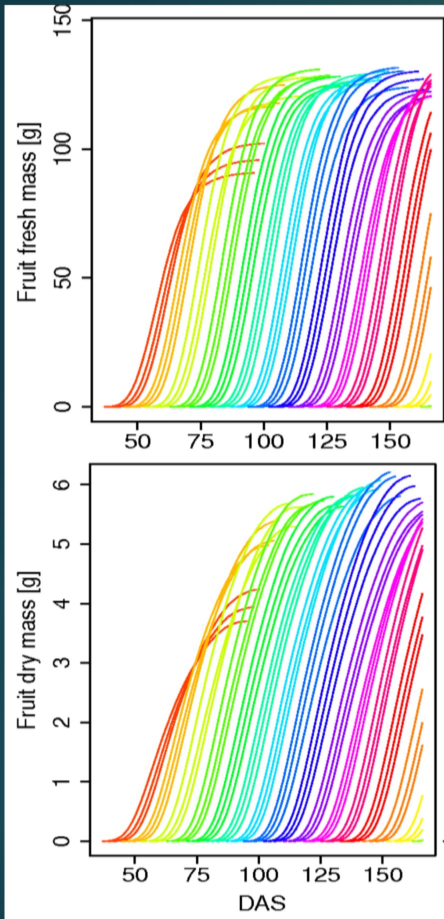


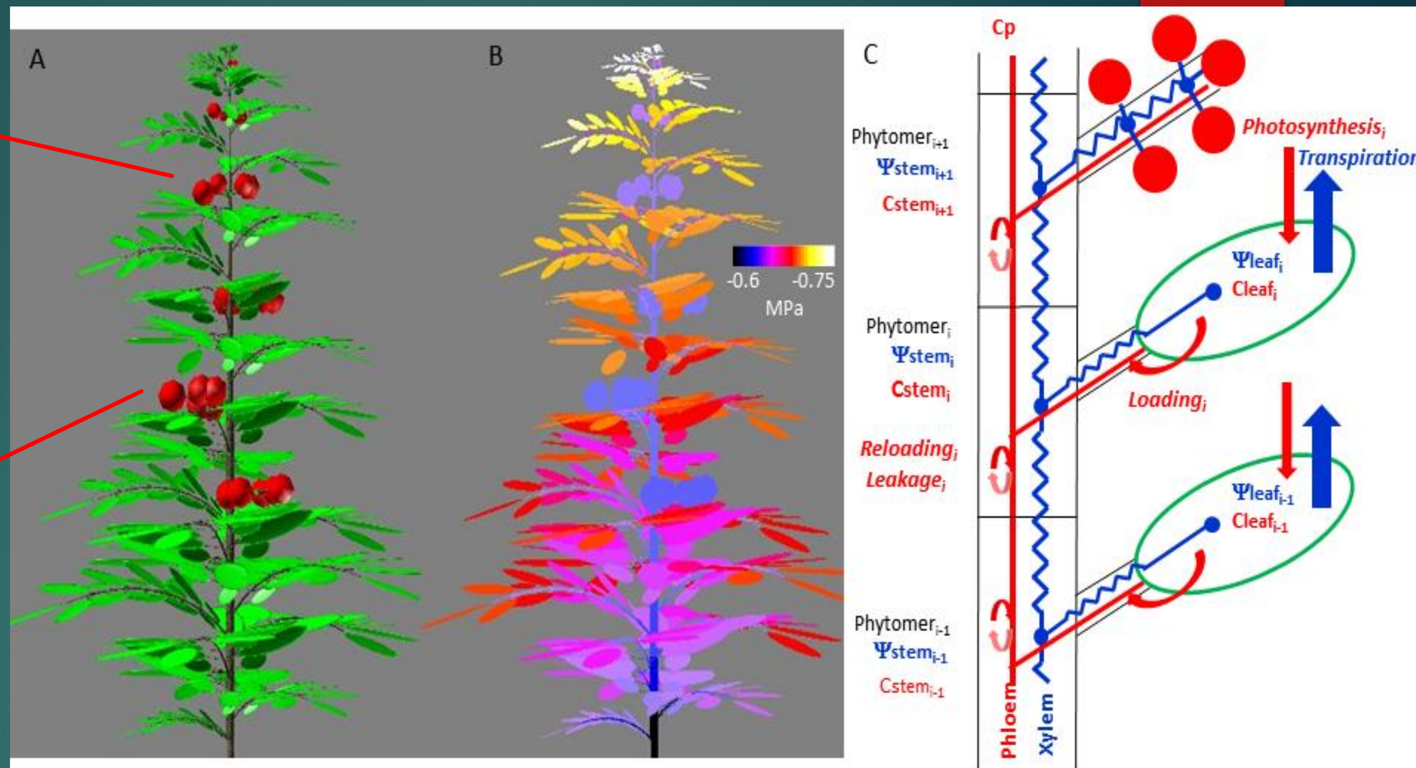




Environnement (T, H, plant status)

Linking Virtual plant and fruit models

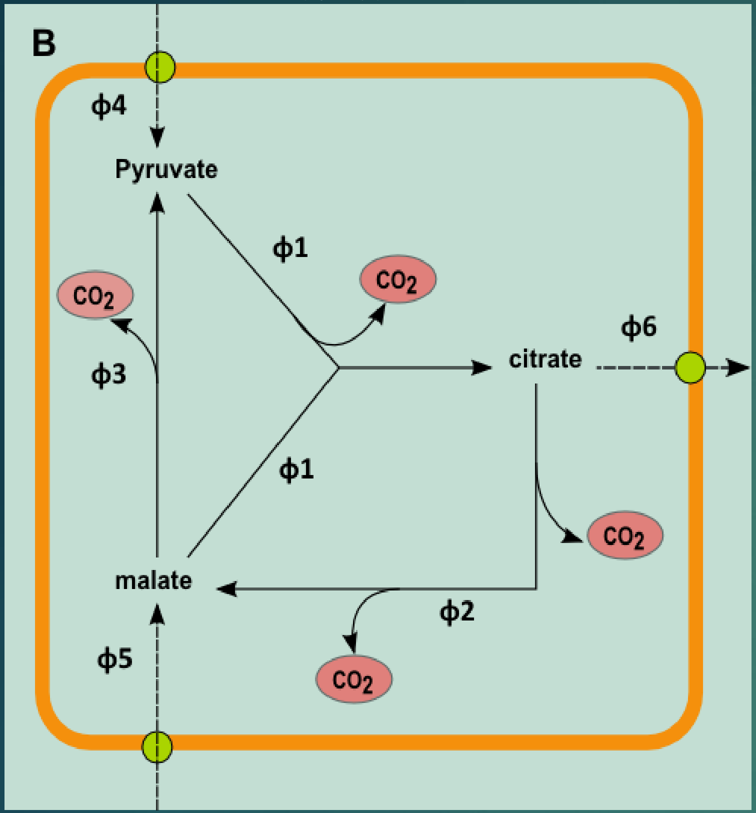




- Plant architecture calibrated according to experimental data (control, shade and water stress)
- Water transport within the plant -> gradient of water potential
- Unique phloem compartment with storage volume
- Fruits growth described individually, according to the Virtual Fruit Model -> heterogeneity in final fruits fresh and dry mass

Composition

Equations du modèle Citrate



- **Equations de stœchiométrie**

$d(Mpyr)/dt= \Phi_4 + \Phi_3 - \Phi_1 = 0$

$d(Mmal)/dt= \Phi_5 + \Phi_2 - \Phi_3 - \Phi_1 = 0$

$d(Mcit)/dt= \Phi_1 - \Phi_2 - \Phi_6 = 0$

$Resp= \Phi_1 + 2\Phi_2 + \Phi_3$

- **Réactions enzymatiques**

$\Phi_i = k_i * [S]$

Activité enzymatique

- **Réactions de transports membranaires**

$\Phi_j = k_j * ([S]_{mit} - [S]_{cyt})$

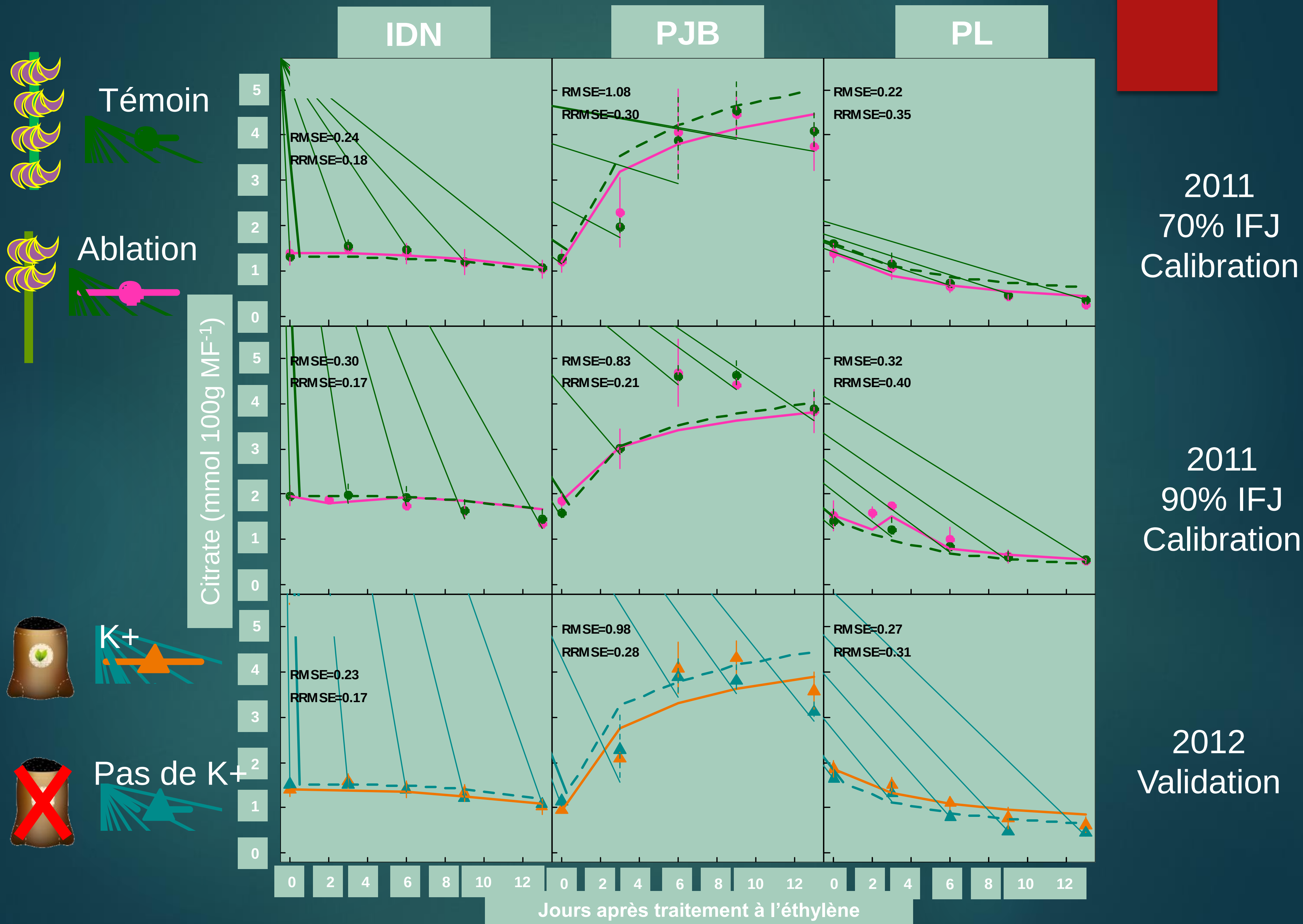
Activité transporteur

Flux net de production de citrate: $\mathbf{\Phi_6 = f(Resp, [Pyr]_{cyt}, [Mal]_{cyt}, k_i, k_j)}$

$$[Cit] = \frac{100}{PF} * (MCit_{t_0} + \int_{t_0}^{t} \phi_6 dt)$$

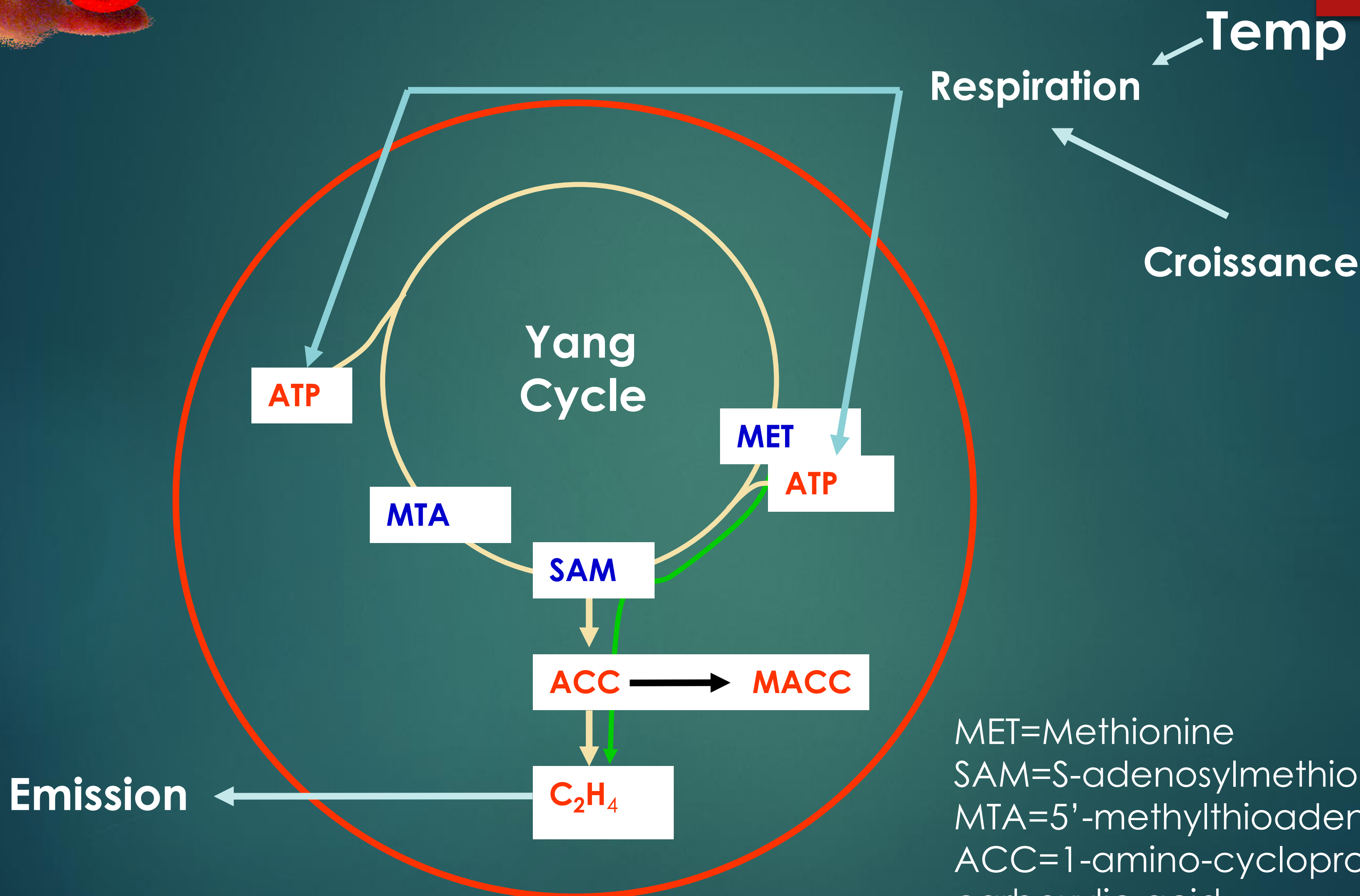
Equation de Respiration *(Cannell and Thornley, 2000)*: $$Resp = q_g \frac{dPS}{dt} + q_m PS\, Q_{10}^{\frac{T-20}{10}}$$

Calibration et validation du modèle post récolte

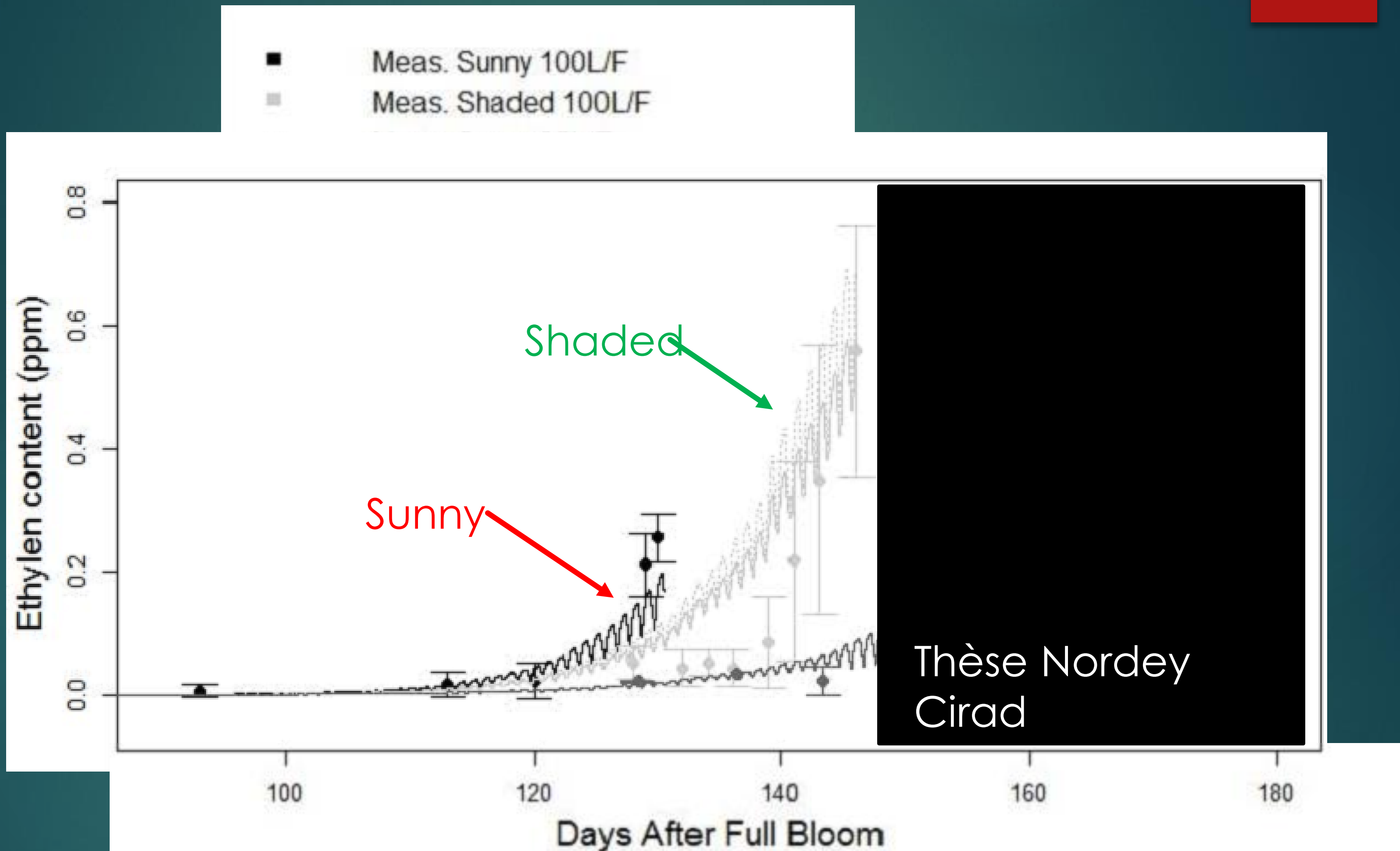


Maturation

Ethylène

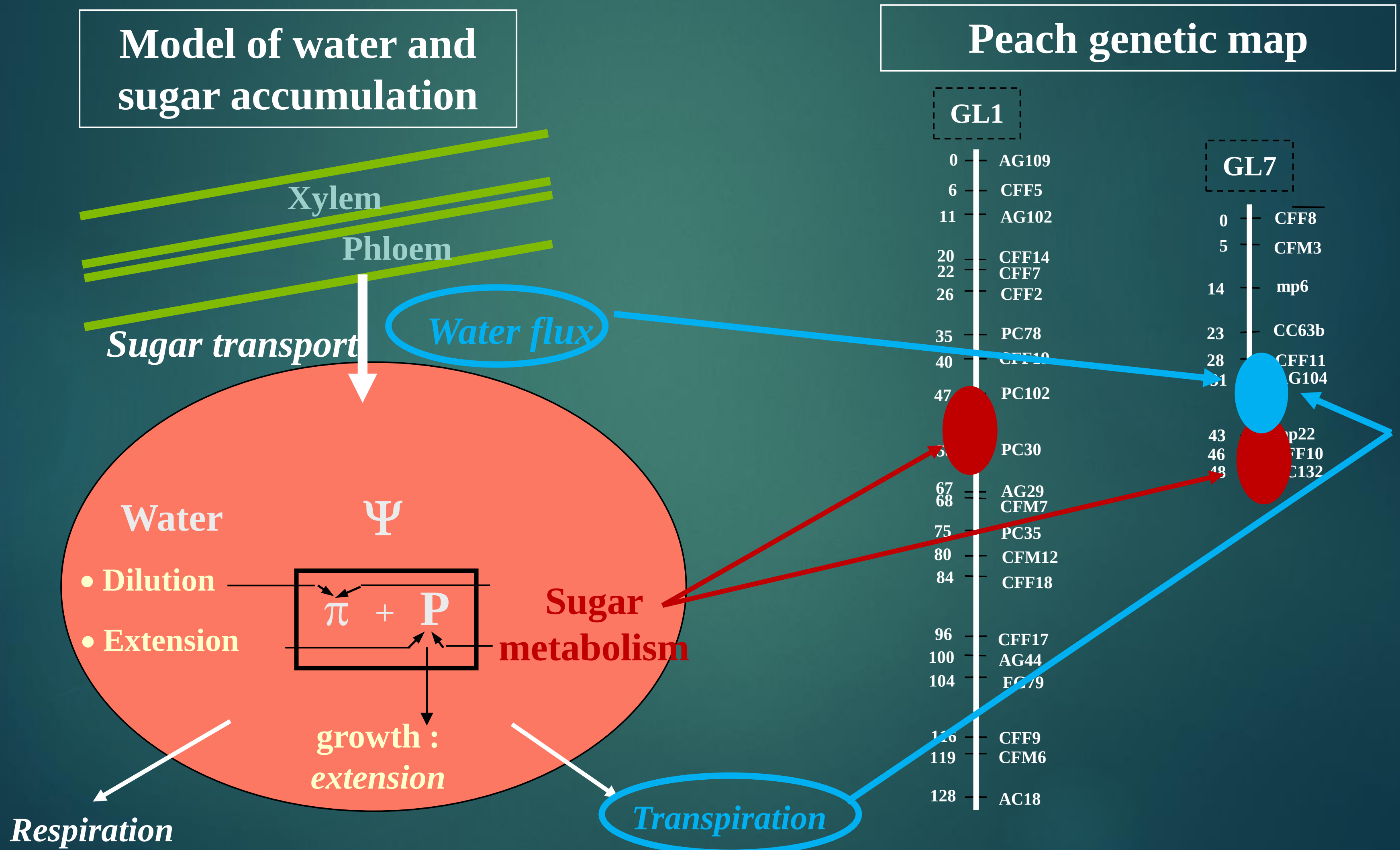


MET=Methionine
SAM=S-adenosylmethionine
MTA=5'-methylthioadenosine
ACC=1-amino-cyclopropane-1-carboxylic acid
MACC= Malonyl-ACC


Meas. Sunny 100L/F
Meas. Shaded 100L/F
Ethylen content (ppm)
0.0
0.2
0.4
0.6
0.8
Shaded
Sunny
Thèse Nordey
Cirad
100
120
140
160
180
Days After Full Bloom

Fruit virtuel et génétique (pêche)

QTL-based model



Combination of virtual fruit and QTLs

Estimation of genetic coefficient θ for a genotype i

n QTLs of θ and m epistatic interactions between 2 locus

0 or 1 according to the allele in Qn

0 or 1 according to the combination of alleles in Em

$$\theta_{n,m} = \mu + \sum_{n=1}^{N} \left(i_n \times e(Q_n) \right) + \sum_{m=1}^{M} \left(j_m \times e(E_m) \right)$$

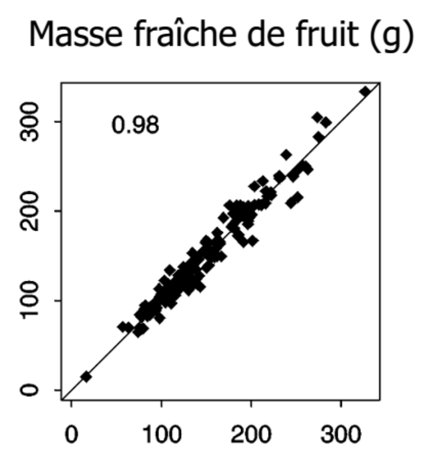
Value of the genetic coefficient

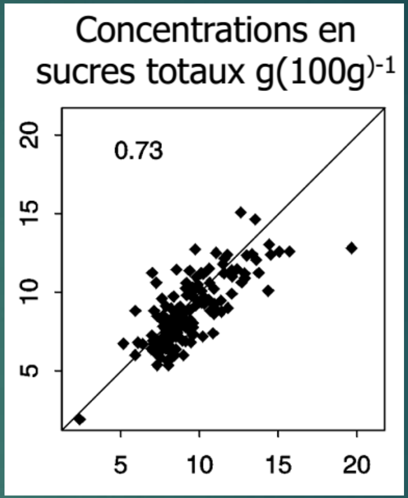
Effect of QTL Qn

Effect of epistatic interaction Em

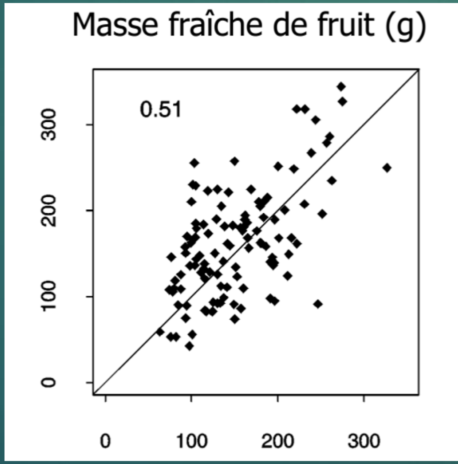
Prédictions du Fruit virtuel couplé aux QTLs

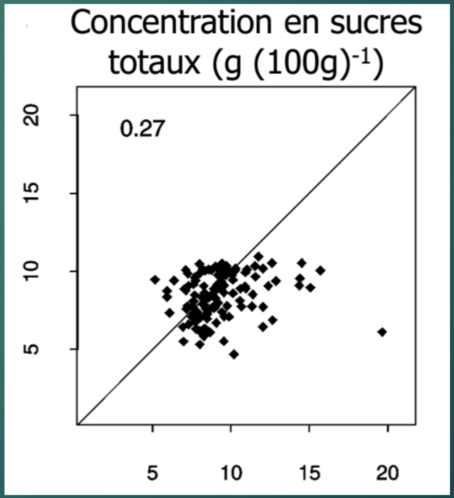
Fruit virtuel
1 jeu de param
par génotype





Fruit virtuel
param génotype
=f(QTLs)





Conclusion

Nos impressions :

- Assez bonne représentation du stress hydrique à l'échelle du fruit

- Beaucoup de travail reste à faire sur l'effet de la température du fruit sur sa croissance et sa maturité (date de récolte)

- Effets sur le métabolisme primaire (sucres-acides) et secondaire: peu de modélisation

- Les interactions avec la plante sont essentielles à prendre en compte car il est souvent difficile de découpler les effets directs du climat des effets via la plante

- Intégration du contrôle génétique souvent limité par le faible niveau de prédiction des QTLs. Nécessité d'un gros travail sur des populations.


Merci !