Model-based analysis of the genetic variability in tomato fruit growth under contrasted water conditions

Dario Constantinescu, Mohamed-Mahmoud Memmah, Gilles Vercambre, Michel Génard, Valentina Baldazzi, Pierre Valsesia, Nadia Bertin

Introduction

- **Drought stress**:
  - one of the major **abiotic stresses**
  - primary cause of **crop loss** worldwide

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- **CHALLENGE**: Identify the main mechanism of adaptation to water deficit

Objectives

- Highlight the **genetic variability**
- Identify the **main processes** of drought resistance
- Guideline for the **design of ideotypes**

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Combine a **modelling** approach based on **experimental** data and **optimization**

Combining data and models

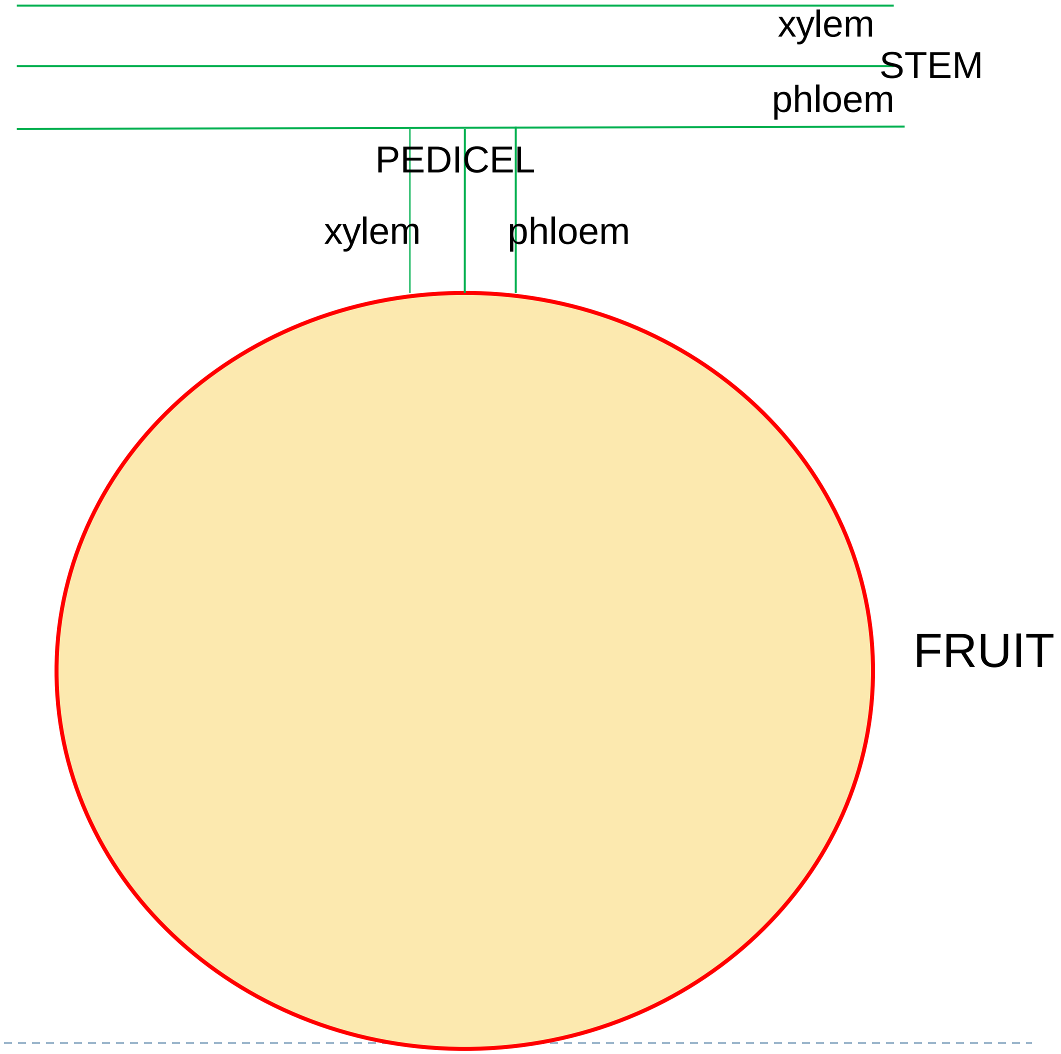
- **Vegetal material**: 117 recombination lines of a bi-parent breeding (parents: Cervil, Levovil)
- Two different **environmental conditions**:
  - CONTROLLED (C)
  - WATER DEFICIT (WD):
    - -75% of water supply
    - ≈ 50% of the real ETP needs
    - Drainage 20% / 0%

- **MODELLING APPROACH**: Virtual Fruit Model

(Fishman and Génard , 1998)

Virtual Fruit Model

- The fruit is considered as a one big cell



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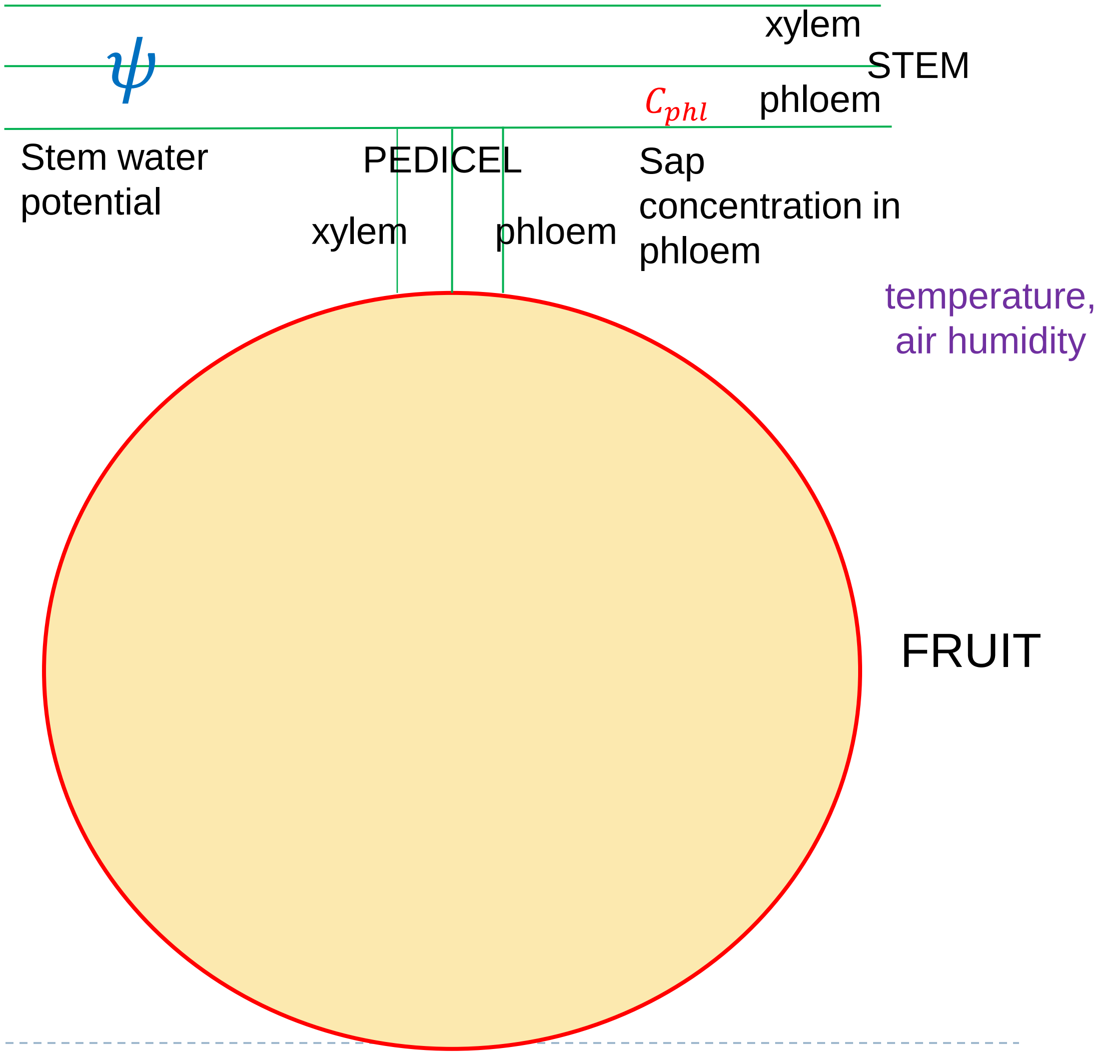
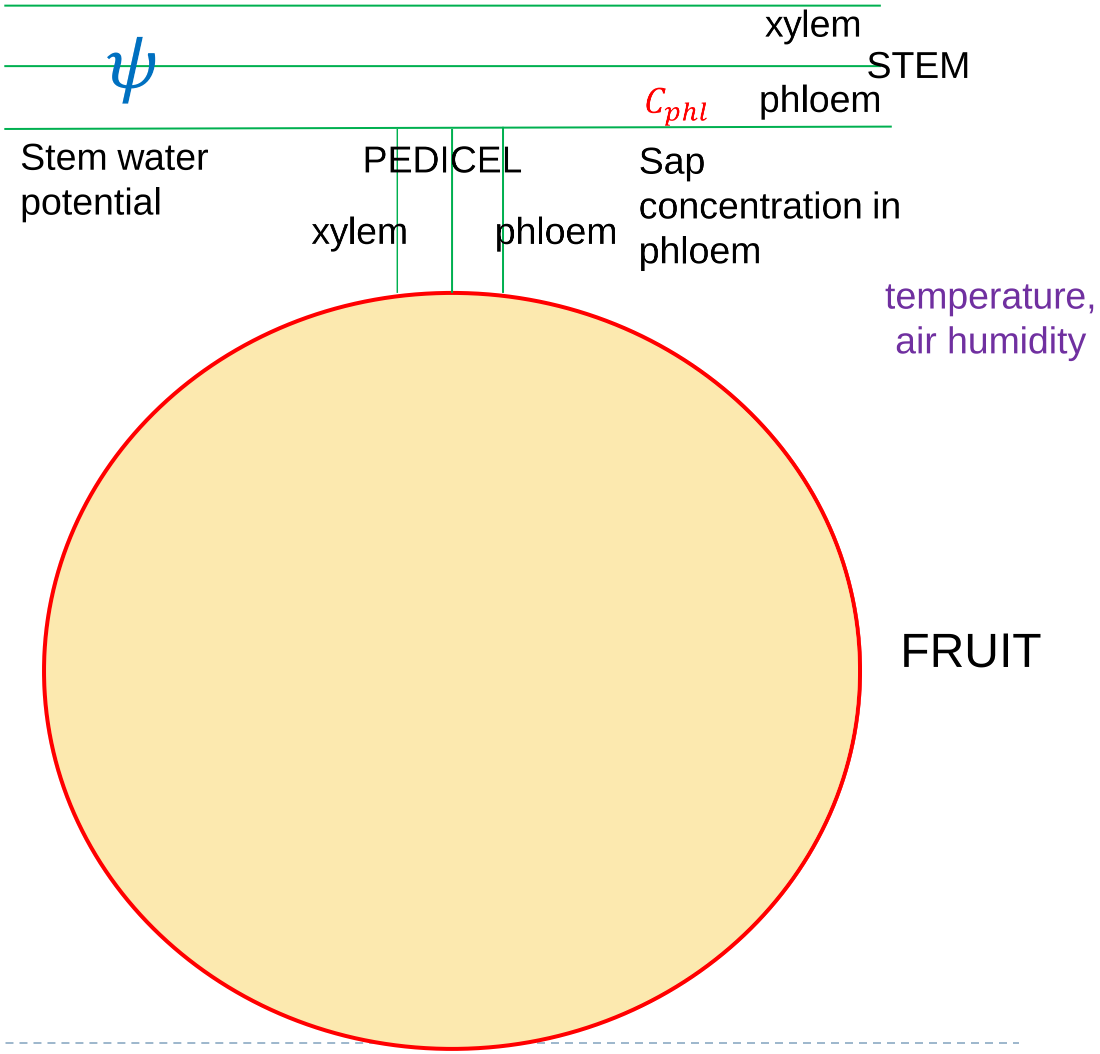


Virtual Fruit Model

- The fruit is considered as a one big cell
- Water and sugar accumulation rates are described by two equations of state:

$$\frac{dw}{dt} = U_x + U_p - T_f$$

$$\frac{ds}{dt} = U_s - R_f$$



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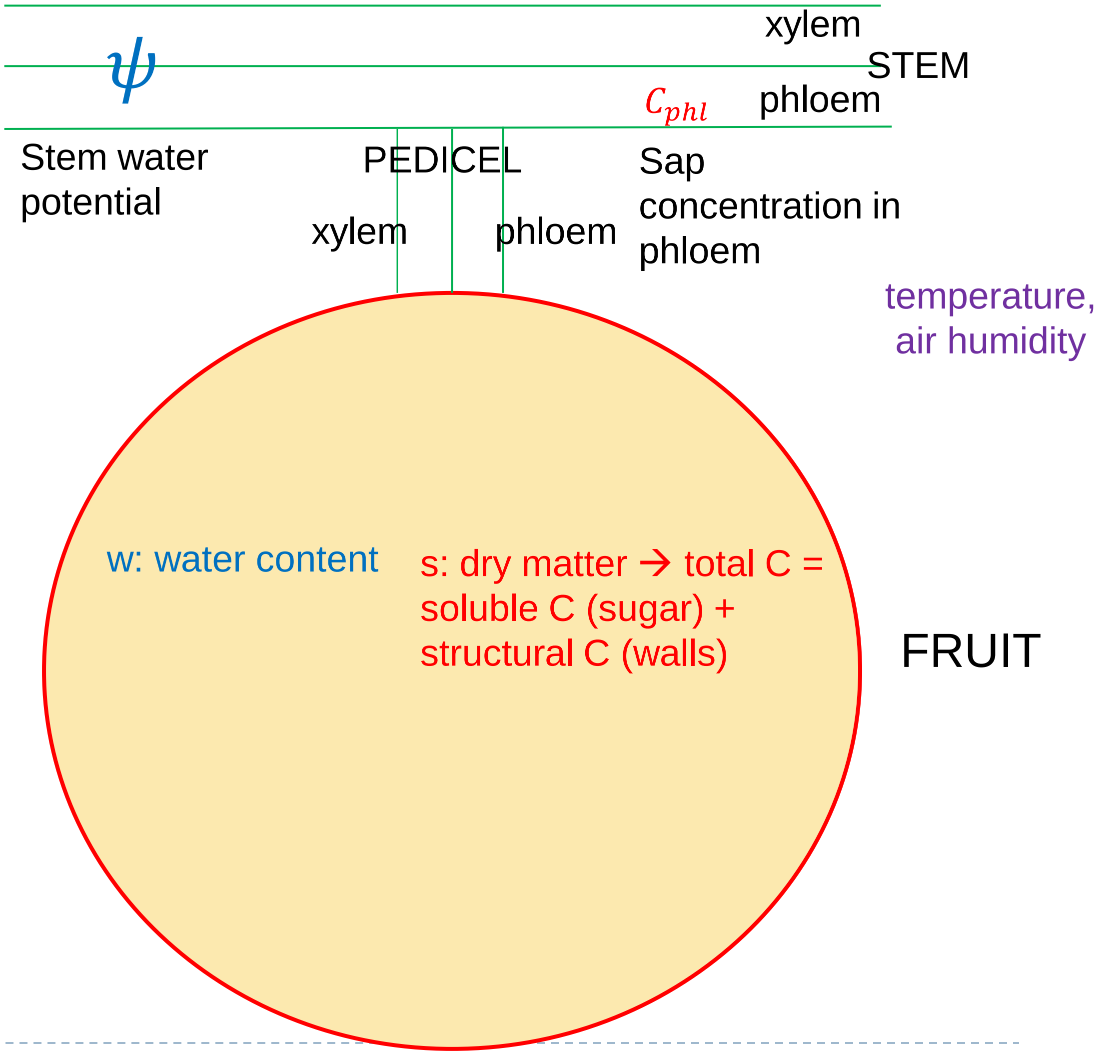

xylem

STEM

phloem

ψ

Stem water potential

C_{phl}

Sap concentration in phloem

PEDICEL

xylem

phloem

temperature, air humidity

w: water content

s: dry matter → total C = soluble C (sugar) + structural C (walls)

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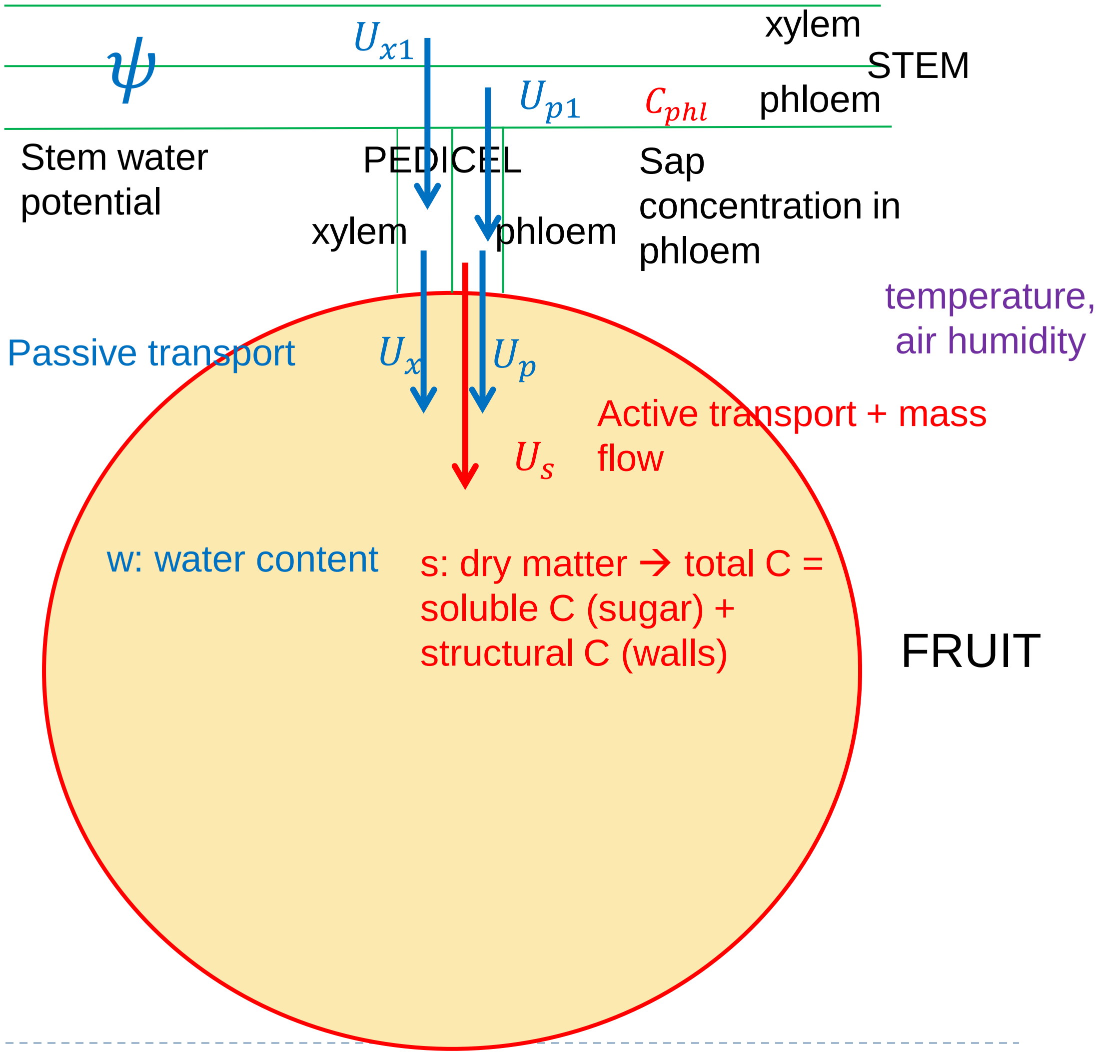

U_{x1} xylem

ψ STEM

U_{p1} C_{phl} phloem

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Passive transport U_x U_p

Active transport + mass flow U_s

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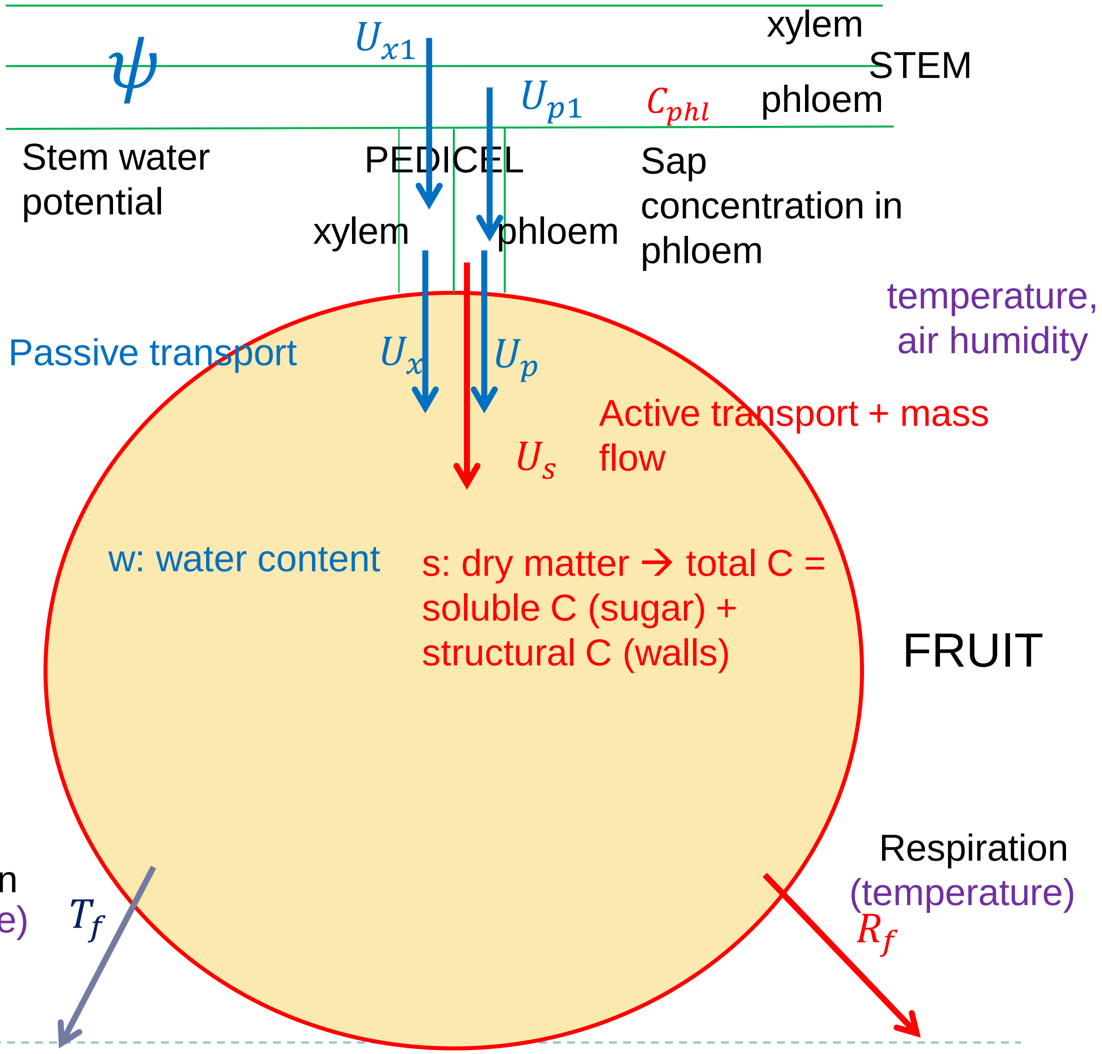

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FRUIT

Transpiration (air humidity , temperature)

T_f

Respiration (temperature)

R_f

Virtual Fruit Model calibration: parameters

- Parameters **do not depend on environmental conditions**

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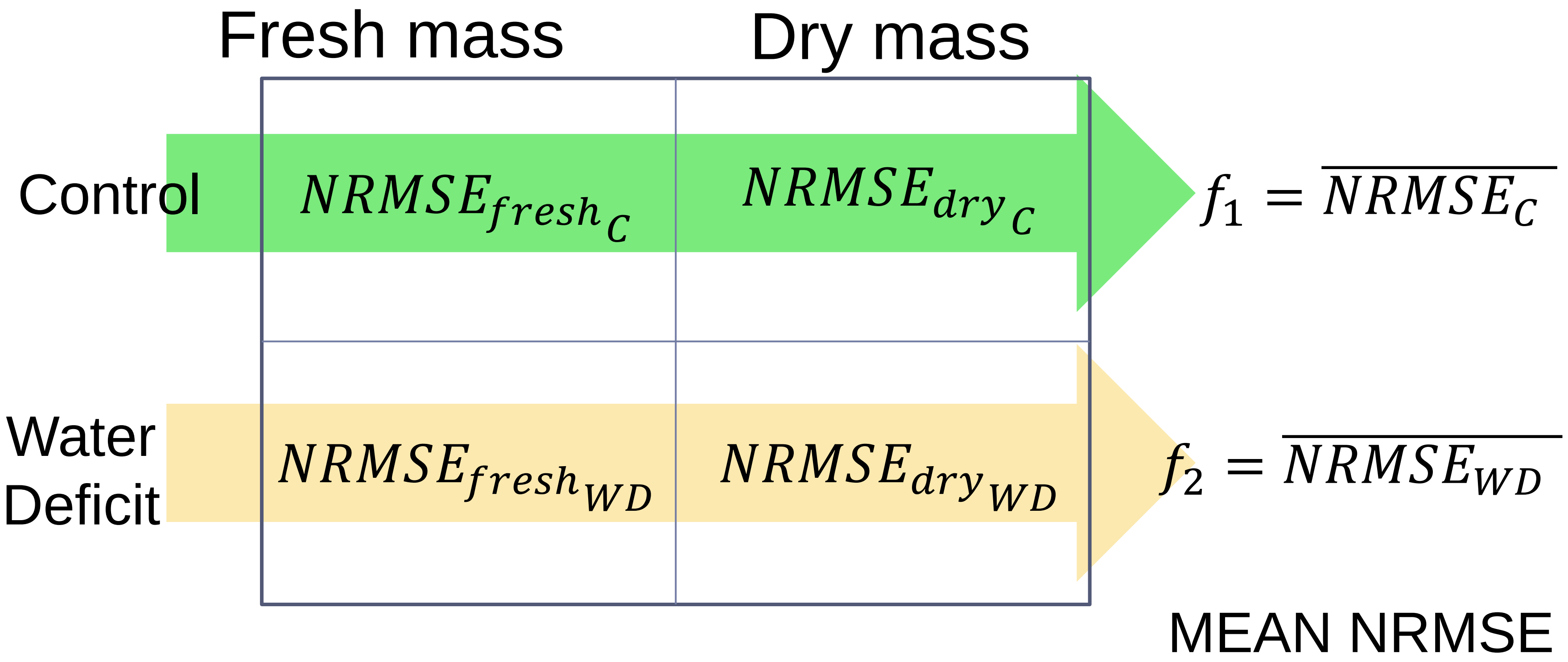
- Parameters **do not depend on environmental conditions**
- **8 parameters** for the calibration

Cell expansion 1 parameter	Sugar active uptake 4 parameters	Water conductivities 3 parameters

Optimization problem: model calibration

	Fresh mass	Dry mass
Control	$NRMSE_{fresh_C}$	$NRMSE_{dry_C}$
Water Deficit	$NRMSE_{fresh_{WD}}$	$NRMSE_{dry_{WD}}$

Optimization problem: model calibration



	Fresh mass	Dry mass
Control	$NRMSE_{fresh_C}$	$NRMSE_{dry_C}$
Water Deficit	$NRMSE_{fresh_{WD}}$	$NRMSE_{dry_{WD}}$

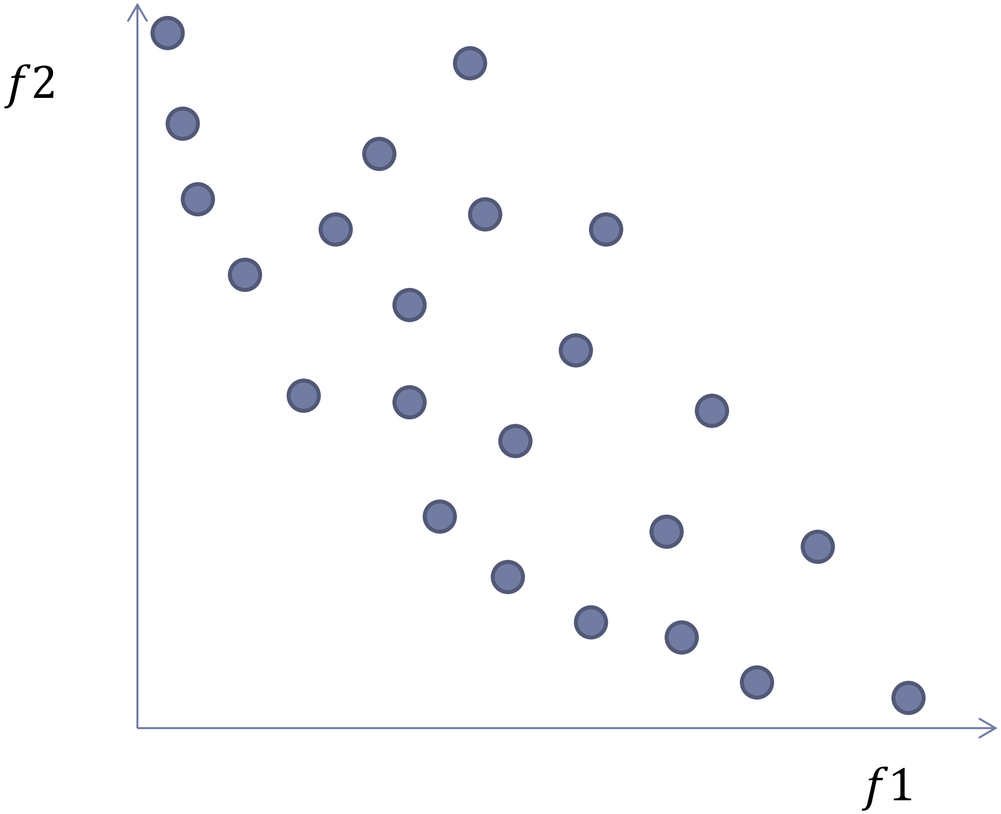
$$f_1 = \overline{NRMSE_C}$$

$$f_2 = \overline{NRMSE_{WD}}$$

MEAN NRMSE

Model calibration: choose the best solution

- Optimization problem ← NSGA-II algorithm (Evolutionary algorithm)



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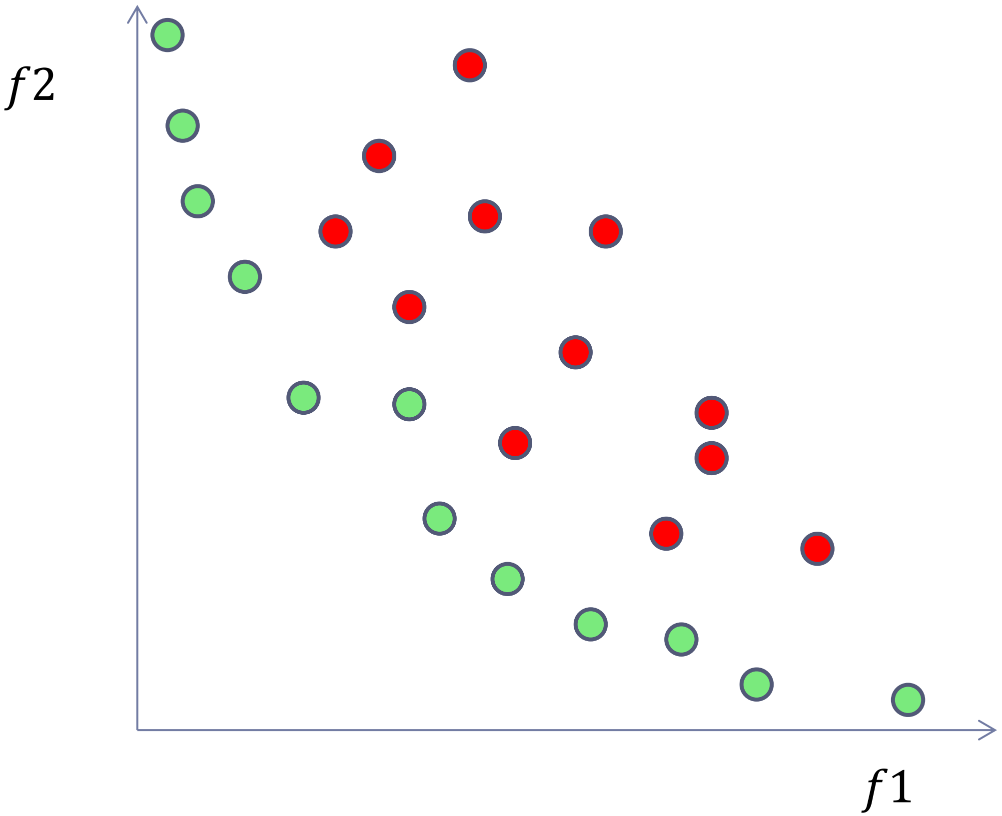
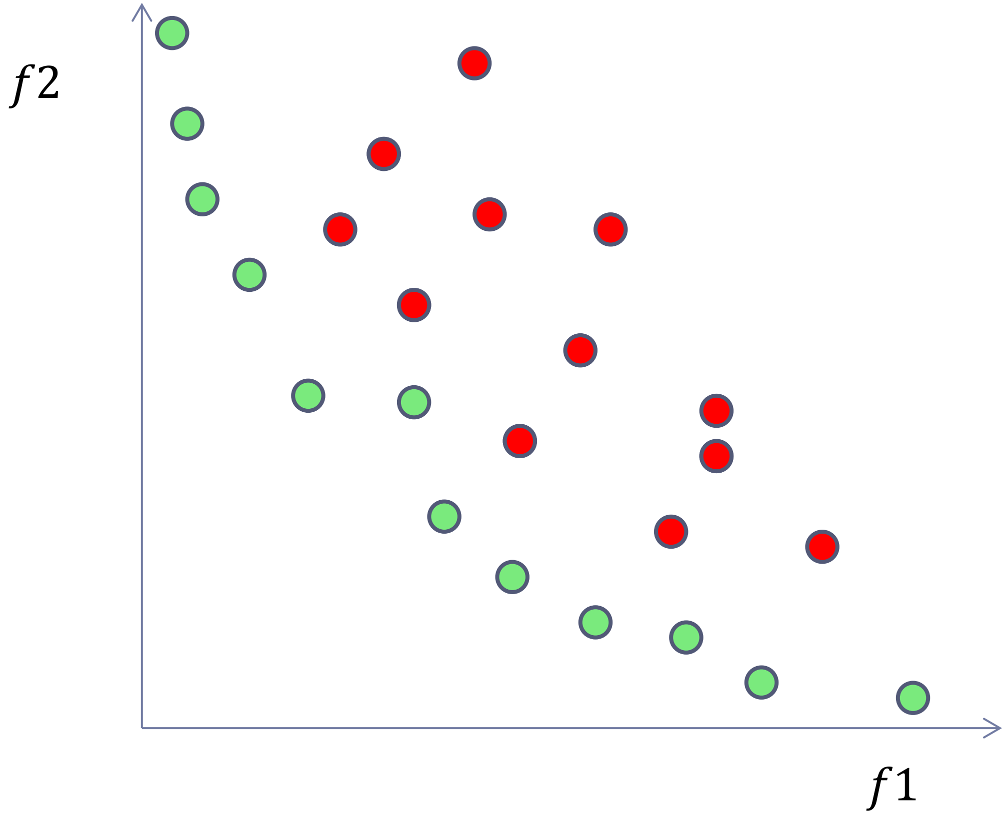


Model calibration: choose the best solution

- Decision criterion:

Minimum of all the worst objectives values



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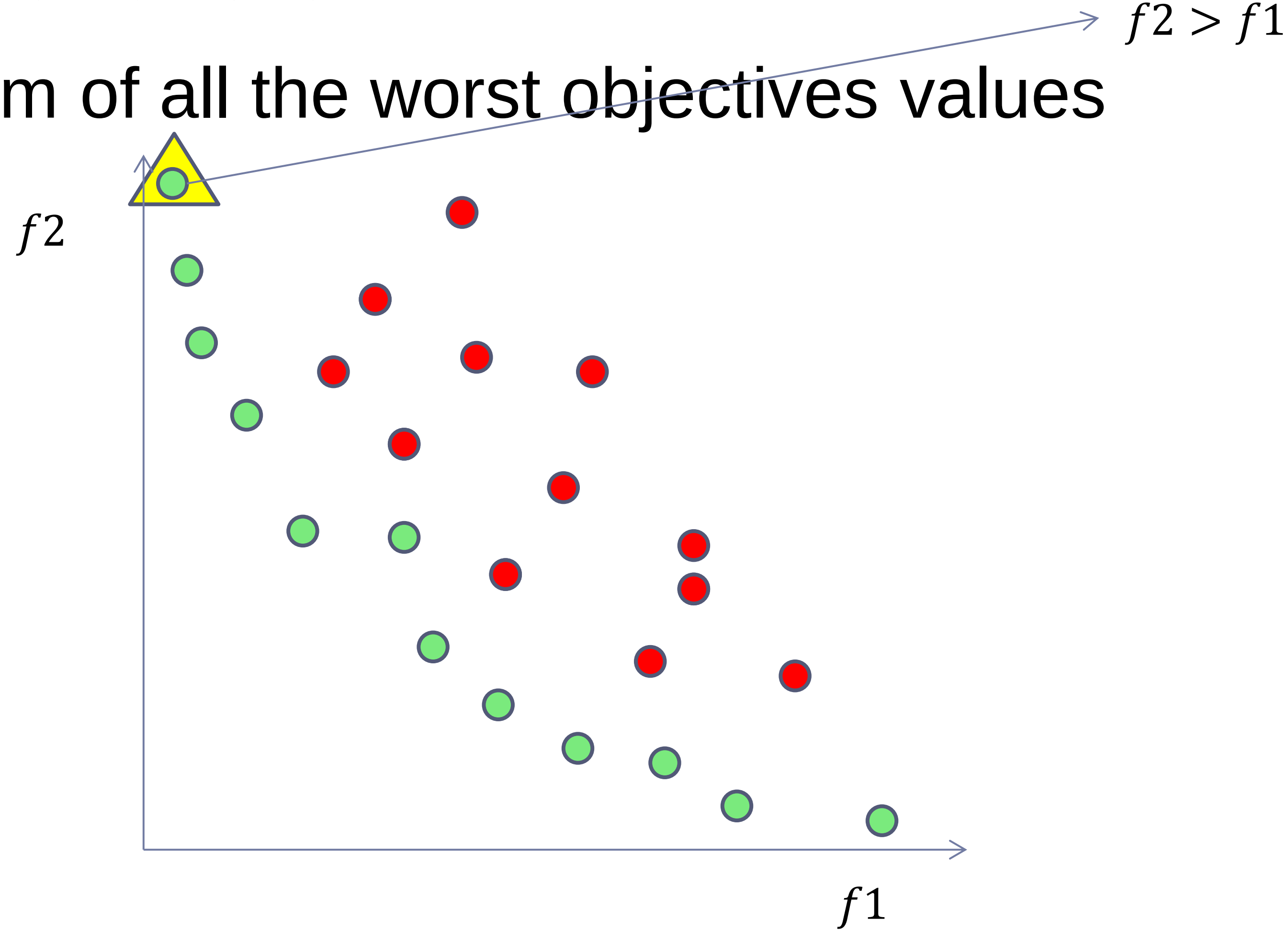

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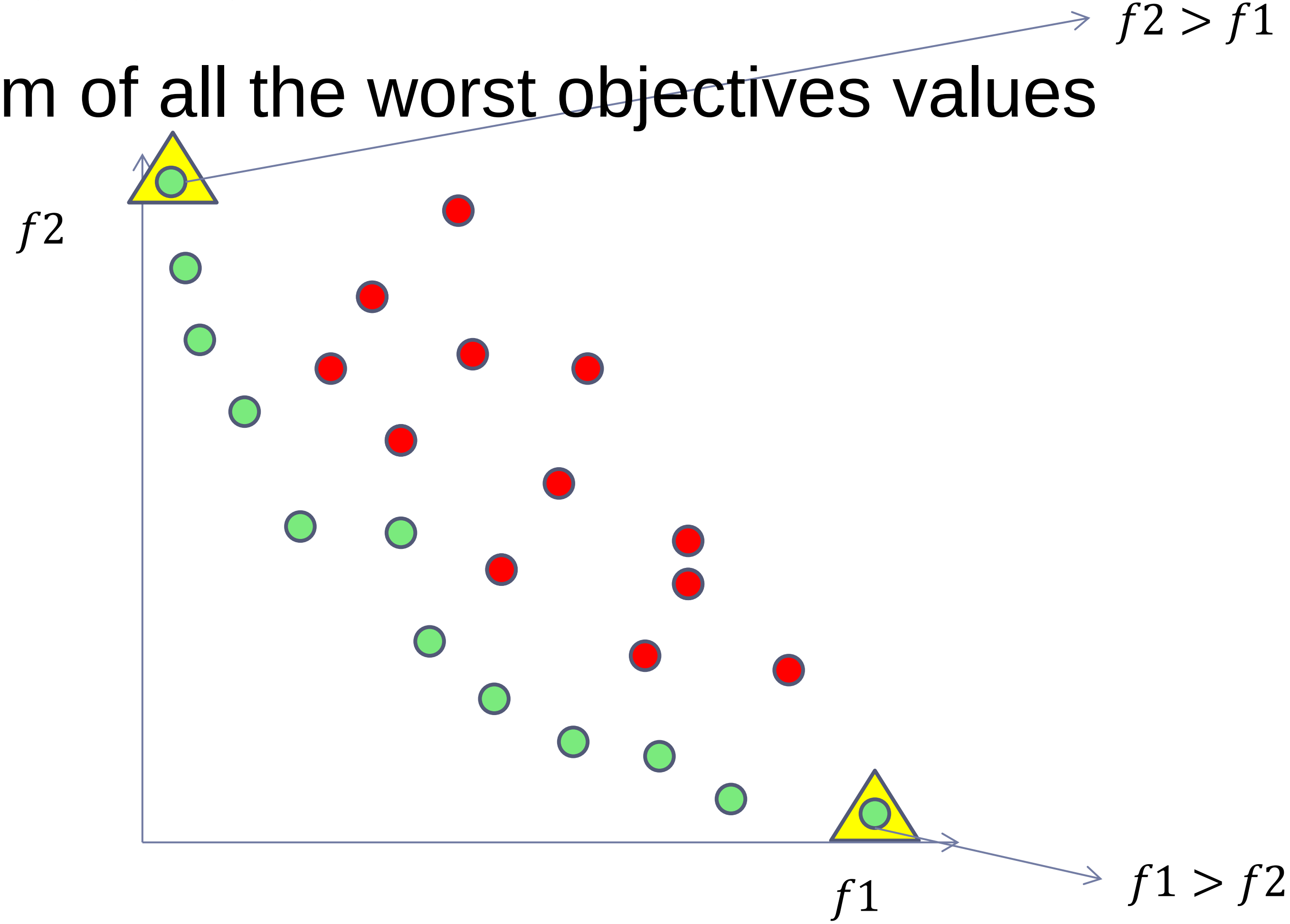

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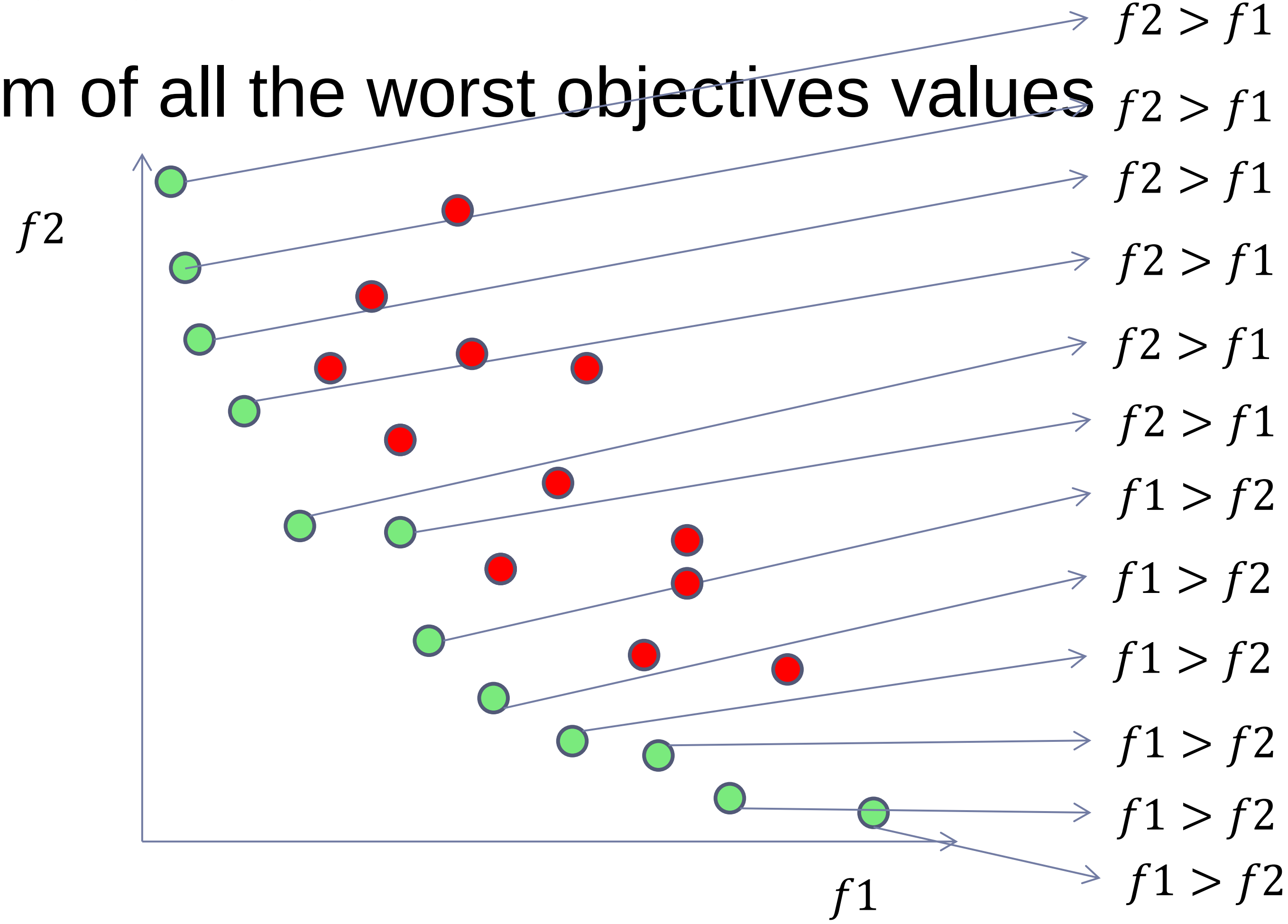

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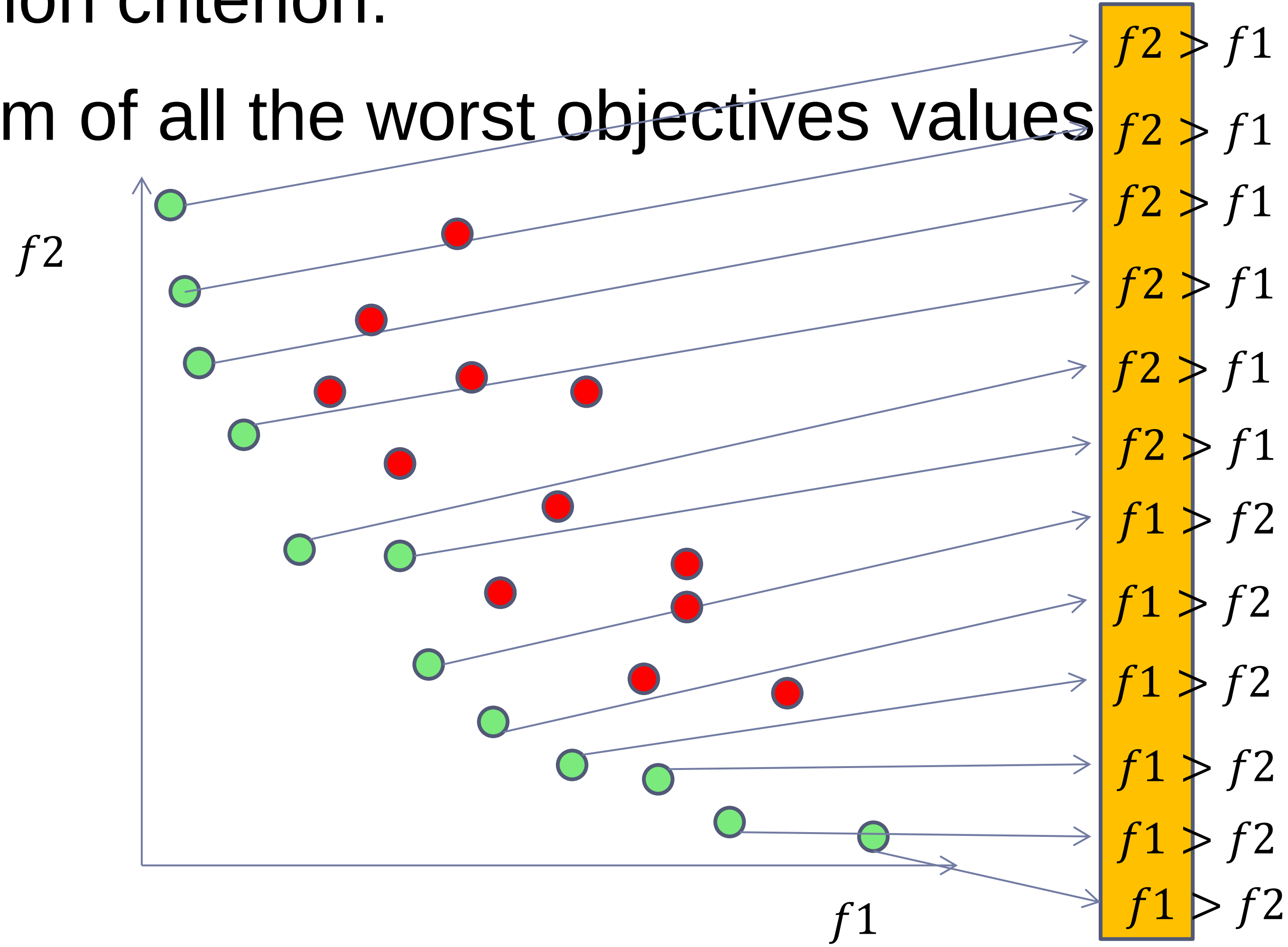

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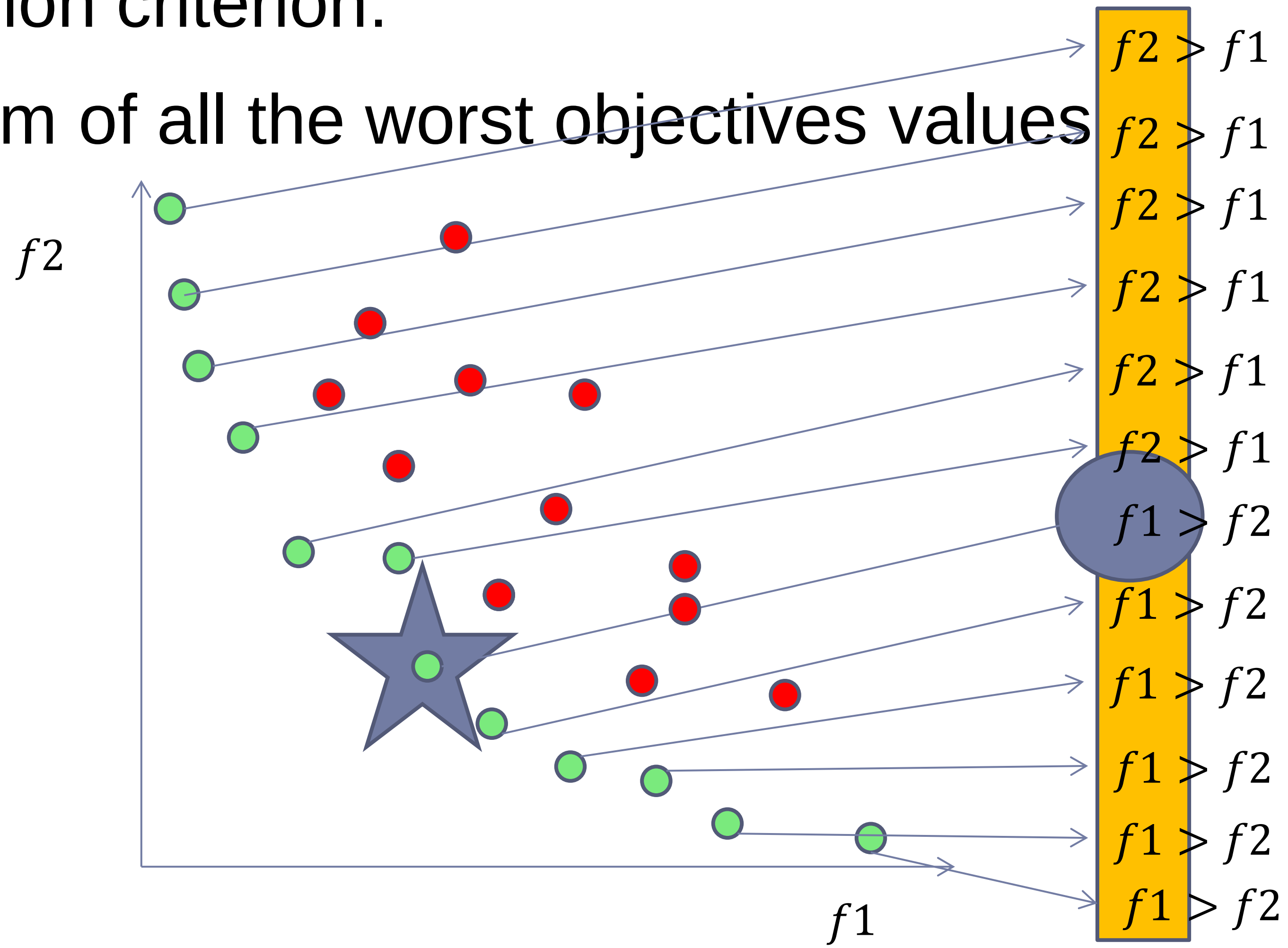
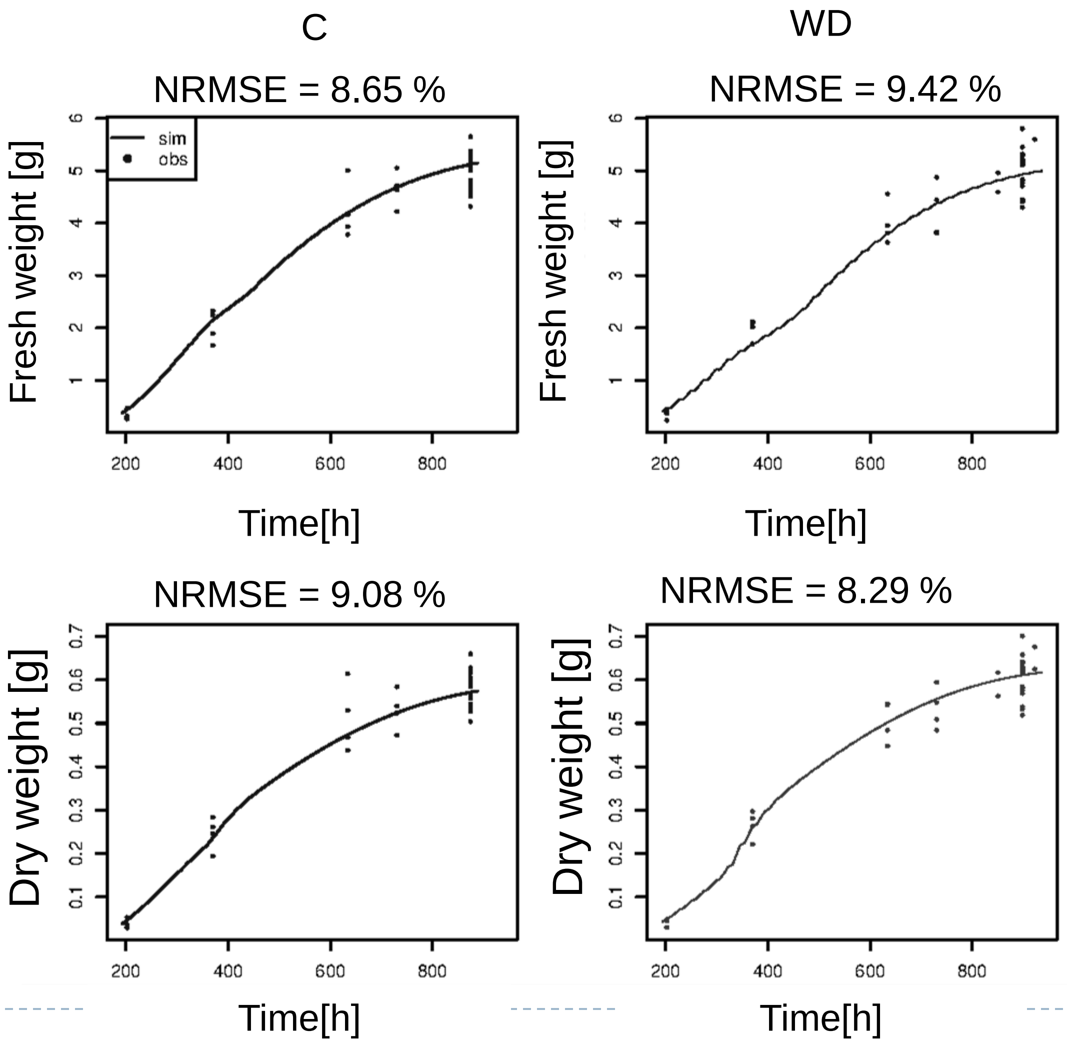


Results: model calibration

Parental line Cervil

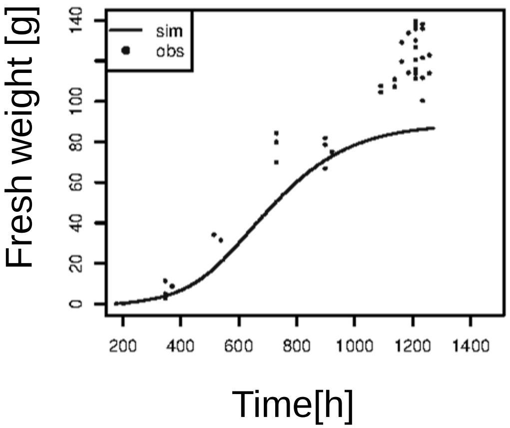


Results: model calibration

Parental line Levovil

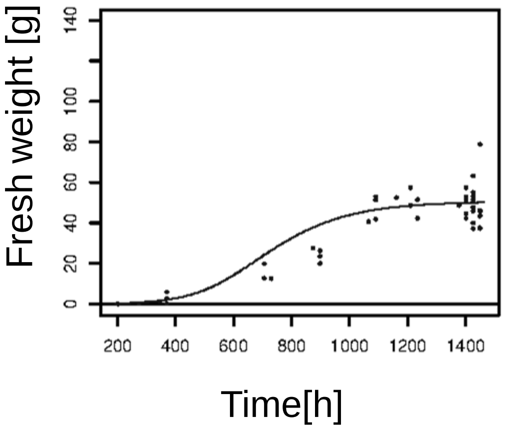
C

NRMSE = 34 %

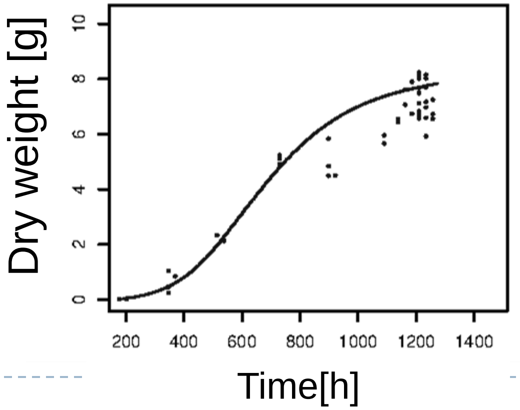


WD

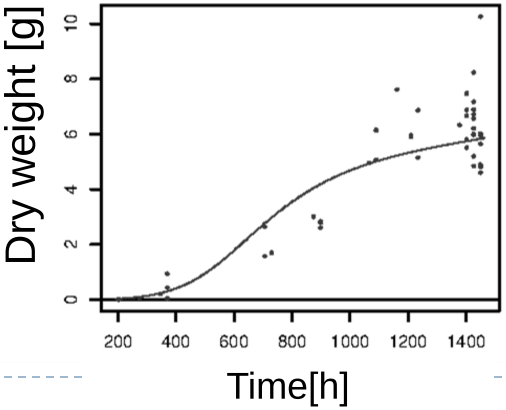
NRMSE = 24.11 %



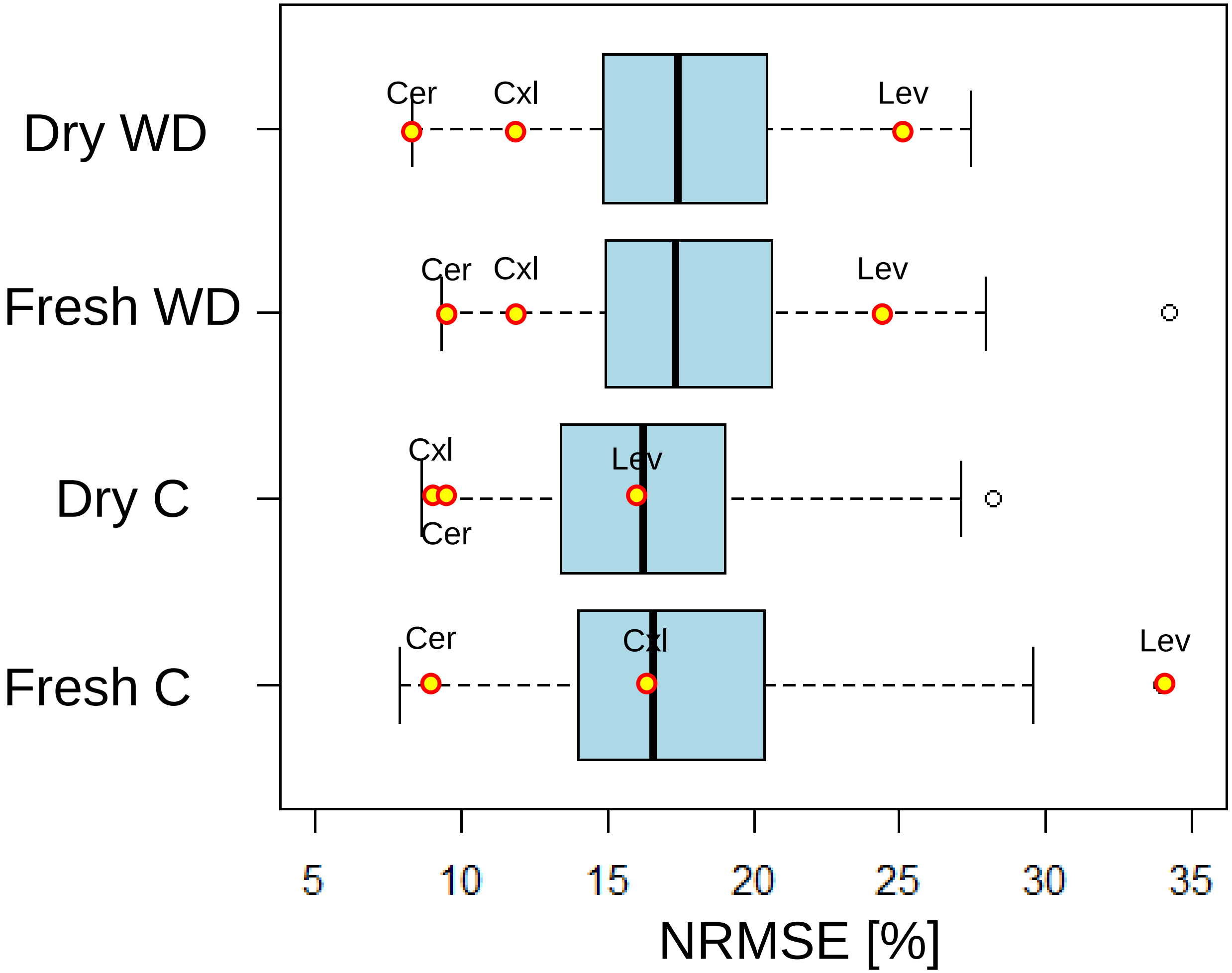
NRMSE = 15.78 %



NRMSE = 25.19 %



Results: model calibration whole population

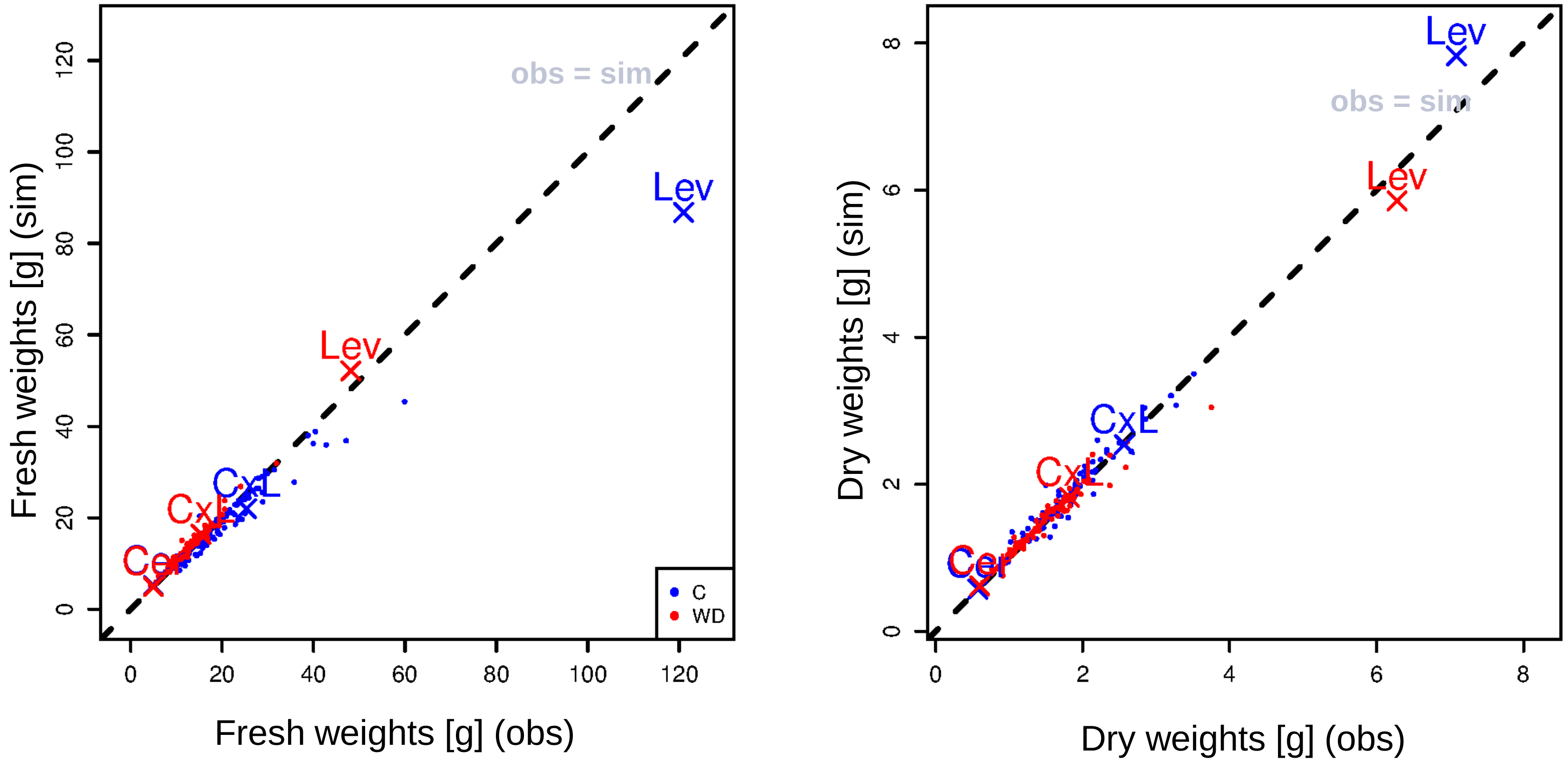


- Good calibration performances

$\overline{NRMSE}$ [%]	Fr	Dry
C	17.41	16.48
WD	17.76	17.75

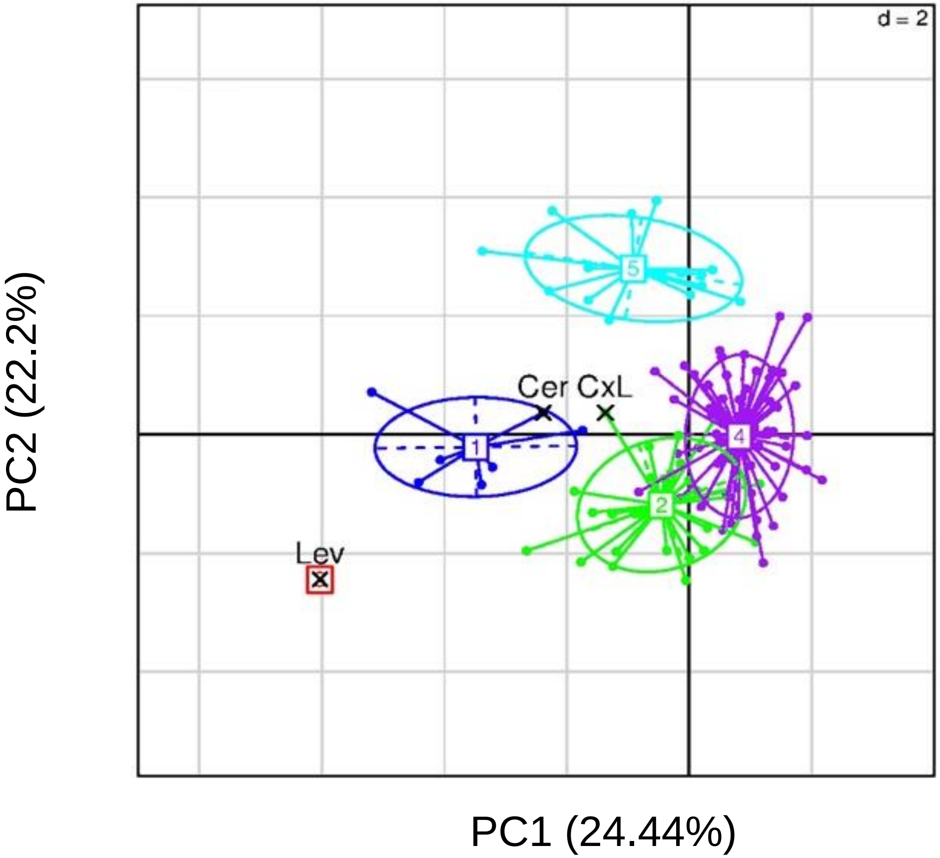
Results: model calibration

Simulated vs observed mass values at ripening



Results: PCA on model parameters

Principal component analysis performed on the RILs parameters
→ Hierachical cluster analysis on the individual coordinates in the PC space

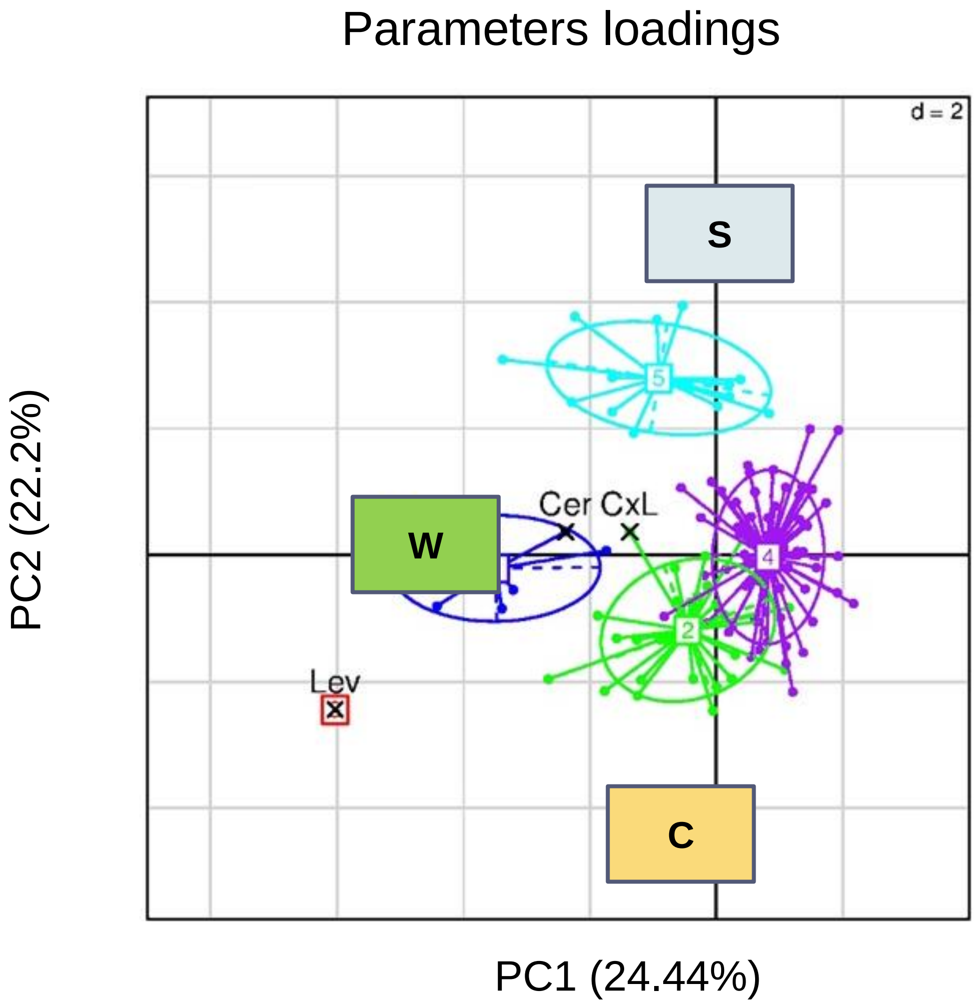


Results: PCA on model parameters

Cell expansion

Sugar active uptake

Water conductivities



First PC
Water conductivities

Second PC
Sugar uptake
opposed to
Cell expansion

Results: PCA on model parameters

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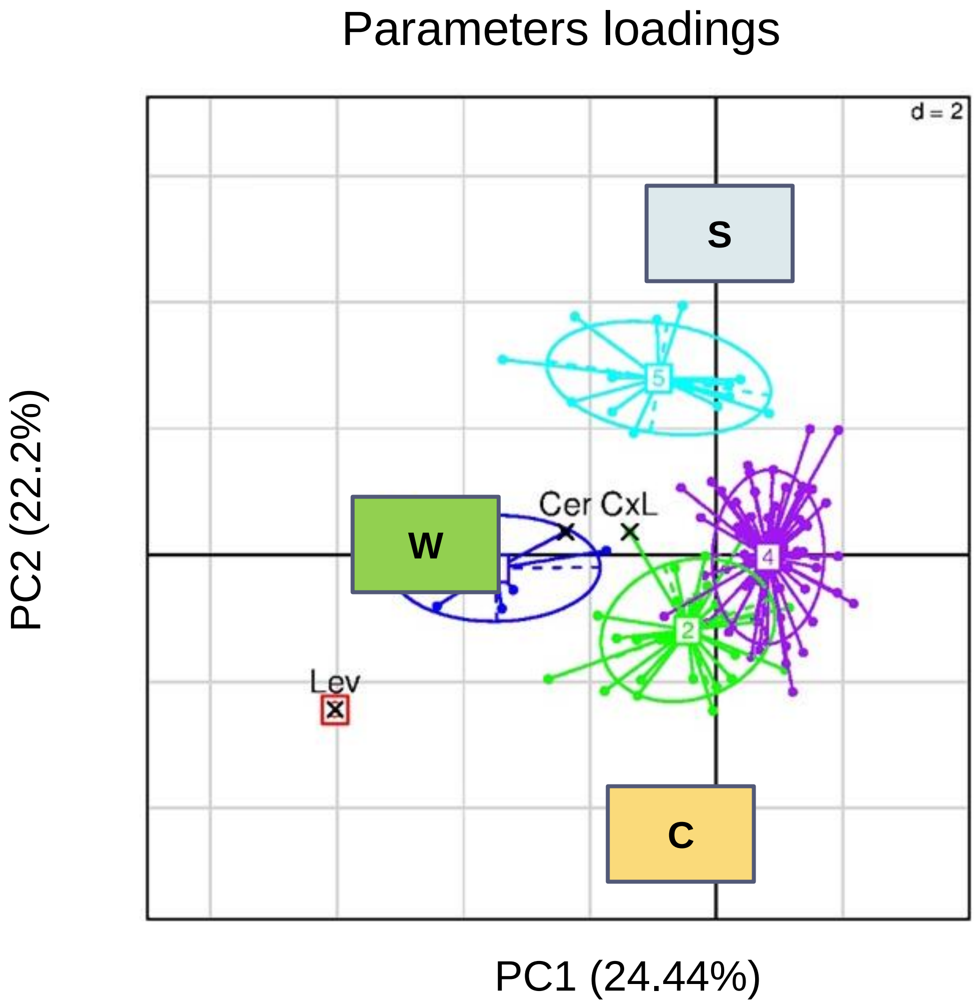


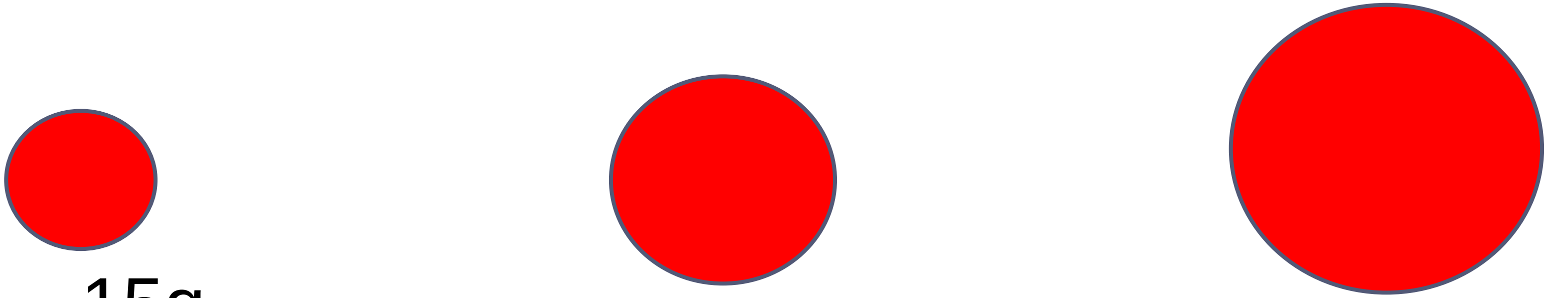
First PC
Water conductivities

Second PC
Sugar uptake
opposed to
Cell expansion

Group 5 RILs
low water loss
associated to **high sugar uptake**

Optimization problem: design of ideotypes

- Three classes of fruit sizes:



5 – 15g

20 – 80g

100 – 300g

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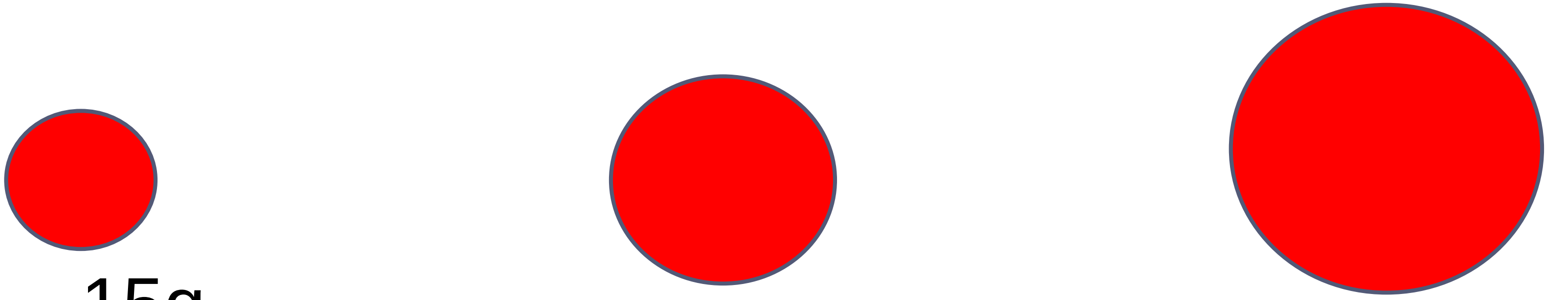

5 – 15g

20 – 80g

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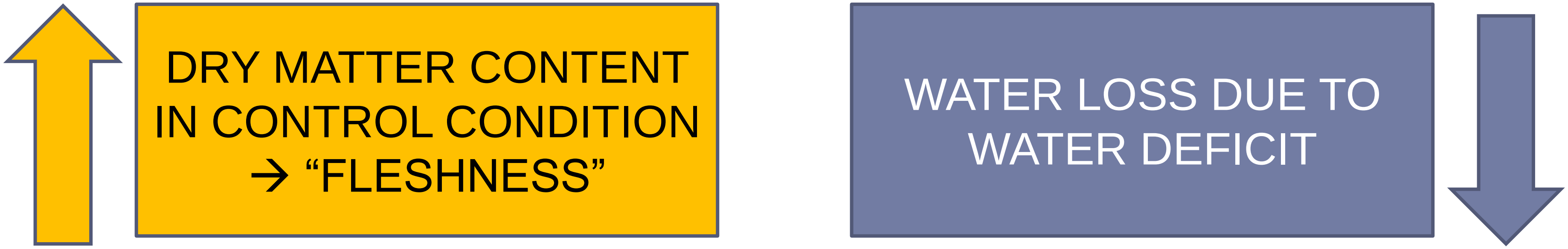
- Objectives:



DRY MATTER CONTENT IN CONTROL CONDITION → “FLESHNESS”

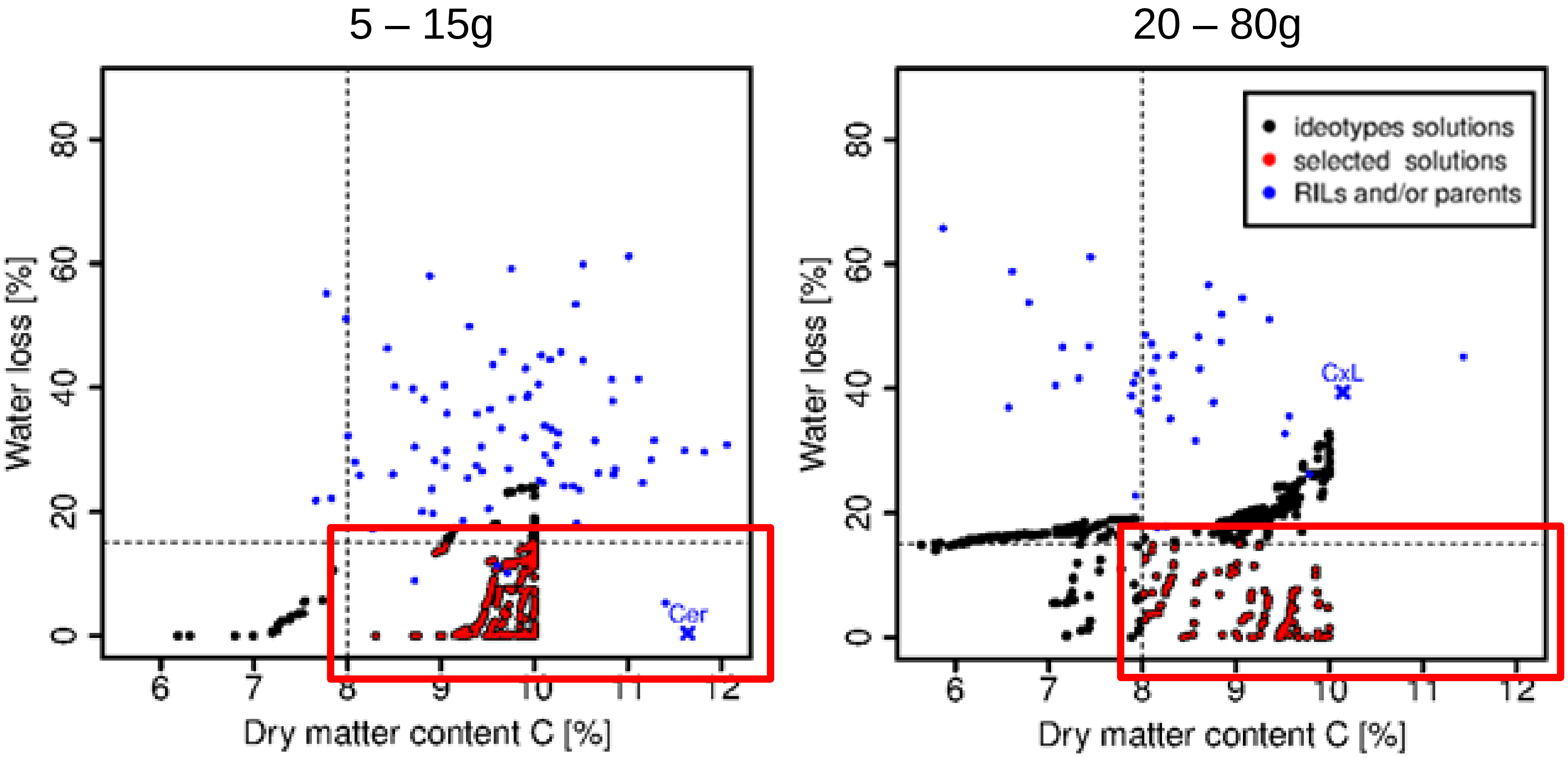
WATER LOSS DUE TO WATER DEFICIT

Results: design of ideotypes

The *ideal* fruits are selected according to the criteria:

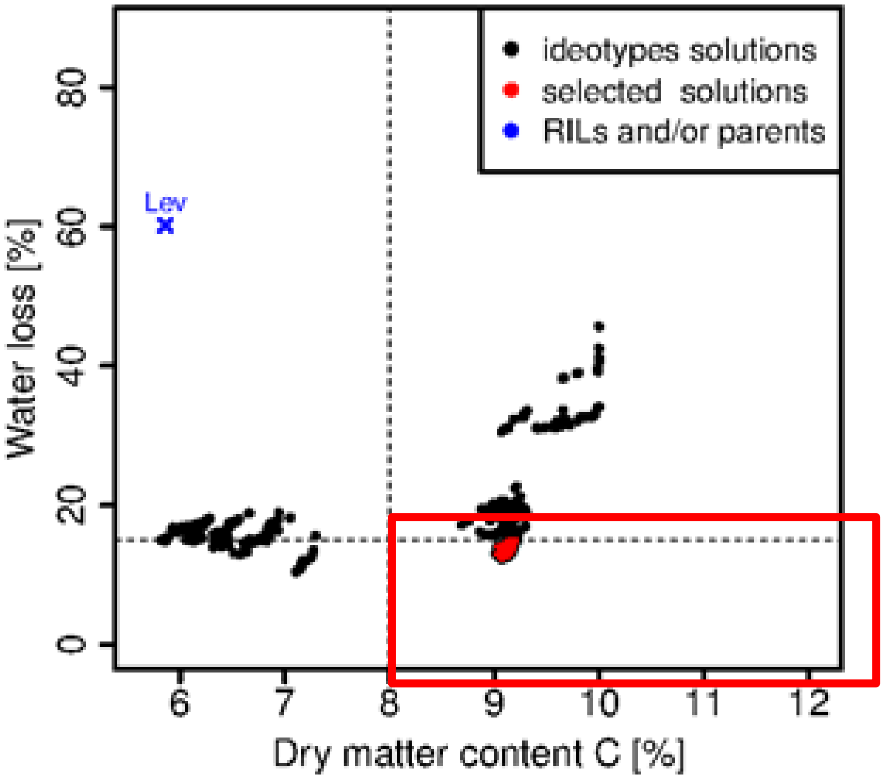
- **Dry matter content** in C condition **more than 8%**
- **Water loss** due to WD conditions **less than 15%**

Results: design of ideotypes



Results: design of ideotypes

100 – 300g



Conclusions

- **Traits** for water deficit resistance **highlighted**

- Modelling + optimization approach is suitable for ideotypes research

- The model should be evaluated on a different population

Thank you!

PSH UR 1115

Project TomSec CTPS (2013-2015)
Project AdapTom (ANR 2014-2017)

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