

# Biophysical models to support breeding programs

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#### **Climate change**

#### Agricultural productions are highly exposed to direct/indirect effects of climate change

Regional climate impacts in 2100 - Experimental sensitivity (Billion USD/yr).

CSIRO climate model							
Region	Agr	For	Ene	Wat	Cst	Total	%GDP
L America	-35.1	0.3	-9.5	-4.5	-0.0	-49.0	-0.23
Africa	-66.7	0.2	-3.0	-1.4	-0.0	-71.0	-1.56
Asia	-180.	1.3	-29.1	-15.9	-0.2	-224.0	-0.32
Oceania	-10.1	0.0	-1.4	-0.5	-0.0	-11.0	-0.48
N America	34.5	1.2	-28.2	-11.5	-0.1	-4.1	-0.01
W Europe	29.9	1.1	-4.5	-6.3	-0.1	20.1	0.04
USSR&EE	179.7	1.0	1.6	-2.0	-0.0	180.2	1.42
Globe	-47.9	5.1	-74.3	-42.1	-0.5	-159.6	-0.08

(Mendelsohn et al., 2004)

(GDP = gross domestic product)

CGCM1 climate model							
Region	Agr	For	Ene	Wat	Cst	Total	%GDP
L America	-92.7	0.3	-17.8	-8.6	-0.2	-118.9	-0.55
Africa	-99.1	0.2	-6.0	-2.1	-0.0	-107.0	-2.35
Asia	-295.5	1.8	-48.4	-21.9	-1.7	-365.7	-0.53
Oceania	-19.1	0.0	-2.4	-0.8	-0.0	-23.4	-0.89
N America	9.0	1.5	-44.2	-16.4	-0.7	-50.8	-0.10
W Europe	8.0	0.8	-8.8	-9.9	-1.1	-11.0	-0.02
USSR&EE	183.4	1.1	-0.3	-2.9	-0.1	181.3	1.42
Globe	-305.9	5.7	-127.9	-62.7	-3.8	-494.6	-0.24

Economic impacts in agriculture, forestry, energy, water, and coastal sectors.

- Differences among regions are due to:
  - ✓ Production context (technology, infrastructure, education)
  - ✓ Soil-climate conditions
  - Crops (species, varieties/hybrids)



#### **Climate change**





 Sets of mathematical equations that represent crop growth and development as a function of "environmental variables"

#### ✓ Weather

- Physical and chemical soil properties
- ✓ Interaction between crops and other organisms
- ✓ Management



- Sets of mathematical equations that represent crop growth and development as a function of "environmental variables"
  - ✓ Weather
  - Physical and chemical soil properties
  - ✓ Interaction between crops and other organisms
  - ✓ Management
- Mechanistic... empiric...
  - ...Better process-based







#### Parameters

 They describe morphological or physiological features of a species or of a genotype (genetic coefficients) (e.g., specific leaf area)

G

Μ

 $G \times E \times M$ 

- Events
  - ✓ Management practices (e.g., sowing)
- Variables
  - ✓ Driving variables (e.g., global solar radiation)
  - Rate variables (e.g., aboveground biomass increase during the time step)
  - State variables (e.g., aboveground biomass at time t, leaf area index at time t, plant height at time t)



A (very simplified) example of a sub-model for a specific process:

Development

$$GDD_{r} = \begin{cases} (T_{max} + T_{min})/2 - T_{base} & T_{base} \leq (T_{max} + T_{min})/2 \leq T_{cutoff} \\ 0 & (T_{max} + T_{min})/2 < T_{base} \\ T_{cutoff} - T_{base} & (T_{max} + T_{min})/2 > T_{cutoff} \end{cases}$$

- ✓  $T_{max}$  and  $T_{min}$  are maximum and minimum air daily temperatures (°C) → driving variables
- ✓  $T_{base}$  and  $T_{cutoff}$  are minimum and maximum cardinal temperatures (°C) → parameters
- ✓ GDD<sub>r</sub> are the growing degree days cumulated in the day (°C-d) → rate variable



A (very simplified) example of a sub-models for a specific process:

Development

$$GDD_{s,d} = \sum_{i=p}^{d} GDD_{s,d-1} + GDD_r$$

- ✓ GDD<sub>s,d</sub> are the growing degree days at day d and at day d –
   1 (°C) → state variables
- ✓ p is the planting day  $\rightarrow$  event



#### Development of crop ideotypes



Fig. 1. WARM model flowchart.



- Crop models allow defining **adaptation strategies** 
  - ✓ Management
    - Sowing date
    - Different cultivars/hybrids





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- Crop models allow defining **adaptation strategies** 
  - ✓ Management
    - Sowing date
    - Different cultivars/hybrids
    - Irrigation techniques
    - Cropping systems



Different cropping systems to maintain the same level of feed selfsufficiency in dairy cattle farms



- Crop models allow defining **adaptation strategies** 
  - ✓ Management
    - Sowing date
    - Different cultivars/hybrids
    - Irrigation techniques
    - Cropping systems

#### ✓ Genetics



 Crop models can be used to support breeding programs by reducing time and resources needed to release new varieties



Development of crop ideotypes

Why crop models (biophysical models) can support breeding programs?

- They formalize our knowledge on genotype × environment × management (G × E × M) interaction
  - ✓ If properly developed, evaluated and parameterized, they can explore a wide range of conditions with minimum effort (time, resources)
- They have parameters that represent morphological and physiological features of species/varieties/hybrids

...**traits**?



# **Crop models and breeding**

#### Two main strategies

- 1. Identifying most promising traits (and trait values), also targeting "future" conditions
  - Estimating potential benefits
    - ...in silico ideotyping



- 1. Define ranges/statistical distributions for trait values
  - How?
    - ✓ Searching in the literature papers where the trait/parameter of interest has been measured.
    - ✓ Checking distribution (normal, log-normal, etc.).
    - Deriving distribution parameters (e.g., mean and standard deviation in case of normal).
  - Problems:
    - Are we dealing with a specific germplasm or with "a crop"?
    - ✓ Are the values from the literature representative?
    - The values from literature refer to traits or parameters?



- 1. Define ranges/statistical distributions for trait values
  - Solutions
    - ✓ Try to clearly **understand** 
      - what a trait is



- "Trait":
  - ✓ First time defined by Darwin (1859)?
  - Development of disciplines
    - quantitative genetics
    - ecophysiology
    - functional ecology

Solutions:

 Classification frameworks based on the trait role in determining individual fitness (e.g., Arnold, 1983; Violle et al., 2007)

"Dialects"? The term assumed a variety of connotations... ...the underlying concept is sometimes (often?) unclear

(Violle et al., 2007)



#### Development of crop ideotypes



#### Solutions:

 Classification frameworks based on the trait role in determining individual fitness (e.g., Arnold, 1983; Violle et al., 2007)



#### Development of crop ideotypes



#### Solutions:

- Classification frameworks based on the trait role in determining individual fitness (e.g., Arnold, 1983; Violle et al., 2007)
- Trait ontologies...



#### • Trait ontologies:

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Comment	None						
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Database Cross-References (3)							
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#### Development of crop ideotypes

• Trait ontologies:

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- Trait ontologies:
  - They appear as good solutions but unfortunately they are not as good as they would like to be
    - Definitions are not completely unambiguous
    - Sometimes traits are **not** described in a **quantitative** way
    - The impression is that they were not developed by ecophysiologists
- The datasets we can use are mainly collected by breeders
  - ✓ Phenotyping hundreds of lines
  - In a short interval of time

Trait = "something that can be measured easily and rapidly"



- 1. Define ranges/statistical distributions for trait values
  - Solutions
    - Try to clearly understand
      - what a trait is





...Crop models were **not developed to explicitly target ideotyping** studies... and they are simplified representation of underlying systems.

Traits for ideotyping are often selected according to "what the model can do".



- 1. Define ranges/statistical distributions for trait values
  - Solutions
    - ✓ Try to clearly **understand** 
      - what a trait is
      - relationships between traits and parameters.
    - ✓ Whenever possible
      - Measure exactly what you are interested in
      - Targeting a specific germplasm