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).

(GDP = gross domestic product)

Region	CSIRO climate model 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**

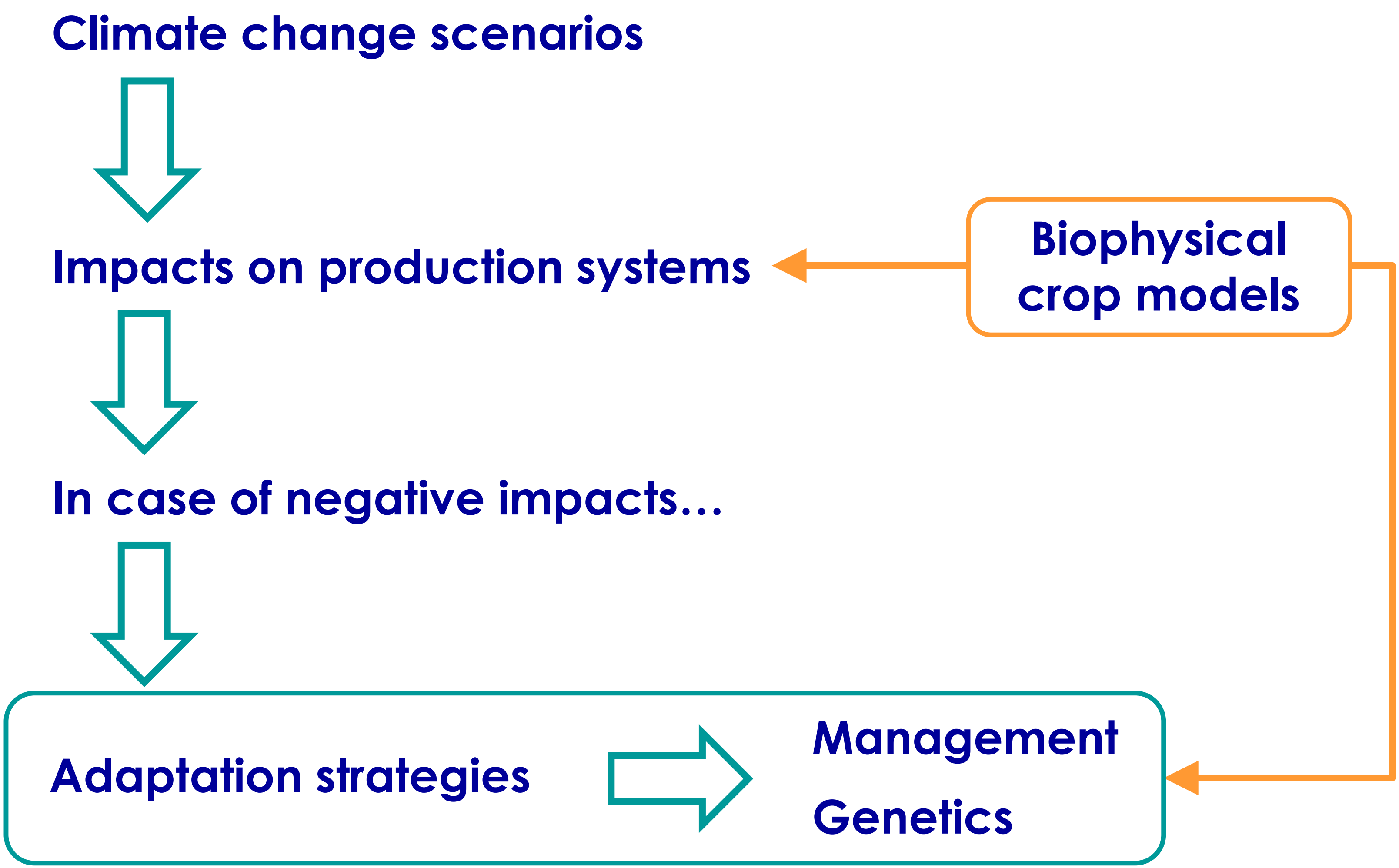
(Mendelsohn et al., 2004)

Region	CGCM1 climate model 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



Crop models

- 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**

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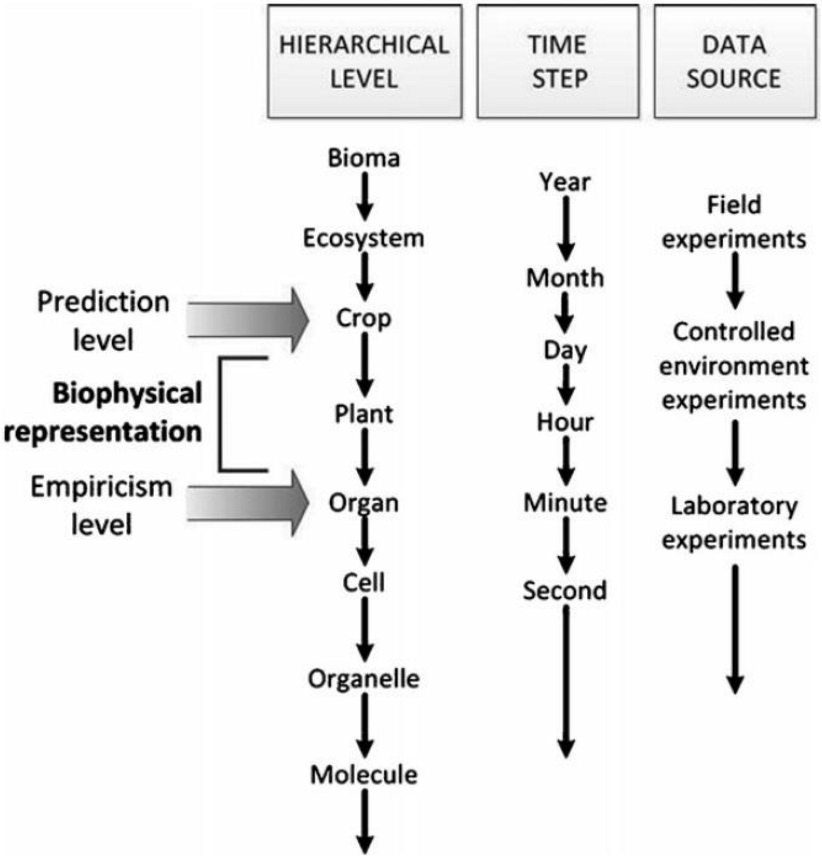
- Mechanistic… empiric…

  …Better ***process-based***



???

Crop models

- **Parameters**
  - ✓ They describe morphological or physiological features of a species or of a genotype (genetic coefficients) (e.g., specific leaf area) — G
- **Events**
  - ✓ Management practices (e.g., sowing) — M
- **Variables**
  - ✓ **Driving** variables (e.g., global solar radiation) — E
  - ✓ **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)

  (Rate and State variables) — G × E × M

Crop models

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_r 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**

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

✓ $GDD_{s,d}$ are the growing degree days at day d and at day $d-1$ (°C) → **state variables**

✓ p is the planting day → **event**

Crop models

Development of crop ideotypes

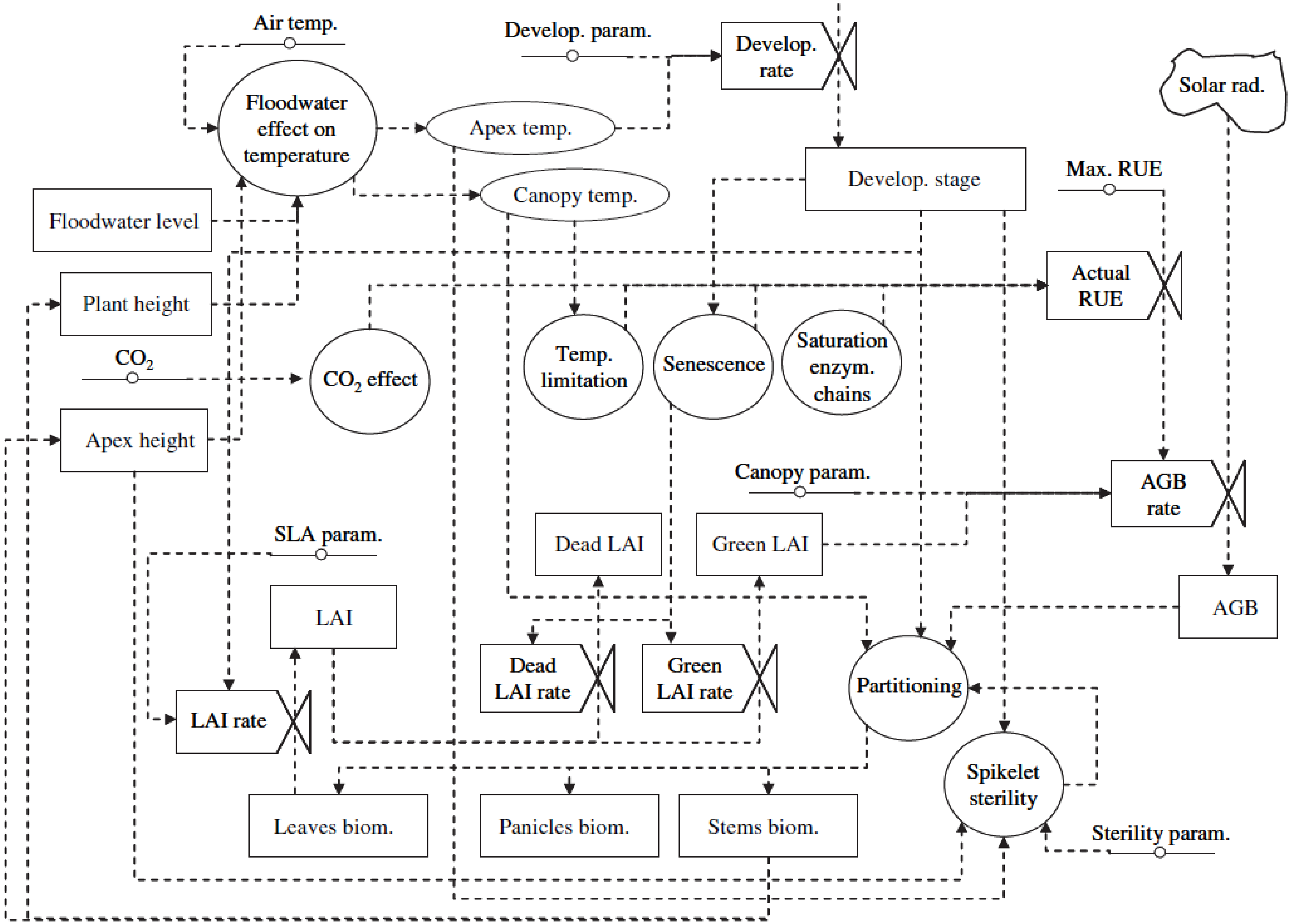
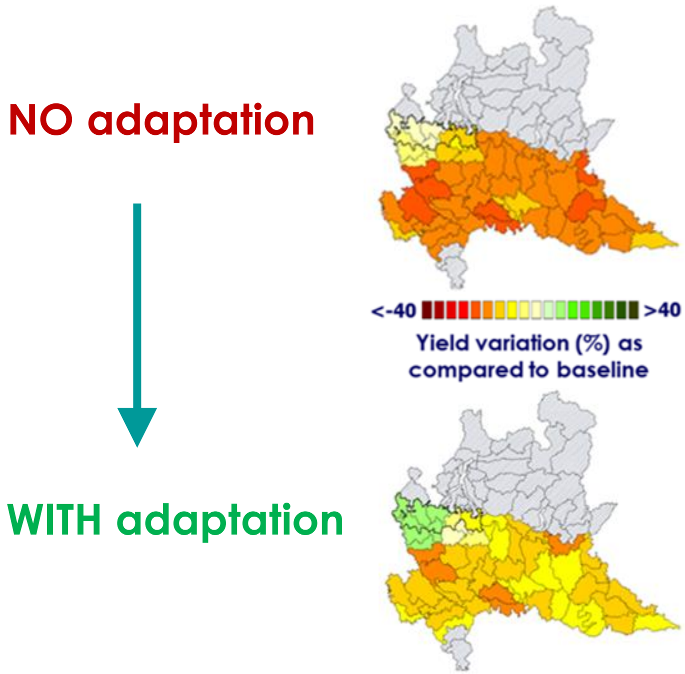


Fig. 1. WARM model flowchart.

Adaptation strategies

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



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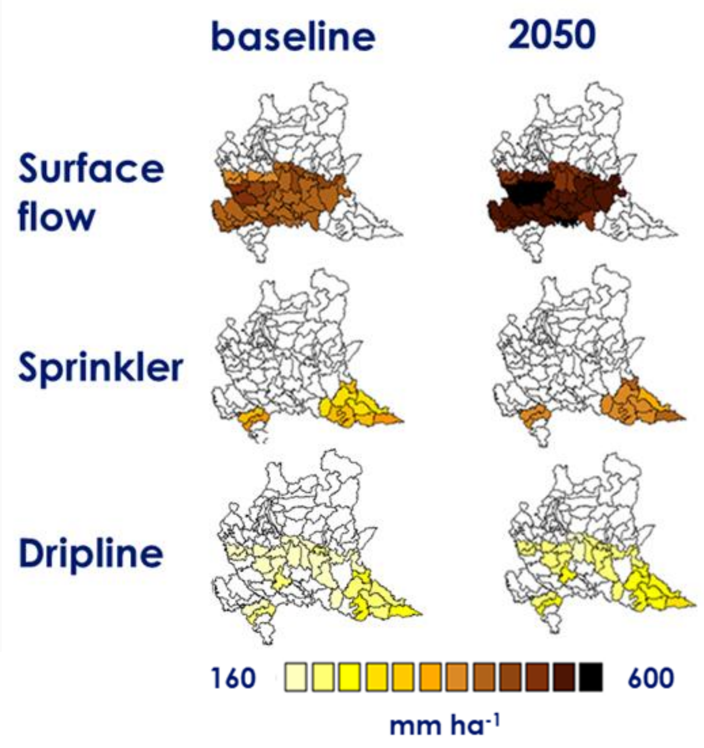

Adaptation strategies

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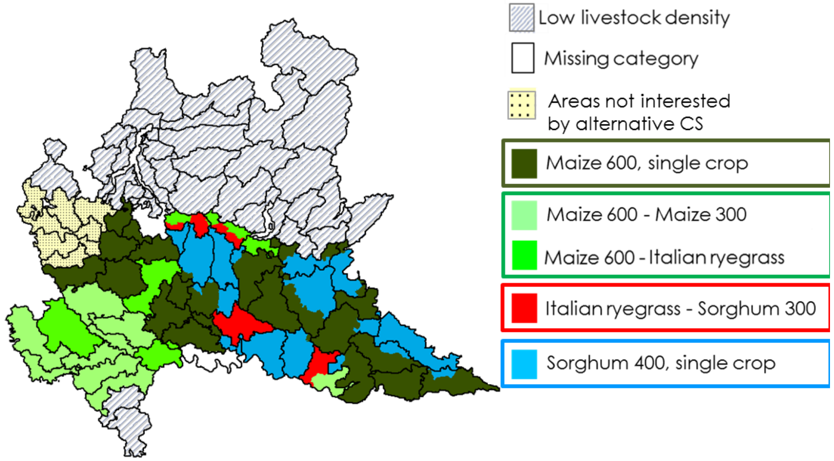
    - Cropping systems



Different cropping systems to maintain the same level of **feed self-sufficiency** in **dairy cattle farms**

Adaptation strategies

- 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

Crop models and breeding

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**

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**?

In silico ideotyping

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

In silico ideotyping

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

→ **"Dialects"?**

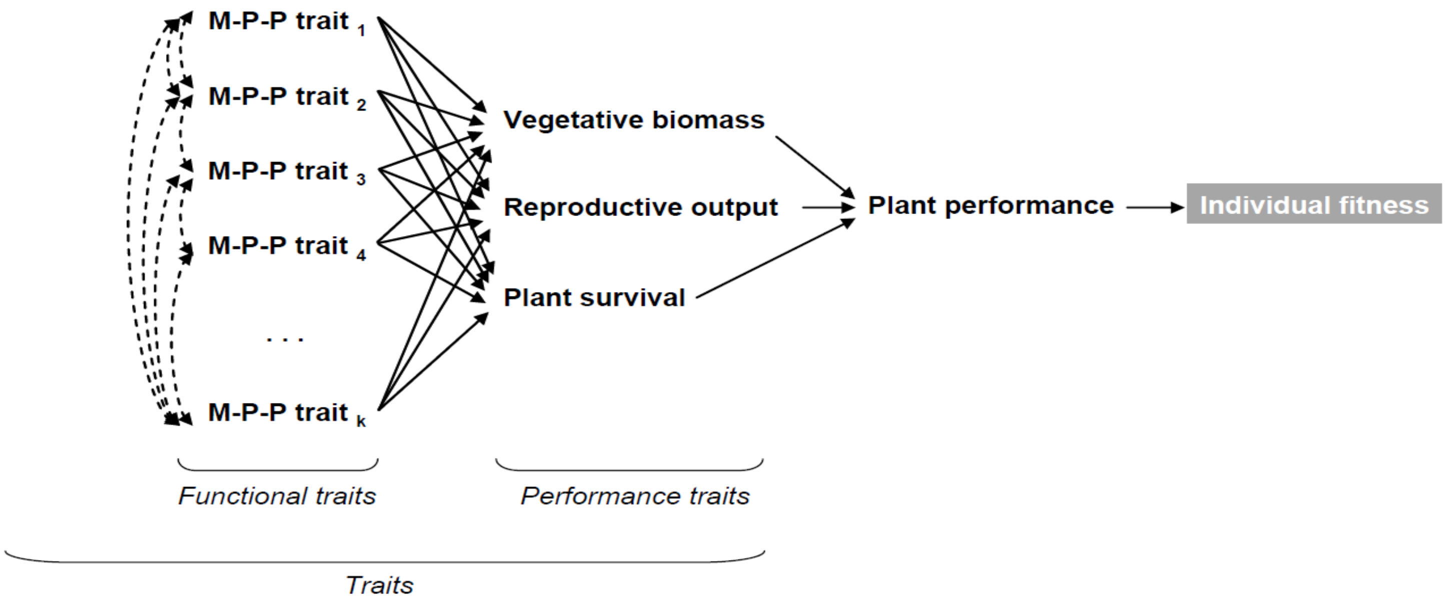
The term assumed a variety of connotations…

…the underlying concept is sometimes (often?) unclear (Violle et al., 2007)

Solutions:

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

In silico ideotyping



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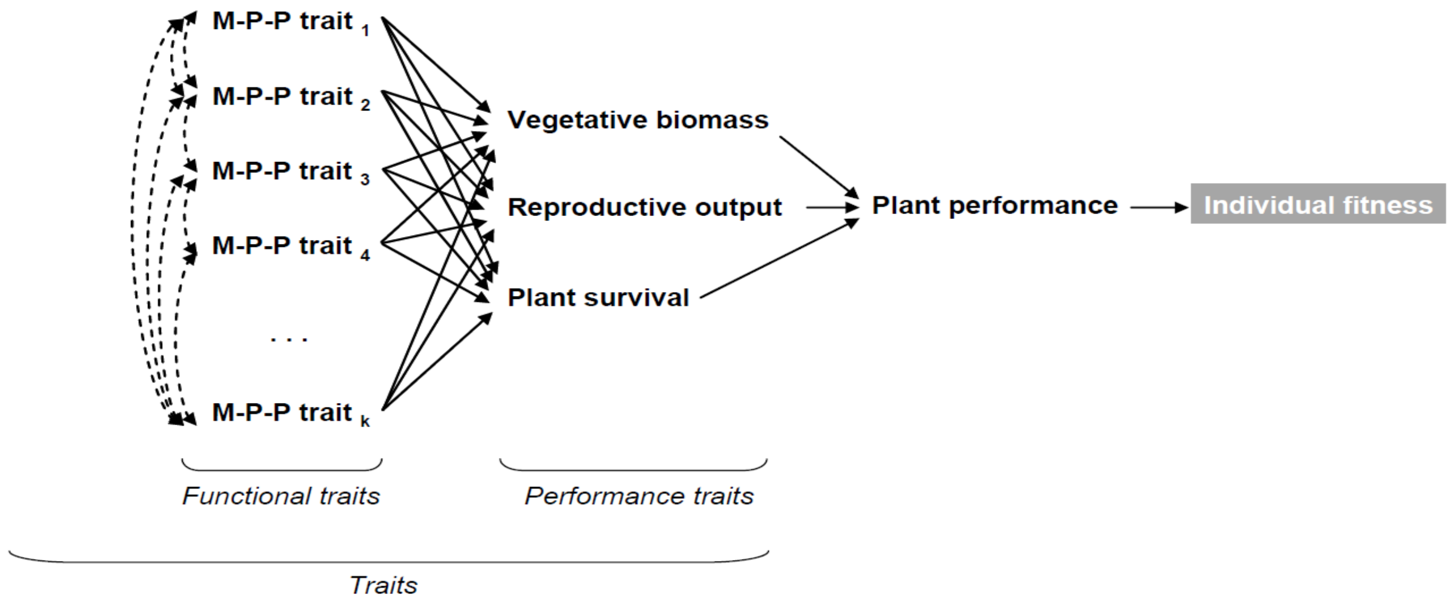
In silico ideotyping



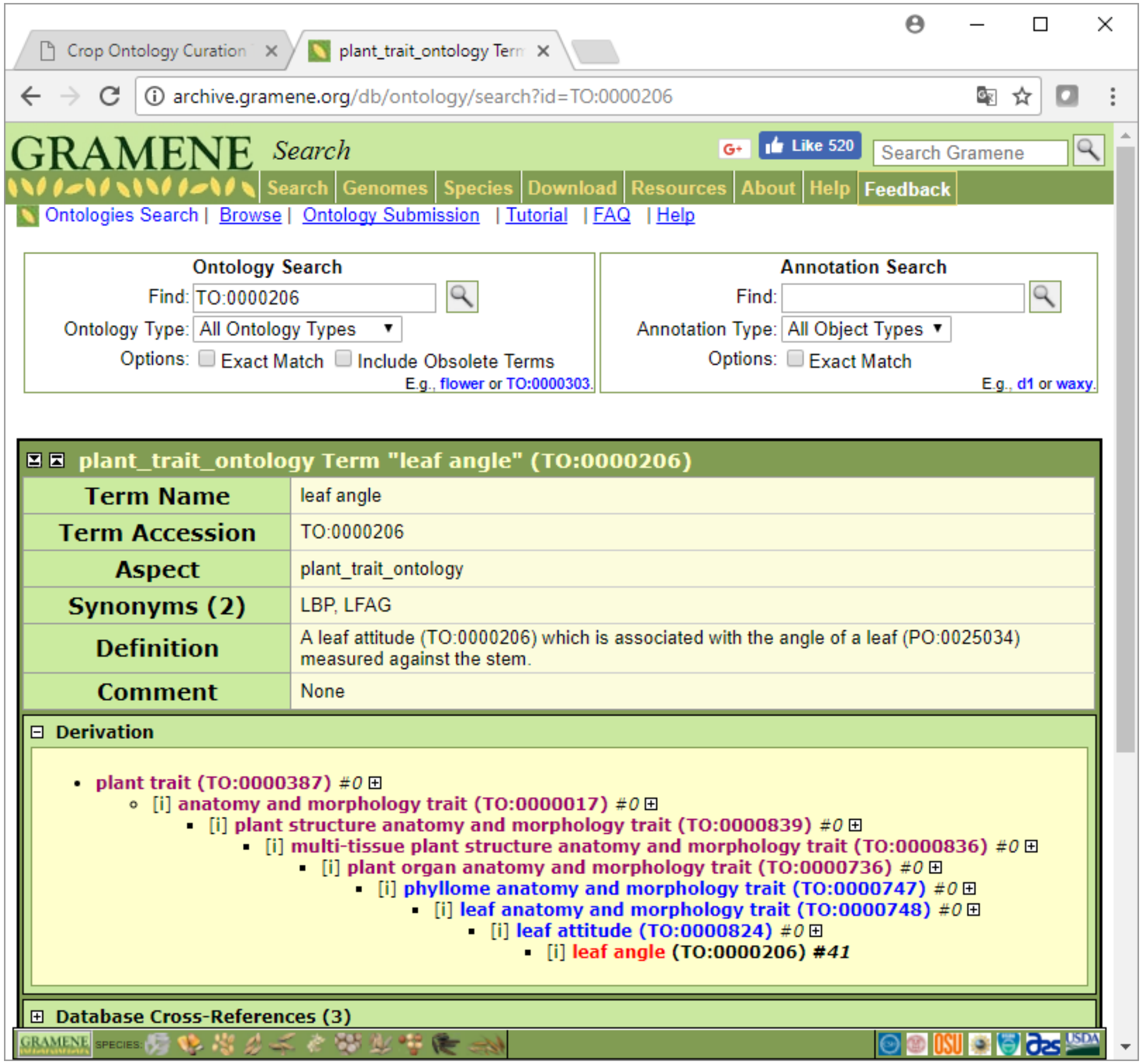
Solutions:

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

In silico ideotyping

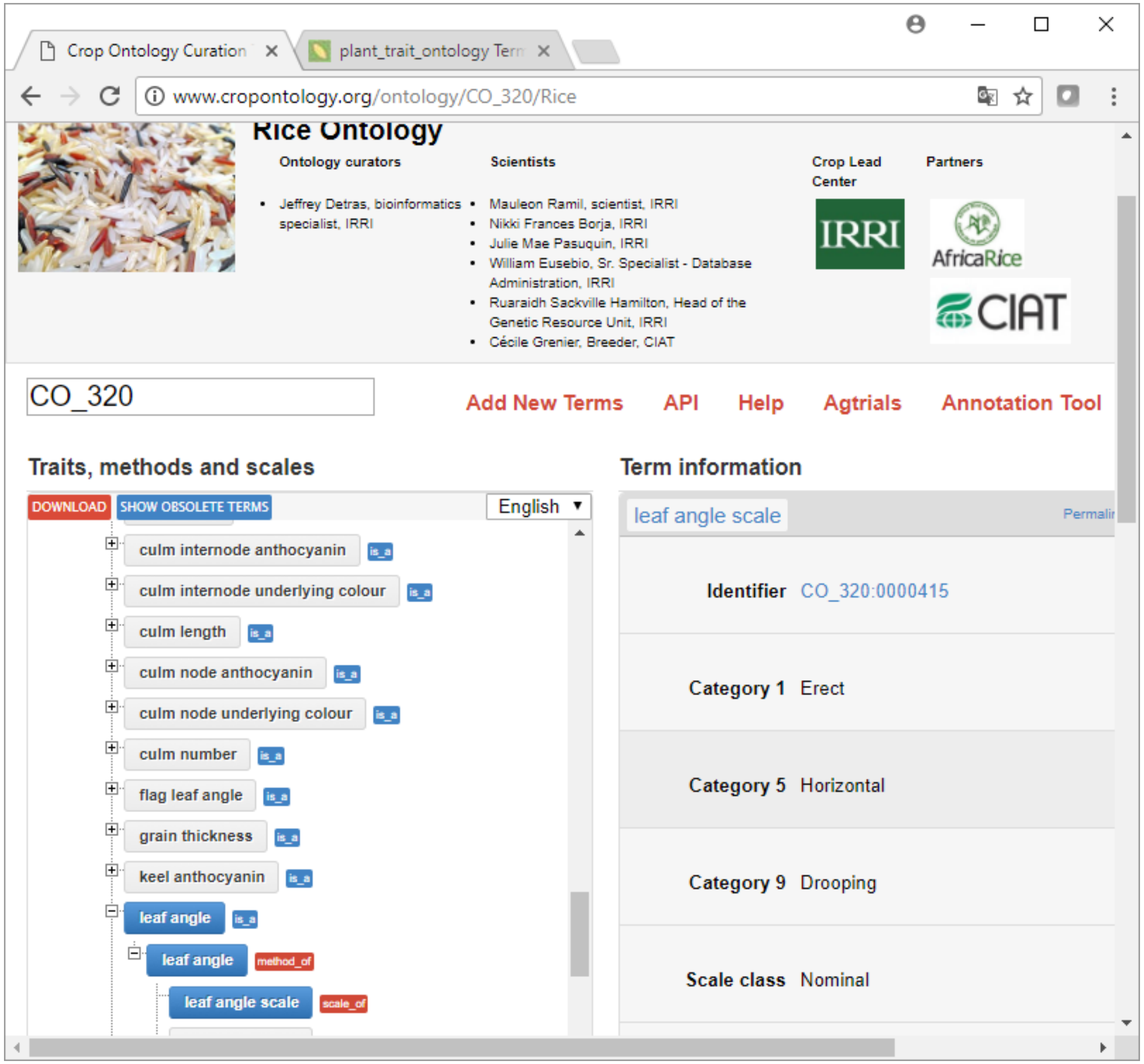
Development of crop ideotypes

- Trait ontologies:



In silico ideotyping

- Trait ontologies:



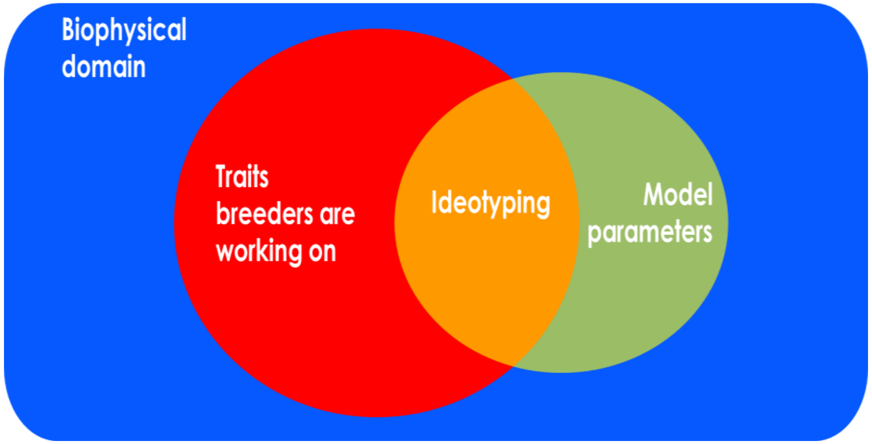
In silico ideotyping

- 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"

In silico ideotyping

1. Define **ranges/statistical distributions** for **trait** values
   - **Solutions**
     - ✓ Try to clearly **understand**
       - ▪ **what a trait is**
       - ▪ **relationships** between **traits and parameters**.



…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**".

In silico ideotyping

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**