CN-Wheat: a Functional-Structural Plant Model of CN Metabolism in Wheat

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Project Breedwheat
Introduction

Context & Approach

Context of global change

- Improve crop production and environmental impacts.
- Better comprehension of crop functioning and how the effects of multiple environmental factors are integrated by plants.

Functional Structural Plant Models (FSPMs): what is it?

(Godin & Sinoquet, 2005)

- Individual-based models, crop represented as a population of individuals.
- Explicit and botanical description of plant architecture.
- Accounts for the interactions between plant architecture, functioning and environment.
Introduction
Why use mechanistic FSPMs?

- At present, FSPMs are not really predictive rather exploratory tools.
- Improve our comprehension of plant functioning, e.g., how some traits or processes that take place at local scale affect the whole plant functioning?
- A lot of parameters and internal variables, measurable experimentally.
- Explore plant behaviour under new growing conditions: climatic change, low N practices…
- At present, most FSPMs deal with the structure. Few take into account the functioning. Various approaches: empirical rules, teleonomic principles (optimisation and coordination theories), mechanistic models.
Introduction

Aims of the Wheat FSPM

- Breedwheat project: improve the competitiveness of the French wheat breeding sector

Definition/identification of ideotypes, parameters of interest maximizing grain yield and quality under sustainable agricultural systems and climate scenarios

- Expected outputs from the model:
  - Representation of wheat architecture (3D).
  - Allocation of Carbon (C) and Nitrogen (N) within the plant.
  - Grain production and filling.
  - Interactions between CN status and morphogenesis (leaf growth, tillering).
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Model description
Model description

Model compartments

Plant structure

- Culm scale and described as:
  - A set of photosynthetic organs
  - A root compartment
  - Grains
- Interactions among culms through light competition and a simplified sub-model of soil

CN metabolites

- Each organ includes the main CN materials:
  - Structural mass
  - Storage metabolites: fructans, starch, proteins.
  - Mobile metabolites: sucrose, amino acids, nitrates.
Model description

Model physiological processes

Environmental variables

- Acquisition of resources and respiration
- Morphogenesis and tissue death
- Syntheses and degradations; transports

Grain filling

PAR
HR
Air temperature

CO₂

Photosynthesis

Transpiration and temperature

Respiration

CO₂

N₂O⁻³ uptake

Soil N (N₂O⁻³)

C-N fluxes

Carbon

Nitrogen

Foliar extension and mass growth: see the poster of Anne Schneider

Tissue death

Tillering dynamic

Root morphogenesis

Environmental variables

- Acquisition of resources and respiration
- Morphogenesis and tissue death
- Syntheses and degradations; transports
Model description

Some key aspects of the model

- Transports of CN among organs through:
  - A common pool mimicking the phloem: loading (diffusion), unloading (roots, grains)
  - The transpiration flux

- Physiological processes driven by:
  - Environment (light, temperature, CO₂, N soil...)
  - Metabolite concentrations
- Set of differential equations
Model evaluation & behaviour
Model evaluation & behaviour

Green area, dry & N masses

- Experimental data: winter wheat with 3 different fertilisations applied at flowering (H0, H3 and H15)
- Accurate simulations for green area, dry and N masses
Model evaluation & behaviour
C-N in shoot & roots

- Model provides access to internal variables.
- Metabolite concentrations, distribution and dynamics

Flag leaf lamina

- Roots N uptake
- C unloading

C metabolite concentration

(µmol C g⁻¹)

N metabolite concentration

(µmol N g⁻¹)

Time from flowering (hour)
Conclusions
Conclusions

- Fully mechanistic approach for integration of Carbon (C) and Nitrogen (N) metabolisms.
- Central role given to metabolite concentrations
- Resource allocation is an emergent property of the model
- Our results suggest that this approach is pertinent.
- Identification of potential traits for plant breeding (production, low N practices...).
Thank you for your attention
Model description

Model implementation

- Model developed in Python
- Scipy libraries for ODE solver
- Coupled to a 3D model of wheat providing the architecture (MTG as a central interface among models)
- A beginning of documentation using Sphinx
- For more details…wait for the talk of Camille 😊