An FSPM of barley including the allocation and effects of carbon, nitrogen and gibberellic acid

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GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

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Outline

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Motivation

- Simulation of crop response to nitrogen fertilisation
- Influence of nutrient budget on the rate of leaf and tiller appearance (to a lesser extent than temperature and day length)
- Relations between carbon and (soil) nitrogen (nitrogen uptake, photosynthesis)
- Crop yield determined by nitrogen availability
- Optimisation of nitrogen fertilisation to increase crop yield in cereals and to decrease costs and environmental pollution

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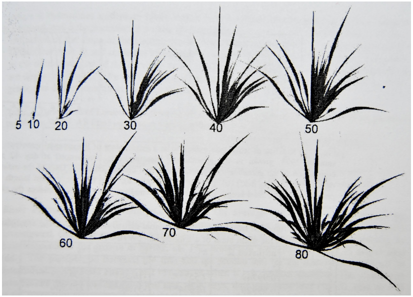
FSPM of winter barley (*Hordeum vulgare* L.) (L-studio)

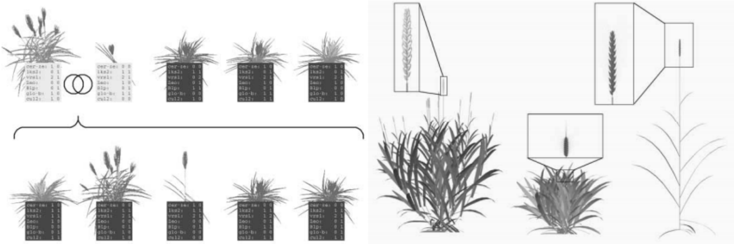
- Vegetative growth (Buck-Sorlin 2002[1])



[1] L-system model of the vegetative growth of winter barley (*Hordeum vulgare* L.). In: Polani, D., Kim, J., and Martinetz, T., editors. Fifth German workshop on artificial life: *Abstracting and synthesizing the principles of living systems*, March 18-20, 2002, Lübeck, Germany. Akad. Verl.-Ges. Aka, Berlin, 53-64.

FSPM of winter barley (*Hordeum vulgare* L.) (GroIMP)

- Breeding, genetic control, hormonal regulation of internode elongation (Buck-Sorlin et al. 2005[2], 2007[3])



[2]Barley morphology, genetics and hormonal regulation of internode elongation modelled by a relational growth grammar. *New Phytologist*, 166 (3): 859-867.

[3]A grammar-based model of barley including virtual breeding, genetic control and a hormonal metabolic network. In Vos, J., Marcelis, L.F.M., de Visser, P.H.B., Struik, P.C., and Evers, J.B., editors. *Functional-Structural Plant Modelling in Crop Production*, volume 22 of Wageningen UR Frontis Series, chapter 21, pages 243-252. Springer, 1 edition.

FSPM of winter barley (*Hordeum vulgare* L.) (GroIMP)

- Gibberellic acid signal transduction, radiation and shading (Buck-Sorlin et al. 2008[4])

[4] A rule-based model of barley morphogenesis, with special respect to shading and gibberellic acid signal transduction. *Annals of Botany*, 101 (8): 1109-1123.

Outline

Model organisation

- Model organised in sub-models / modules:
  - Morphology (vegetative and generative part)
  - Genetics
  - Hormonal control
  - Radiation and shading
  - Global parameters (e.g., environment)
  - Carbon (C) and nitrogen (N) partitioning

Outline

Components of the C and N sub-model

- Partitioning of substrates between shoot and root (Johnson et al. 1985[5], Thornley et al. 1989[6])
  - Compartment-based model of crop response to light, temperature and nitrogen
- Partitioning within the shoot (Marcelis 1996[7], Yin et al. 2003[8])
  - Sink strength concept

[5] Dynamic model of the response of a vegetative grass crop to light, temperature and nitrogen. *Plant, Cell & Environment*, 8(7):485-499.

[6] A model of nitrogen flows in grassland. *Plant, Cell & Environment*, 12(9):863-886.

[7] Sink strength as a determinant of dry matter partitioning in the whole plant. *Journal of Experimental Botany*, 47 (Special Issue), 1281-1291.

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Partitioning between shoot and root - submodels (1)

- Light interception (radiation model of GroIMP)
- Photosynthesis model
  - 4 different models testet: not N-sensitive (Thornley[9], LeafC3[10]), N-sensitive (Thornley[11], LeafC3-N[12])

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[9] Thornley, J.H.M., Johnson, I.R. (1990): *Plant and crop modelling: A mathematical approach to plant and crop physiology*. Clarendon press, Oxford.

[10] Nikolov, N.T., Massman, W.J., Schoettle, A.W. (1995): Coupling biochemical and biophysical processes at the leaf level: an equilibrium photosynthesis model for leaves of C3 plants. *Ecological Modelling*, 80(2- 3):205-235.

[11] Thornley, J.H.M., Verberne, E.L.J. (1989): A model of nitrogen flows in grassland. *Plant, Cell & Environment*, 12(9):863-886.

[12] Müller, J., Braune, H., Diepenbrock, W. (2008): Photosynthesis-stomatal conductance model LEAFC3-N specification for barley, generalised nitrogen relations, and aspects of model application. *Functional Plant Biology*, 35(9 & 10):79-810.

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Partitioning between shoot and root - submodels (2)

- Nitrogen uptake, soil nitrogen
- Growth, partitioning
  - Shoot: lamina, sheath & stem
- Substrate utilization, respiration
- Senescence, recycling

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Partitioning between shoot and root - submodels (3)

- Submodels dependent on environment
- Climate data obtained for period of 288 days: 1.10.1998 - 15.7.1999 (mostly from IPK Gatersleben, Germany)
  - Air and soil temperature
  - Temperature sum
  - Global radiation
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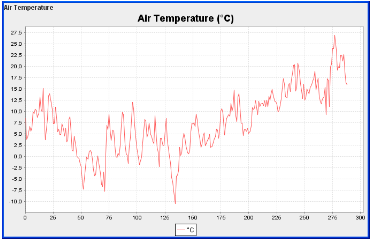

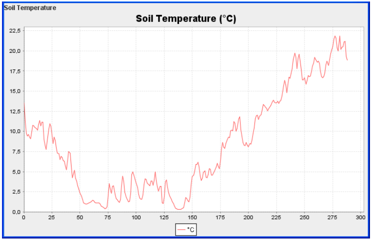

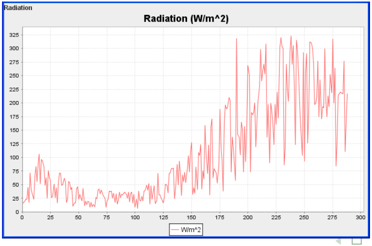

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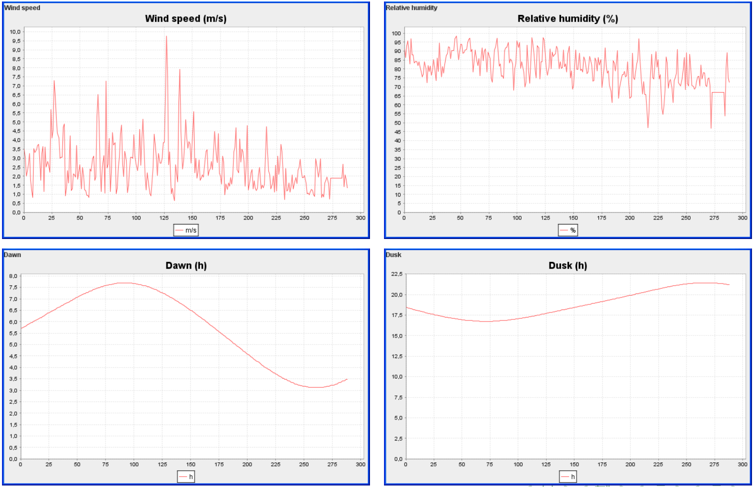

Partitioning within the shoot

- Partitioning of assimilates into organs of shoot controlled by sink strength concept
- Described by beta sigmoid function

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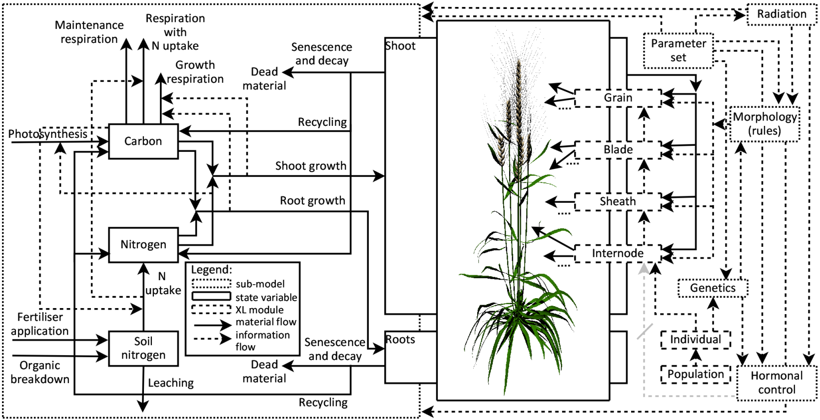
Schematic model diagram



Outline

Solving ODEs in the model

- Growth (time course of growth process) described by growth functions
- Growth simulated with differential equations
- In the model, ODEs solved using a *rate assignment operator* of XL
- Example: exponential growth function

$$W = W_0 e^{kt}$$
$$\frac{dW}{dt} = kW$$

W - dry mass
k - growth rate
t - time

```
const double k = 0.3; double W;

protected void init()
{ W = 1; }

public void getRate()
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Model run (simplified)

- Set initial structure
  - `Population`, `Individual`, `Meristem` (associated with several hormones)
- At each derivation step:
  - Compute ODEs (inside the function `getRate()`)
    - Source:
      Run radiation model (can be run before computation of ODEs)
      Compute light interception per organ (can be run before)
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    - Sink:
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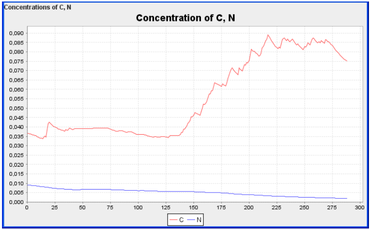
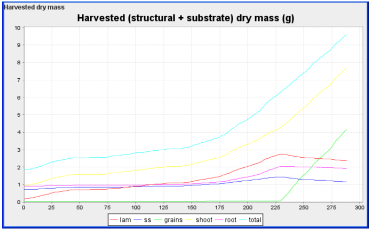
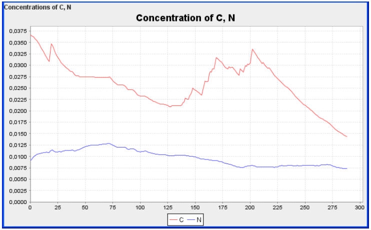
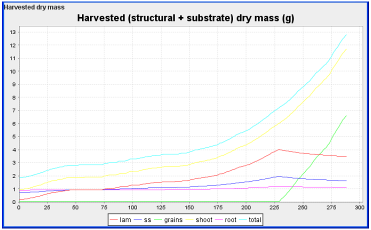
Simulation of growth at different N fertilisation scenarios





$0kgN/ha$
$(t = 0)$

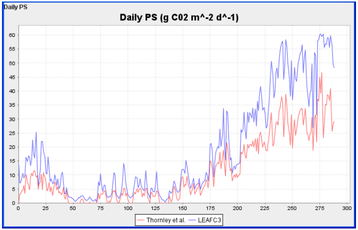




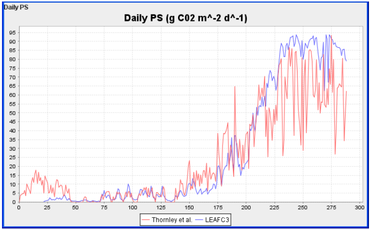
$100kgN/ha$
$(t = 0)$

Photosynthesis with/without sensitivity to nitrogen

- Comparison of photosynthesis rate models
  - Non-rectangular hyperbola (Thornley et al. 1990 / Thornley et al. 1989)
  - Photosynthesis-stomatal conductance model LEAFC3 / LEAFC3-N (Nikolov et al. 1995 / Müller et al. 2008)



not sensitive to N



sensitive to N

leaf area $1 m^2$

$100 kgN/ha$ $(t = 0)$

Conclusions and future work

- Implementation of concepts to model effects of C and N
  - Within-shoot C and N partitioning (e.g., N remobilization) needs to be improved
- Model evaluation and further parameterisation needed
- Coupling of partitioning and hormonal regulatory network sub-models
  - Internode elongation
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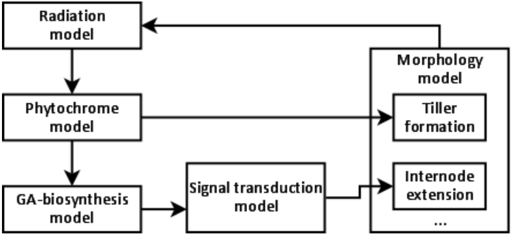

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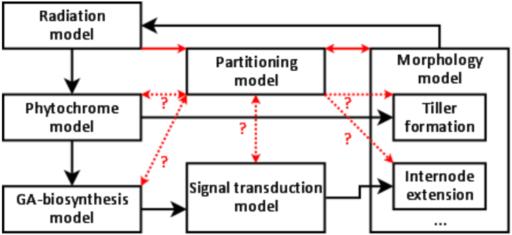

Thank you for your attention.