

## A 3D architectural model of grass shoot morphogenesis and plasticity, driven by organ metabolite concentrations and coordination rules

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### Introduction

Phenotypic plasticity - the ability of one genotype to produce different phenotypes depending on growth conditions - is a core aspect of the interactions between plants and their environment. For instance, leaf traits define the ability of plants to capture light, as well as their exposition and responses to various signals and stresses. In turn, leaf traits such as dimensions, composition and mass are highly regulated by growth conditions. The explicit description of shoot architecture in functional-structural models (FSPM) open new possibilities to express these feedback loops, which regulate plant fitness and productivity. However, formalizing into models the processes that build the plastic responses of traits to growth conditions is a major bottleneck to date. Most FSPMs that address the coupling between resources availability and growth consider only carbon (C) and drive resource allocation by sink priorities defined from empirical relations. Besides, the determinism of traits such as the areal density, which links mass growth with dimension growth, are poorly understood, so that these traits are frequently approximated as constant, while they have been shown to vary widely with growth conditions. Finally, the lack of process-based formalisms of existing models impairs our ability to simulate morphogenesis under contrasting growth conditions. As a step toward more mechanistic approaches to simulate shoot morphogenesis, we propose a plant-scale FSPM of C and nitrogen (N) economy of the growing grass in which the morphogenesis is fully integrated with the plant metabolism.

### Model description

The model represents the plant as a collection of tillers made of several growing and mature shoot phytomers (identifying lamina, sheath and internode mature tissues and growth zones), a single roots compartment and a shared pool mimicking the phloem. Each compartment has a structural mass and concentrations in mobile and storage metabolites. The plant is seen as a self-regulated system which relies on two processes: i) local C and N concentrations in the growth zones drive organ elongation rate, specific structural mass and width, ii) coordination rules link the timing of extension of the organs between successive phytomers. These processes were implemented into CN-Wheat (Barillot et al., 2016ab), a detailed FSPM of C and N metabolism previously developed for a culm with a static architecture. The new version of CN-Wheat presented here is the coupling of (i) a model of leaf, internode and root growth, (ii) a dynamic representation of the 3D geometry of plants which builds on the ADEL-Wheat

model (Fournier et al., 2003), (iii) a model of light distribution (Chelle and Andrieu, 1998), and finally (iv) a model simulating photosynthesis, N acquisition, synthesis and allocation of C and N metabolites, and senescence at the organ level, which extends the initial version of CN-Wheat. All above mentioned processes are regulated, at organ scale, by the environmental conditions and the concentrations in C and N metabolites.

### Results and Discussion

The model was calibrated for wheat during the vegetative stages (from seedling emergence to the beginning of stem extension). First, the model was evaluated in field conditions representative of North-Western Europe, which resulted in realistic patterns of leaf dimensions, extension and senescence dynamics, organ mass and composition. A key result was the ability of the model to simulate, as emerging properties, key plant and agronomic traits e.g. the phyllochron, shoot/roots ratio dynamic, N dilution and radiation use efficiency. Then, we evaluated the model's ability to simulate plant plasticity under different scenarios of plant density, incoming light and soil nitrate concentration. The model simulated realistic responses of leaf traits such as dimensions, specific leaf area and specific leaf N; the figure illustrates the simulated variations of lamina dimensions and N vertical gradient with N resources.

### Conclusion

Our model is innovative by the high level of explicitation of the processes underlying shoot morphogenesis, which provides new possibilities to link the phenotypic plasticity of plants to their C and N metabolic status at the place and time where traits are built. The approach could be extended to include other factors involved in plasticity, such as hormones or direct responses to the environment perceived. The genericity of the modelling frame makes it also applicable to explore shoot morphogenesis in other grass species.

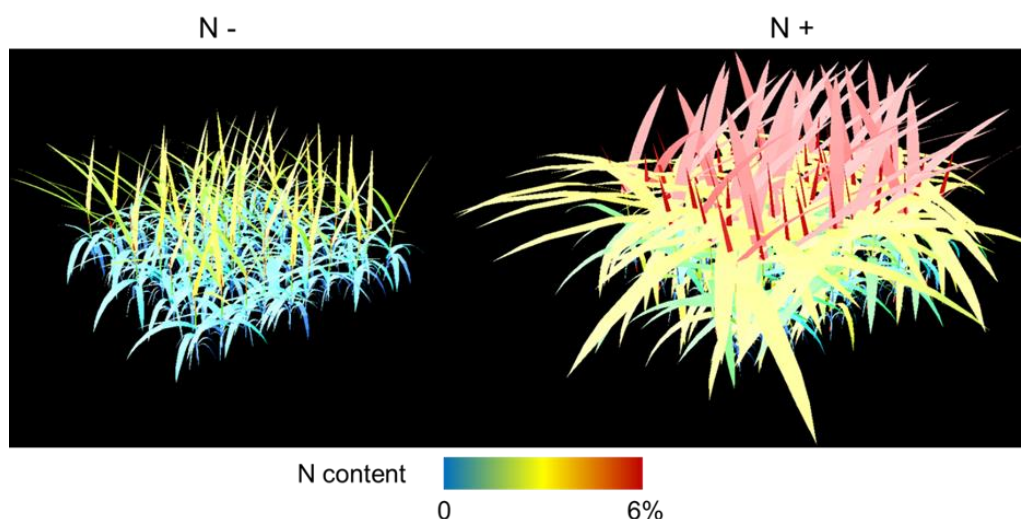


Figure: 3D-simulation of the growth of vegetative grass in contrasting N treatments. Seedlings initialised at stage 2.5 leaves with identical dimensions, mass and composition were grown under two N nutrition treatments for ~1200°C days.

### References

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