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CN-Wheat: a Mechanistic Structural-Functional Model for Carbon and Nitrogen metabolism in wheat

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In a context of global change, it is necessary to identify new practices and plant characteristics determining crop production and that can be potential targets for plant breeding. This could be achieved by numerical simulation, using mechanistic and integrative models that provide a holistic view of plant functioning. However, a central difficulty lies in building a coherent view of the involved processes and how to integrate them at plant and crop level. The model proposed here, called CN-Wheat, represents a significant progress to address these issues by using a fully mechanistic approach for integration of Carbon (C) and Nitrogen (N) metabolisms within wheat plants after anthesis.

CN-Wheat is defined at culm scale; the crop is represented as a population of individual culms that compete for light and soil N. Culm structure is composed of a root compartment, a set of photosynthetic organs and the grains. Each module includes structural, storage and mobile materials. Fluxes of C-N among modules take place through a common pool and/or through the transpiration flow. The modelled physiological activities are the acquisition of C and N, the synthesis and degradation of primary metabolites (sucrose, fructans, starch, amino acids, proteins and nitrates), C respiration, C-N exudation and tissue death. A central role is given to metabolite concentrations as drivers of (i) physiological activities and (ii) transfers between organs. Thus, the integration within the plant results from that all processes act in parallel on interconnected metabolite pools, which is represented as a set of differential equations, solved numerically. Model behavior was evaluated against a field experimentation with three levels of N fertilization applied at anthesis.

For each N treatment, CN-Wheat accurately predicted the post-anthesis kinetics of (i) C-N distribution among organs, (ii) green areas of laminae and (iii) dry mass and N content of grains. In our simulations, when soil N was non-limiting, N in grains was ultimately determined by the availability of C for root activity. Dry matter accumulation in grains was mostly affected by photosynthetic organ lifespan which was regulated by protein turn-over and C-regulated root activity. Whereas the use of response functions to metabolite concentration is accepted for each of the processes described in the model, here we show that it can be used for an integrative modelling of the whole plant. Besides, CN-Wheat provides insights into the interplay of C-N metabolism which is expected to improve our knowledge on the regulation of plant functioning. This approach also enables to identify potential targets for plant breeding in order to improve crop production and N efficiency as well as crop adaptation to climate changes and low N agronomical practices.