Simulation of leaf growth response to elevated atmospheric carbon dioxide concentration ([CO2]) using CN-Wheat, a model of morphogenesis driven by trophic dynamics

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Introduction

The Earth is facing an increase in the atmospheric carbon dioxide concentration ([CO_2]). Elevated [CO_2] affects plant growth and development by modifying a range of physiological processes. Stimulation of leaf area development by elevated [CO_2] is important in terms of plant productivity because green leaf area determines total biomass and final grain yield. As atmospheric [CO_2] is currently a limiting factor for C3 photosynthesis, it has been demonstrated that the primary effect of elevated [CO_2] is a stimulation of photosynthesis due to both enrichment of substrate for Rubisco carboxylation and an inhibition of competitive Rubisco oxygenation (Long *et al.*, 2006). High [CO_2] also induces stomatal closure leading to a decrease of transpiration per leaf area unit. Elevated [CO_2] has also been shown to reduce plant demand for nitrogen (Dong *et al.*, 2022). The resulting interactions between water, photoassimilates and nitrogen are complex, and the underlying mechanisms by which elevated [CO_2] affects leaf growth are still not clearly understood. To address remaining knowledge gaps and uncertainties in estimating the effects of elevated [CO_2] and climate change on plants, research should expand experiments under a wider range of growing conditions and improve the representation of responses to climate in models. Functional Structural Plant Models (FSPMs), which account for the interactions between biological processes and environmental factors, are among key tools to explore plant responses to climate change and possible adaptation mechanisms. In this work, we evaluated the ability of CN-Wheat (Barillot *et al.*, 2016 and Gauthier *et al.*, 2020), a wheat FSPM, to simulate leaf growth response to contrasting CO_2 concentrations.

Model description

CN-Wheat represents the plant as a collection of tillers. Tillers are considered as a set of botanical modules representing several mature and growing shoot organs (blades, sheaths, internodes and growth zones), a root compartment and a common pool mimicking the phloem and allowing fluxes of metabolites among organs. Each organ includes structural, mobile (sucrose, nitrates, and amino acids) and storage (fructans, proteins) materials. CN-Wheat accounts for the main biological processes occurring in plants: resource acquisition (N uptake, photosynthesis) and allocation within the plant, morphogenesis (leaf and internode growth) and senescence. Leaf growth is represented as a self-regulated system driven by: i) the local concentrations of carbon (C) and nitrogen (N) in the growth zones which regulate the rate of organ elongation, specific structural mass and width, ii) coordination rules linking the timing of leaf extension between successive phytomers. CN-Wheat allows for a dynamic representation of the 3D geometry of plants, which is used to compute light distribution at organ scale. In this work, CN-Wheat sensitivity to [CO_2] was assessed by simulating the growth of wheat plants for ~105 days and exposed to low [CO_2] = 200 ppm, medium [CO_2] = 360 ppm, and high [CO_2] = 800 ppm. Only the morphogenesis of the main stem leaves was considered, the tillering was kept constant between simulations. Except for [CO_2], virtual set-up was similar to Gauthier *et al.* (2020) and come from plants grown in the field in Grignon (France) in 1998 and 1999.

Results and Discussion

Simulation results indicated that [CO_2] increased plant photosynthesis by ~40% between [CO_2] = 200 ppm and 800 ppm (data not shown). LAI increased by ~20% between [CO_2] = 200 ppm and 800 ppm but was similar between 360 and 800 ppm (Fig. 1a). On the contrary, N content in shoot was lower at high [CO_2] until day 55 (Fig. 1b). N concentration increased on this day, due to particular weather conditions. After that date, N concentration started to decrease drastically at [CO_2] = 200 ppm, as a result of complex interactions. At the end of the simulation, cumulated blade transpiration was ~40% lower at [CO_2] = 800 and 360 than at 200 ppm. Phyllochron was little affected by [CO_2] (Fig. 1d), except for the last leaf which appeared later at low [CO_2]. There was no difference in leaf length across [CO_2] treatments (data not shown), but leaf width increased with CO_2. On the last leaf, width was ~30% higher at [CO_2] = 800 than at 200 ppm (Fig. 1e). The specific structural leaf weight (Fig. 1f) was also greater at [CO_2] = 800 than 200 ppm (~25%). Overall, CO_2 effects were greater between 200 and 360 ppm than between 360 and 800 ppm.

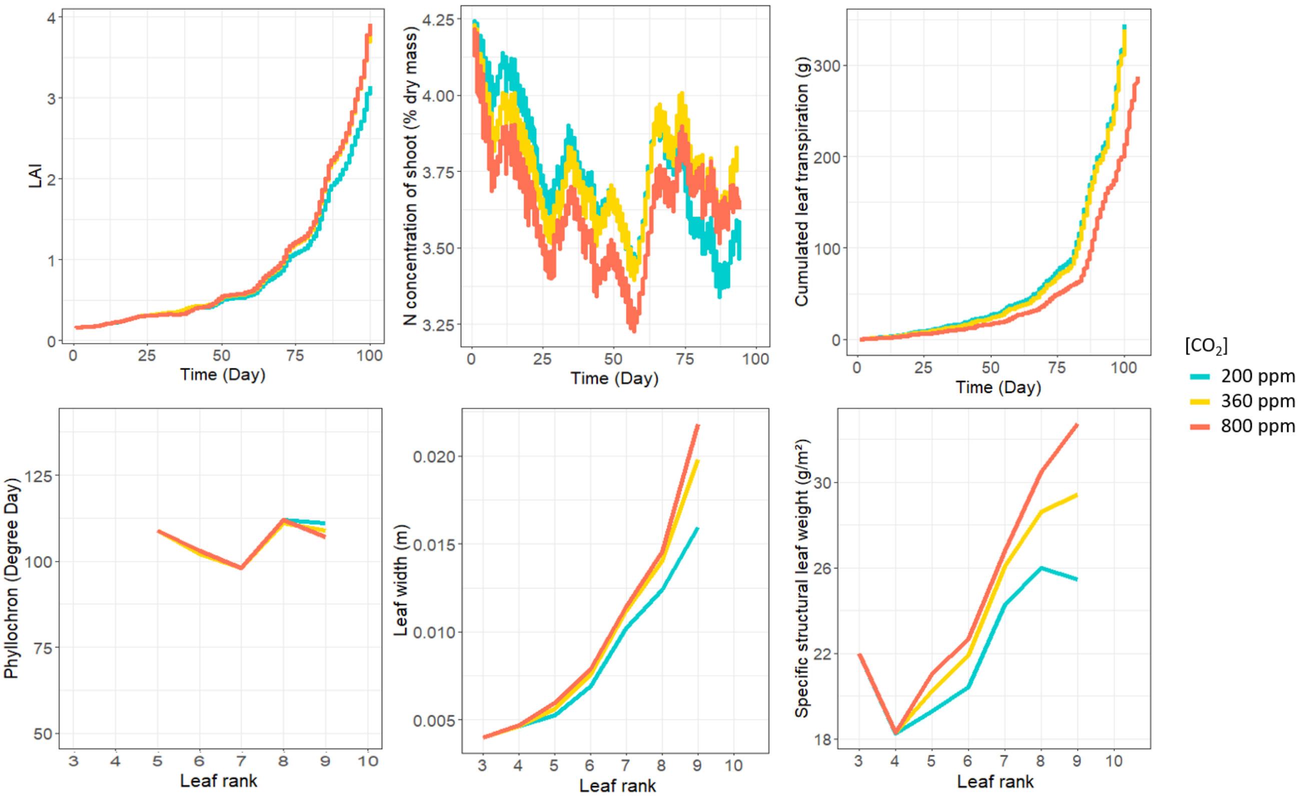

Figure 1: Simulation results of dynamics of LAI (a), N mass of shoot (b), cumulated leaf transpiration (c), phyllochron (d), leaf width (e), and specific structural leaf weight (f) as function of the leaf index, at three different [CO_2]: 200 ppm, 360 ppm and 800 ppm.

Conclusion

CN-Wheat showed interesting properties for exploring leaf growth response to [CO_2] for plants grown in optimal water conditions. The further step is the implementation of water dynamics within CN-Wheat to extend the approach in simulating the response of leaf growth to [CO_2] x drought interactions.

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