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Integration of root system in a ryegrass perennial model based on self-regulation

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Highlights: An individual-based functional-structural model of heterogeneous mini populations of ryegrass plants can be a useful tool to improve our understanding of the grassland use-value creation. Here we present the L-grass model that allows simulating the shoot and root development of plants with different morphologies using self-regulation rules in an auto-organized architectural system.

Keywords: L-system, perennial ryegrass

INTRODUCTION

Grasslands are one of the major sources of forage in Europe. They are exploited via foraging and mowing. In the European changing political context regarding environmental questions, social perception of grasslands has shifted. Grasslands are now seen as important due to two main functions: forage production and environmental roles (biodiversity preservation, carbon sequestration, soil conservation). They are well inserted in the multifunctional paradigm. In addition, compared with other land uses, grasslands present some particularities that justify their specific study. For example, they are perennials populations repeatedly exploited via defoliation-regrowth cycles while growing under changing conditions. Grasslands also show high intra and inter specific variability.

Both the canopy structure and the genotypic composition of the population are determinants of the grassland use-value (quantity and quality of the harvested biomass) as well as of its environmental roles. Canopy structure and the genotypic composition of the population are emergent properties resulting from the behaviour of individual plants and their interactions during the grassland lifespan. Thus, the study of the morphogenesis of the individual is a relevant element to better understand the dynamic of the canopy structure and the population composition.

Several major environmental factors affect plant morphogenesis such as: light resource (trophic and photomorphogenetic signals), intensity and frequency of defoliation, nutrient supply, water availability, and temperature dynamics. However, it is difficult to quantify the contribution of each of these factors to the phenotypic plasticity because of their multiple interactions.

OBJECTIVES

Our aim is to build up an individual-based functional-structural model of heterogeneous mini populations of perennial ryegrass plants. A functional-structural model of shoot morphogenesis exists (Verdenal *et al.*, 2008). It dynamically simulates the shoot structure of the plant by using auto-regulation rules in an auto-organized system (Verdenal *et al.*, 2012). In its current version, the model is based on the assumption that resources from the soil are not limiting plant growth. Nevertheless, in order to better understand the impact of soil resources on the shoot architecture and therefore on the biomass harvested, our objective is to endow the model with a module of root morphogenesis.

THE MODEL

Our L-grass model is based on the L-system formalism (Lindenmayer, 1968; Prusinkiewicz, 1999) using the L-Py simulation framework (Boudon *et al.*, 2012) from OpenAlea platform. The topology of the whole plant is modelled using the MTG package (Godin *et al.*, 1999).

The plant model simulates the 3D development of the shoot and root parts of plants in the vegetative phase. It is largely inspired from a shoot morphogenesis model (Verdenal *et al.*, 2008) and the root system model ArchiSimple (Pagès *et al.*, 2012). The model ArchiSimple allows the root system to be simulated with a low number of parameter. Moreover, carbon resources provided by shoot are considered in this model.

Establishment of plant topology

The plant is represented by a set of phytomers organized as a tree. Each branch of the tree represents a tiller. Phytomers are composed of internode, leaf, root bud, and axillary buds. This composition of phytomers is inspired from a representation of another poaceae, the rice plant (Nemoto *et al.*, 1995). The rate of phytomer production is a function of leaf emergence from sheaths. Emission of new primary root, from a root bud, depends on the tiller rank (primary tiller, secondary tiller,…) and on the number of phytomers in the tiller.

Elongation of organs

Elongation of a leaf starts when its phytomer is created. Leaf parameters such as final length, elongation duration, and proportion of sheaths and blades, are determined as functions of the time that the leaf spends growing within the whorl. Thus, they are partially determined by the sheath length of the previous leaf.

Root development is inspired from the model ArchiSimple (Pagès *et al.*, 2012). It allows to represent the 3D architecture of roots using nine parameters (such as inter-branching distance, tip diameter of emitted roots) estimated from rhizotron and pot experiments. Elongation of the root is regulated by the behaviour of the shoot by an allometric relationship. Indeed, root tips have a growth potential (defined as function of root tip diameter), which is achieved only if the shoot part of the plant provides enough carbon resources for growth and associated respiration.

RESULTS AND DISCUSSION

The model allows simulating the development of ryegrass plants with different morphologies. For example, two contrasting genotypes (Hazard *et al.*, 1996) developing short or long leaves were simulated (Fig. 1).

Fig. 1. Results of simulations of two ryegrass plants with different morphologies, at the same age of development, (Short Leaves (left); Long Leaves (right))

The model allows simulating different root system morphologies without changing root parameters. Indeed, the plasticity of the root system architecture is related to the plasticity of the aerial part transmitted via a self-regulation rule that triggers the emission of new primary roots and the tip growth potential that depends on leaf area. In addition, simulations of different cutting management regimes are also possible (Fig. 2). Indeed, a cut reduces significantly the leaf area thus the effective growth of roots becomes quasi null. The development of the root system, at this time, is thus very slow. Simulation results are in good agreement with observations.

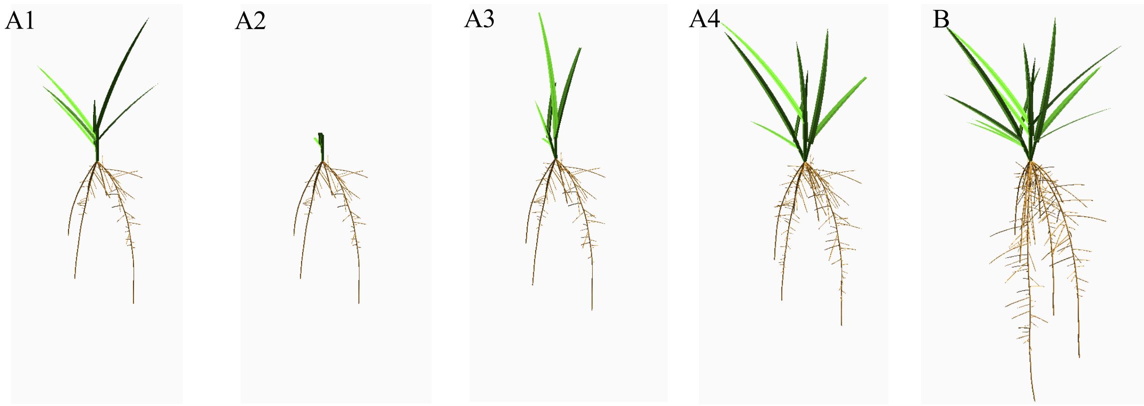

Fig. 2. Sequence illustrating the simulation of the development of a plant undergoing defoliation at 300 °C.d (A1 to A4) and without cutting (B). A1 and A2 represent the plant just before and after the cut. A3 and A4 represent the plant regrowth at time 350 °C.d and 400 °C.d.

The root system representation using all the architecture details is CPU-consuming. Therefore, simulations of canopy undergoing different management could result long and unpractical.

PERSPECTIVES

Time-consuming. In order to overcome the time-consuming calculation due to an explicit architecture of the root system, the use of the root density approach (Dupuy *et al.*, 2010) could be explored.

Environmental condition. Inclusion of a virtual soil (water and nitrogen availabilities) in the model is possible. Estimation of the quantity of resources uptake from soil could modify leaf growth potential, and thus the architecture of the shoot. Thus aerial architecture will be modified and therefore the root system architecture too. These kinds of simulation will help to understand the aerial architectural (so the grassland use-value) response to modification of water and nutrient supply.

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