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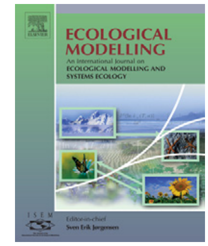

An architectural model of spring wheat: Evaluation of the effects of population density and shading on model parameterization and performance

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ABSTRACT

ADELwheat is an architectural model that describes development of wheat in 3D. This paper analyzes the robustness of the parameterization of ADELwheat for spring wheat cultivars in relation to plant population density and shading. The model was evaluated using data from two spring wheat experiments with three plant population densities and two light regimes. Model validation was done at two levels of aggregation: (a) by comparing parameterization functions used as well as parameter values to the data (leaf and tiller appearance, leaf number, blade dimensions, sheath length, internode length) and (b) by comparing ground cover (GC) and leaf area index (LAI) of simulated virtual wheat plots with GC and LAI calculated from data. A sensitivity analysis was performed by modulating parameters defining leaf blade dimensions and leaf or tiller appearance rate.

In contrast to population density, shading generally increased phyllochron and delayed tiller appearance. Both at the level of the organ and at the level of the canopy the model performed satisfactorily. Parameterization functions in the model that had been established previously applied to independent data for different conditions; GC and LAI were simulated adequately at three population densities. Sensitivity analysis revealed that calibration of phyllochron and blade area needs to be accurate to prevent disproportional deviations in output.

The robustness of the model parameterization and the simulation performance confirmed that the model is a complete architectural model for aboveground development of spring wheat. It can be used in studies that require simulation of spring wheat structure, such as studies on plant–insect interaction, remote sensing, and light interception.

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1. Introduction

Architectural plant models provide the possibility to explicitly simulate plant and canopy structure, i.e. the three-dimensional geometry of leaves and other organs. For the Gramineae family, architectural models have been described for maize (Fournier and Andrieu, 1998, 1999; Guo et al., 2006), sorghum (Kaitaniemi et al., 1999), barley (Buck-Sorlin, 2002) and rice (Watanabe et al., 2005).

For wheat (*Triticum aestivum* L.) ADELwheat has been developed. Previous work presented this model in detail, its concepts based on winter wheat (Fournier et al., 2003) and the parameterization for spring wheat (Evers et al., 2005). ADELwheat is based on the L-system formalism (Lindenmayer, 1968; Prusinkiewicz, 1999) using the CPFG simulation program (Prusinkiewicz et al., 2000; Měch, 2004). L-systems provide a modular approach to modelling, in which a basic unit is reproduced over time to simulate plant development. In ADELwheat, the basic unit is the wheat phytomer, which consists of an internode with a tiller bud at the bottom, and a node, a leaf sheath and blade at the top. These phytomer components are called modules. Each module is provided with its own set of variables and parameters, which define for example the module's current length or age, or geometrical properties like inclination. From a given initial spatial arrangement of plants, the model calculates growth and development, size, shape and orientation in space of each organ in relation to temperature. Simulation of tillers is comparable to main shoot simulation, taking into account a certain delay in tiller appearance relative to the development of the main stem. The concept of relative phytomer number (RPN) (Fournier et al., 2003), enables the derivation of properties of individual tiller phytomers from those of the main stem; to this end a 'phytomer shift' is added to the actual rank number of the phytomer, yielding the RPN, i.e. the main stem phytomer number from which properties are inherited. The model has two stochastic elements: curvature of the leaf blades, and tiller configuration through thermal time. Other key variables in the model are phyllochron and leaf blade length and width.

Evers et al. (2005) determined parameters of ADELwheat for spring wheat and discussed differences with the initial parameterization for winter wheat (Fournier et al., 2003). The objectives of the current paper are (a) to measure the effect of plant population density and shade on model parameters under conditions ensuring ample supply of water and nutrients and absence of pests, diseases and weeds, (b) to evaluate model performance, and (c) to carry out sensitivity analysis of model parameters. Model evaluation was achieved by (a) comparing the values of key model parameters, measured in an independent experiment, with the values obtained in the previous parameterization experiment and the actual parameterization as implemented in the model, and (b) comparing measured temporal changes of ground cover (GC), and leaf area index (LAI), with simulated ones. Time courses of GC and LAI are both model outputs incorporating effects of all parameters defining dynamics of development processes and dimensions of organs. Sensitivity analysis was performed by changing model parameters in a systematic way and analyzing the effects on the temporal patterns of GC.

Model parameterization is a laborious job. The objective of the current evaluation and sensitivity analysis is to yield insight in the options to use the model with standard parameter values for different applications, e.g. in remote sensing studies, interspecific and intraspecific competition studies and analysis of spatial aspects of relationships between pests or diseases and plants. Model evaluation as presented in the current paper provides a necessary step towards a generic architectural model of tillering in Gramineae.

2. Materials and methods

2.1. *Experimental setup*

To validate the model parameterization and the robustness of simulation of ground cover and leaf area index, two separate experiments were performed in Wageningen, The Netherlands (51°58′N) in 2004.

An outdoor experiment was conducted from April to June 2004 (referred to in figures as '2004', to distinguish from the experiment '2003' which was used for model parameterization for spring wheat (Evers et al., 2005)). Spring wheat plants (*T. aestivum* L., cv. Minaret) were grown in 70 cm × 90 cm containers (composed of synthetic fibre). These contained a layer of sandy soil of approximately 35 cm and a 3 cm layer of coarse gravel on the bottom for drainage. The soil was enriched with fertilizer resulting in a soil nitrogen content of 15 g m^{-2}. The seeds were sown at a depth of approximately 5 cm below soil surface. Diseases, pests and weeds were controlled by using appropriate biocides. The containers were arranged closely together to ensure canopy homogeneity, and eight guard containers were placed around the test container to avoid border effects on the plants that were to be measured. Seeds were sown at three densities (100, 262 and 508 m^{-2}, one plot per population density) in a regular square grid, i.e. no row structure. Distances between the plants were 10.0, 6.2 and 4.4 cm, respectively. The containers were exposed to full light (control). A similar plot (shade treatment) was placed in a tent constructed of shade material (XLF 17F, US Global Resources, Seattle, USA) that absorbed 75% of the incoming light. The tent was open to the sides at the bottom, at a height of approximately 80 cm. The six different treatment combinations are coded as D1c, D2c, D3c, D1s, D2s and D3s with the number indicating the plant population density (1, low; 2, middle; 3, high) and the letters 'c' or 's' indicating control or shade treatment, respectively. Treatment D1c is comparable to the experimental conditions in the parameterization experiment of 2003 (reported in Evers et al., 2005), and data from D1c is therefore used as independent data to validate the model parameterization. The tent had a negligible effect on temperature. Effects on humidity were not measured but can be expected to be virtually absent due to the open tent. Light reflected from the inside of the tent had a negligible effect on the red/far-red ratio of the light above the canopy. An additional plot, exposed to full light, contained plants at the same three population densities for destructive measurements (harvests).

To collect additional data, spring wheat plants (cv. Minaret) were grown in eight similar containers at 100 plants m^{-2}, in a growth chamber (referred to in figures as '2004b'). Light period