Calibration of fruit cyclic patterns in cucumber plants as a function of source-sink ratio with the GreenLab model

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Introduction

The cyclic pattern in cucumber fruit production has been studied by several authors (Heuvelink and Marcelis, 1989; Marcelis, 1992) and it has been linked with the distribution of dry matter in the plant. We intend to test the influence of the biomass (assimilate) partitioning on these cycles (Marcelis, 1994; Bertin, 1995). To do so, the cucumber plant growth is reproduced with the functional structural plant model GreenLab, a generic model based on carbon production and allocation to control the plant architecture (Cournède et al, 2006). A new version of the model has been developed in which interactions between growth and development are taken into account through the introduction of a variable representing the source-sink ratio of the plant (Mathieu, 2006). For some set of parameters, the dynamic evolution of this variable generates rhythms in fruit set, and theoretical studies were presented in (Mathieu et al, 2006). As GreenLab is a mathematical model, its parameters can easily be estimated by inverse methods. Here, the growth of a cultivated cucumber plant is calibrated. Functional parameters are first estimated. As we suppose that fruit apparition depends on the source-sink ratio through parametric functions, we can compute in a second step the parameters controlling the interactions between growth and development.

Materials and Methods

The GreenLab model

In the GreenLab FSM (Yan et al, 2004), the plant growth is discretized by a time step based on the plant phyllochron. At each time step called a growth cycle (GC), the terminal apex builds a new metamer (one internode one flower, one leaf and one or more axillary buds). The model can run based on dry matter as well as fresh matter. For cucumber, fruits contain more than 95% water and are the main part of biomass produced, so it seems reasonable to take fresh mass instead of dry mass. In the model, we assume that assimilates produced by the plant fill a common pool that feed all the organs. At GC t, the amount of biomass Q^t is computed with a photosynthetic equation at the level of a single plant (g/plant).

$$Q^t = \frac{E.S_p}{R}(1-e^{-\frac{S_f^t}{S_p}}) \qquad (1)$$

It depends on the total leaf surfaces S_f^t , an empirical coefficient S_p characteristic of the competition for light in the canopy, E the product of potential evapotranspiration (PET) and transpiration efficiency and R an empirical resistance. Then, this fresh matter is shared between all organs with a proportional allocation model: the distribution to each sink is proportional to its sink strength relative to the total sink strength called the demand D^t. Each organ has a fixed life span and a sink variation function determines the variations of the organ sink strength during its life. It is a flexible mathematical function based on the beta law and its parameters are estimated by inverse methods. A fruit grows during an expansion time of T_e^f GC. After a delay of t_0 growth cycles after its appearance, the fruit can develop if the ratio of biomass to demand at this cycles exceeds the threshold θ_0.

Parameter identification

To fit the growth of a given plant, we estimate hidden parameters of the model: S_p ,R for the biomass production, the organ sink variation functions for the allocation model, t_0 and θ_0. The error to minimize is based on the differences of organ weights and dimensions of simulated and measured plants (Guo et al, 2006). The calibration of the model is made by iterations of two successive steps. Firstly, the position of the fruit abortion on the stem are given as input parameters to estimate the functional parameters. Then, the delay t_0 and the corresponding threshold θ_0 are identified with a heuristic method as the error is a non continuous function of parameters.

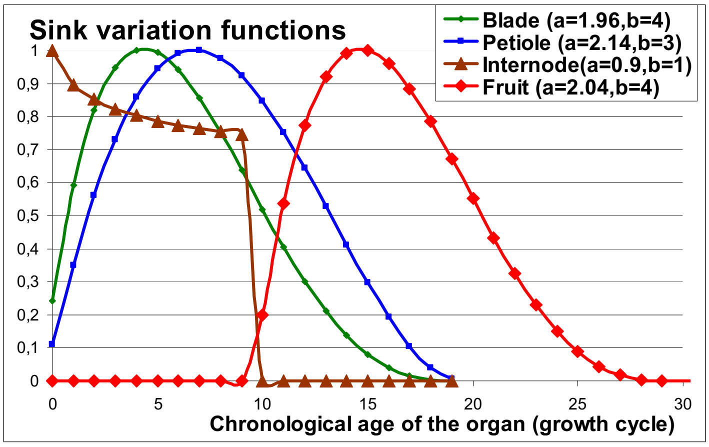
Plant observations and measures

Cucumber plants (*Cucumis sativus* cv. mini2) were grown in a greenhouse of Beijing academy of agricultural sciences (BAAS) from 20 March to 15 June 2006. Plants received no supplementary light. Air temperature inside the greenhouse varying from 15 to 30 degrees and GDD (growing degree day) were calculated with a base temperature of 12 degrees. The plants were grown in containers with row spacing of 1 m and 0.5 m within a row. Cucumber plants were pruned with all axillary buds removed immediately after appearance. At each of the harvest dates, 4 plants were taken randomly and separated into root system and shoot, the later further divided into metamers. Length and diameter of internodes, leaves and petioles were measured with a digital vernier caliper, surface of individual leaves was analyzed by a software developed in BAAS.

Results

Three plants harvested at 10 May, 17 May and 13 June were fitted with the *Digiplante* software (Cournède et al, 2006). The growth cycle (GC) expressed in thermal time is equal to 30 GDD. The estimated seed values are similar for all the plants (0.34 g). The specific leaf weight of blades is set to an average value of 0.02 g.cm^{-2} and leaves are photosynthetically active during 20 GC. Blades, petioles are growing during 20 GC, internodes during 10 GC and fruits during 25 GC. In equation (1), E is set to 1 and the parameters are estimated $\boldsymbol{R} = 29.28, \boldsymbol{Sp} = 0.78$ m². The sink of an organ is the product of a maximum value that is estimated to 1 for blades, 0.51 for internodes, 0.62 for petioles and 68.5 for fruits and of a function of its age controlled by two empirical parameters *a, b* (see on figure 1a). Figure 2 shows the comparison between simulations and measures for the three measured plants.

When we fix the fruit position, the identification of the functional parameters gives the evolution of the ratio of biomass to demand (see figure 3). Then, we use inverse methods to compute the delay t_0 of 7 GC and the threshold $\theta_0 = 0.67$.



a)

b)

Fig.1 a. Sink variation functions of the different organs of the plant. b. Visualization of the simulated plant.

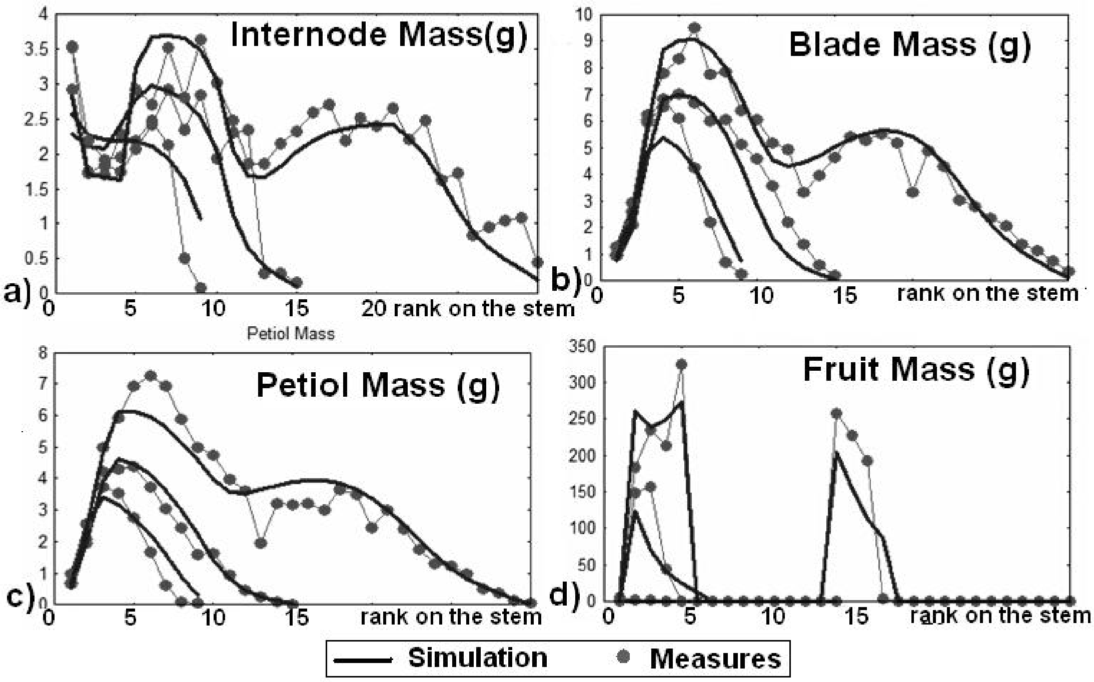


Fig 2.Simulated (lines) and measured (dots) fresh mass of a) internode, b) blade, c) petiol, d) fruit.

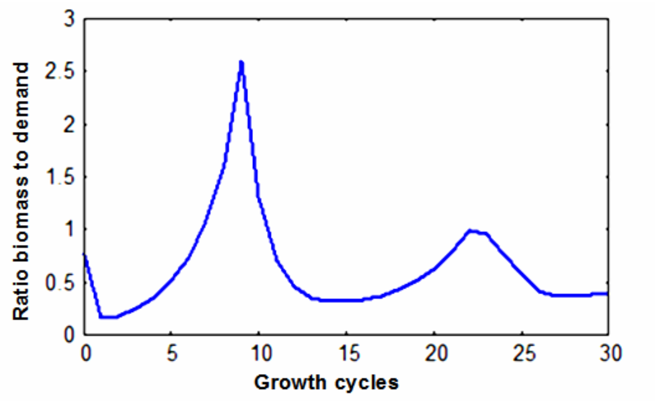


Fig. 3: Evolution of the ratio biomass to demand during growth. It shows the strong action of the fruits sinks that induces waves.

Discussion and conclusion

In the studied cucumber cultivar, every node bore flowers at emergence, and all flowers became fruits but some of them aborted sometimes later. We used our model to test a hypothesis proposed in (Marcelis, 1994) that the low assimilate availability was a cause of fruit abortion. In the model, the feedback of biomass partitioning on topology is set at the level of fruit apparition. The parallel between the rapid growth of fruits at some nodes and abortion of those on the following nodes did suggest a competition of assimilate and inhibition of early established fruits on the younger ones (and also on leaves and corresponding phytomers as their final sizes and biomass were smaller than the one of phytomers bearing the fruits).

The results we obtained are encouraging as we could fit the growth of the cucumber (sizes of organs) and the positions of the fruits with a small number of parameters. Although the model still needs further validation and some phenomena that could have a great influence on plant growth and biomass partitioning should be implemented (energetic cost of the structure, storage compartment), it simulates with success the assimilate competition among organs and confirms the hypothesis that the growth and abortion of fruits depend on assimilate availability.

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