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Sixth International Conference on Sensitivity Analysis of Model Output

The use of Sensitivity Analysis for the design of Functional Structural Plant Models

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1. main text

INTRODUCTION: Developed recently, Functional Structural Models of Plant Growth (FSPM) aim at describing plant structural development (organogenesis and geometry), functional growth (biomass accumulation and allocation) and the complex interactions between both. They serve as a framework to integrate complex biological and biophysical processes in interaction with the environment, at different scales. The resulting complexity of such models regarding the dimensionalities of the parameter space and state space often makes them difficult to parameterize. There is usually no systematic model identification from experimental data and such models still remain ill-adapted for applicative purposes. The objective of this study is to explore how global sensitivity analysis can help for the parameterization of FSPM, by quantifying the driving forces during plant growth and the relative importance of the described biophysical processes regarding the outputs of interest. The tests are performed on the GreenLab model. Its particularity is that both structural development and functional growth are described mathematically as a dynamical system (Cournède et al., 2006). Its parameterization relies on parameter estimation from experimental data. Sensitivity analysis may help to optimize the trade-off between experimental cost and accuracy. This is crucial to develop a predictive capacity that scales from genotype to phenotype for FSPM.

MATERIALS AND METHODS: We present the source-sink equations of GreenLab in the simple case of maize (and refer to Ma et al., 2008 for a full description, including organogenesis and the values of parameters used for the tests). At each architectural growth cycle (GC), dry biomass accumulation q(i) is computed as a function of the photosynthetically active radiation PAR(i):

$$q(i) = PAR(i) \cdot \mu \cdot Sp \cdot \left[1 - \exp(-\frac{\lambda}{Sp} S(i)) \right]$$

(1)where μ is the radiation use efficiency, λ is the extinction coefficient of Beer's Law, Sp is a characteristic surface related to plant density, S(i) is total leaf surface area at GC i. Plant morphogenesis-including leaf surface-depends on biomass allocation to expanding organs. They receive an incremental allocation of biomass that is proportional to their relative sink strengths, defined as an empirical function of its age in terms of GCs: $p_o(j) = P_o f_o(j)$,where o denotes organ type (b: leaf blade; s: sheath;e: internode; f: cob; m: tassel). P_o is the sink strength associated to organ type o. $f_o(j)$ is a normalized beta function characterized by α_o and β_o.

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Standardized Regression Coefficients (SRCs) were first computed. Model Coefficient of determination (R^2) was used to see how much model variance the SRCs can explain. Then to get the main effect and interactions between the parameters, an improved Sobol's method was applied with a control on the estimation error obtained from random computing theory,see T.Homma et al.

RESULTS: We first perform a Standardized Regression for the biomass production across time with respect to all the parameters usually obtained by estimation from experimental data in GreenLab. It shows a very high R^2 ,(always above 0.98) proving that the SRCs indices are reliable here. The crucial importance of the Radiation Use Efficiency is also demonstrated (SRC always above 0.65). It shows that a special care should be taken in its determination, including complementary experiments.

Second, to get a better understanding of the driving forces regarding allocations, we fix the radiation use efficiency and a linearity analysis is performed with three methods: the sum of the SRCs, R^2 and the sum of first order Sobol's index S_i, cf. Fig1. Even though the shapes of the 3 curves are similar, it confirms that Sobol's method is more reliable to detect non-linearity. Regarding maize growth, the non-linear period emphasized by this analysis is a key one in terms of biophysical processes, since it corresponds to an abrupt change: the allocation priority is no longer given to the leaves but to the cob. Since parametric estimation for GreenLab relies on multi-stage observations, it seems important not to miss this crucial period.

Third, with Sobol's method, we also computed the sobol's index S_i and ST_i representing the total effects that the parameter brings to the model. The difference between the two indices characterizes the interaction of this parameter with others. The understanding of parameter interaction is crucial for genetic improvement. FSPM parameters may be linked to plant genes, and thus may help breeders to design ideotypes. If a parameter has little interaction with others (like P_f), we can directly concentrate on this trait for the design ideotypes. If the interaction is strong, like for α_b (cf Fig. 2, the interaction between α_b and α_s being the most important), it is more complex. If the parameters are strongly genetically related (determination by the same genes, which for α_b , α_s is probable since they are both characteristic of leaf geometry), the model parameterization should be improved to take into account this fundamental interaction. If they are not genetically related, breeding strategy relies on multi-dimensional optimization to handle the interacting processes.

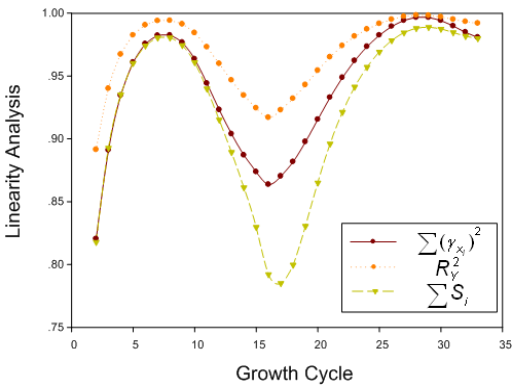

Fig.1

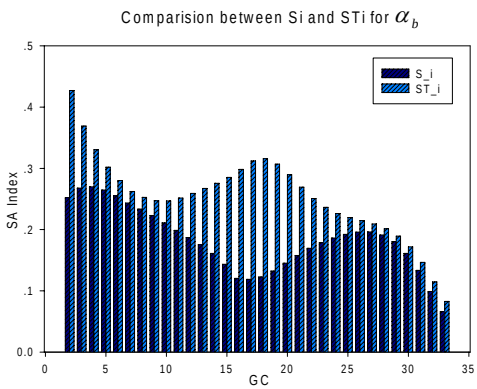

Fig.2

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