Concept and Calibration of Virtual Wheat Including Stochastic Tillering

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Highlights: Present study has introduced a comprehensive theoretical architecture to note probability of phytomer occurrence to describe wheat structural development. This provided an intermediary to compute the overall level of growth functions. The model then was calibrated on observation of variform individuals.

Keywords: Functional structure plant models (FSPM), GreenLab model, stochastic architecture, plant model calibration, durum wheat (*Triticum turgidum* L. *var Dakter*)

INTRODUCTION

Plastic tillering of wheat delivers growth adaptation to its environment, depending on various internal and external factors (Evers et al. 2011). Modeling studies devote to approach the essential drive of architecture variation, for a better understanding of interaction with internal functions (Evers et al. 2007; 2010). However, stochastic architecture makes research on growth function particularly difficult to link real plants. Present work aims to combine growth functions with a stochastic tillering development modeling to achieve the model calibration on the field observation.

EXPERIMENT AND MEASUREMENTS

An experiment was conducted in 2009 on the loamy soil of the experimental site of the IRSTEA Institute (43°40' N, 3°50' E) in Montpellier, France. Durum wheat (Dakter variety) was sown on 2008/11/9 at 150 kg/ha. Owing to rainfall events during spring (736 mm on the cropping cycle), irrigation was not necessary. The soil was enriched with fertilizer (230 kg/ha of N) in three applications on the basis of the initial soil N content in order to achieve the potential yield (9.0 Mg/ha). Appropriate herbicides were sprayed to ensure a non-limited development. Meteorological data including precipitation, global radiation and air temperature were fully recorded at the station.

Nine harvests have been conducted about every two weeks since the seventh blade was visible till the final crop mature. Eight plants per harvest were sampled destructively. Leaf blades, sheaths, internodes, spikes and roots were dissected. Organ fresh masses were measured along the main stem and in the compartment per each tiller. Four plants were dried and weighed for evaluation of the dry mass.

IMPROVED STOCHASTIC GREENLAB MODEL

GreenLab (Yan et al., 2004) is an FSPM dedicated to capturing the sink-source relationship underlying plant growth. The stochastic GreenLab (GL2) introduces probabilities to account for bud dynamics of growth, death and branching, so architectures with variation can be processed. Instead of computing the mean and variance of biomass production of plant from the mean and variance of the number of organs (Kang et al., 2008a), improved method simulates the sink-source function according to theoretical architecture.

If buds branching, growth and survival are certain events, plant architecture will develop all potential phytomers and tillers. Theoretical architecture is built from the potential architecture but with occurrence probability of each phytomer explicitly indicated.

Supposing all buds of a plant share the same probability *a*, *b* and *c* of branching, growth and survival, the probability of each phytomer presents in the potential architecture can be accurately estimated, and therefore the theoretical architecture can be built (Fig.1 a). This architecture is essentially a comprehensive view of the architecture of a species. The estimated probability of existence can be regarded as the right "number" of the corresponding organs of the theoretical average plant. Therefrom, theoretical demand and function can be represented accurately with the theoretical number of organs. The rest principles are common to the classical GreenLab model.

Topology and PA definition

In the current study, mainstem of wheat carries a maximum number of 12 internodes, with one branching order tillers emerging from the first four to five phytomers. We used three physiological ages (PA) (Barthélémy and Caraglio, 2007) to distinguish gradients of organs properties. PA1 represented mainstem under top flower, PA2 indicated first-order tillers under top flower, and PA3 stood for all top flowers, consisting of an internode with a spike. Maximum numbers of phytomer were 11, 8 and 1 respectively.

Probabilities estimation

Branching probability of an axillary bud used the percentage of tiller counts in sample numbers. The estimation of Growth probabilities was by the mean and variance of phytomer number (renewal process, see de Reffye et al., 2012) for the mainstem and by the mean and variance of "summed phytomer number" (Kang et al., 2008b) for tillers. Survival probability for the mainstem was set to 1 since all main stems reproductive. For tillers, they were estimated as constant values for each tiller position (Tab. 1). The theoretical architecture of durum wheat was then derived (Fig.1b).

Tab. 1 Estimated bud probabilities according to *PA* and tiller rank on mainstem (*Rk*)

	Branching Probability (a)					Growth Probability (b)			Survival Probability (c)						
PA	*1*					*1*	*2*	*3*	*1*	*2*					*3*
Rk	*1*	*2*	*3*	*4*	*5*					*1*	*2*	*3*	*4*	*5*	
Value	0.87	0.91	0.50	0.13	0.20	0.99	0.91	1	1	0.95	0.94	0.86	0.74	0.52	1
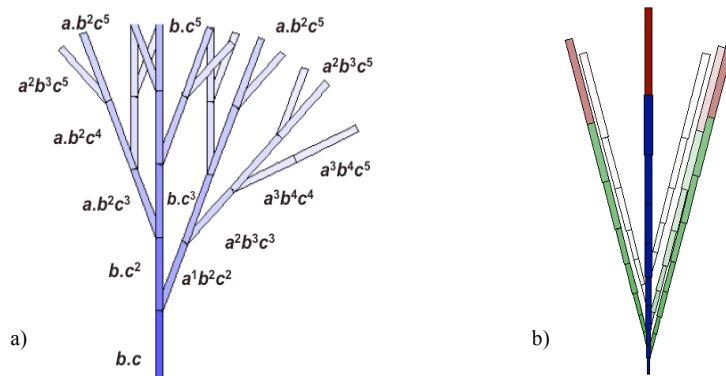
Fig. 1 Theoretical architecture schematic (a) and the example of durum wheat (b). Products of *a*, *b* and *c* indicate occurrence probability of the phytomer, corresponding to the color depth.

Target data and calibration of sink-source function

GreenLab model has been calibrated on both phytomers and compartments grouped by PA. To sum up measurements from variform individuals, phytomers and compartments were processed in bottom-up or top-down alignment. Therefore aligned phytomers or tillers were a mixture of different ages. Analogue simulation was necessary to make modeling output matchable to the observation. We used binomial distribution (B(k, p)) to simulate mixture of phytomers at rank k from the bottom, and negative binomial distribution (NB(k, p)) to simulate the mixture of phytomers at rank k from top.

For PA 1 organs were averaged with top-down alignment. For PA2 and PA3, tillers and top flowers were treated as substructure attached to mainstem, and their compartments were averaged with bottom-up alignment.

A target file was built with 32 plants from four harvests, one single set of sink-source parameters (Tab. 2) were estimated by non-linear least square method (Zhan et al., 2003) to minimize the root mean square error between the target and model output. Calibrated model provides simulation close to the measurements (Fig.2).

Tab. 2 Calibrated parameters of sink-source function, their value and coefficient of variation (*)

Parameter	R	S_p	B_b	B_p	B_i	B_f	P_{b2}	P_{p1}	P_{p2}	P_{i1}	P_{i2}	P_{i3}	P_{f3}
Value	65.76	92.25	1.66	2.54	2.75	1.07	1.56	1.21	0.26	0.83	0.57	1.16	2.13
*	9.89	18.39	0.26	0.6	0.44	0.34	0.73	0.11	0.74	0.09	0.08	0.25	1.21

R - Empirical parameter of assimilate function; S_p - Theoretical projective area (cm^2);
P - Sink factor; B - Parameter of beta function describing the sink variation;
Subscript 1, 2, 3 - PA 1, 2 and 3;   Subscript b, p, i, f - indicate organ blade, sheath, internode and spike
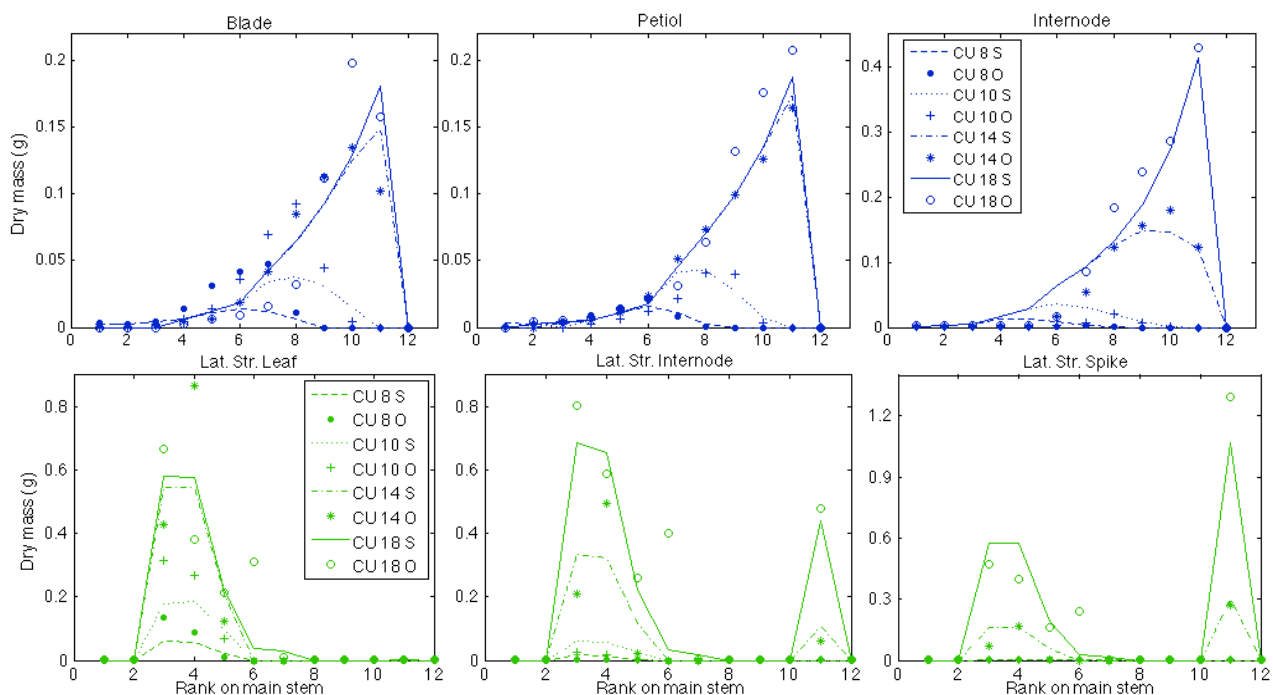
Fig. 2 Four dates (computing time units, abbr. CU, of 8, 10, 14, 18) organ weights of PA1 (up, in blue), and compartment weights per each tillers and top flowers of PA2 and PA3 (bottom, in green). Measurements (O) in symbols and simulation (S) in lines.

CONCLUSION

The improved stochastic GreenLab model applied theoretical architecture as an intermediary to simulate growth functions of wheat from an overall level. Binomial distribution and negative binomial distribution were employed to simulate mixture of phytomers picked in bottom-up or top-down from variform individuals. Therefore, observations and modeling output could be comparable, and the virtual wheat was then calibrated.

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