Parameterizing a simple model of photosynthetic active radiation absorption by complex aerial structures of oilseed rape resulting from genotype x nitrogen interactions

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Abstract

Biomass accumulation depends on photosynthetically active radiation (PAR) absorbed by crop aerial structures ; crop aerial structures, described in terms of number, dimensions, orientation, spatial distribution and optical properties of photosynthetic surfaces, highly depend on nitrogen availability and genotype.

During the whole oilseed rape reproductive phase, the dynamics of photosynthetic organs aerial structure is complex, because of i) the progressive substitution of leaves by pods ii) the spatial mix of these organs due to ramification iii) the position of flowers at the top of the canopy, reducing transmitted light to photosynthetic organs. The main consequences of this complexity are the difficulty to measure photosynthetically active radiation absorbed by leaves and/or by pods, and therefore the difficulty to parameterize usual simple radiative models, based on « one type of organ-one layer » discretization of canopy structure.

We combined semi-dwarf and normal oilseed rape genotypes with different Nitrogen fertilization levels, in order to obtain and describe contrasted aerial structures dynamics. In order to simulate radiative fluxes in these structures, we used a 1D-model allowing to mix different types of photosynthetic surfaces in each layer, according to measured vertical distribution of photosynthetic organs. The comparison between PAR profiles simulated and measured inside the canopy, indicates that a single set of parameters is necessary to model the radiative fluxes inside the different contrasted canopy structures obtained ; moreover, the model is not sensitive to the differences observed concerning the vertical distributions of the different photosynthetic surfaces. We can therefore conclude that a simple model, based on organ layers discretization of canopy structure and using a single set of parameters, is sufficient to calculate the PAR absorbed by photosynthetic organs in the context of genotype-nitrogen interaction studies. Such a model will be useful for biomass accumulation estimation and for sensitivity analysis to aerial structure characteristics, to quantify source-sinks relationships during reproductive phase in order to better understand yield and seed quality, or to precize the influence of transmitted light on bottom leaves falling off.

Key words : oilseed rape, genotype x nitrogen interactions, absorbed photosynthetically active radiation

Introduction

The development of oilseed rape for biofuel production is among others conditionned by the improvement of its environmental impact, especially reducing nitrogen losses due to leaves abscission. Genetic selection may be a promising way of improvement, if it is possible to define pertinent criteria, non-resulting of genotype x nitrogen interactions : the use of pertinent ecophysiological models calculating for one genotype the effect of environment on the plant functionning (Jullien *et al.,* 2006) could be a way to improve criteria accuracy.

Crop biomass accumulation is known to be directly linked to Photosynthetically Active Radiation (PAR) absorbed by crop aerial structures (Monteith, 1972) ; most existing biomass accumulation models are therefore based on a simple Beer-Lambert law to determine absorbed PAR, depending on crop actual Leaf Area Index (LAI), a single structure-dependant extinction parameter (k) and a reflexion coefficient (ρ), as follows :

$$PAR_{absorbed} = PAR_{incident}\,(1\text{-}\rho)\,(1\text{-}\exp^{(\text{-}k.LAI)}) \qquad \text{(eq. 1)}$$

During the whole oilseed rape reproductive phase, photosynthesis result from both leaves and pods activity ; the dynamics of photosynthetic organs aerial structure is complex, because of i) the progressive substitution of leaves by pods ii) the spatial mix of these organs due to ramification iii) the position of flowers at the top of the canopy, reducing temporarily transmitted light to photosynthetic organs. A radiation balance scheme has been proposed (Chartier *et al.,* 1983 ; Justes *et al.,* 2000) using a form of Beer-Lambert law : it allows to calculate absorbed PAR in a three-layers system, respectively leaves, pods and flowers, assuming no spatial mix between these aerial structures. The main consequence of photosynthetic surfaces spatial mix is the difficulty to measure photosynthetically active radiation absorbed by leaves and/or by pods, and therefore the difficulty to parameterize such simple radiative models (Chartier *et al.,* 1983 ; Justes *et al.,* 2000).

Moreover, both genotype and soil nitrogen availability are known to have a great influence on crop aerial structure dynamics and photosynthetic surfaces characteristics (number, dimensions, orientation, spatial distribution and optical properties). In the scientific context of oilseed rape genotype x nitrogen interactions studies, it appears therefore important to determine the relevance of a three-layers radiation balance scheme and the range of parameters to be used in order to precisely calculate absorbed PAR.

In this aim, we compared for contrasted observed oilseed rape structures, the results of a discrete model simulating radiative transfer in an aerial structure mixing different photosynthetic surfaces, with the results of a three-layers radiation balance scheme.

Material and Methods

Experimental design :

Field experiments were carried out in Thiverval-Grignon, France (48.9° N, 1.9° E) on a sandy-loamy soil, on a plot sown at a density of 60-70 plants/m^2 in September 2004. Three contrasted aerial structures have been obtained, resulting from i) the choice of 2 cultivars differing by their final size : Capitol (final height : 1,80 m) and Saturnin (semi-dwarf, final height : 1,30m) ii) Two levels of soil nitrogen availability (0 and 200 kg Nitrogen / ha). The 3 contrasted structures have been named : C0 for Capitol with 0 kg N /ha, C2 for Capitol with 200 kg N /ha and S2 for Saturnin with 200 kg N /ha.

Transmitted radiation measurement and aerial structure description :

Since the onset of flowering to ripening, we measured weekly during 24 hours incident PAR and transmitted PAR at 4 levels in the canopy ; fluxes measurements were logged every 10s and averaged every 15 mn (Campbell data logger), and summed at the day level in order to calculate daily PAR transmission efficiencies (Σ daily transmitted PAR / Σ daily incident PAR). The description of the aerial structures was made on the same plot the day after PAR fluxes measurement ; combining optical (using leaf area meter LI3100, Li-Cor Inc, NE, USA) and gravimetric technics, we determined for each canopy layer between 2 consecutive transmitted PAR sensors, four organ area indices : leaf area index, stem area index, flower area index and pod area index.

RIRI3D is a discrete model simulating radiative transfer in mixed structures (Sinoquet and Bonhomme, 1992); the space occupied by vegetation is divided into cells owning to horizontal layers, empty or containing photosynthetic surfaces of one or several types. Within a cell, leaf area density of each photosynthetic surface is uniformly distributed, and leaf inclination is constant ; thus variations between cells represent the spatial distribution of organs areas, which as to be measured and used as input file. Soil, leaf, pods and flowers optical properties and inclinations used as a set of parameters for simulations were considered as constant during the experimentation, and either measured or found in literature. RIRI3D allows to compute i) the profiles of the different terms of the radiative balance ii) and to assess variables difficult to measure, for instance to distinguish PAR absorbed by leaves from PAR absorbed by pods or stems in a canopy where these organs are mixed.

Results

Aerial structures plasticity :

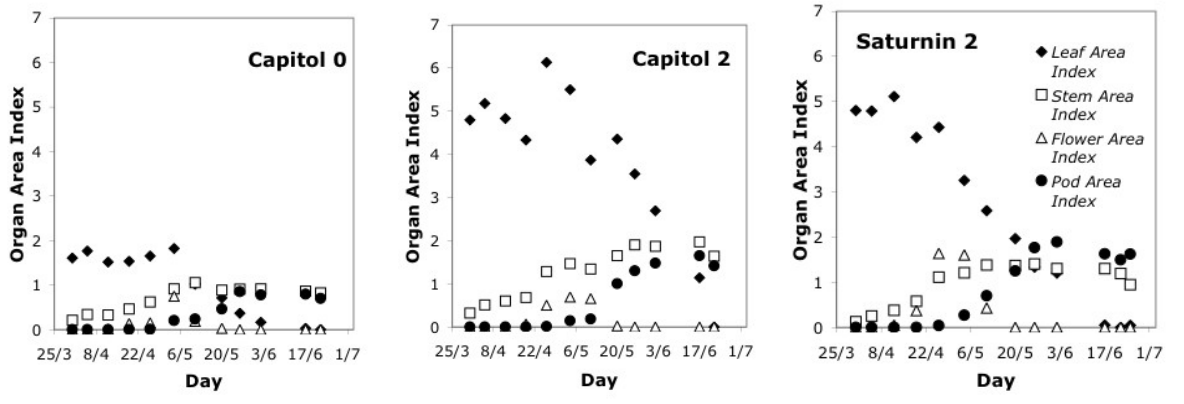


Figure 1 : Time-course of Organ Area Indices (m^2/ m^2) during reproductive phase : leaves, stems, flowers and pods

The time-course of Organ Area Indices during reproductive phase (fig. 1) follows a classical pattern (Müller *et al.,* 2006) for the three treatments: due to leaf abscission Leaf Area Index decreases to 0, whereas Flower Leaf Area index is typically bell-shaped, and Stem and Pod Area Indices follow a typical sigmoïd growth course. Differences between Capitol and Saturnin are slight: rape beetles damages reduced Capitol FAI, and the dwarf character of Saturnin induced lower stem surfaces. Reducing nitrogen availability dramatically reduces all surface indices.

A description of the vertical profile of layer organ area indices has been made weekly. On 3 May for instance (fig. 2), we notice that pods and leaves are always mixed in the upper layer of the canopy, and that the mix proportions are quite different, may be linked to ramification intensity. On the other hand, stem surfaces distribution is more or less constant along the profile, and the major part of stem surfaces takes place like leaves, in the lower part of the profile.

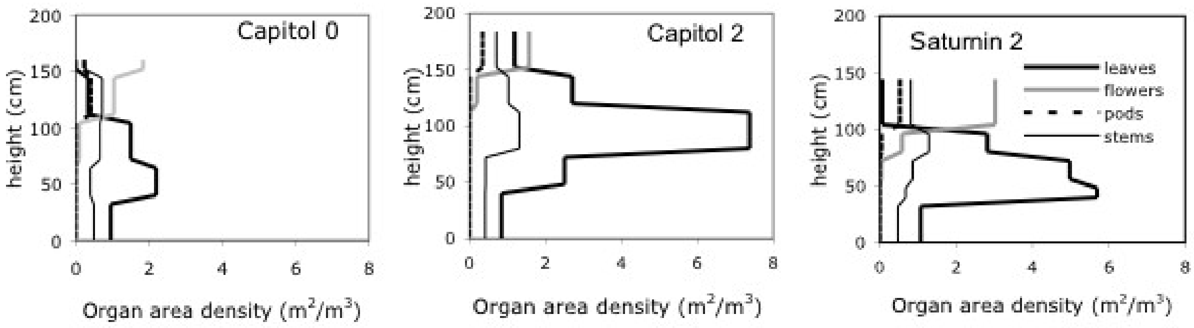


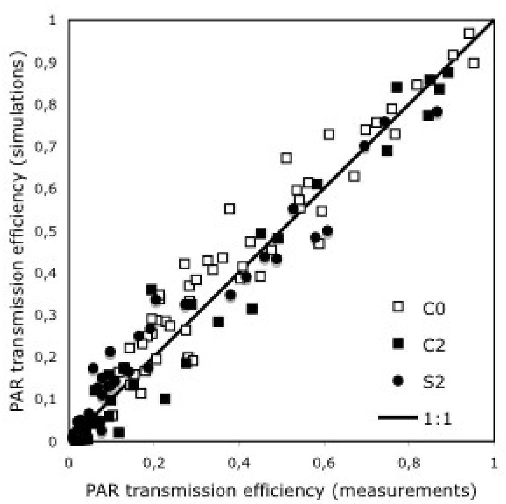
Figure 2 : Leaf, flower pods and stem area Density profiles on 3 May for the 3 treatments.

Comparing PAR transmitted profiles to RIRI3D simulations :

Daily PAR transmission efficiencies (Σ transmitted PAR / Σ incident PAR) at different canopy levels have been calculated from measurements and then compared to RIRI3D profiles simulations (fig 3). The slope of the relation obtained was close to unity, and no significant difference was found between treatments. The model used is therefore considered able to simulate radiative transferts in different oilseed rape complex structures, using a single set of parameters and knowing the real vertical distribution of the surfaces. That means that the effect of genotype and nitrogen on aerian structures doesn't modify the physics of radiative transfert, and only concerns time-course and spatial distribution of photosynthetic surfaces.

Model Sensitivity to vertical distribution of surfaces :

The measurement of Organ Area density profiles is time consuming, depending on number of organs and height of each layer considered ; it is therefore interesting to test the interest of this variable for oilseed rape structures. We can in this aim hypothesize that organ surfaces are not mixed, but vertically distributed as three morphological layers (from the bottom up leaves, pods and flowers) ; since the major part of stem surfaces takes place like leaves in the lower part of the profile, we can moreover consider that the basal layer represent leaves and stems. Based on PAR absorbed by morphological compartments calculation, the comparison between simulations using a description of the real structure, and simulations using a 3 layers structure description (fig 4) presents a slope close to unity, whatever the treatment and the morphological layer ; we can thus consider that the 3 layers scheme is relevant in the range of structures considered, and calculate extinction and reflexion parameters for each layer (tab1), adjusting to eq.(1) the relations between XAI and absorption efficiency for each layer. The values obtained are quite different from the values published by Justes *et al.* (2000), but we can notice that we find similar coefficients for leaves and pods, indicating a continuity between leaves and pods layers regarding to radiative transferts.



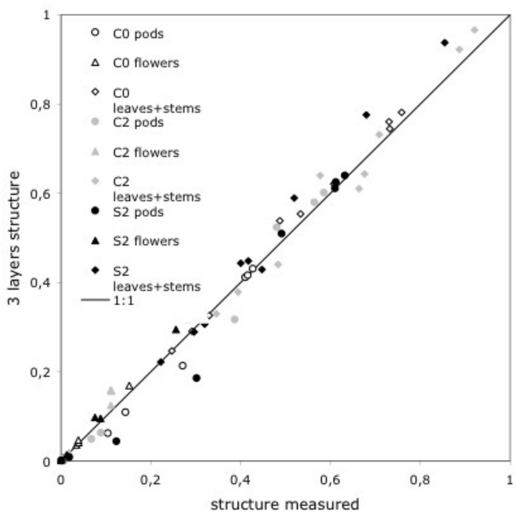


Fig 3 : Comparison of measured and simulated PAR transmission efficiencies at different levels in the canopy, for 2 genotypes under 2 nitrogen availabilities.

Fig 4 : Comparison between absorption efficiencies simulated with a description of the real structure, and absorption efficiencies simulated with a 3 layers structure description ; absorption efficencies are calculated for 3 morphological compartments (leaves + stems, flowers, and pods) under 3 experimental treatments.

Table 1: Value of parameters used in calculation of the radiative balance for each layer

	Extinction coefficient	Reflexion coefficient
leaves	1,08	0,03
pods	1,03	0,03
flowers	0,80	0,30

Discussion

The parameterization of a simple 3 morphological layers model is valuable for the large range of aerian structure plasticity experimentally obtained; this range could may be larger, with more contrasted genotypes or nitrogen availabilities, or with lower sowing densities inducing higher ramification intensity. It would be therefore of great interest to consider the sensitivity analysis of the model to the « mix intensity », especially between green and yellow surfaces, because the extinction coefficients of leaves and pods are similar.

Conclusions

In the scientific context of genotype x nitrogen interactions, it is possible to parameterize a simple model of PAR absorption, using only surface indices and a single set of parameters. This model allows to calculate PAR absorbed by the whole canopy, or by each morphological component. In the case of pods growth, it will allow to estimate the role of their own photosynthesis in their growth. Moreover, knowing transmitted PAR at each leaf level will allow to test new hypothesis concerning putative links between photosynthesis and leaf senescence, or to quantify source-sink relationships during reproductive phase in order to better understand yield and seed quality.

References

Sinoquet H., Bonhomme R., 1992.Modeling radiative transfert in mixed and row intercropping systems. Agric.

Chartier M., Fabre B., Gosse G., Rode J.-C., 1983. Bilan radiatif d'un couvert de colza. Actes de 6ème Congrès international sur le colza. 17-18-19 /5/1983., Paris, tome 1, pp 154-165

Jullien A., Allirand J.-M., Cournède P.-H., Matthieu A., de Reffye P., Ney. B. 2006 Is it possible to simulate rapeseed organ mass in relation to N nutrition? Calibration of the functional-structural model GREENLAB for the oilseed rape Brassica napus L. during the vegetative phase for two nitrogen nutrition levels. Actes de 12ème Congrès international sur le colza. Mars 2007., Wuhan.

Justes E., Denoroy P., Gabrielle B., Gosse G., 2000. Effect of crop nitrogen status and temperature on the radiation use efficiency of winter oilseed rape. European Journal of Agronomy, 13, 165-177.

Monteith J.L., 1972. Solar radiation and productivity in tropical ecosystems. J. Appl. Ecology, 9, 747-766.

Müller J., Berhens T., Diepenbrock W., 2006. Use of a new sigmoïd growth equation to estimate organ area indices from canopy area index in winter oilseed rape (*Brassica napus* L.). Field Crop Research, 96, 279-295.