

Modelling winter oilseed rape carbon accumulation during the reproductive phase

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Abstract : The observed decrease in oilseed rape conversion of intercepted radiation efficiency during reproductive phase could be due to leaf falling off, pod senescence or to the specific energy cost of oil production. In reason of its interest in modelling, we tried to identify and quantify the processes really involved in this decrease, for different genotypes under contrasted nitrogen fertilisations.

Key-word: dry matter accumulation, photosynthetically active radiation, interception efficiency, radiation use efficiency, oil content

Introduction

Ecophysiological modelling of carbon accumulation in pods and grains during oilseed rape (OSR) reproductive phase could be a good tool to both integrate current knowledge on the processes involved in fatty acids production and cake quality elaboration, and to design oilseed rape ideotypes adapted to new environmental and technical constraints. Few eco-physiological models already exist in literature (for example, CERES-rape, Gabrielle *et al*, 1998). Most of them are based on the classical Monteith dry matter production scheme, analysing the production *via* a distinction between the processes involved in light interception by photosynthetic green surfaces (leaves and pods), and the processes of conversion in dry matter, synthesized by Radiation Use Efficiency (accumulated dry matter (DM) / sum of intercepted radiation). This efficiency is commonly known as RUE, but not clearly defined in terms of dry matter characterization, possibly aboveground DM, or total DM, or total DM + fallen organs DM.

In Ceres-rape, a constant value of RUE (2,4 g DM.MJ⁻¹.m⁻²) has been successfully used to model dry matter accumulation before flowering. Concerning reproductive phase, an apparent RUE decrease has soon be described (Rode *et al*, 1983). Ceres-rape therefore assessed a lower constant RUE value (2,0 g DM.MJ⁻¹.m⁻²) during the first part of pod growth, and then a linearly decrease to 0,1 g DM.MJ⁻¹.m⁻². Otherwise, a stress factor based on specific N content of leaves and pods was used to account for nitrogen stress on RUE. The apparent RUE decrease observed could be due to leaves falling off, pods senescence or to the cost of oil production (Gabrielle *et al*, 1998), but the processes involved in were not precisely identified and quantified. Moreover, oil content at harvest was only considered in Ceres-rape as a function of grain nitrogen final concentration.

It seems therefore necessary to reconsider the post-flowering determinism of RUE decrease, accounting for oil accumulation, with a data set obtained with this objective.

Material and methods

- The experimental design consisted of two OSR genotypes (Aviso & Montego) slightly differing in their precocity, cultivated in Rennes (France) in 2009-2010 under two nitrogen availability regimes (N- = 30 kg/ha ; N+ = 110 kg/ha). From the beginning of flowering to harvest, we measured at 8 dates with 3 replications OSR morphological compartments dry matter. Photosynthetically Active incident Radiation (PARi) data were measured at a local weather station. The part of PARi intercepted by the crop is evaluated using the approach described by Allirand *et al*, 2007.

- $DM_{meas.}$ was the total (above & underground) dry matter by m^2 measured in the field. The generated total dry matter $DM_{gen.}$ was the sum of $DM_{meas.}$ and the fallen leaves dry mass.

- The specific energy content of the whole generated biomass is C_1 (Kcal/g), and therefore $DM \times C_1$ represents the energy contained in biomass. In order to calculate oil accumulation dynamics, we hypothesized that:

- During the whole reproductive period, the process of conversion of intercepted radiation into energy contained in biomass is not affected, and the energy contained E in total biomass for a given level of intercepted radiation PAR_{int} was:

$$E = (DM_{gen-init} + RUE \times \sum PAR_{int}) \times C_1 \quad \text{equation (1)}$$

where $DM_{gen-init}$ is the total dry matter generated at the beginning of reproductive phase.

- Considering that during oil accumulation, the generated total dry matter $DM_{gen.}$ could be divided into oil dry matter and the rest of the biomass generated:

$$DM_{gen.} = DM_{oil} + DM_{restBM} \quad \text{equation (2)}$$

the apparent RUE decrease during reproductive period could be due to the difference between a high and constant specific energy content C_2 of oil (Kcal/g), different from a low and constant specific energy content of the rest of the biomass, supposed to be C_1 .

We can then write that after the beginning of oil accumulation, for a given PAR_{int} :

$$E = (DM_{restBM} \times C_1) + (DM_{oil} \times C_2) \quad \text{equation (3)}$$

and thus, combining equations (1), (2) and (3) :

$$DM_{oil} = \left[\left(DM_{gen-init} + RUE \times \sum PAR_{int} \right) - DM_{gen.} \right] / \left(\left(C_2 / C_1 \right) - 1 \right)$$

According to Varlet-Grancher (1982), we considered that $C_1 = 4$ kcal/g and $C_2 = 9$ kcal/g

Results

- Photosynthetic surfaces dynamics

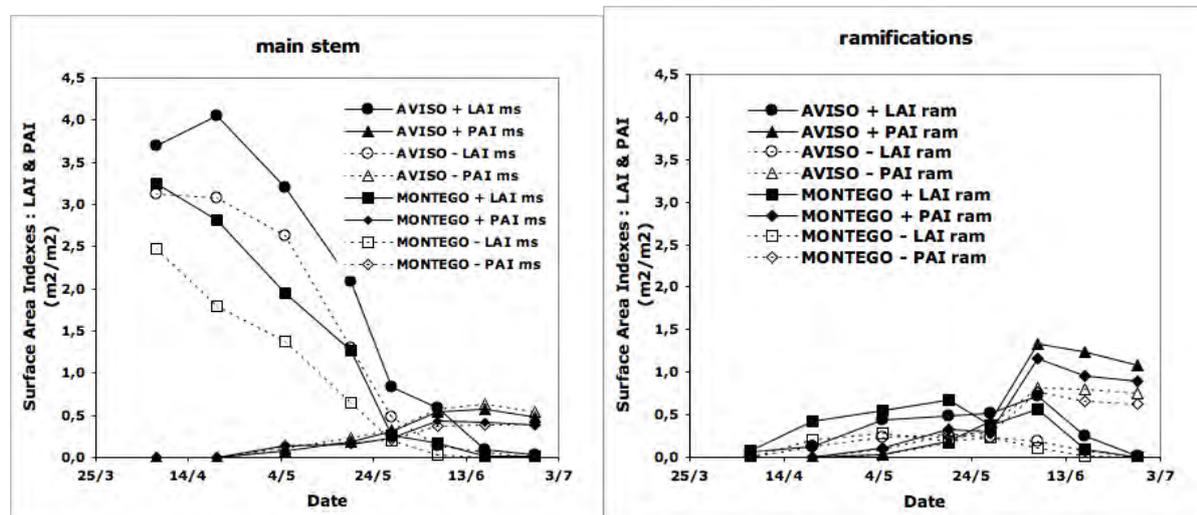


Figure 1 : Leaf Area Index (LAI) and Pod Area Index PAI dynamics for main stem and ramifications

The main characteristics of photosynthetic surfaces dynamics during reproductive phase are an important decrease of main stem LAI due to leaf falling off, a reduction of both LAI and PAI on main stem and ramifications of the two genotypes due to low nitrogen availability, and a genotypic effect on the initial values.

- Efficiency of PAR interception

Figure 2 indicates the dynamics of the calculated efficiency of interception of the two genotypes under two nitrogen availability levels. Combined with daily incident PAR data, these values allowed to calculate the sum of intercepted PAR for each treatment.

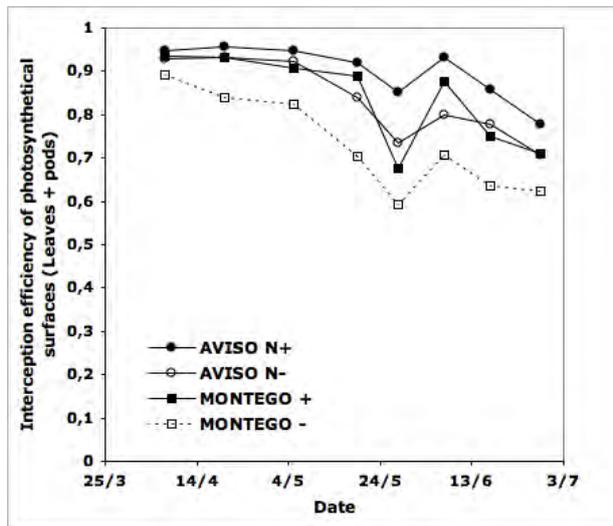


Figure 2 : efficiency of interception dynamics by photosynthetic green surfaces of the 2 genotypes Aviso & Montego under two nitrogen availability levels N+ and N-.

For all the treatments, PAI growth does not compensate the LAI decrease. As a result, the efficiency of interception slightly decreases during the studied phase. This decrease became more marked when initial values were

lower (Montego), and when nitrogen availability decreased.

- Efficiency of the conversion dynamics

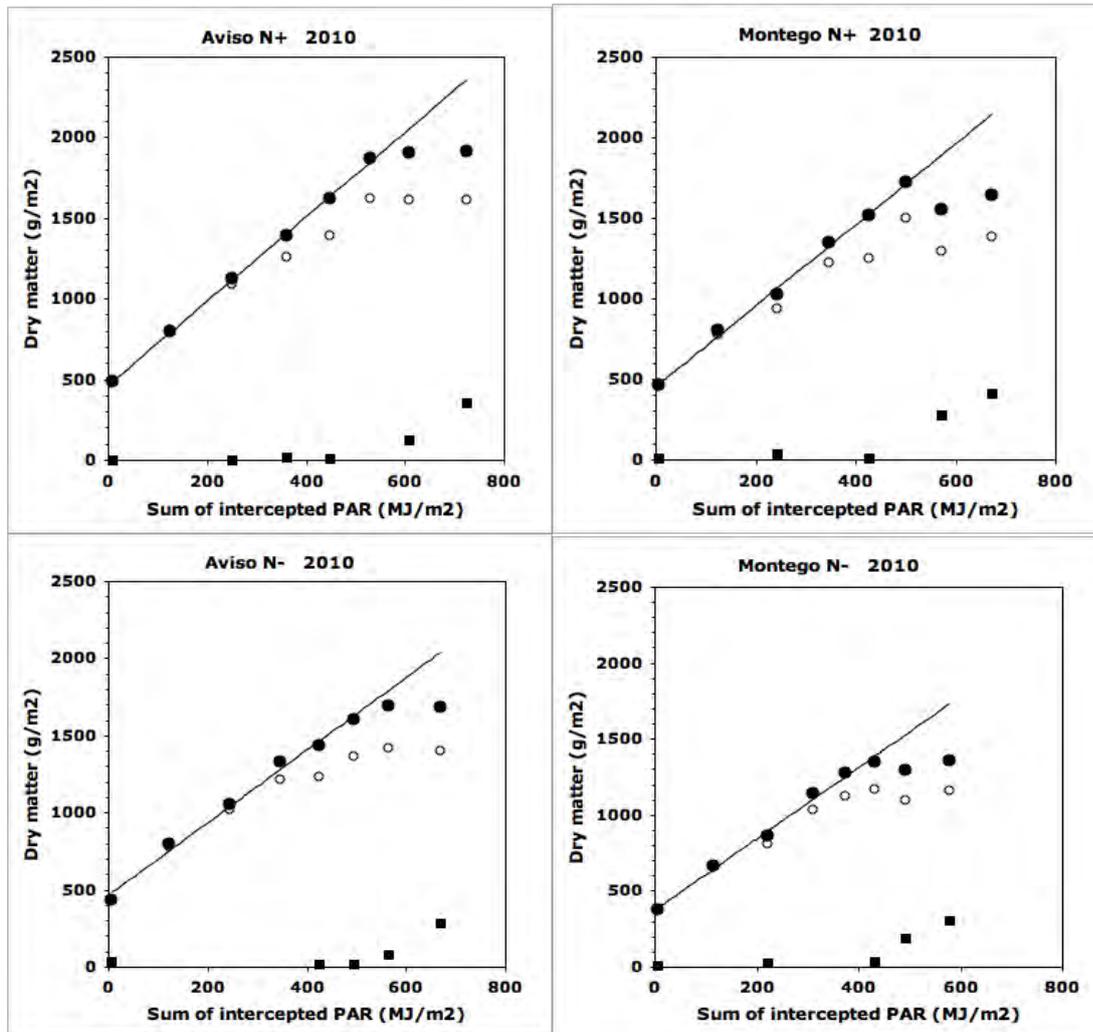


Figure 3 : Dry matter accumulated by two genotypes (Aviso and Montego) under two nitrogen availability levels (N+ and N-), versus the sum of PAR intercepted. (open circle = dry matter measured $DM_{meas.}$, bold circle = dry matter generated DM_{gen} , bold square = calculated oil dry matter DM_{oil} , straight line represents the linear regression of DM_{gen} on the sum of intercepted PAR for the 6 first values.

Treatment	Intercept ($DM_{gen-init}$)	Slope (RUE)	R ²
Aviso N+	464,3	2,62	0,99
Aviso N-	467,0	2,35	0,99
Montego N+	455,3	2,52	0,99
Montego N-	378,6	2,34	0,99

Table 1 : coefficients of linear regression of DM_{gen} on intercepted PAR for 4 treatments (only considering the six first dates of the dynamics)

*The results represented in figure 3 clearly indicated that the relation between $DM_{meas.}$

and the sum of intercepted PAR was never linear during the reproductive phase, for the four treatments. Therefore RUE calculated with total measured dry matter decreased during the major part of reproductive phase. Conversely, the regression of DM_{gen} on the sum of intercepted PAR was linear for the four treatments, only considering the six first dates of the dynamics (table 1).

*The values of the different slopes represented different values of the RUE. The quality of the adjustments indicated that:

- RUE estimated with $DM_{gen.}$ was constant during a major part of the reproductive phase
 - according to values found in literature, RUE values obtained ranged between 2,34 and 2,62 ; Montego RUE values are slightly lower than Aviso values, and the effect of nitrogen deprivation is strong.
- *Oil accumulation dynamics simulations (fig 3) were consistent, but led to overestimated values of final oil production, ranging from 2,8 T/ha to 4,0 T/ha.

Discussion

Our original dataset combining genetic and environmental sources of variation, led to precise the origins of the observed decrease in RUE during OSR reproductive phase. The definition of RUE is essential, since we demonstrated that taking into account total measured DM + fallen leaves DM allows to get a constant RUE during the major part of the reproductive phase. Taking into account the differences in specific energy content for tissues of variable biochemical composition is a promising way. The overestimation observed would no doubt be reduced when considering a reduction (or a stop) of photosynthesis, linked to pod walls nitrogen content as described by Gammelvind *et al* (1996). Applied to both leaves and pods, this solution could be used to assess RUE reduction due to nitrogen availability during the whole reproductive period (table 1). Another hypothesis to reduce oil production simulation results should be to quantify pod falling off, visible for all the treatments in figure 1.

Conclusion

If necessary, this work reminds of the importance of photosynthetic surfaces dynamics (growth and decrease) and of their photosynthetic capacities on the final yield, even during the reproductive phase. As a consequence, the major role of variations in these dynamics, due to genetic characteristics or to environmental constraints is emphasized. Combining this variability of surfaces dynamics to our model, when achieved, could be a promising way for oilseed rape phenotyping.

Moreover, a connection of our approach with models describing oil quality (fatty acids content) could easily later be done.

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