Modelling N uptake in B. napus plants in the field conditions: estimation of active roots involved in nitrate uptake by a synthetic parameter, the integrated root system age (IRSA)

Erwan E. Le Deunff, Philippe P. Malagoli

U.M.R. PIAF

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Erwan LE DEUNFF [1], Philippe MALAGOLI [2]

[1] UMR 950 INRA / Université de Normandie " Ecophysiologie Végétale et Agronomie, Nutritions N, C, S ", Caen, France

[2] UMR 547 INRA / Université Blaise-Pascal, " Physique et Physiologie Intégratives de l'Arbre Fruitier et Forestier ", Clermont-Ferrand, France

Introduction

A mechanistic structure–function model was developed to predict nitrogen (N) uptake throughout the growth cycle by a winter oilseed rape (*B. napus*) under field conditions. Because of the overestimations of N taken up regarding both influx rates measured with ^{15}N tracer and total root length measured under field conditions [1], a parameter called ARB (Active Root Biomass) was developed in order to estimate the active root absorbing biomass [2]. It was based on an other synthetic parameter called IRSA (Integrated Root System Age) that accounts for changes in root uptake properties with root age [3]. Although the effect of root ageing on the nitrate influx rate is very strong (**Fig. 1**), it is hardly ever introduced into N uptake agronomic models [1,3].

Methods

Oilseed rape plants fed on a wide range of external nitrate concentrations showed a continuous decrease in the nitrate uptake rate with plant age under field and hydroponic conditions (**Fig.1**). However, increasing external concentrations of nitrate extend the functioning of the roots and their capacity for nitrate uptake (**Fig.1B**). A synthetic IRSA parameter takes into account this specific root behaviour [3,4].

Integrate Root System Age parameter (IRSA)
IRSA parameter (in °Cday) is defined as the sum of the average age of the root segments in °Cday relative to the final sampling date [3]:

$$IRSA_{ti} = \sum_{ti=1}^{maturity} [a_{ti} * \Delta l_{ti} / l_{maturity}]$$

Where a_{ti} is the average root age of the root produced from plant age d_{ti-1} to d_{ti}, i is the ith °Cday of root sampling and Δl_{ti} represents the change in root length from d_{ti-1} to d_{ti} (**Fig. 3A**).

Estimate of the Relative NO$_3$- uptake capacity of Fine-root (RF$_{ti}$)
According to **Fig. 1B**, the RF_{ti} parameter is calculated assuming that the lowest value of the IRSA parameter (young root segments) for each soil layer corresponds to full nitrate uptake capacity (100 %), while the highest IRSA value (old root segments) was reached for absorption equal to zero (**Fig. 2B**):

$$RF_{ti} = 1 - (IRSA_{ti} / IRSA_{maturity})$$

Estimate of the Active Root Absorbing Biomass (ARB$_{ti}$)
Then, the active root biomass (ARB) involved in nitrate absorption within the different soil layers during the whole growth cycle (**Fig. 3**) is calculated according to:.

$$ARB_{ti} = 1 - (IRSA_{ti} / IRSA_{maturity}) * Dw_{root,ti}$$

Results

Plants absorb nitrate with few active root biomass
Use of ARB parameter induces a drastic reduction of the root biomass involved in nitrate uptake in the top soil layers (0-30; 30-60 cm; **Fig. 3A and B**). Predicted values of N exported by the crop match well with field-measured values (**Fig. 4B**).

Estimate of relative capacity of NO$_3$- absorption by root
Although the ARB parameter allows to estimate a weighted active root biomass across the whole root system, it can not identify which fraction of the fine-root system is active in nitrate uptake. However, it points out that root ageing is a critical component to model the N uptake rate at field level (**Figs. 1 and 4**). Due to a close interaction between the building of root structure and root properties, the N uptake efficiency can not be improved without reconsidering the thermodynamic aspects involved in root absorption and shaping [5,6,7].

Conclusion

The ARB is a powerful parameter to assign a root absorption capacity at a specific age of the root in 1-dimensional N uptake models. Hence, the effect of N applications on root senescence delay needs to be unravelled at molecular and physiological levels. It will allow to develop quick screening methods to improve the N uptake efficiency of crop species in breeding programs.
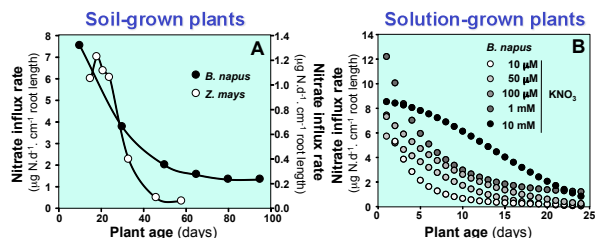

Fig. 1: Down-regulation of NO$_3$- uptake rate with the root aging. **(A)** Effect of root age on nitrate uptake rate of field-grown *B. napus* and *Z. mays* plants (from Edwards and Barber, 1976 and Barraclough, 1989). **(B)** Effect of root age on nitrate uptake rate of solution-grown *B. napus* plants (from Bath et al., 1979). The plants were grown in a continuous flow culture system and supplied with different external nitrate concentrations.
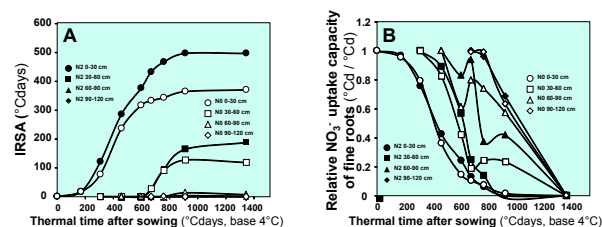

Fig. 2: Variations of the Integrate Root System Age parameter (IRSA) **(A)** and the relative NO$_3$- uptake capacity of fine roots (RF) **(B)** during the whole growth cycle in each soil layers for N0 (0 Kg N/ha), N1 (135 kg N/ha) and N2 (272 kg N/ha) fertilization levels.
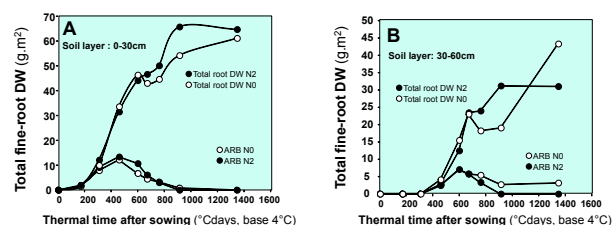

Fig. 3: Estimation of Active Root Biomass (ARB) in the different soil layers for two levels of fertilization (N0= 0 Kg N /ha and N2 = 272 kg N/ha). **(A)** Estimates of ARB in first soil layers (0-30 cm) and **(B)** estimates of ARB in the second soil layer (30-60 cm).
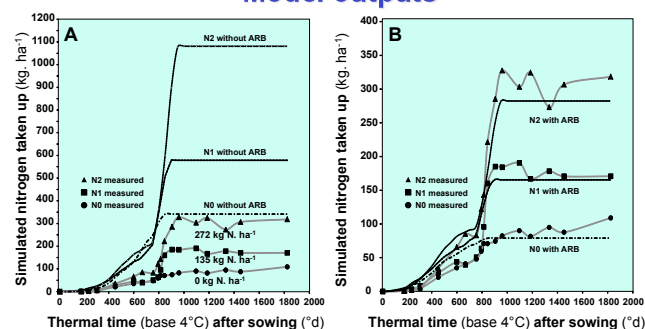
Model outputs

Fig. 4. Simulated (dotted lines) versus measured outputs (symbols) of the total nitrogen taken up by a winter oil seed rape crop at field level (*Brassica napus* 'Capitol'). **(A)** The simulated values are obtained without using ARB parameter. **(B)** The simulated values are obtained after using of ARB parameter to estimate the active root biomass. The simulated values are indicated by a dotted line and the values measured in the field by simple symbols and a full line .

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