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SuMoToRI, a model to predict growth and sulfur content in oilseed rape during the vegetative phase

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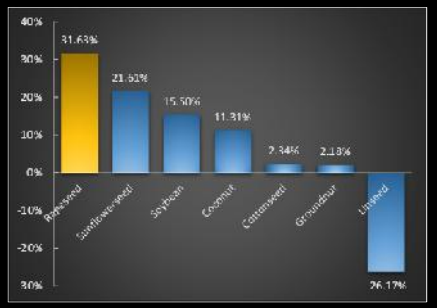
Oilseed rape: production and uses

- Wordlwide production 2012: **65 Mt** with **22.3 Mt** from **UE-27**
- **Greatest worldwide production increase** among oilseeds (+ 31.6 % 2002-2012)

Production increase (% yrs 2002-2012)

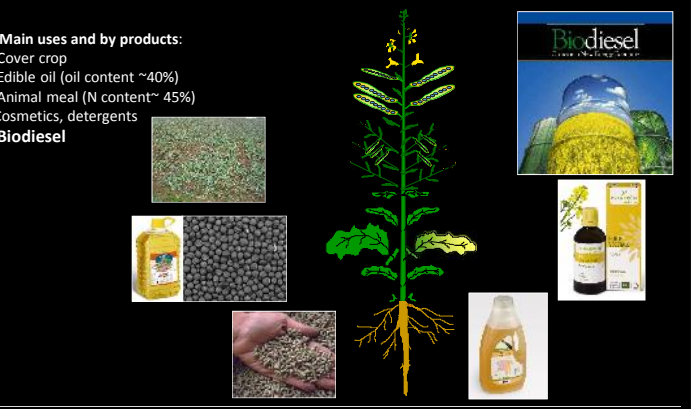


source: FAO

Oilseed rape: production and uses

- Wordlwide production 2012: **65 Mt** with **22.3 Mt** from **UE-27**
- **Greatest worldwide production increase** among oilseeds (+ 31.6 % 2002-2012)

- **Main uses and by products**:
  - Cover crop
  - Edible oil (oil content ~40%)
  - Animal meal (N content~ 45%)
  - Cosmetics, detergents
  - **Biodiesel**



Rapeseed is a high S demanding crop

SO_3 (Kg/Ha)	Total needs	Grain export
Wheat (yield 55 q/Ha)	50	25
Rapeseed (yield 35 q/Ha)	215 (x 4)	72 (x 3)

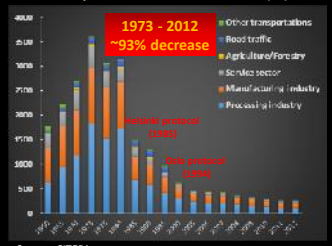
Sources : Aspach DGER 1992 Cetiom

From: Schnug and Haneklaus 1994

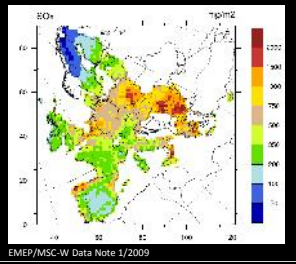
Observation of S oligotrophy in soils

As a consequence of
- Reduction in industrial emissions (SO_2)

Atmospheric SO2 emissions in France (kT)



Source: CITEPA



EMEP/MSC-W Data Note 1/2009

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Observation of S oligotrophy in soils

As a consequence of

- Reduction in industrial emissions (SO_2)
- Substitution of S-containing N and P fertilisers
- Declining use of S compounds used for plant protection
- Increase in crop productivity → increases in S exportation

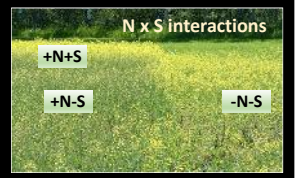
Empirical S fertilisation : *optimum timing, forms, amounts? 75 U (SO_3) at bolting (CETIOM)*

Environmental context | Protocol | Ecophysiological Results | Model functioning | Simulations | Discussion

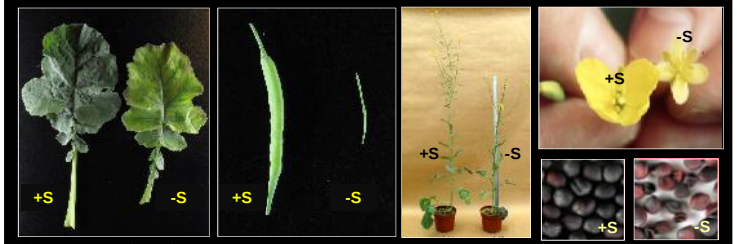
Impacts of S deficiency

-**Yield components** (seed weight, pod length)
-**Germination capacity**
-**Seed quality** i.e. protein, oil, glucosinolate contents
(Schnug et al., 1993; Fismes et al., 2000; Dubousset et al. 2010)

…up to a reduction of 2t/ha



Source: www.canolawatch.org



Photos courtesy: D. Goudier, L. Dubousset

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Framework and objective of the modelling approach

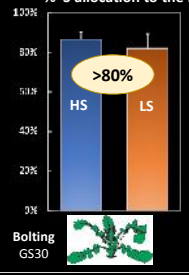
Why the vegetative phase?

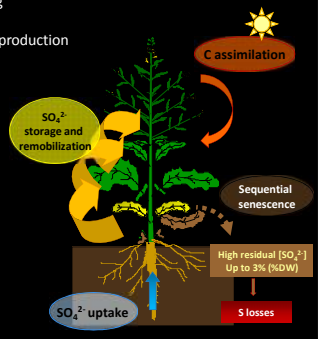
- Strong **correlation** between **S availability at budding** and final **yield** (Dubousset *et al.* 2010)
- **Low S availability** during the vegetative phase: S leaching and slow mineralisation (Suhardi *et al.*1992, Merrien *et al.*1998)

Why leaf growth?

- Leaves are the major **source of S** = 80% of total S at bolting
- **Sequential senescence leads to important S losses**
- Photostynthetic leaves are the main site for carbohydrate production

% S allocation to the leaves





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Why leaf growth?

- Leaves are the major « **S source** » for remobilization towards reproductive organs
- **Sequential senescence leads to important S losses**
- Photostynthetic leaves are the main site for carbohydrate production « **C source** »

Objectives in a context of S limitation:

- ✓ **Establishment of a framework for the analyis of crucial processes driven by T°C, PAR and S availability**
- ✓ **Prediction of leaf S content : relevant indicator of further plant performances**

→**Model outputs**: **tool to rectify S deficiency** occuring during the vegetative phase

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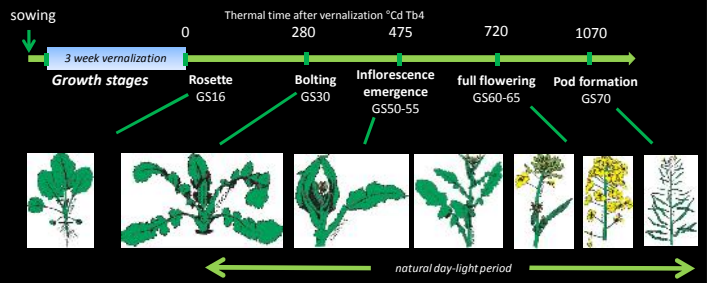
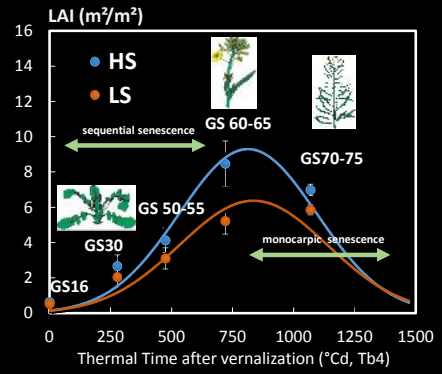
Experimental design

- Greenhouse, cv. Yudal, T°C and PARi recordings
- 2 contrasting S supplies (HS-LS)
- 5 Harvests until early pod formation
- Dry Weight/organ, LAI, Q_S/organ, Q_{SO42-}/organ



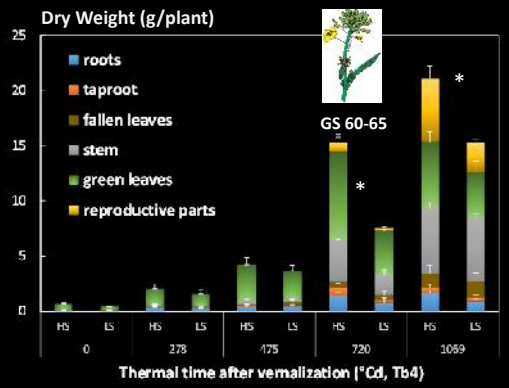
Picures: CETIOM
BBCH decimal system: Lancashire et al., 1991

Leaf area expansion rate



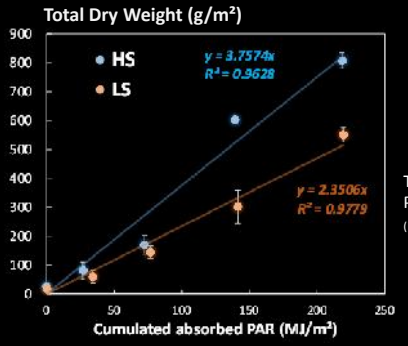
- ✓ Potential **Leaf Area Expansion Rate (LAER)** depends on **thermal time:** ***Bell shaped dynamics*** **:** change in balance *senescence :newly formed leaves*
- ✓ Leaf Area Expansion Rate is affected by S supply

Biomass production and Radiation Use efficiency (1/2)



- ✓ Growth reduction at flowering under LS (GS 50-55)
  - Reduction in leaf area and stem elongation
  - Delay in flowering initiation stage

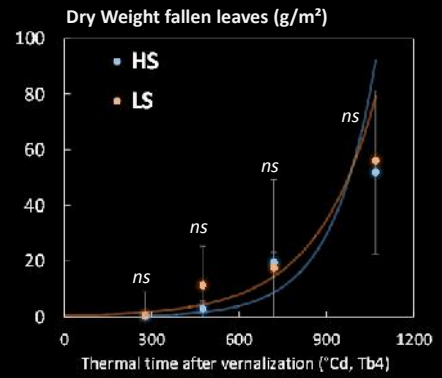
Biomass production and Radiation Use efficiency (2/2)



TDW = RUE x PAR abs
PAR*abs* = PAR*i* (1- exp(-k*LAI))
(Beer's law, Gosse et al., 1983)

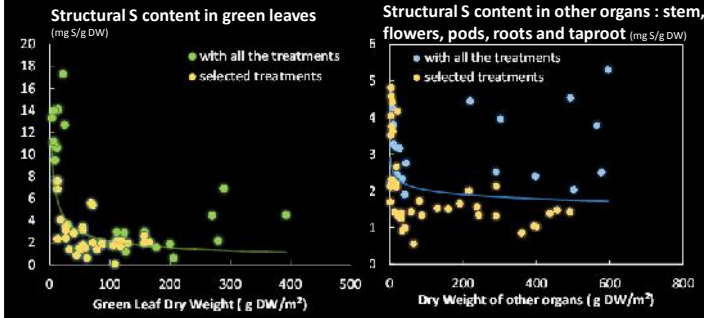
- ✓ **Modelling of biomass production (C offer) based on Monteith eq.** (conversion of PAR into biomass via RUE)
- ✓**RUE** depends on plant S status

S remobilization process throught leaf senescence



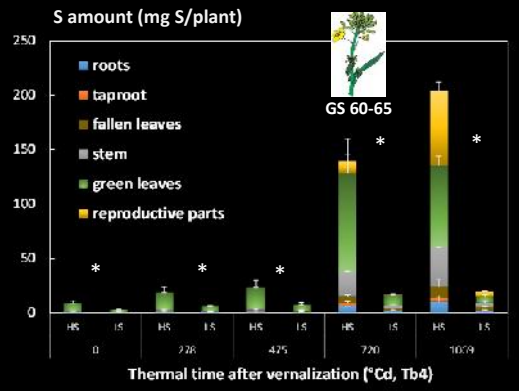
✓**Sequential senescence is <u>not dependant on plant S status</u>** (similar parameter values for the formalism describing the dynamics of fall of leaves)

Structural S requirements :Critical dilution curves



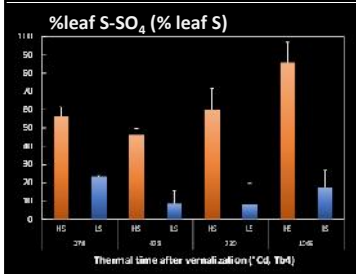
✓ Structural S was estimated as the difference between total S amount and S-SO_4^{2-}
✓ Adjustments for structural S requirement predictions

S allocation and S mobile pool partitionning (1/2)



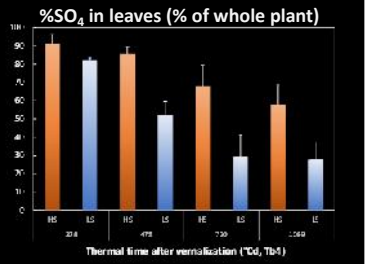
✓ Pattern of S allocation similar to biomass allocation
→ **Leaves : main sink for S**

S allocation and S mobile pool partitionning (2/2)



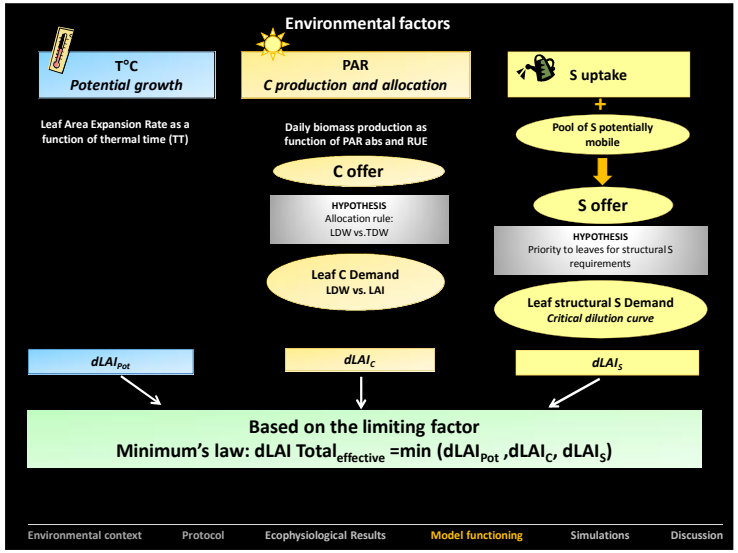
✓ S from SO4 represents more than 50% under HS
→ **main S form for remobilization: SO_4 ~Pool of mobile S**

✓ Leaves are the major storage compartment: up to 90% of total SO_4
→ **Allocation rule to quantify mobile S in leaves**



SuMoToRI: Sulfur MOdel TOwards Rapeseed Improvement

- **Limiting environmental conditions:** T°C, PAR, S
- **Period for simulations**: from the end of the vegetative rest period until pod formation
- **Daily time step**
- **At the plant level**
- **Processes: C production, C allocation, S assimilation, S allocation, S remobilization**
- **Three-compartment model:** Green leaves - Fallen Leaves - the rest of the plant
- **Two Pools of S: structural vs. mobile**
- **An offer-demand model of C and S**
  - Satisfaction of compartment S structural demands with priority order
  - Pool of mobile S used for remobilization
- **Prediction of the dynamics** of
  - **Leaf Area Index** (LAI), **Dry Weight** (DW) of green leaves and the rest of the plant
  - **Distribution of S amount** in green and fallen leaves, in the rest of the plant
  - **Repartition of both structural S and mobile pools**



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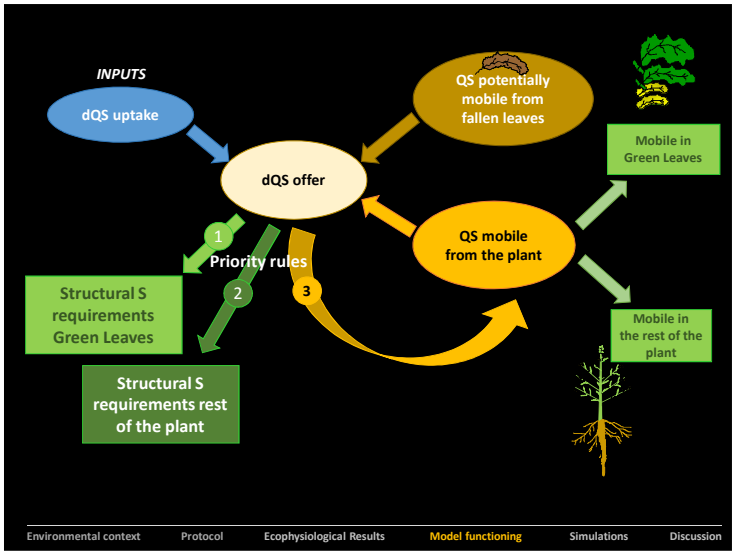

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SuMoToRI: Functioning principles

Carbon processes	Sulfur processes
✓ Potential **leaf area expansion rate (LAER)** depends on **thermal time**	✓ Leaf area expansion rate is dependent on S supply
✓ **Biomass production** (C offer) depends on PAR and RUE (Monteith eq.)	✓ S uptake, S potentially mobilisable from fallen leaves and S mobile pool from the plant represent S offer
✓ **RUE** **depends on plant S status**	✓ S offer is used to (i) prioritary satisfy **structural demands** i.e. leaves followed by the rest of the plant and (ii) maintain a **pool of mobile S**
✓ Leaf growth determines **leaves C demand** which is **dependant on plant S status** i.e. distinct parameter values for LDW vs. LAI	✓ S structural requirements for leaves depend on critical S content and SLA i.e. leaf C demand which is **not dependant on plant S status**
✓ **Allocation rules for C partitioning are not dependant on plant S status** until GS70 i.e. similar parameter values for *LDW vs. TDW adjustment*	✓ **Allocation rule for mobile S pool partitioning** in proportion of compartment size with a priority to leaves independently of S status → leaves are the main storage compartment
✓ **Sequential senescence is not dependant on plant S status** i.e. similar parameter values for the formalism describing the dynamics of fall of leaves	

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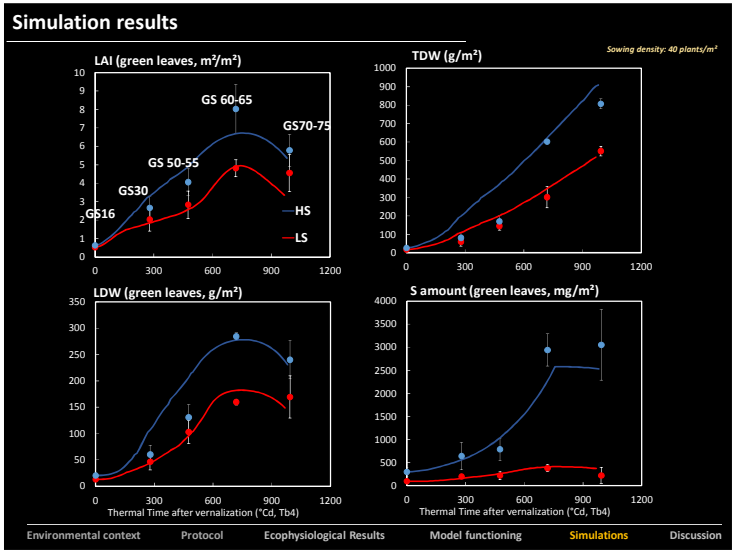
Simulation results



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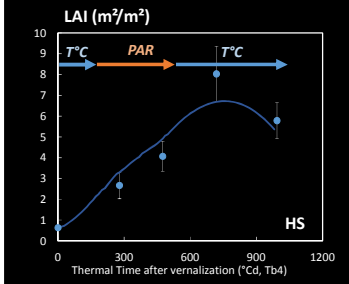
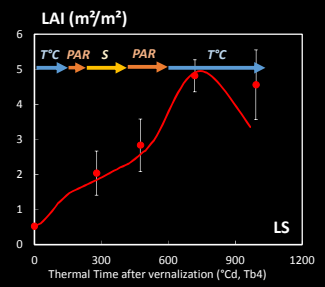


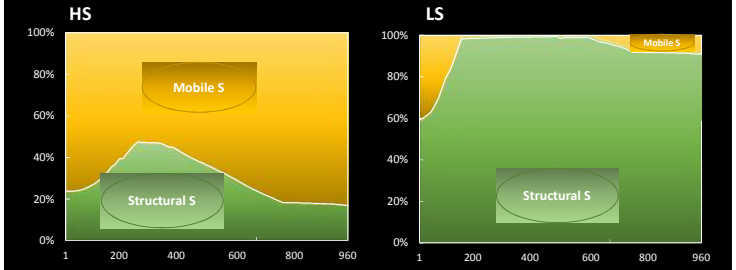


→ **Under HS: growth is limited by**
-temperature (*growth potential*)
-light (*carbohydrate production*)
-temperature (*growth potential*)

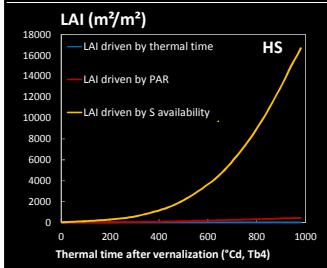
→ **Under LS: growth is limited by**
-temperature (*growth potential*)
-light (*carbohydrate production*)
-S availability
-light (*carbohydrate production*)
-temperature (*growth potential*)
→ Plant has adjusted its S requirements to its growth

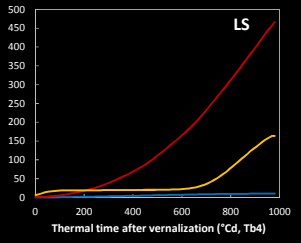
Simulation results

Repartition of S pools *mobile vs. structural* in leaves



Simulation results





→ **Under HS, the highest LAI is permitted by S availability**

→ **Under LS, the highest LAI is permitted by S until 200°Cd after vernalization and then by Carbohydrate availability**

Pas le temps snif

Perspectives and improvements

- Extension of the prediction period until seed harvest:
  Need to a finer shoot description to quantify GAI including pods to estimate the effective C production when leaf area starts declining

- Finer description of mobile S pool :
  - what are the other forms involved in remobilization under high restricting S conditions?
  - which organ is involved in remobilization according to the development stages?

- Screening diversity and sensitivity analyses to explore the range of variations of the model parameters and to assess impact of variations on simulated growth

- Towards a « gene to phenotype» approach

In collaboration with
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