Modelling sulphur allocation and partitionning in winter oilseed rape (*Brassica napus* L.)

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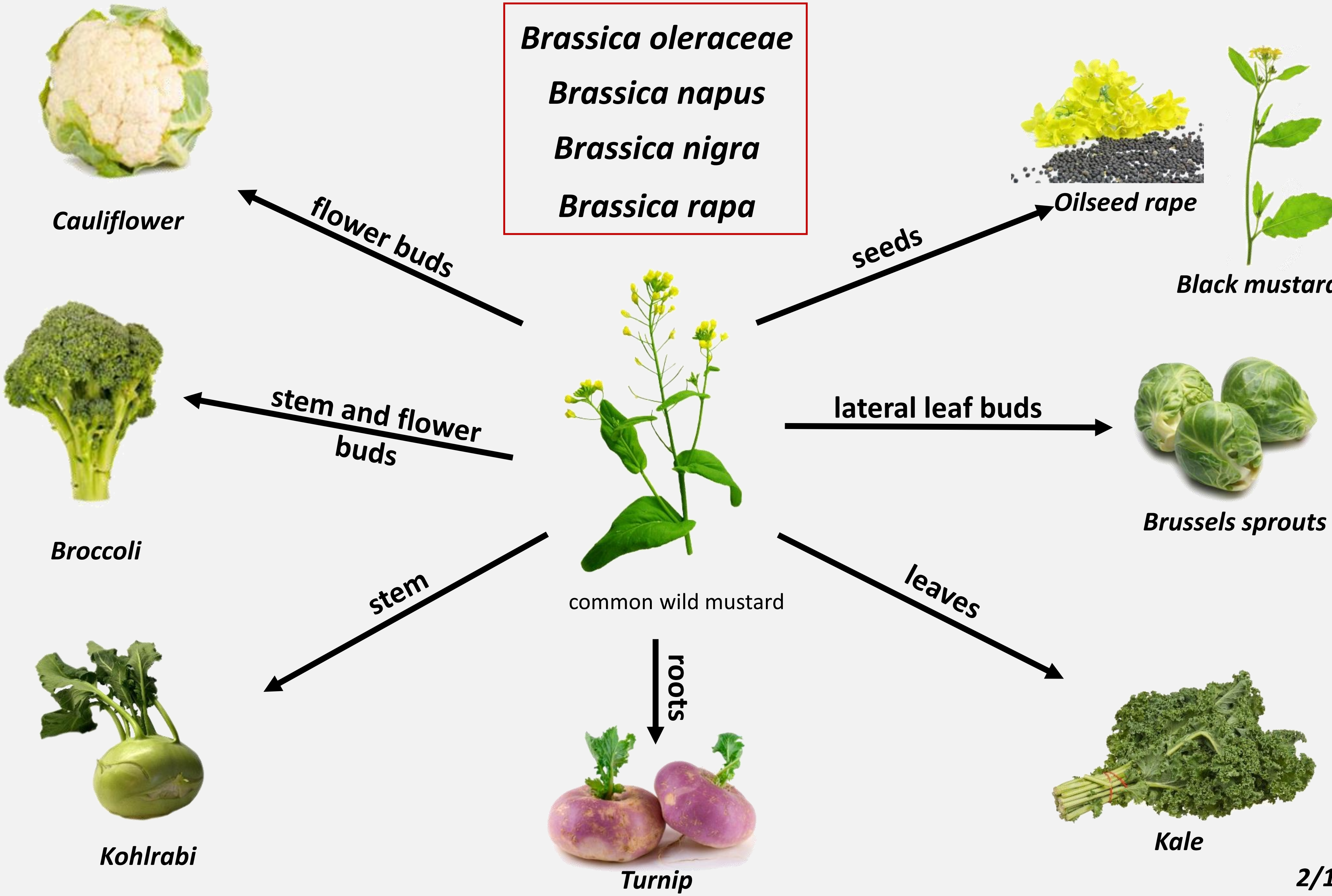
Brassicaceae family

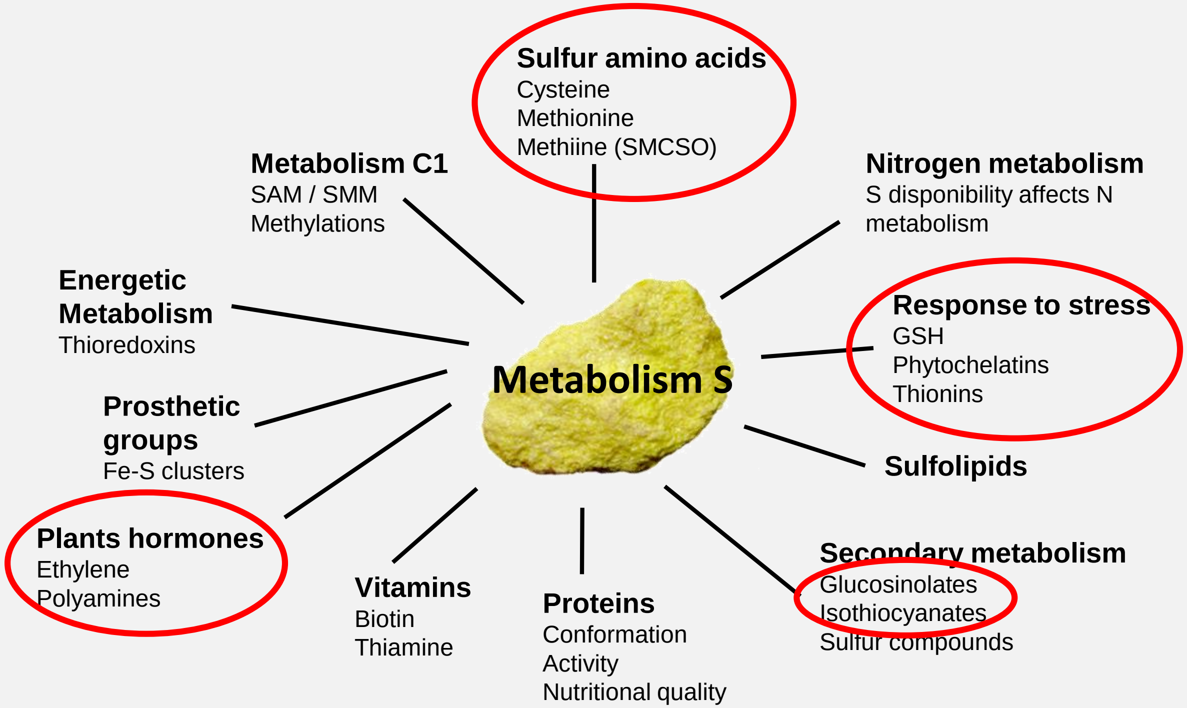
www.huiles-guenard.com
blog.golbsalt.com
www.haustiere-kaninchen.de

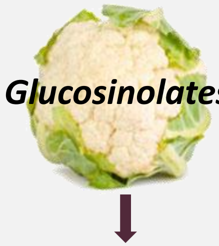
- 340 genera and 3700 species
- The most consumed amongst vegetables in Europe



Brassicaceae family : importance of S-molecules

Nikiforova *et al*. (2004)





3.34 to 22.89 µmol.g^{-1} DW
(source : Vegenov)

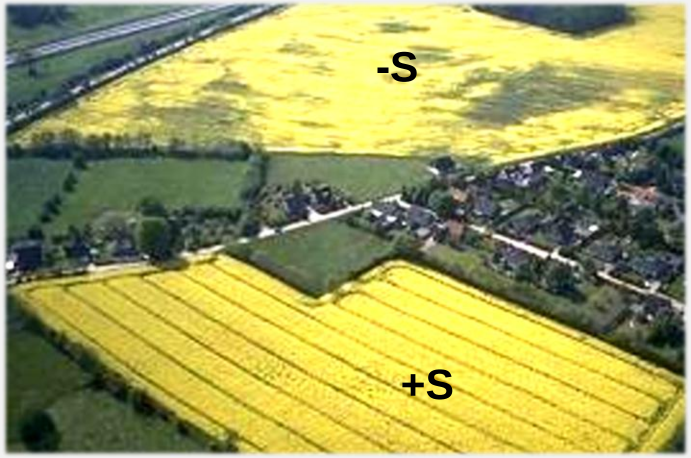
S compounds are involved in :

- Organoleptic properties (bitterness)
- Nutritional interests : **Beneficial effects on human health**
  - Glucosinolates : antibacterial, anticarcinogenic, antioxidant and anti-inflammatory properties
  - Methiine (SMCSO) : lipid and cholesterol lowering effects, antidiabetic, antioxidant and antimutagen properties.

Brassicaceae: high S-demanding crops

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

Aspach DGER 1992 Cetiom

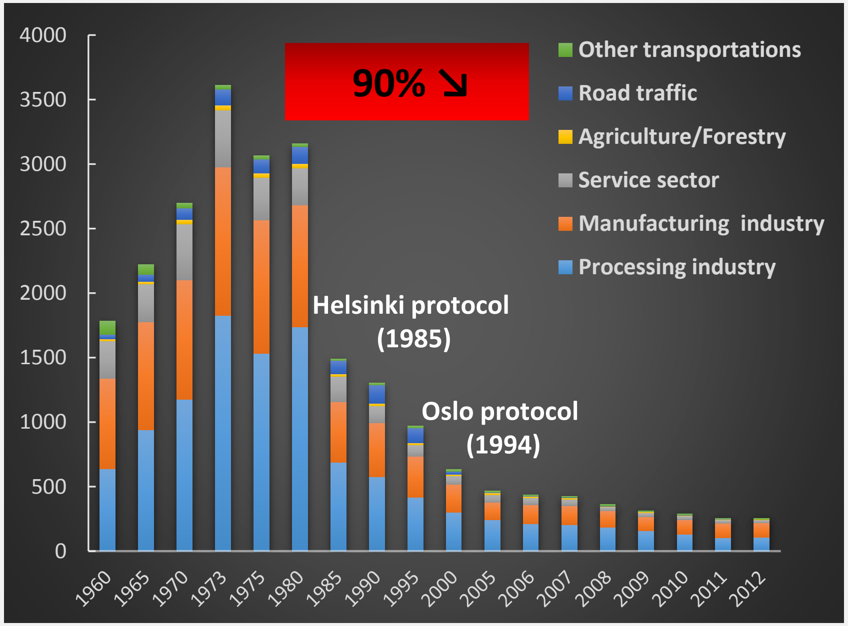


Schnug and Haneklaus 1994

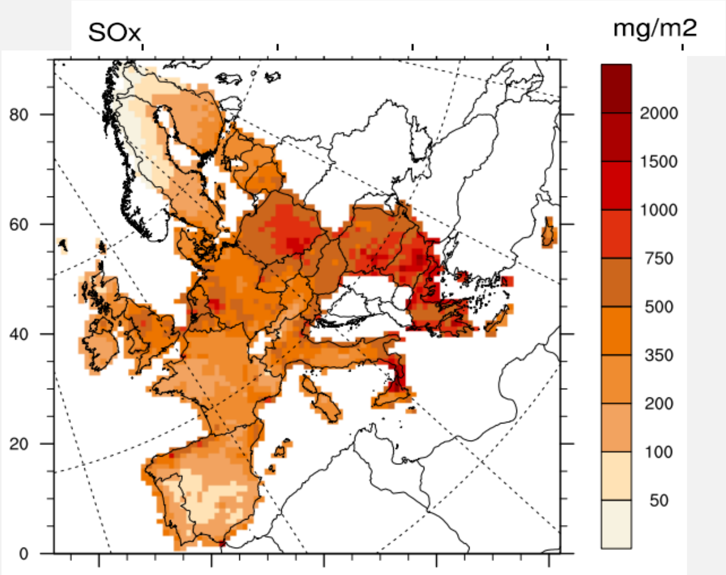
Observation of S oligotrophy in soils

- Reduction in industrial emissions rich in sulfur (SO_2)

Atmospheric SO2 emissions in France (kT)



CITEPA



EMEP/MSC-W Data Note 1/2014

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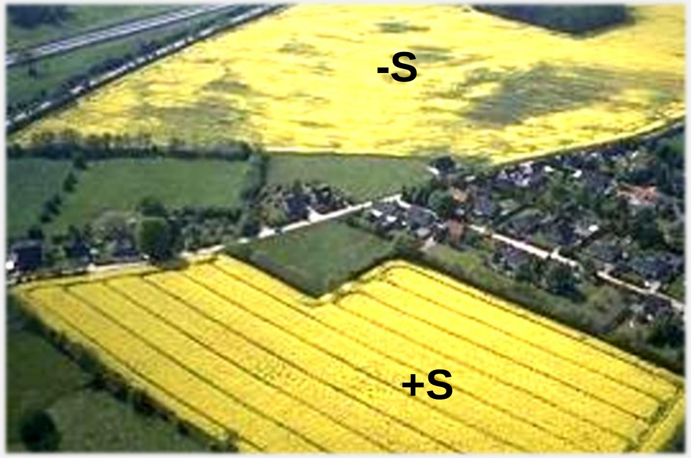
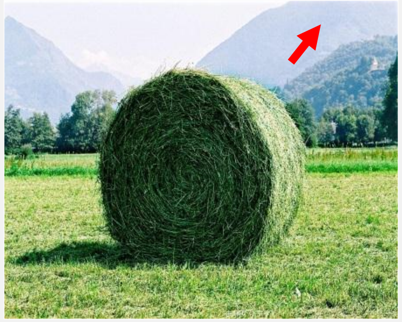


Schnug and Haneklaus 1994

Observation of S oligotrophy in soils

- 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 : no optimised practices (75 kg/ha SO_3, Terres Inovia)**

Impacts of S deficiency

SCPA, Mulhouse

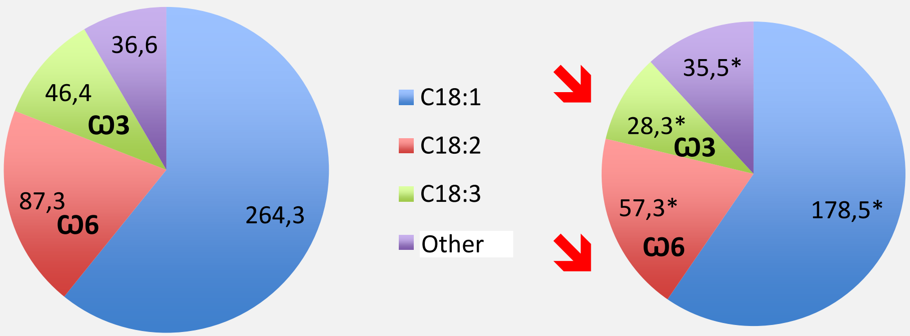
polysulphate.com

Photos courtesy: D. Goudier, L. Dubousset

- **Yield components** (seed yield, seed weight) Dubousset *et al*. 2009
- **Germination capacity** D'Hooghe *et al*. 2014
- **Seed quality** (oil, protein contents) D'Hooghe *et al*. 2014

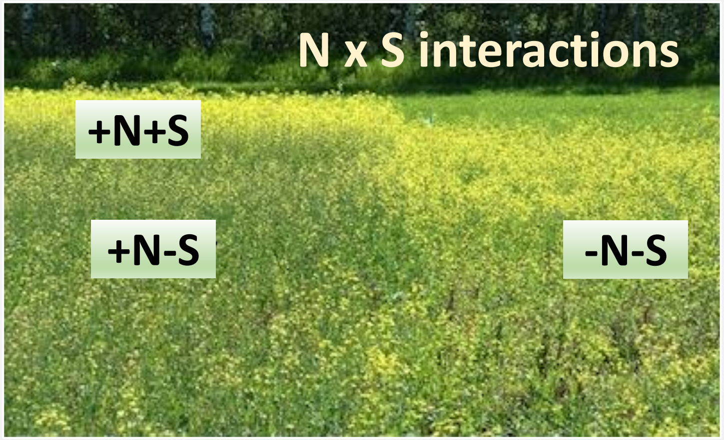
Control

S limitation applied at GS32 (bolting stage)



Fatty acid mg.g^{-1} DW
FA total = 434,6 mg.g^{-1} DW

Fatty acid mg.g^{-1} DW
FA total = 299,6 mg.g^{-1} DW *



www.canolawatch.org

Importance of N/S balance

D'Hooghe *et al*. 2014

SuMoToRI « SUlfur MOdel Towards Rapeseed Improvement »

- Framework to analyse the impact of environnemental factors that drive growth i.e. T°C, PAR and S availability
- Prediction of leaf S content from the end of winter until the onset of pod formation: indicator of further plant performances (yield and grain quality)

Brunel-Muguet *et al*. 2015

Framework of the modelling approach

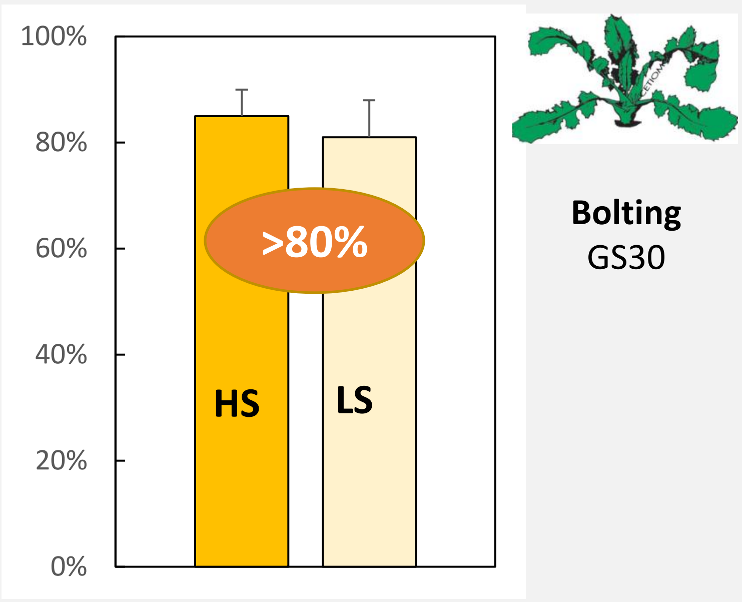
- **Why the vegetative phase?**

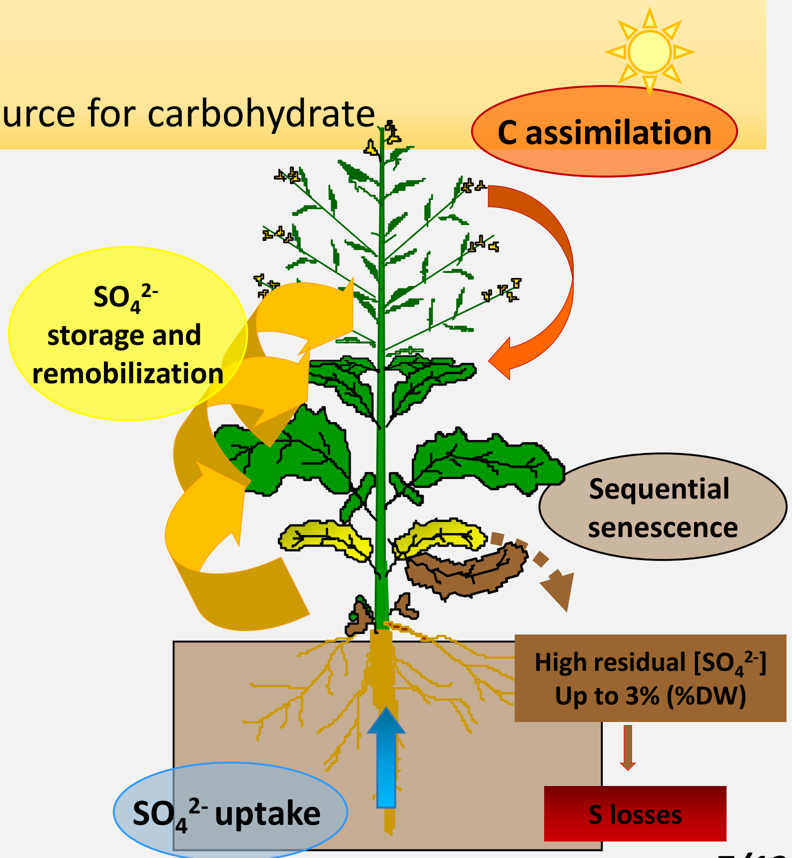
- Strong **correlation** between **S availability at budding** and final **yield** (Dubousset *et al*. 2010)
- Low S availability during the vegetative phase: S leaching and slow mineralisation (Suhardi *et al.*1992, Merrien *et al.*1998)

- **Why leaf growth? central variable**

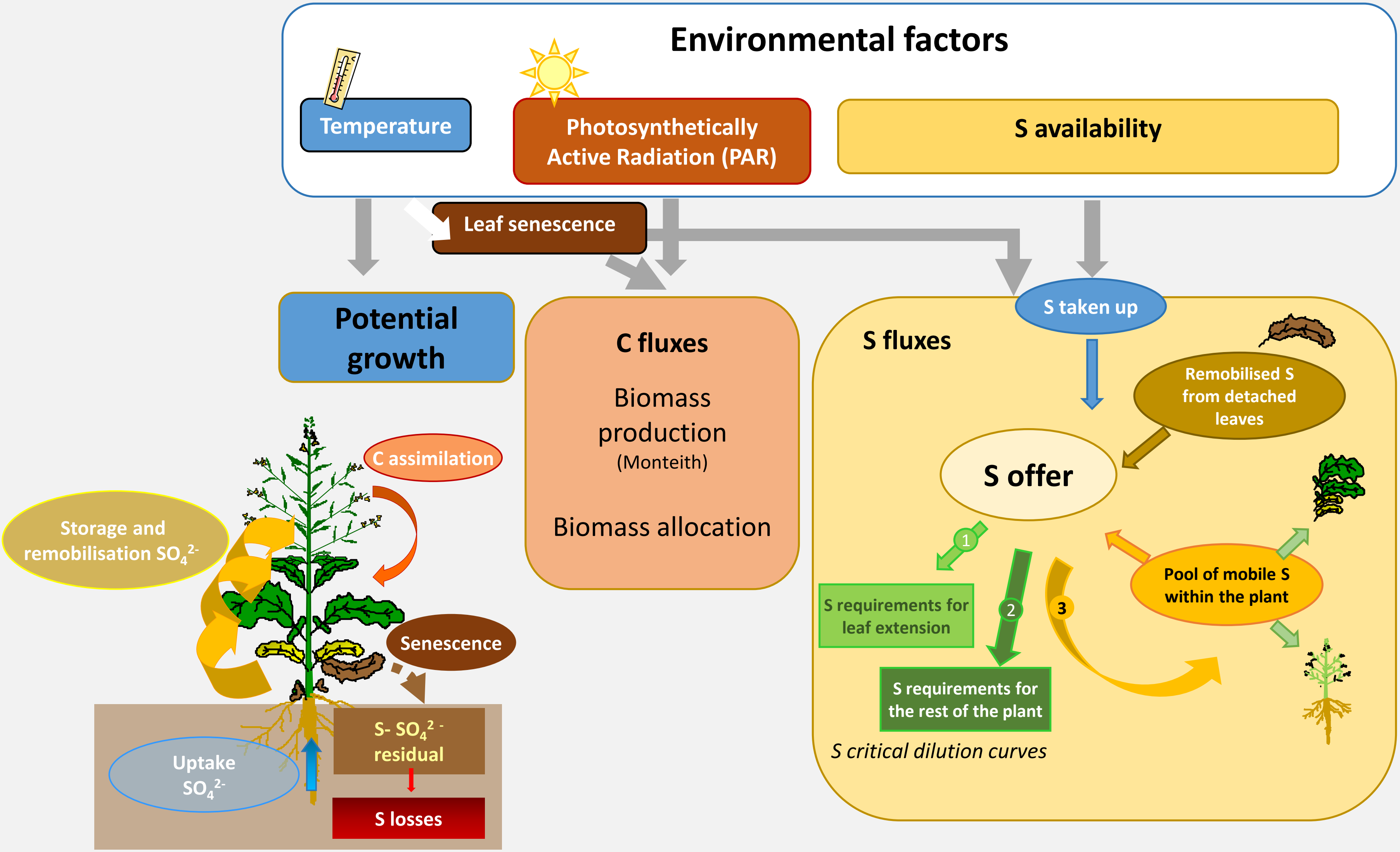
- Leaves are the major **source of S** = 80% of total S at bolting
- **Sequential senescence leads to important S losses**
- Leaves are the main site for photosynthesis and the main source for carbohydrate

% S allocation to the leaves





Description of the model SuMoToRI



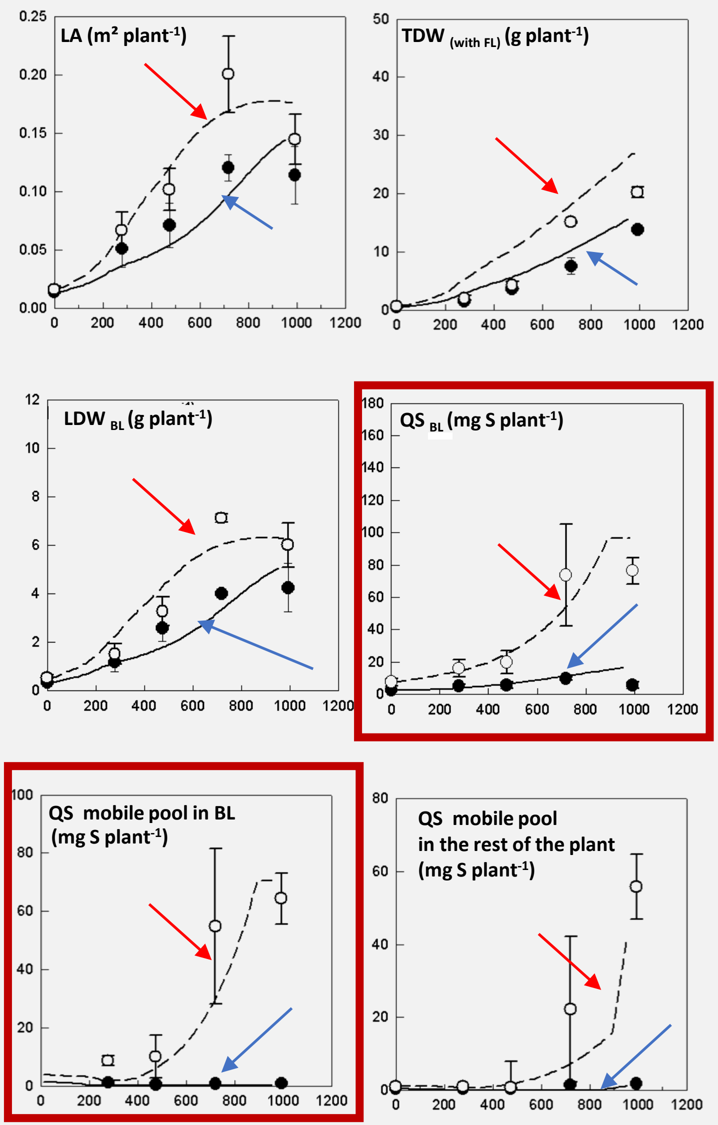
OUTPUT VARIABLES *until the onset of pod formation*

Biomass, S amounts, Fractions of organic and mineral S (~potential of remobilization)

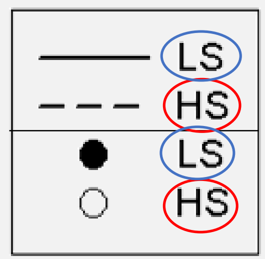
In the three compartements (BIG LEAF, Detached Leaves, Rest of the plant)

Simulations outputs

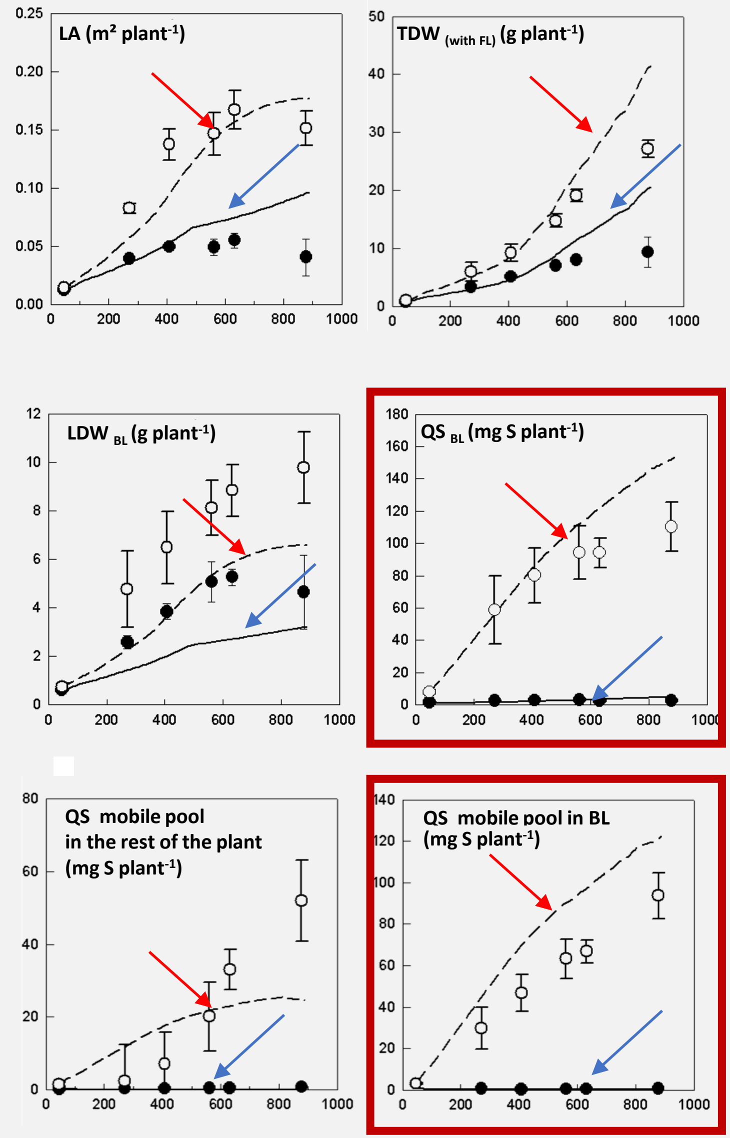
Model calibration (greenhouse dataset 2011)



Thermal time after vernalization (°Cd, Tb=5)



Model evaluation (greenhouse dataset 2013)

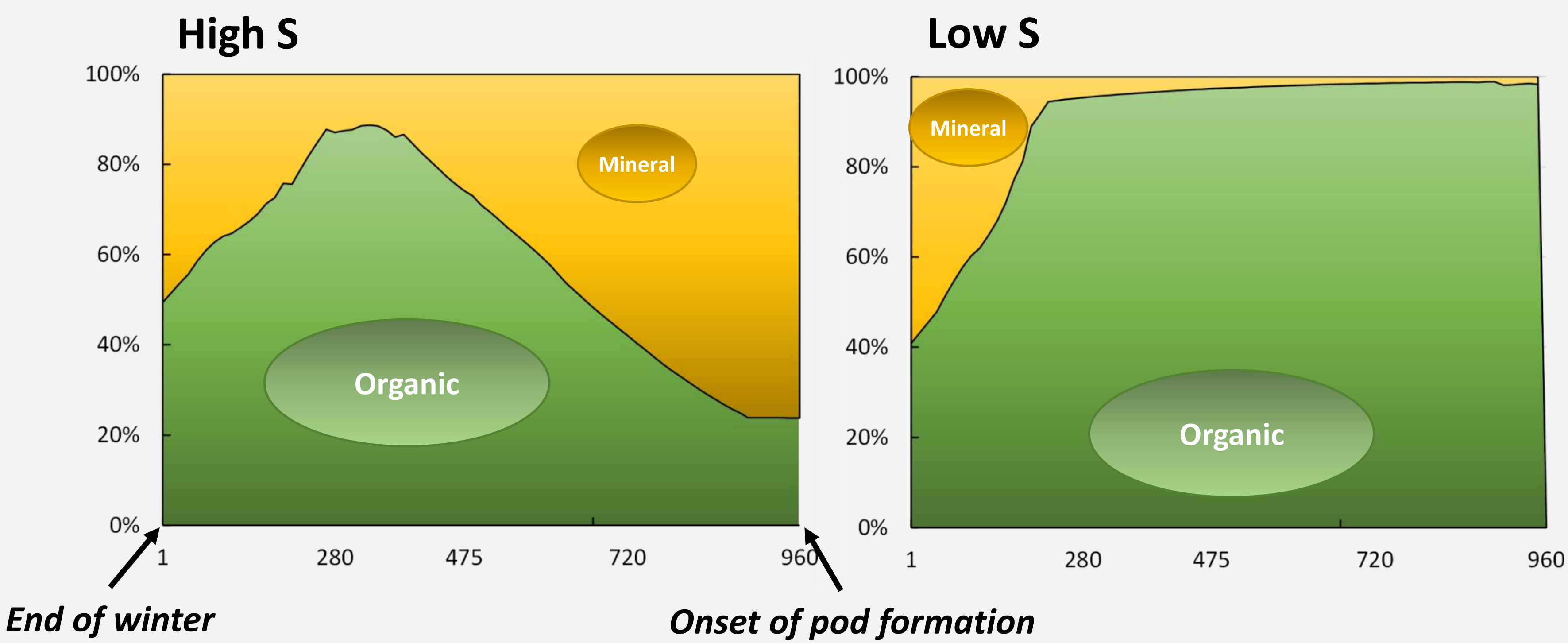


Thermal time after vernalization (°Cd, Tb=5)

Brunel-Muguet *et al.* 2015

S-pools partitioning : mineral (sulfates) vs. organic (structural + metabolic) fraction

→ An estimation of the potential for S remobilisation toward growing sinks at later stages (pods)



Thermal time after end of winter (°Cd, Tb5)

Perspectives

- **Expanding** the **prediction period** until **seed maturity** :

  → Green Area Index including pod area especially when green leaf area starts declining at the onset of pod formation

- Finer description of mobile S pool :

  → Are other forms involved in remobilization under LS?

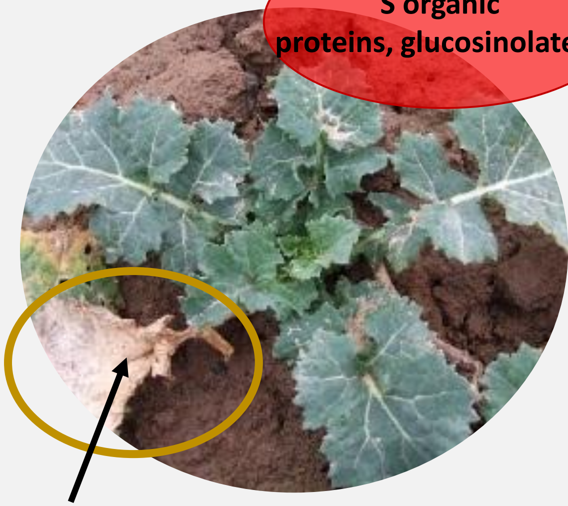
  → Methiine ? (Gaudin 2013)

  → Are other organs involved in remobilization throughout growth?

- Sensitivity analyses

Adaptation for other Brassica?

Oilseed rape

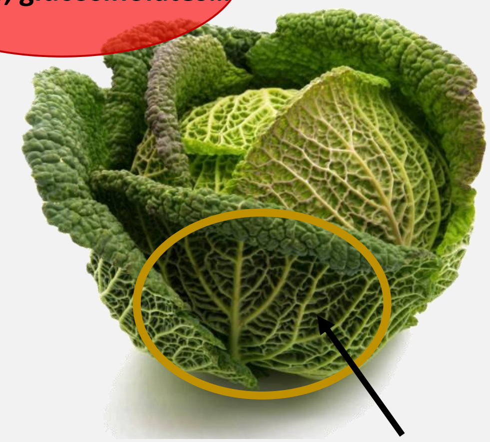


S organic
proteins, glucosinolates…

SO_4^{2-}
storage and
remobilization

detached leaves

Cabbage



SO_4^{2-}
storage and
remobilization
?

S organic
proteins, glucosinolates…

senesced leaves

Methiine
Glutathione
Cystein
SMM
SAM
↓
Mobile pool for remobilisation?

Some food for thought

- **Compartments**

No more detached leaves: senescence followed by leaf detachement is very specific to WOSR → adaptation of the remobilization equations

- **Indicators**

- Is SO_4^{2-} still the most important S mobile form used for remobilisation?
- Which are the most relevant compounds to predict organoleptic properties ?
  → glucosinolate ?

Thank you for your attention

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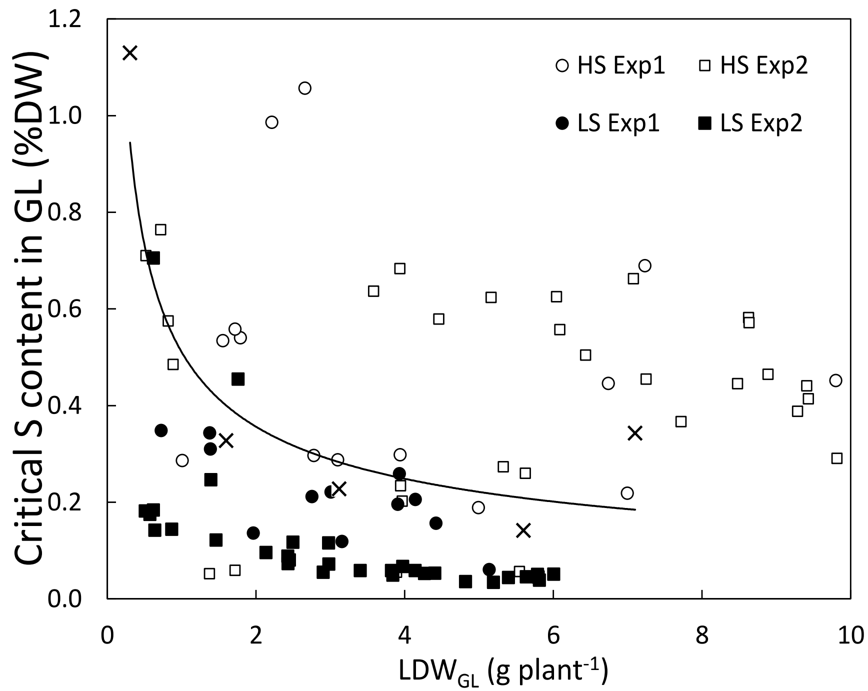
Estimations of critical requirements in S

Dilution curve based on N critical dilution curves calibrated for rapeseed (Colnenne et al. 1998)

But…luxury uptake in SO_4^{2-} that is not **readily assimilated unlike NO3-**
-> [Critical S] = [Total S] – [S-SO_4^{2-}]



Plant Parameters: definition

TABLE 2 | Symbols, definitions and units of the parameters used in the equations presented in the Appendices.

Symbol	Definition	Unit	Equations
Sowing condition			
ds	Plant density	plant m^{-2}	
PAR interception			
k	PAR extinction coefficient	m^2 m^{-2}	Eq. 2
S uptake			
QS_{ini}	Initial S uptake	mg S $plant^{-1}$	Eq. 5
aQS	Parameters of the function describing QS as a function of TT	mg S $plant^{-1}$	
bQS		$°Cd^{-1}$	
Potential leaf growth			
LA_0	Initial leaf area of photosynthetic leaves	m^2 $plant^{-1}$	Eq. 1
LA_{max}, K, *n*	Leaf area expansion parameters	m^2 $plant^{-1}$, °Cd, dimensionless	
C acquisition and plant offer			
$PARabs_{ini}$	Initial absorbed PAR	MJ m^{-2}	Eq. 2
TDW_{ini}	Initial total dry weight	g DW $plant^{-1}$	
RUE	Radiation use efficiency	g DW MJ^{-1}	
DW_{FLini}	Initial dry weight of fallen leaves	g DW $plant^{-1}$	Eq. 12
$aLDW_{FL}$	Parameters of the function describing the time progression of dry	g DW $plant^{-1}$ $°Cd^{-1}$	
$bLDW_{FL}$	Weight of the fallen leaves	dimensionless	
C allocation to leaves			
β	Coefficient of dry weight allocation to the leaves	dimensionless	
Big leaf C demand			Eq. 3
$LDW_{BL\ ini}$	Initial dry weight of the big leaf	g DW $plant^{-1}$	
SLA	Specific leaf area	m^2 g DW^{-1}	
Growth S demand			
α_{BL}, β_{BL}	Parameters to estimate critical S content in BL as a function of the dry weight of the BL	mg S $plant^{-1}$ dimensionless	Eq. 7
α_{rest}, β_{rest}	Parameters to estimate critical S content in the rest of the plant as a function of dry weight of the rest of the plant	mg S $plant^{-1}$ dimensionless	Eq. 9
Mobile S allocation to leaves			
ε_{pot}	Coefficient of potential repartition of mobile S to the leaves	dimensionless	Eq. 17

Plant Parameters: values

données serre 2011 (Exp1)

TABLE 3 | Parameter values of *SuMoToRI* used for model calibration under HS and LS conditions (with dataset from Experiment 1).

Symbol	Definition	HS		LS	Unit	Source
PAR interception						
k	PAR extinction coefficient		$k = 0.75$		$m^2\ m^{-2}$	Bonhomme et al., 1982
Potential leaf growth						
LA_{max}	Leaf area expansion parameters		$LA_{max} = 0.20$		$m^2\ plant^{-1}$	Estimated
K			$K = 872.96$		$°Cd^{-1}$	
N			$n = 6.31$		dimensionless	
C acquisition and plant offer						
RUE	Radiation use efficiency	4.59		3.11	$g\ DW\ MJ^{-1}$	Estimated
$aLDW_{FL}$	Parameters of the function describing the time		0.0092		$g\ DW\ plant^{-1}\ °Cd^{-1}$	Estimated
$bLDW_{FL}$	progression of LDW_{FL}		0.0043		dimensionless	
C allocation to leaves						
β	Coefficient of DW allocation to the leaves		0.41		dimensionless	Estimated
C demand of the big leaf						
SLA	Specific leaf area		0.028		$m^2\ g\ DW^{-1}$	Estimated
Growth S Demand						
α_{BL}	Parameters to estimate critical S content in BL as a		5.11		$mg\ S\ plant^{-1}$	Estimated
β_{BL}	function of LDW_{BL}		−0.52		dimensionless	
		For LS: threshold value $[S]_{BL}crit = 3\ mg\ S\ g\ DW^{-1}$ for $LDW_{BL} < 3\ g\ plant^{-1}$				
α_{rest}	Parameters to estimate critical S content in the rest of the plant as a function of DW_{rest}		1.83		$mg\ S\ plant^{-1}$	Estimated
β_{rest}			−0.004		dimensionless	
Potential mobile S allocation to leaves						
ε_{pot}	Coefficient of potential repartition of mobile S to the leaves		0.8		Dimensionless	Estimated

Values genericity except for RUE

Initial state
données serre 2011 (Exp1) et 2013 (Exp2)

TABLE 4 | Initial state values under HS and LS conditions for model calibration (Experiment 1) and evaluation (Experiment 2).

Symbol	HS-Experiment 1	HS-Experiment 2	LS-Experiment 1	LS-Experiment 2	Unit
Potential leaf growth					
LA_0	0.016	0.014	0.013	0.014	m^2 $plant^{-1}$
C acquisition and plant offer					
$PARabs_{ini}$	0	0	0	0	$MJ\ m^{-2}$
TDW_{ini}	0.652	1.031	0.428	0.778	g DW $plant^{-1}$
DW_{FLini}	0	0.05	0	0.04	g DW $plant^{-1}$
C demand of the big leaf					
$LDW_{BL\ ini}$	0.510	0.736	0.328	0.589	g DW $plant^{-1}$
S uptake					
QS_{TOTini}	8.799	10.594	2.865	1.939	mg S $plant^{-1}$
aQS	7.540	23.457	3.14	2.207	mg S $plant^{-1}$
bQS	0.0033	0.0026	0.0021	0.0014	$°Cd^{-1}$
QS_{BLini}	7.48	7.89	2.40	1.38	mg S $plant^{-1}$
$QS_{restini}$	1.32	2.26	0.47	0.55	mg S $plant^{-1}$

aQS and bQS are the parameters of the S uptake function. Their values are adjusted for each experiment (input variables).