How implementing a model with Vensim PLE ? – example of the ModVege model

Florence Garcia-Launay, Anne-Isabelle Graux

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– example of the ModVege model

F. Garcia-Launay & A.-I. Graux

INRA UMR PEGASE unit www.rennes.inra.fr/pegase

anne-isabelle.graux@inra.fr
florence.garcia-launay@inra.fr

Agrocampus Ouest
TD modélisation
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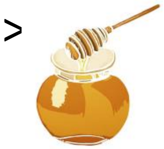
Maintaining grasslands is important

Different grasslands that serve **different benefits** for people

Provisioning

- Fodder =>
- Pollen =>



Cultural

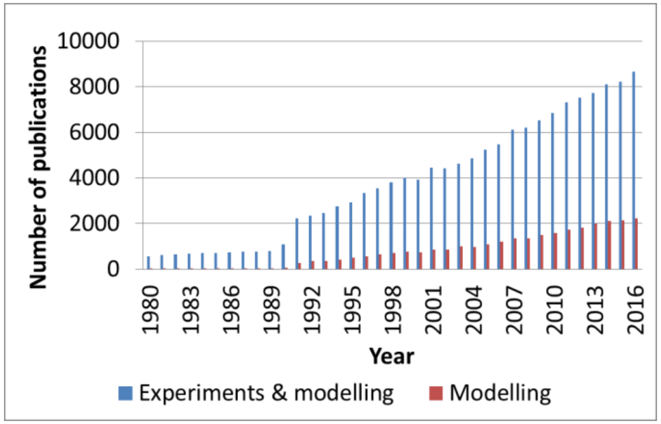
- Landscape maintenance & quality
- Recreation & tourism
- Quality of life

Regulation

- Climate (C storage)
- Nutrient cycling
- Soil erosion
- Water quality
- Biodiversity conservation

Grasslands are threatened

- Fodder deficits due to **climate change & extremes events** => Resilience of grasslands?
- **Grasslands are replaced by maize**, easier to manage
- Growing **pressure on agricultural lands**



⇒ ⬀ **Research works** (experiments & modelling) **since 1990's**

⇒ Modelling grasslands allows adressing **questions on the long term**, accounting for **environmental factors & interactions**, and providing **a lot of informations**

What is a grassland?

- **Single or pluri-species formation** which generally (not always!) consists of a majority of **grasses**, and can also contain **legumes** and/or **dicotyledons**
- **Exists thanks to herbage removals** by grazing and cutting
- **2 types** of grasslands **according to** their **duration** and **species composition**
  - ***Permanent grasslands*** : reseeded every five years or more; multispecies
  - ***Sown/temporary grasslands*** : reseeded every few years to maximize the amount of biomass they provide; monospecies (grass or legume), mixture of several grass/or legume species

What is a grassland?

- **Grassland location** in cropland **and its production level** (e.g. type of soil and vegetation) **conditions its use** (e.g. grazing vs cutting; dairy heifers vs cows)
- The **availability of soil resources** and the **management** (grazing severity, cutting frequency, fertilisation) conditions the biological attributes (called « **functional traits** ») **of the vegetation**

⇒ **A functional classification of grasslands** into 4 plant functional types (PFT) was proposed by Cruz et al. (2002)

A (first) functional classification of grasslands*

Cruz et al., 2002. Fourrages

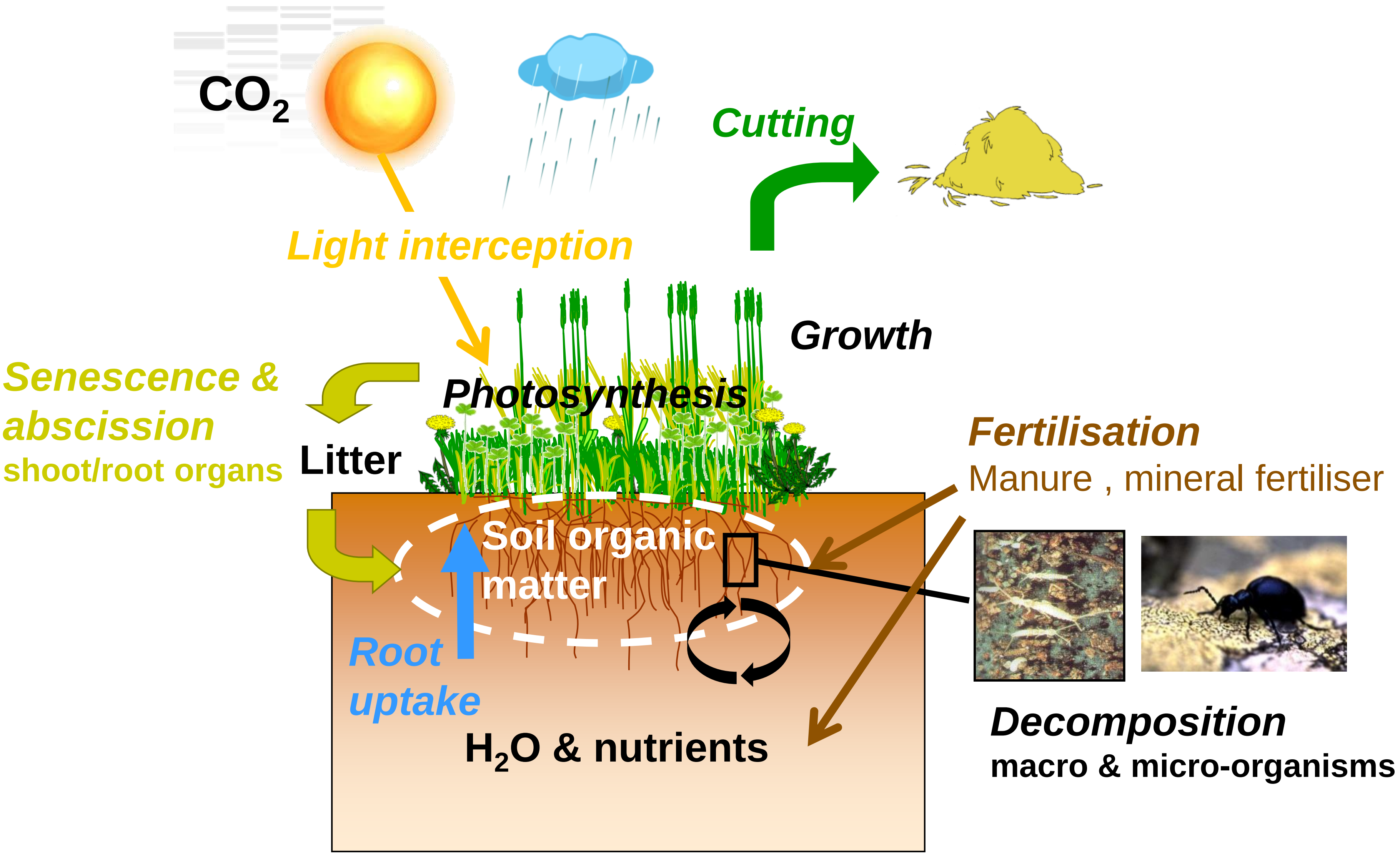
	Rich/fertile sites	Poor/infertile sites
Frequent defoliation	**Group A** *Ex: Lolium perenne, Holcus lanatus* High SLA High digestibility Short leaf lifespan Early reproductive growth & flowering	**Group C** *Ex: Festuca rubra, Agrotis capillaris* Low SLA Medium digestibility Long leaf lifespan Late reproductive growth & flowering
Infrequent defoliation	**Group B** *Ex: Dactylis glomerata, Arrhenaterum elatius* Medium SLA High digestibility Long leaf lifespan	**Group D** *Ex: Briza media, Brachypodium pinnatum* Low SLA Low digestibility Very Long leaf lifespan Late reproductive growth & flowering

* This classification was revised by Cruz et al.(2010)

One grassland = a% Group A + b% Group B + c% Group C + d% Group D

=> Useful to **simplify model parameterisation** and account for **functional diversity**

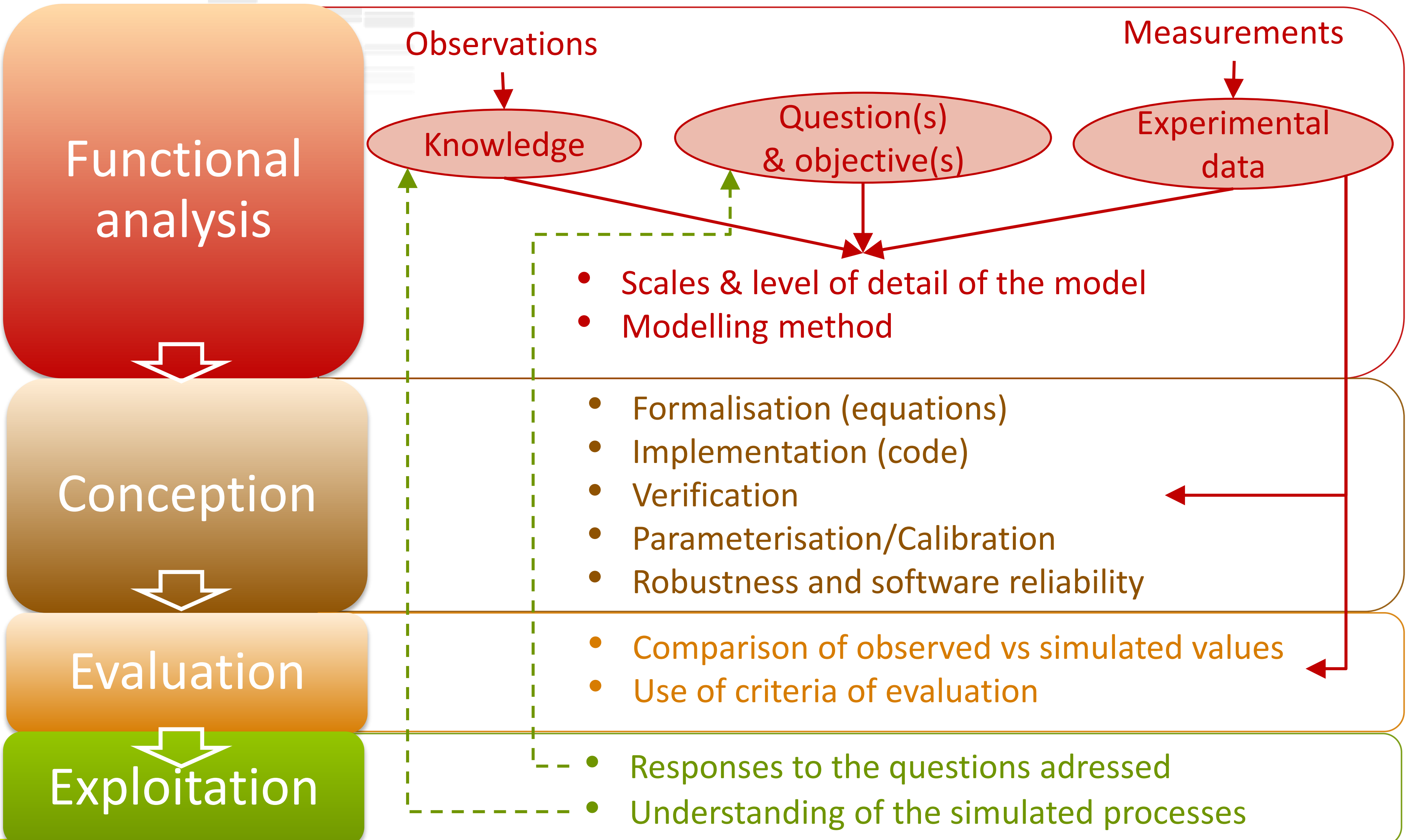
How it works?



CO_2
Cutting
Light interception
Growth
Senescence & abscission
shoot/root organs
Litter
Photosynthesis
Fertilisation
Manure , mineral fertiliser
Soil organic matter
Root uptake
H_2O & nutrients
Decomposition
macro & micro-organisms

The modelling approach : 4 steps

Adapted from Coquillard & Hill, 1997and Hirooka, 2010



Why modelling grasslands ? The example of the ModVege model

- ***Scientific objective***
  - to simulate the dynamics of the **biomass production, structure** and **forage quality** in response to management and climate, in case of permanent pastures and temperate regions
- ***Operational objective***
  - to use this model in a **whole farm simulator** to represent each grassland field

⇒ has to be **simple** ! (not to model each species separately …)

⇒ outputs = **inputs for** an intake and production **model of ruminant livestock**

Why modelling grasslands ? The example of the ModVege model

- *Main assumptions*

1. **Botanical composition** = association (in constant %) of functional groups of species with similar functional traits (Cruz et al., 2002) **: functional approach !**
2. **Sward heterogeneity** = the relative abundance of 4 structural plant components
3. **Growth, senescence & abscission** = continuous flows
4. **Seasonal pattern of shoot growth** = functional trait
5. **Quality (digestibility) of green compartments, senescence and abscission** are affected by compartment ageing
6. During harvest, **10% of the harvestable biomass is lost**

Vegetation compartimentation

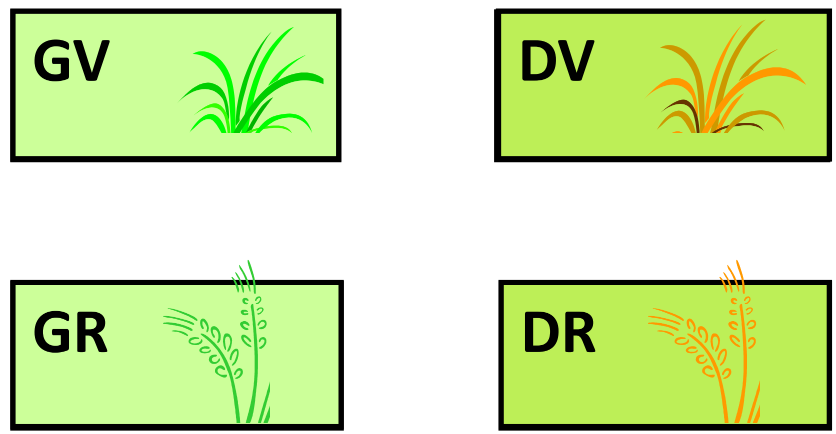
Jouven et al., 2006. Grass and Forage Science

Sward heterogeneity
= **4 structural shoot compartments**

Green (G) **Dead (D)**

2 **vegetative (V)** compartments
= leaves and sheaths

2 **reproductive (R)** compartments
= stems and flowers



Each structural compartment = **3 states variables**
- Standing **biomass** (**BM**)
- Age (**AGE**)
- Organic matter digestibility (**OMD**)

GV compartment **+1 state variable** : **leaf area index** (**LAI**)

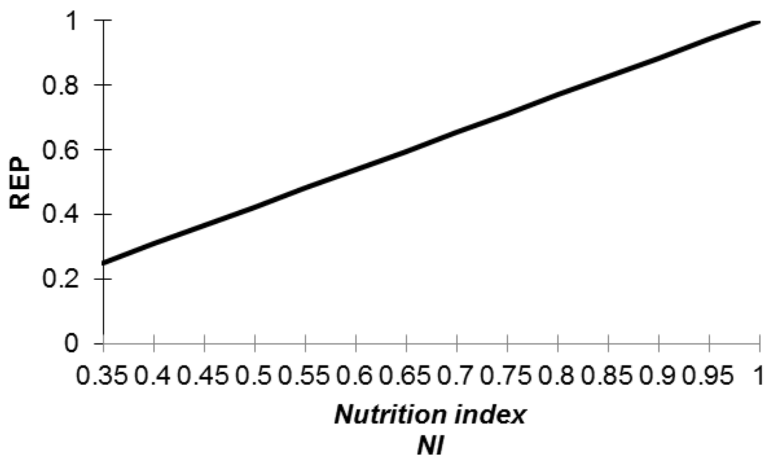
Partitioning of growth between vegetative and reproductive green comparments

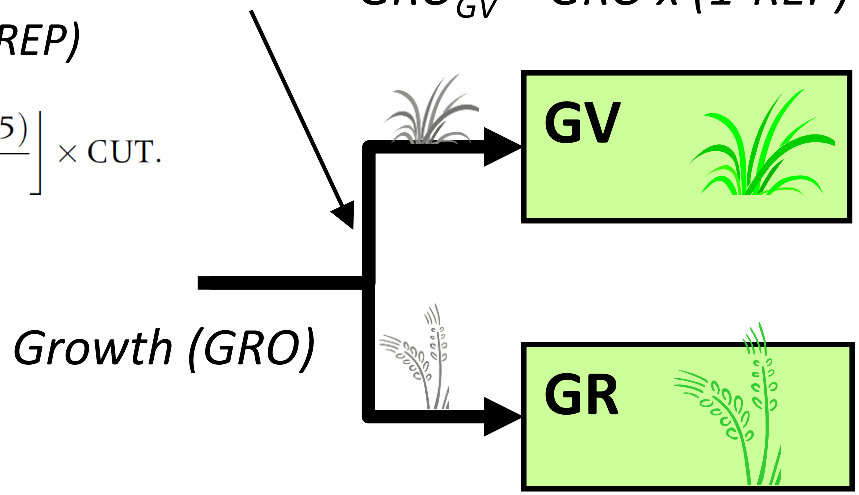
During the reproductive growth, growth is distributed between GV & GR = Reproductive function *(REP)*

$GRO_{GV} = GRO \times (1-REP)$

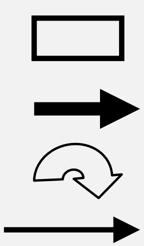
if $ST_1 \leq ST \leq ST_2$ $\quad REP = \left[0.25 + \frac{(1-0.25)\times(NI-0.35)}{1-0.35}\right] \times CUT.$

Else REP = 0





$GRO_{GR} = GRO \times REP$

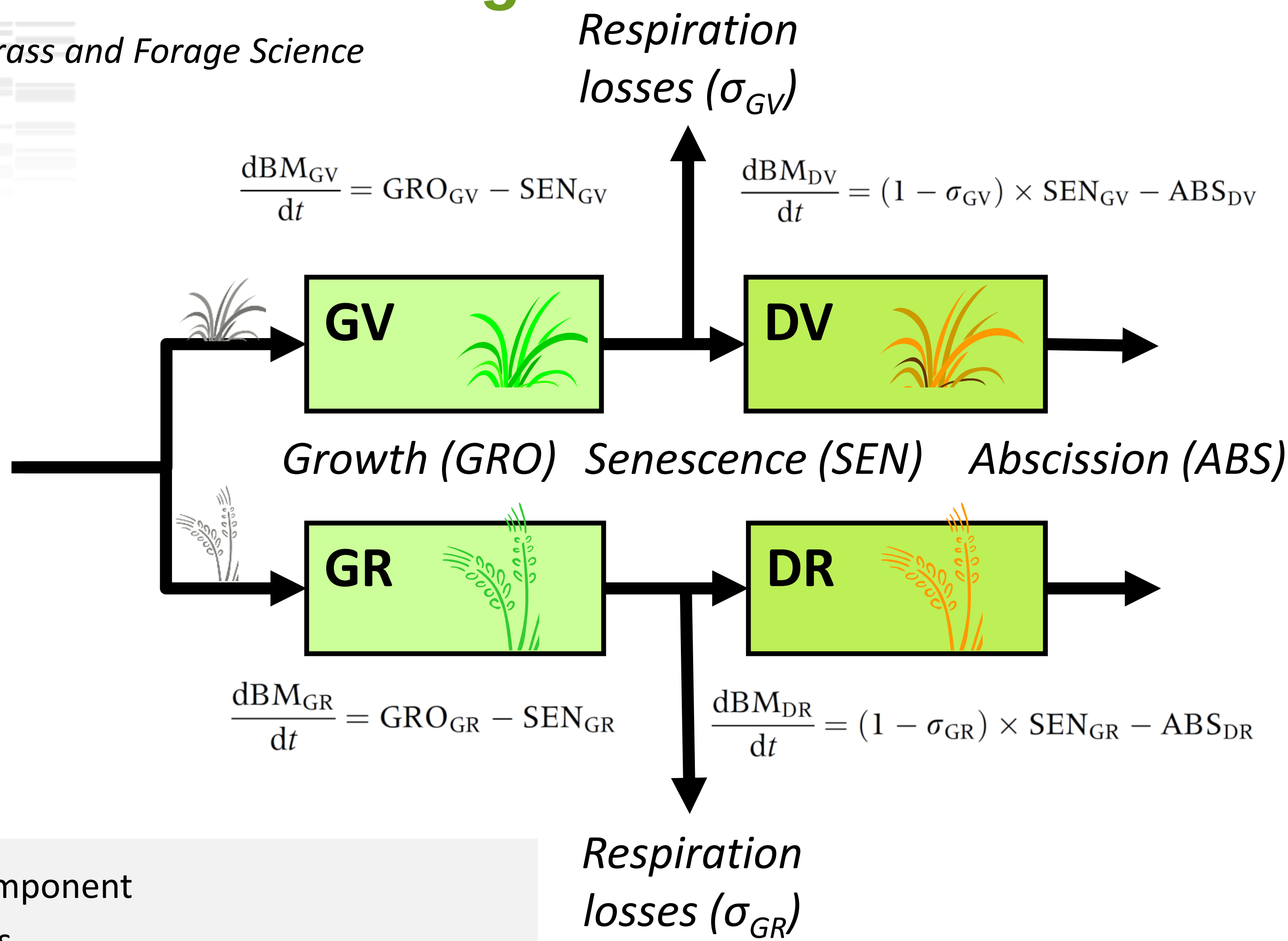


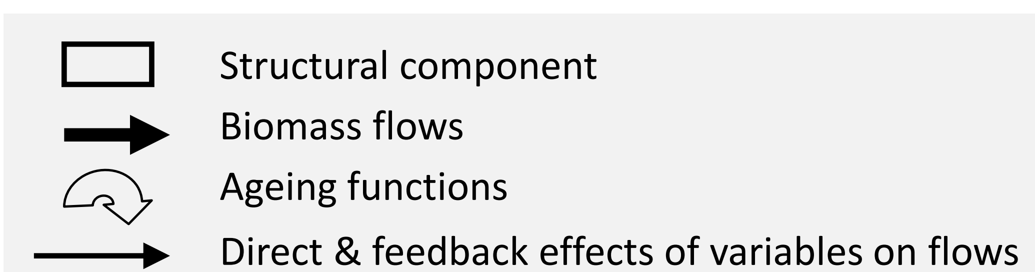
Structural component
Biomass flows
Ageing functions
Direct & feedback effects of variables on flows

- If a cut occurs during the reproductive period, reproductive growth is stopped (REP = 0)
- Only 1 cycle of reproductive growth is modeled

Calculation of the standing biomass

Jouven et al., 2006. Grass and Forage Science

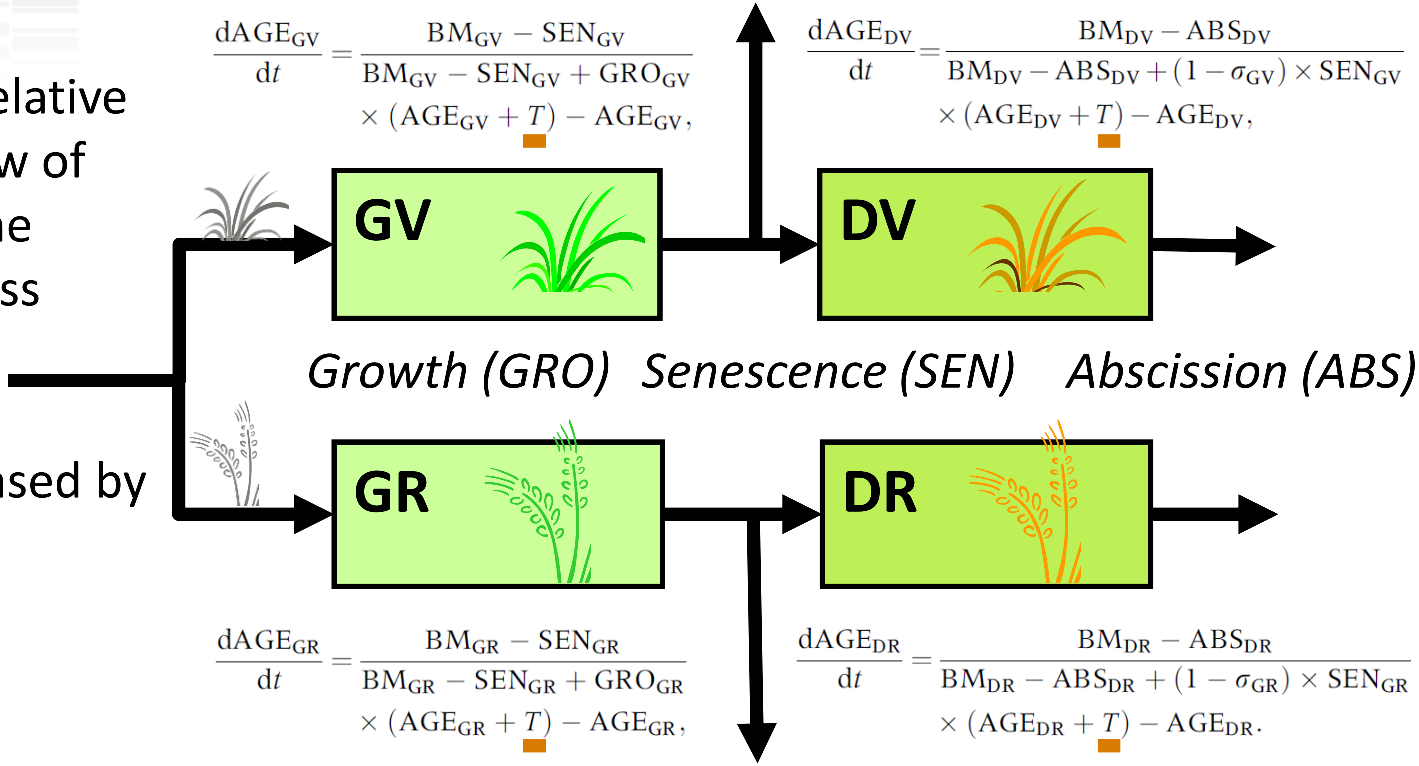




Calculation of the age

Jouven et al., 2006. Grass and Forage Science

- Age can ⬀ or ⬂ depending on the relative impacts of the inflow of new biomass and the ageing of old biomass
- The age is increased by the daily mean temperature (when positive)



$$\frac{dAGE_{GV}}{dt} = \frac{BM_{GV} - SEN_{GV}}{BM_{GV} - SEN_{GV} + GRO_{GV}} \times (AGE_{GV} + T) - AGE_{GV},$$

$$\frac{dAGE_{DV}}{dt} = \frac{BM_{DV} - ABS_{DV}}{BM_{DV} - ABS_{DV} + (1 - \sigma_{GV}) \times SEN_{GV}} \times (AGE_{DV} + T) - AGE_{DV},$$

$$\frac{dAGE_{GR}}{dt} = \frac{BM_{GR} - SEN_{GR}}{BM_{GR} - SEN_{GR} + GRO_{GR}} \times (AGE_{GR} + T) - AGE_{GR},$$

$$\frac{dAGE_{DR}}{dt} = \frac{BM_{DR} - ABS_{DR}}{BM_{DR} - ABS_{DR} + (1 - \sigma_{GR}) \times SEN_{GR}} \times (AGE_{DR} + T) - AGE_{DR}.$$

Structural component
Biomass flows
Ageing functions
Direct & feedback effects of variables on flows

Calculation of the organic matter digestibility

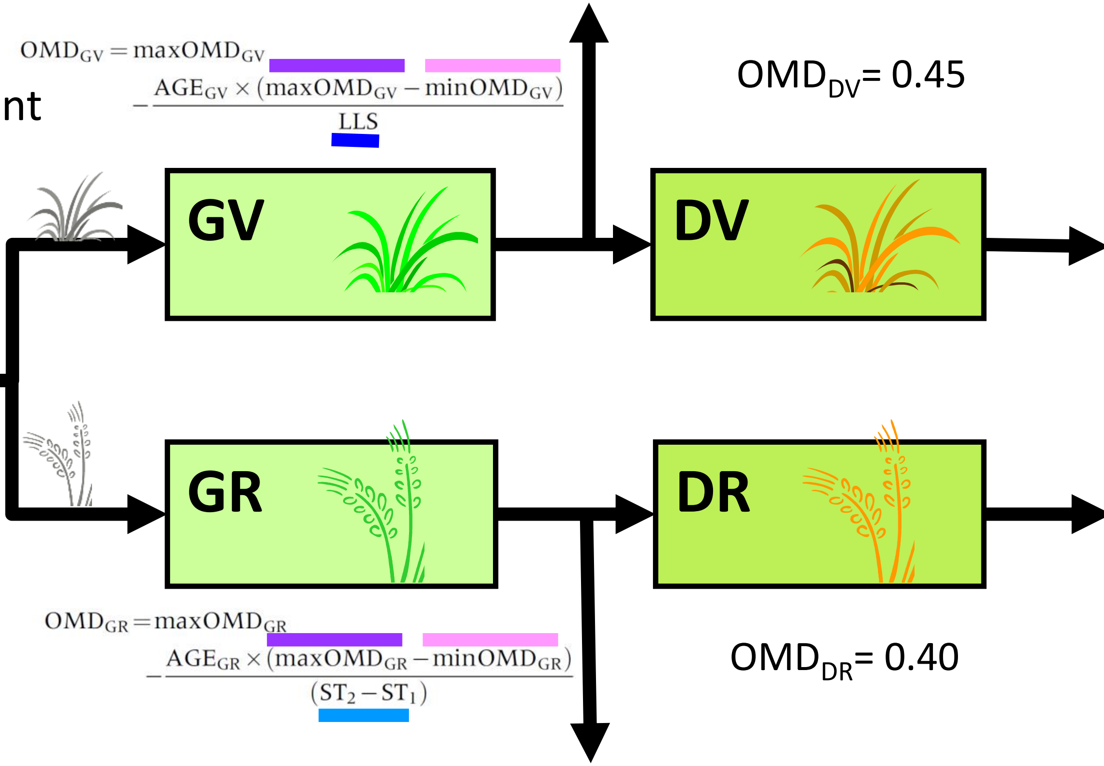
Jouven et al., 2006. Grass and Forage Science

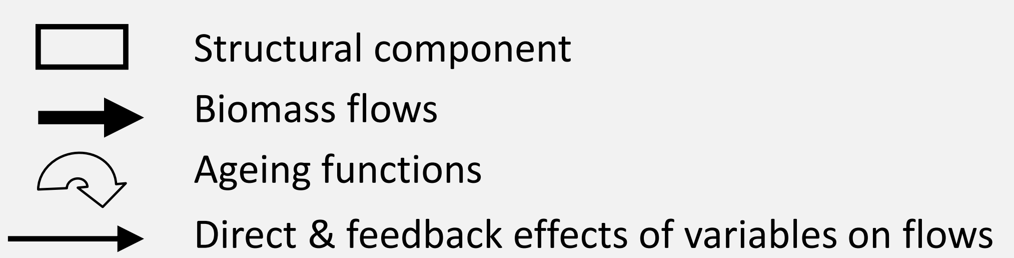
- OMD of dead compartments is constant
- OMD of green compartments
  - ↘ linearly with AGE

from a maximum (at AGE=0)

to a minimum (at maximum AGE)

  - The maximum AGE corresponds to:
    - leaf life span (LLS) for GV
    - duration of the reproductive period (ST2-ST1) for GR





Calculation of growth functions

- ***Shoot growth (GRO)***

$$GRO = PGRO \times ENV \times SEA$$

- Actual growth
- Potential growth (optimum conditions)
- Limitation by environmental variables (climate conditions, soil resources)
- Seasonal pattern of shoot growth (reserve storage/mobilisation)

$$PGRO = PAR_i \times RUE_{max} \times [1-\exp(-0.6 \times LAI)] \times 10$$

- Incident photosynthetically active radiation
- Radiation use efficiency (constant)
- Leaf area index

- ***Leaf area index (LAI)***

$$LAI = SLA \times BM_{GV} / 10 \times \%LAM$$

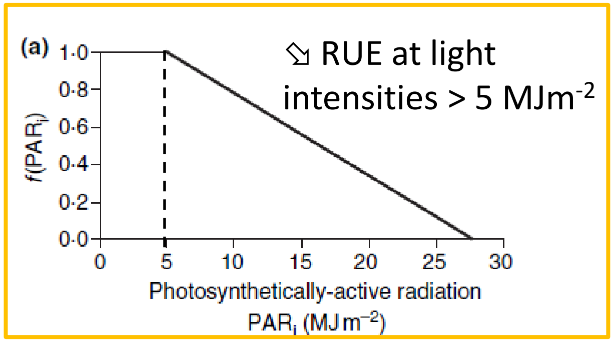
- Specific leaf area (constant)
- GV biomass
- Percentage of laminae in GV (constant)

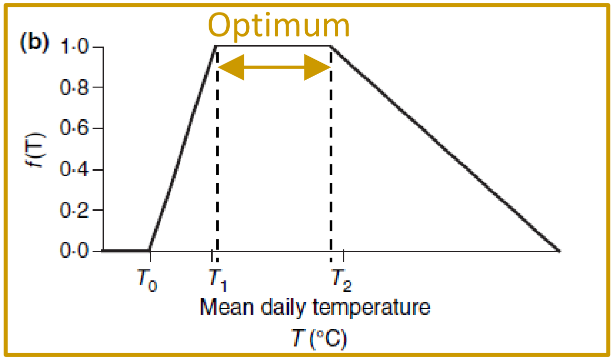
Calculation of growth functions

- ***Limitation by environmental variables***

$$\color{teal}{ENV} = \mathbf{NI} \times f(PAR_i) \times f(T) \times f(W)$$

- Nutrition index (site specific, constant)
- Influence of PAR_i
- Influence of temperature
- Influence of water availability





- Water stress (W)

$$W = \frac{WR}{WHC}$$

$$\text{where } WR = \max(0,\ WR + PP - AET)$$

$$\text{and } AET = \min\left[PET; PET \times \frac{LAI}{3}\right].$$

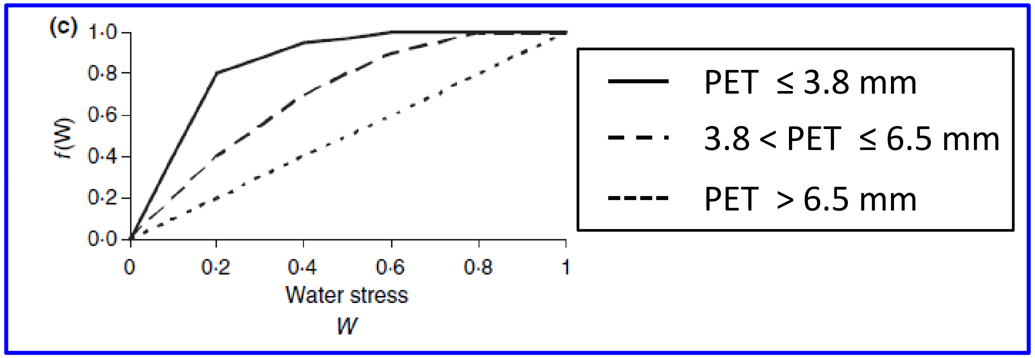
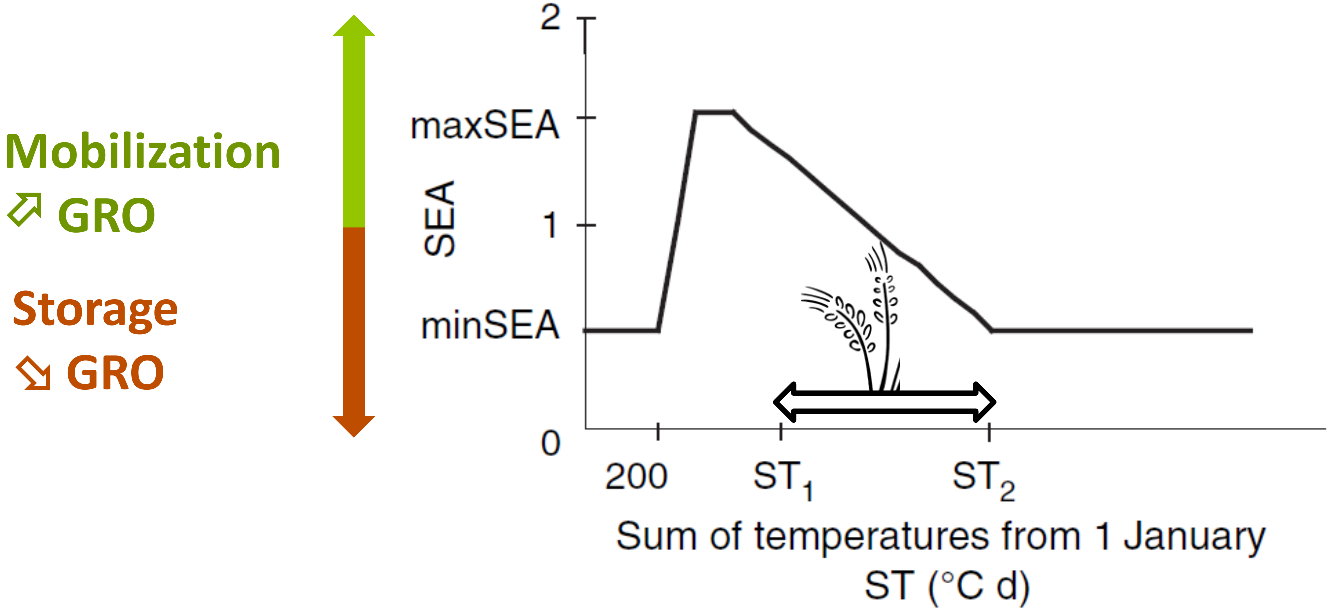


Figure 2 Threshold functions representing growth limitation

Calculation of growth functions

- ***Seasonal pattern of storage/mobilisation of reserves***
  - Empirical function (SEA)
    - ST < 200°C d (winter) = minimum (minSEA)
    - ST1-200 < ST < ST1-100 (growth) : ⬀ to a maximum (maxSEA)
    - ST1-100 < ST < ST2 (summer) : ⬂
    - ST > ST2 (after the end of reproductive growth) = minSEA

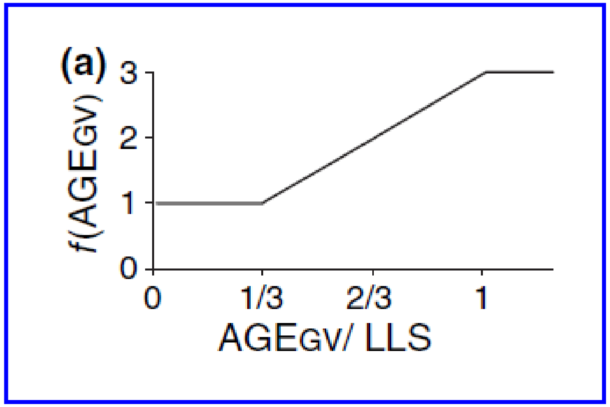


Calculation of senescence & abscission functions

- ***Senescence of green compartments***

$SEN_{GV} = 0$ if $0 \leq T \leq T_0$

$SEN_{GV} = K_{GV} \times BM_{GV} \times T \times f(AGE_{GV})$ if $T > T_0$
and similarly for compartment GR



and

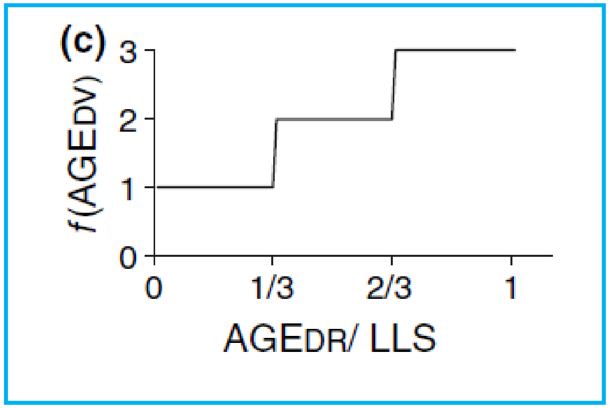
$SEN_{GV} = K_{GV} \times BM_{GV} \times |T|$ if $T < 0$,
and similarly for compartment GR.

(Freezing effect)

- ***Abscission of dead compartments***

if $T > 0$,

$ABS_{DV} = Kl_{DV} \times BM_{DV} \times T \times f(AGE_{DV})$ and,
similarly, for compartment DR.



Calculation of the harvested biomass

- ***Residual biomass after cutting***

The pasture is considered to be cut 5 cm above ground level

$$resBM_{GV} = 0.05 \times 10 \times BD_{GV} \text{ and, similarly,}$$
$$\text{for compartments GR, DV and DR}$$

- ***Harvested biomass in each structural component***

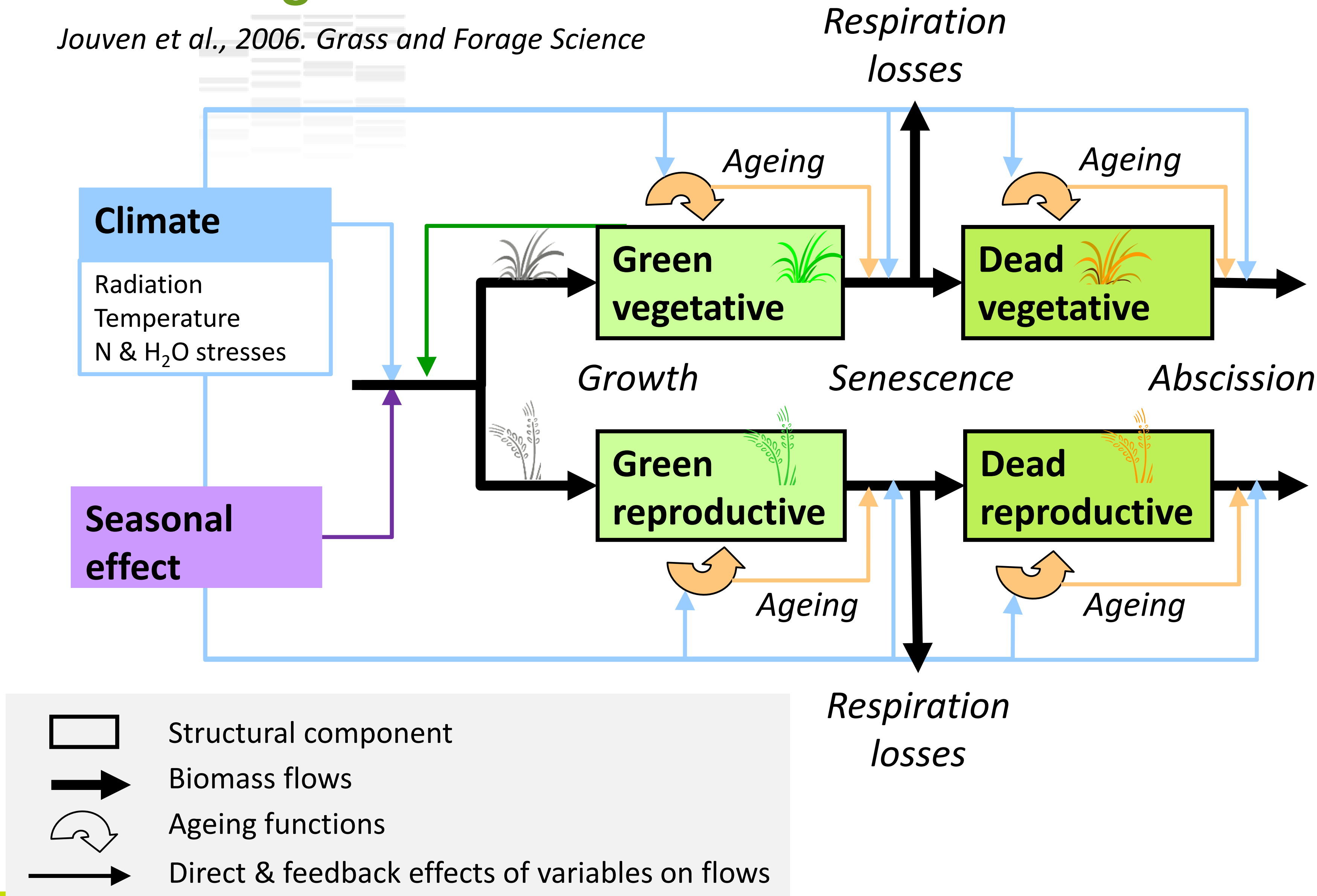
$$hBM_{GV} = BM_{GV} - resBM_{GV} \text{ and similarly}$$
$$\text{for compartments GR, DV, DR}$$

- ***Total harvested biomass***

$$hBM = hBM_{GV} + hBM_{GR} + hBM_{DV} + hBM_{DR}$$

Flow diagram of the model

Jouven et al., 2006. Grass and Forage Science



Model parameterisation

Jouven et al., 2006. Grass and Forage Science

- ***Specific to functional groups***

Table 2. Estimation of the functional traits for groups A–D, described in Table 1 (Cruz *et al.*, 2002).

Functional trait	Value for functional group A	B	C	D	Sources
SLA ($m^2\ g^{-1}$)	0·033	0·025	0·022	0·019	Cruz *et al.* (2002)
%LAM	0·68	0·68	0·68	0·68	Louault *et al.* (2005)
ST_1 (°C d)	600	700	850	1000	Ansquer *et al.* (2004);
ST_2 (°C d)	1200	1350	1550	1850	Louault *et al.* (2005)
maxSEA	1·20	1.30	1.40	1.50	Bausenwein *et al.*(2001);
minSEA	0.80	0.70	0.60	0.50	Thornton *et al.*(1993, 1994)
LLS (°C d)	500	800	900	1400	Ansquer *et al.* (2004)
$maxOMD_{GV}$	0.90	0.90	0.85	0.75	Terry and Tilley (1964); Demarquillly
$minOMD_{GV}$	0.75	0.60	0.65	0.65	and Chenost (1969); Duru (1997);
$maxOMD_{GR}$	0.90	0.90	0.85	0.75	Armstrong *et al.* (1986)
$minOMD_{GR}$	0.65	0.45	0.45	0.45	
BD_{GV} ($g\ DM\ m^{-3}$)	850	850	1200	800	Ferrer Cazcarra and Petit (1995);
BD_{DV} ($g\ DM\ m^{-3}$)	500	500	1800	2200	Ferrer Cazcarra *et al.* (1995);
					Ginane *et al.* (2003)
BD_{GR} ($g\ DM\ m^{-3}$)	300	300	200	150	Louault *et al.* (2005)
BD_{DR} ($g\ DM\ m^{-3}$)	150	150	300	450	

SLA, specific leaf area; %LAM, percentage of laminae; ST_1 and ST_2, initial and end reproductive growth temperatures, respectively; maxSEA and minSEA, maximum and minimal seasonal effects, respectively; LLS, leaf lifespan; OMD, organic matter digestibility; BD, bulk densities.

Model parameterisation

Jouven et al., 2006. Grass and Forage Science

- ***Common to all groups***

Table 3 Estimation of the parameter values of functional traits common to all groups.

Functional trait	Value	Sources
σ_{GV}	0.4	Ducrocq (1996)
σ_{GR}	0.2	
T_0 (°C)	4	Schapendonk *et al.* (1998)
T_1 (°C)	10	
T_2 (°C)	20	
K_{GV}	0.002	Ducrocq (1996)
K_{GR}	0.001	
Kl_{DV}	0.001	
Kl_{DR}	0.0005	
OMD_{DV}	0.45	Garcia *et al.* (2003a; b)
OMD_{DR}	0.40	

σ_{GV} and σ_{GR}, rates of biomass loss with respiration; T_0, T_1, T_2, threshold temperatures for growth; K_{GV} and K_{GR}, basic senescence rates for green vegetative (GV) and green reproductive (GR), respectively; Kl_{DV} and Kl_{DR}, basic abscission rates for dead vegetative (DV) and dead reproductive (DR), respectively; OMD, organic matter digestibility.

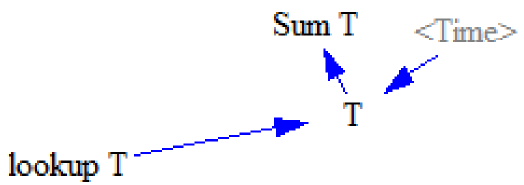
Model implementation using VenSim

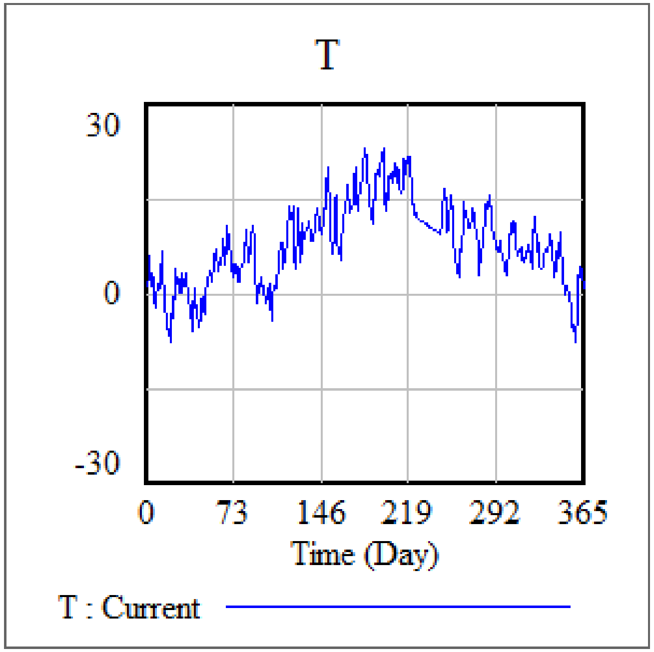
- ***A methodology***

1. Growth limitation functions
2. Growth and senescence flows for one (green) compartment, biomass
3. Reproductive function and differenciation of green vegetative/green reproductive compartment
4. Ageing of green vegetative/green reproductive compartment
5. Same for dead compartments
6. Sward digestibility and cutting
7. Simulations / results

1. Growth limitations functions

- First, start to represent the **main driving force** of the system
  Which variable will affect all the other ones?



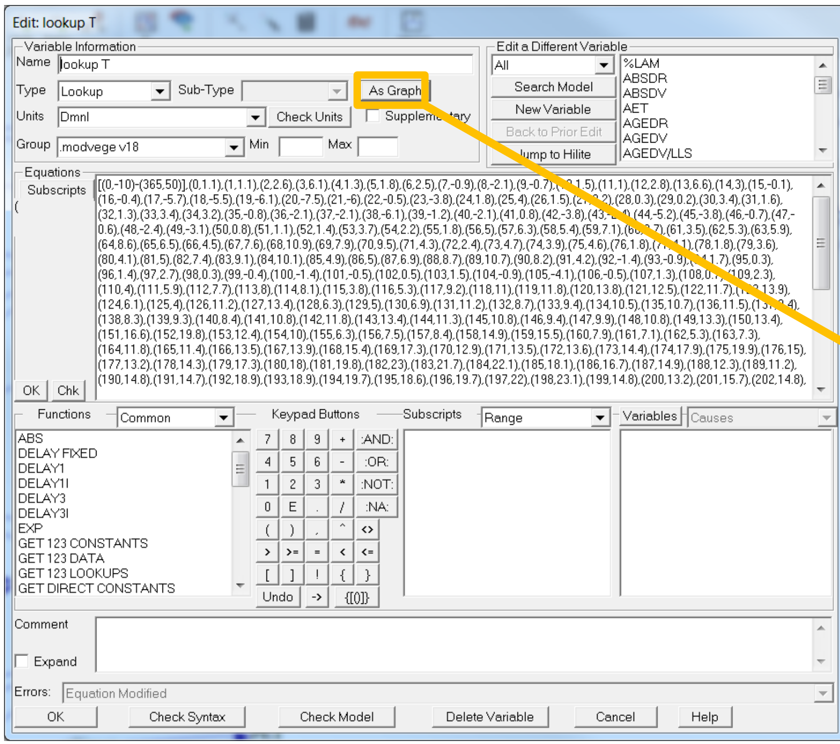


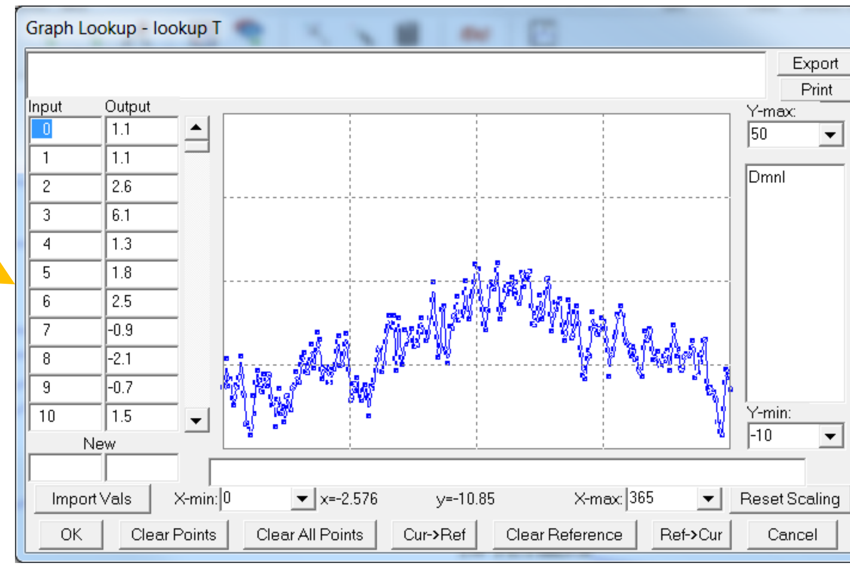
To input data use a lookup variable with the Vensim PLE version

→ **the sum of temperatures**

1. Growth limitations functions

To input data use a lookup variable with the Vensim PLE version : 2 options



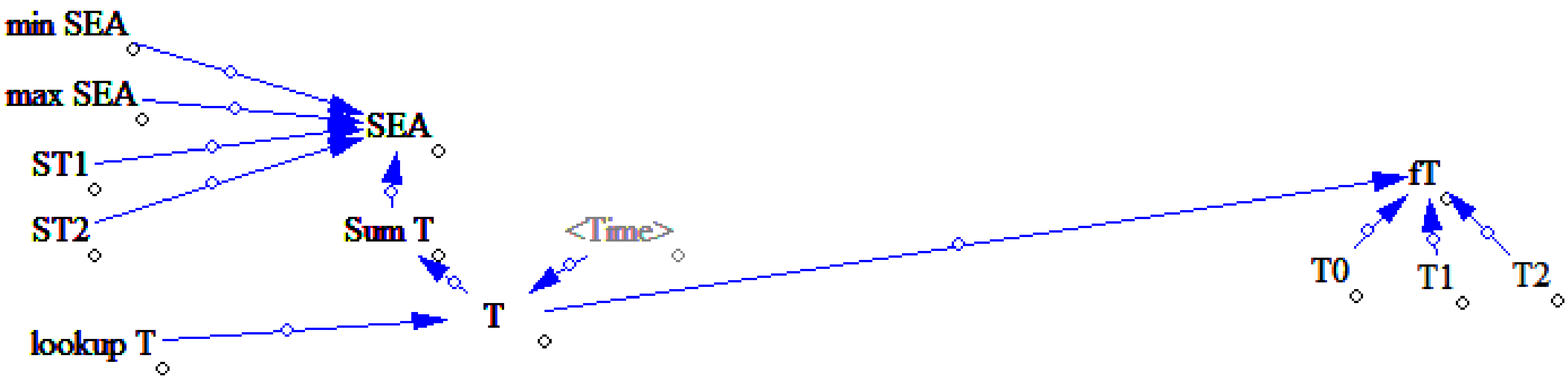


→ A Excel spreadsheet available to build and paste large input datasets (e.g. climate data)

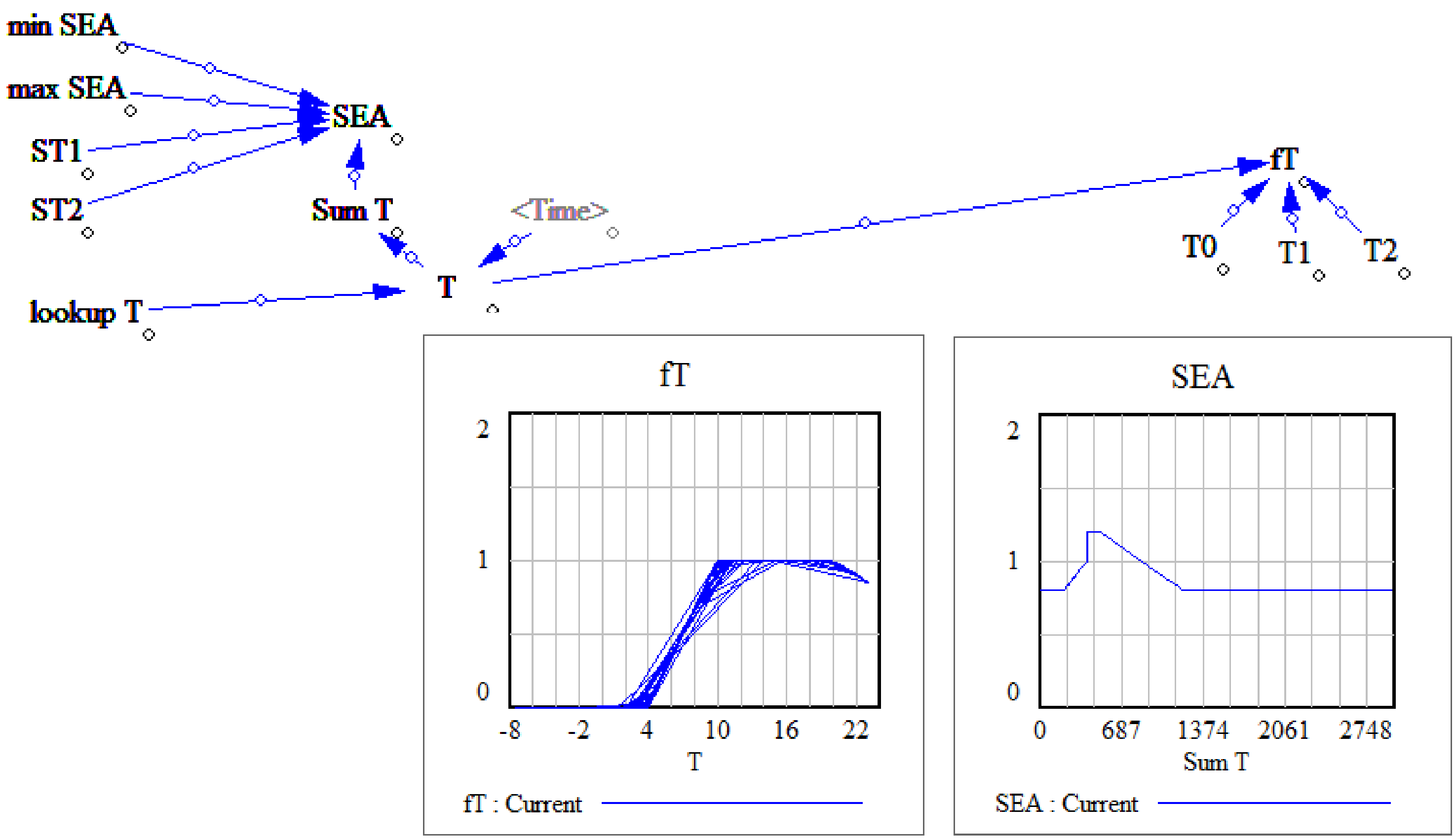
1. Growth limitations functions

- Then, choose to represent **« basic » explanatory variables**, which will not be dependent on many other ones

→ here, the **seasonal pattern of growth** and the **effect of daily temperature**



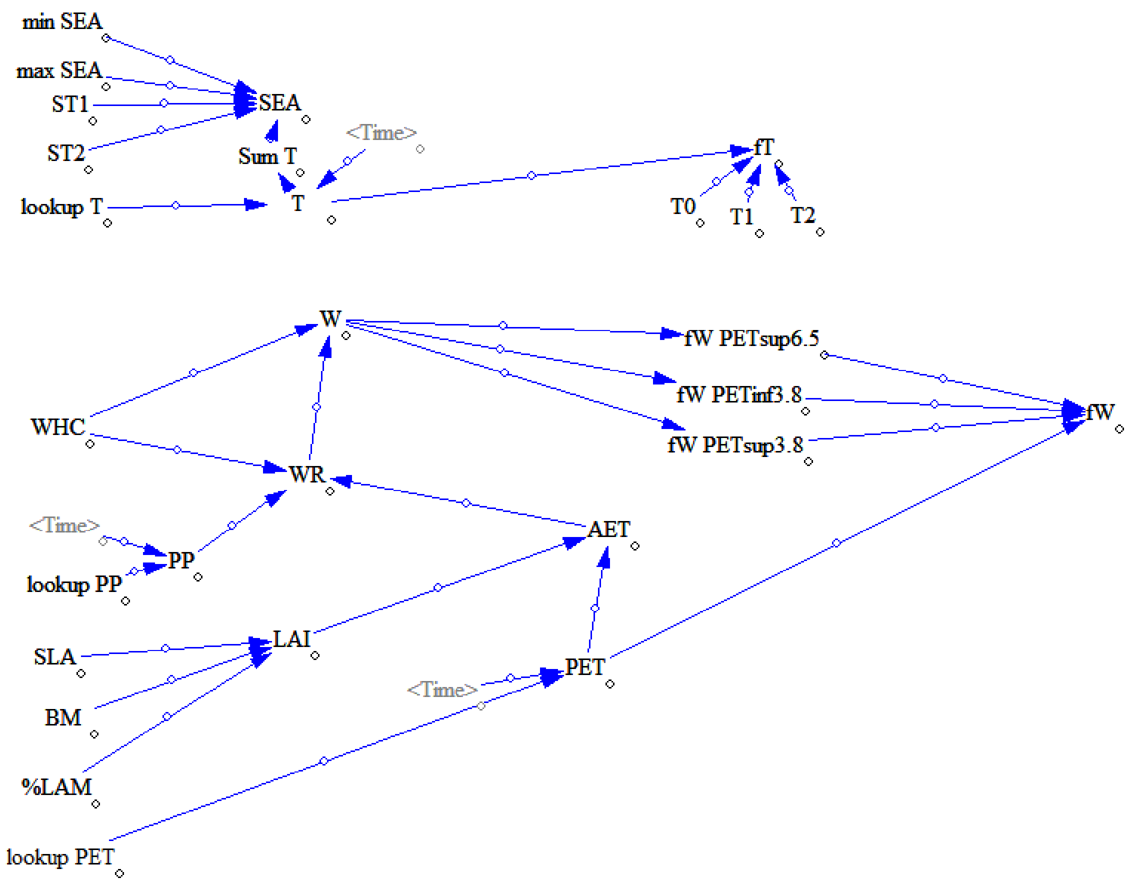
1. Growth limitations functions

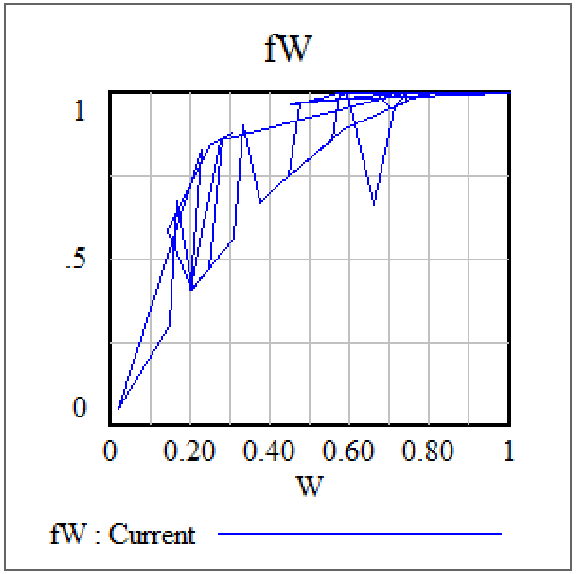


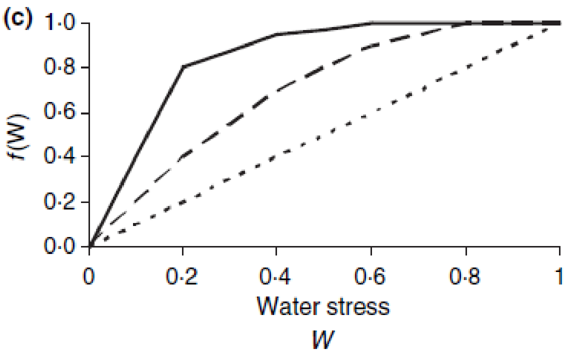
- **Check appropriate behaviour gradually** at each step with figure(s)

→ look at the paper, what do you think about these graphs?

1. Growth limitations functions

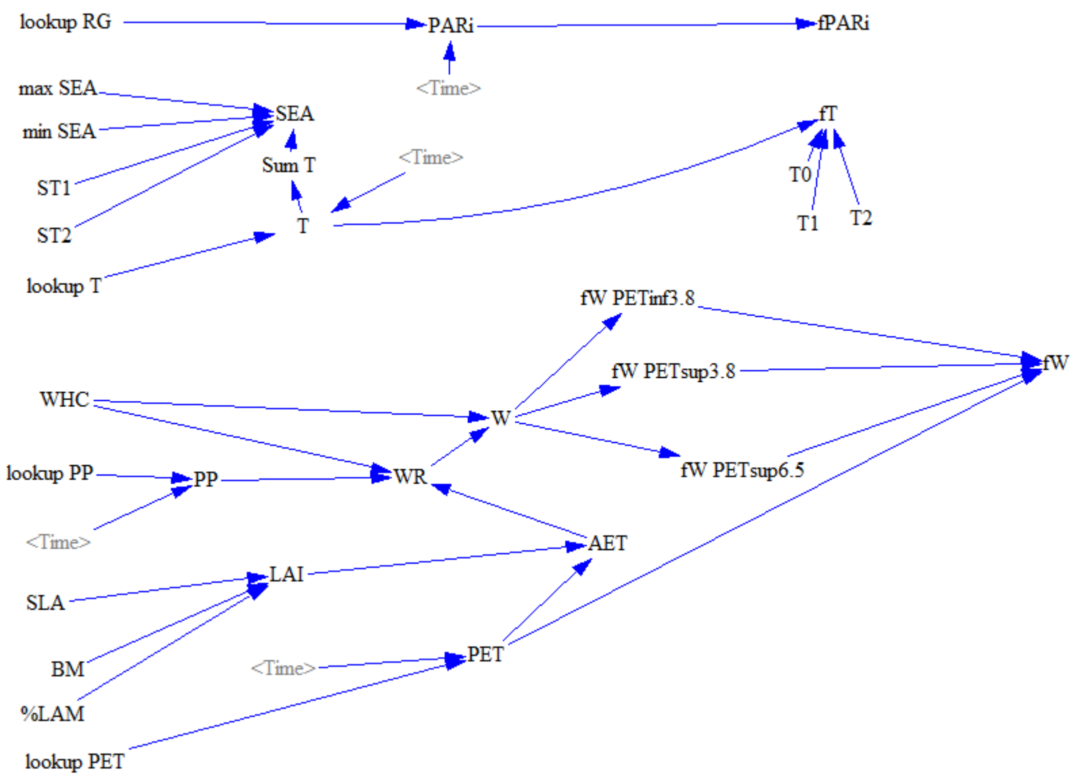


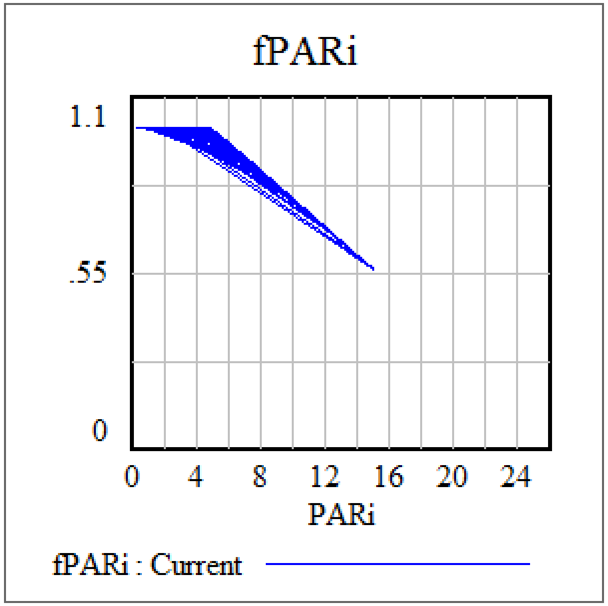




- Add the calculation of the leaf area index (LAI), and the effect of water stress on the function for limitation of growth : f(W)

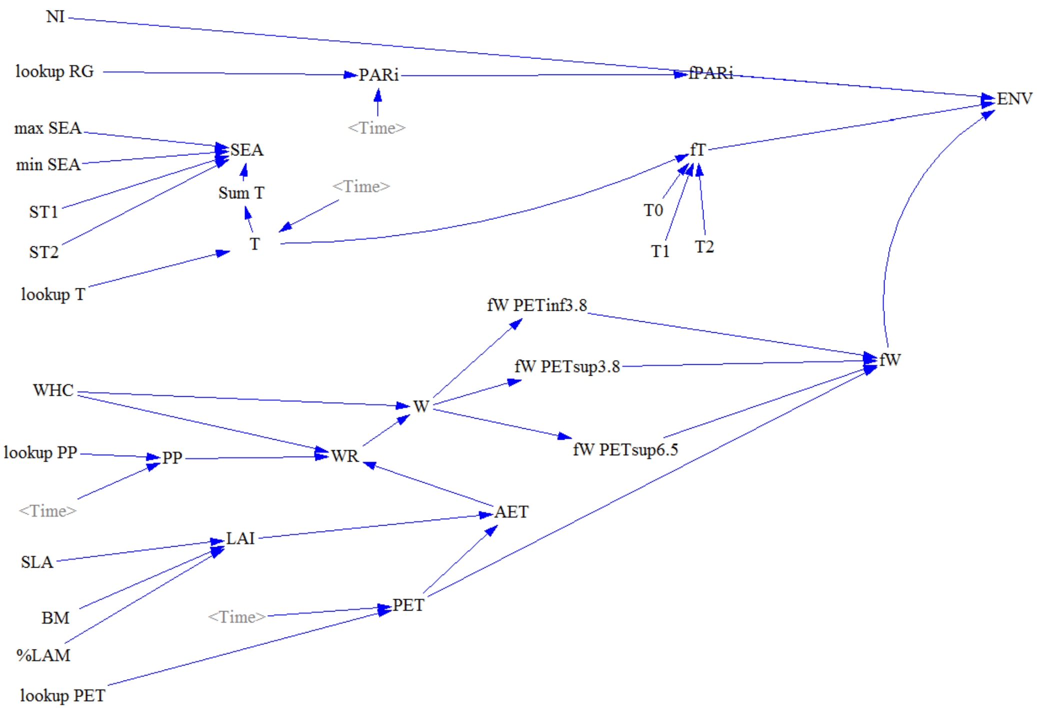
1. Growth limitations functions

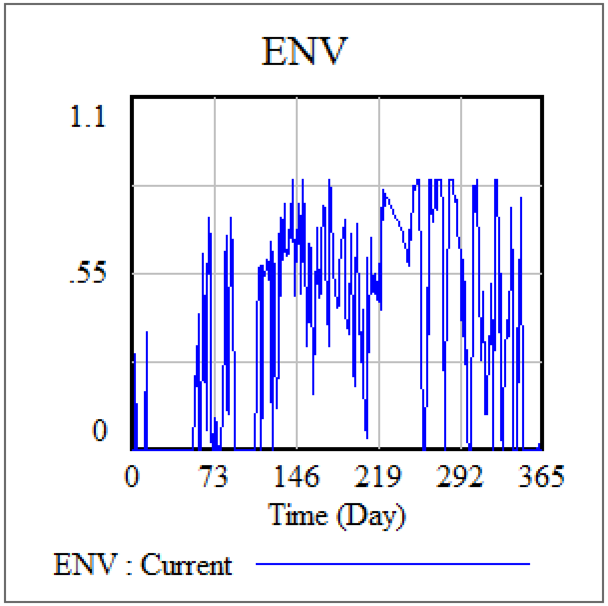




- The effect of the photosynthetically active radiation

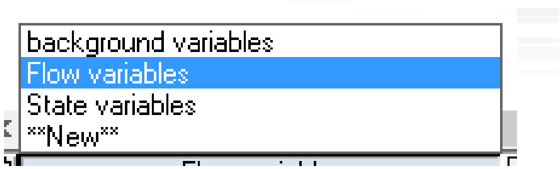
1. Growth limitations functions

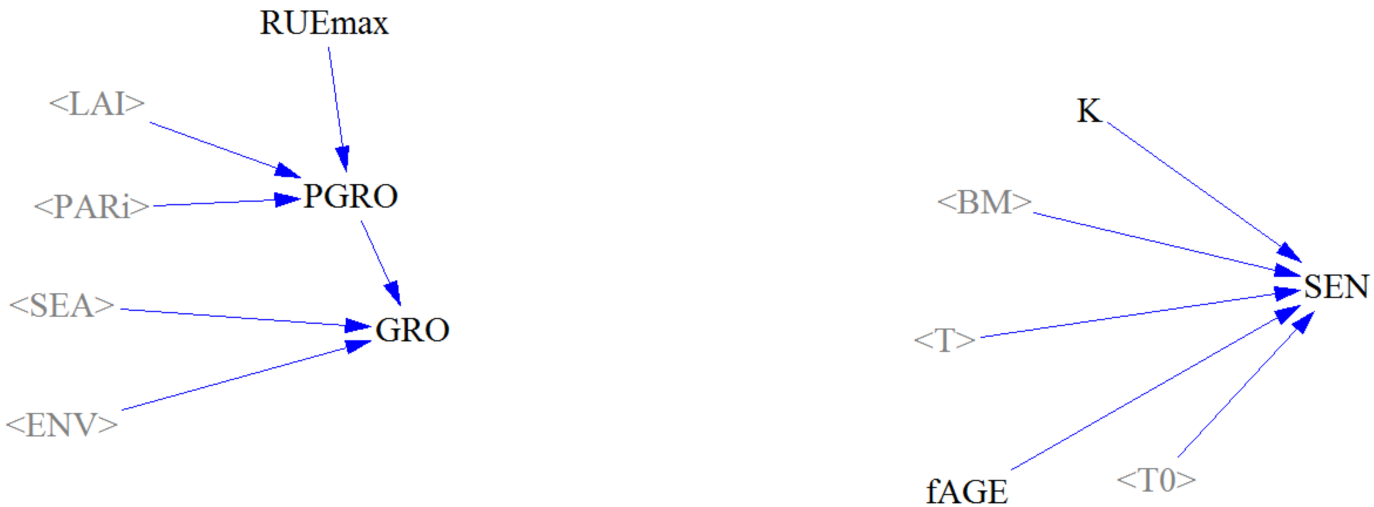




- We end up with this part → we obtain the equation for the environmental limitation of growth
- All this part in one view in Vensim → next new view

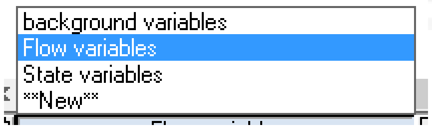
2. Growth and senescence flows for one (green) compartment, biomass

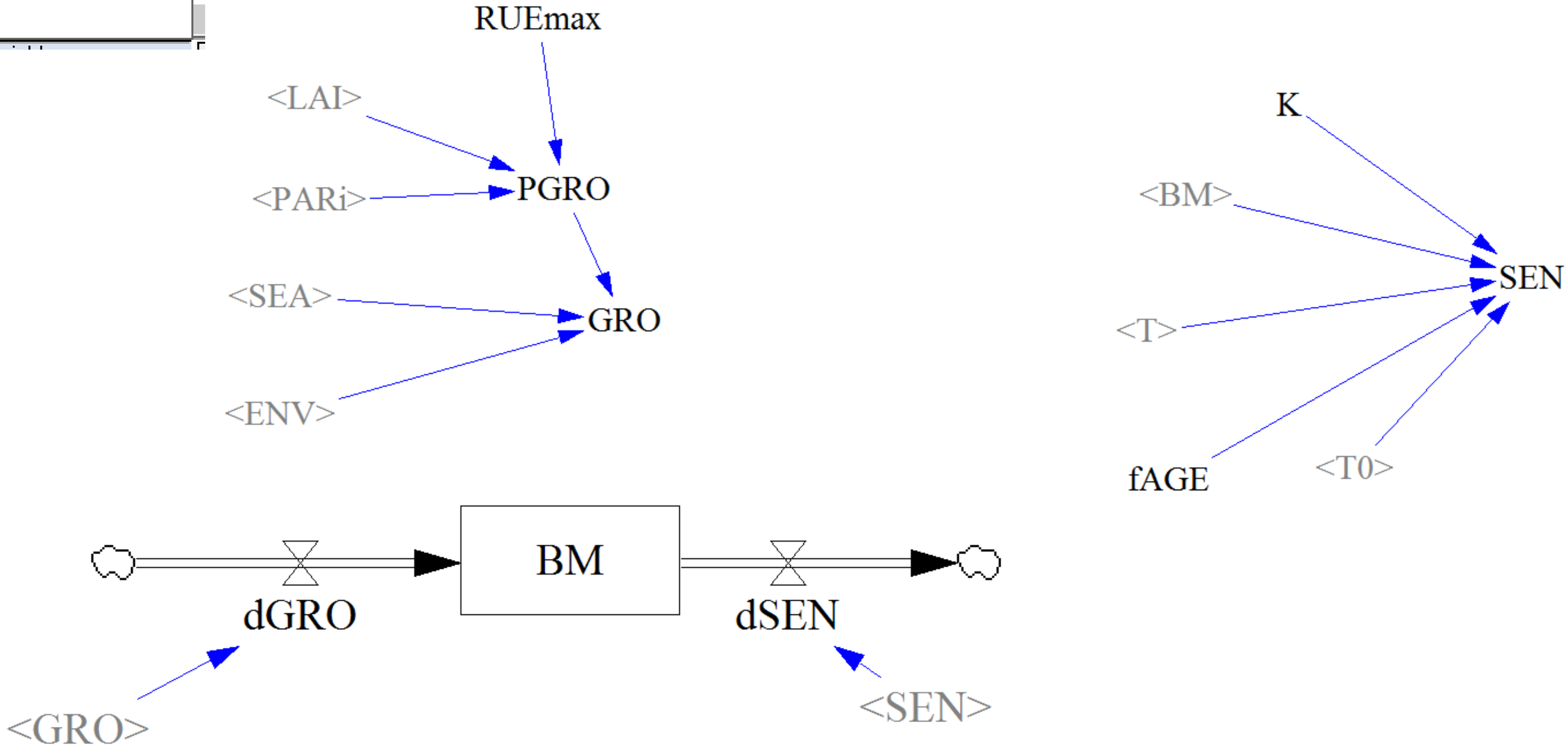




- We first try to implement protential growth, growth and senescence using some temporary variables

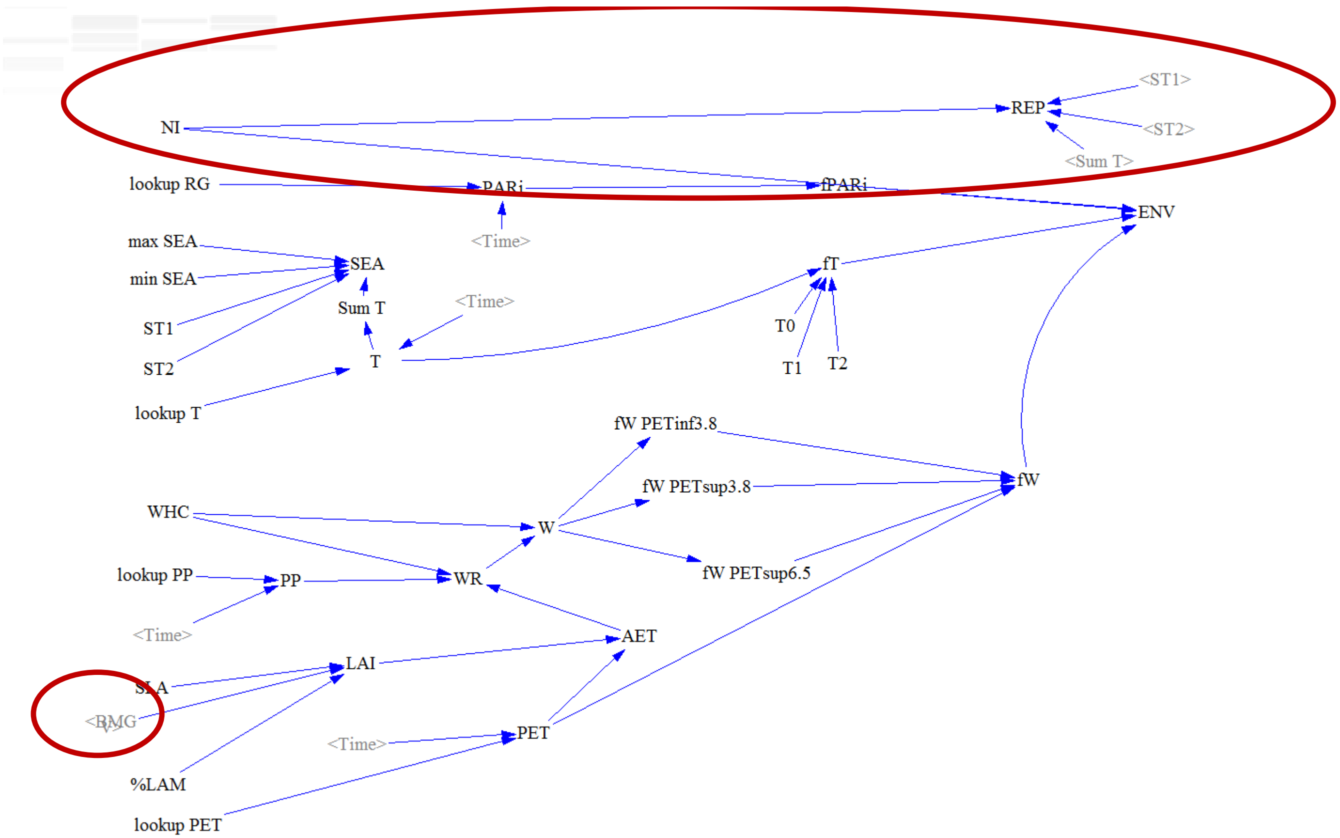
2. Growth and senescence flows for one (green) compartment, biomass





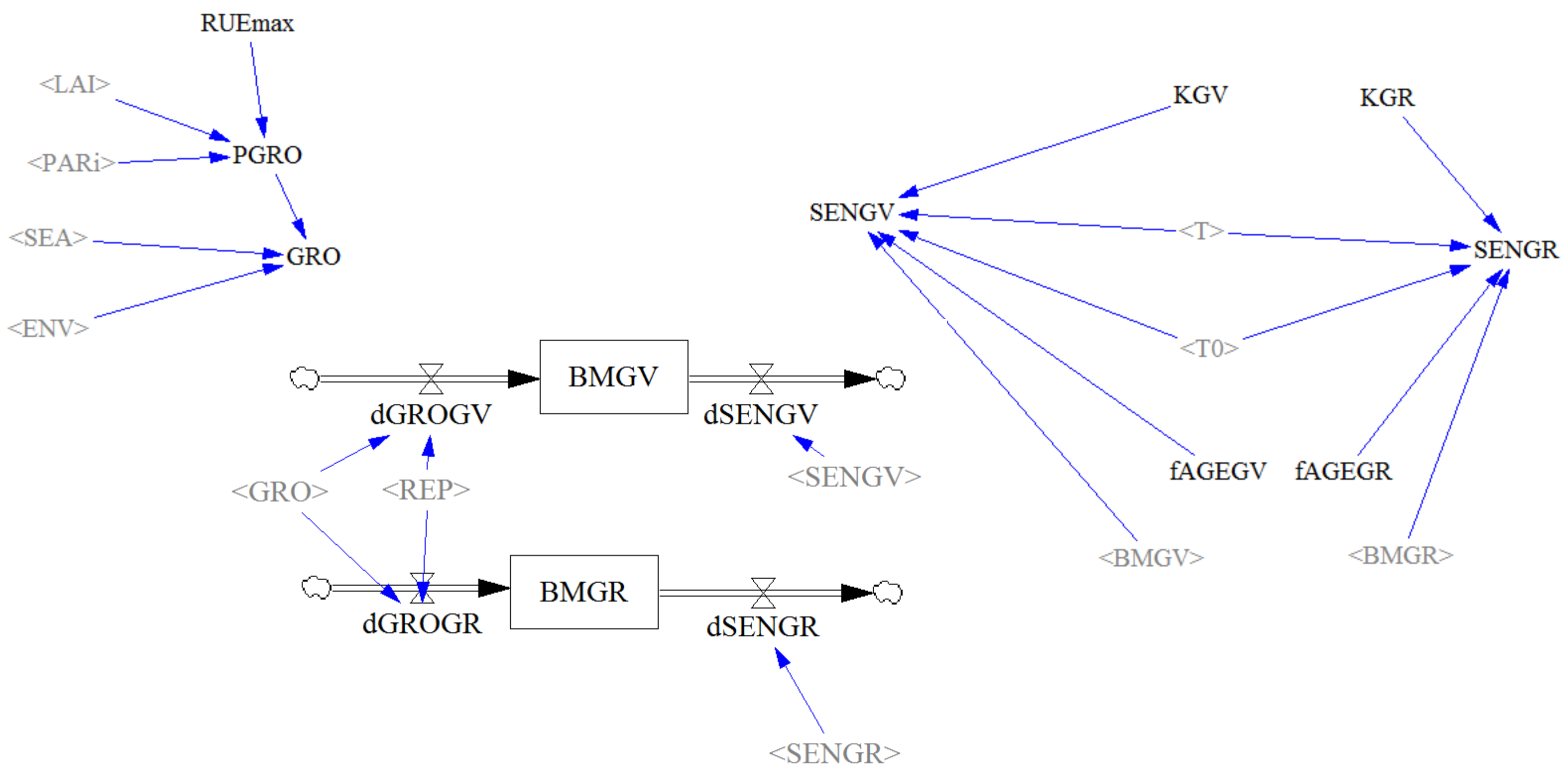
- and we implement a generic biomass compartment (without considering the GR, GV, DR, DV…)

3. Reproductive function and differenciation of green vegetative/green reproductive compartment



- problem / how implementing the various compartments without destroying what has been already done? → first implement the variables needed and a temporary variable BMGV

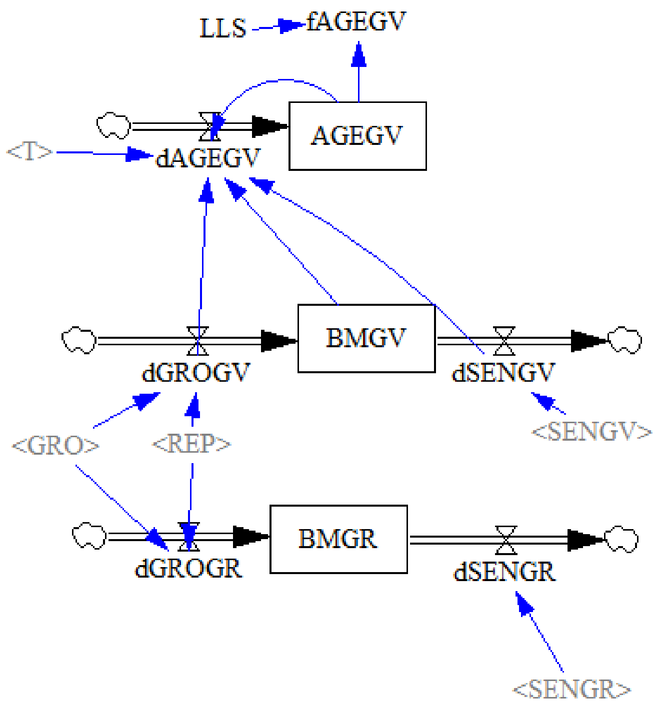
3. Reproductive function and differenciation of green vegetative/green reproductive compartment



- then develop for the two green compartments
- At this stage fAGEGV and fAGEGR are temporary variables as constants

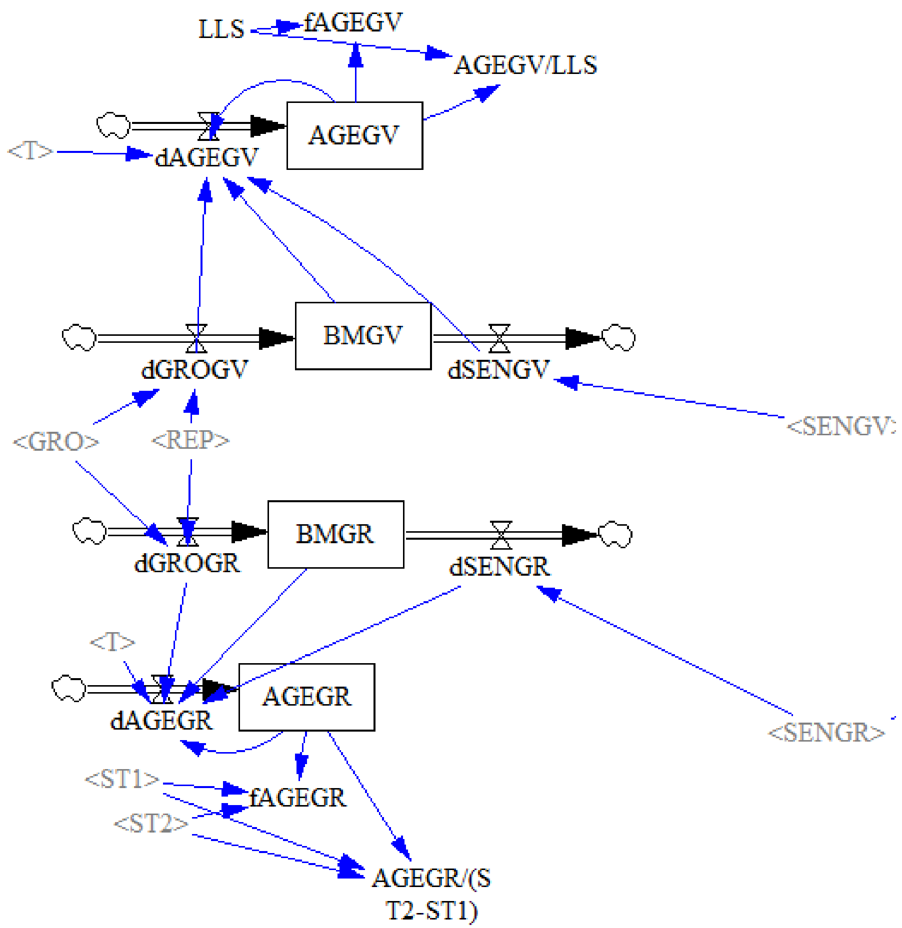
4. Ageing of green vegetative/green reproductive compartment

- What type of variables are AgeGV, AgeGR, AgeDV and AgeDR?
- How implementing them?



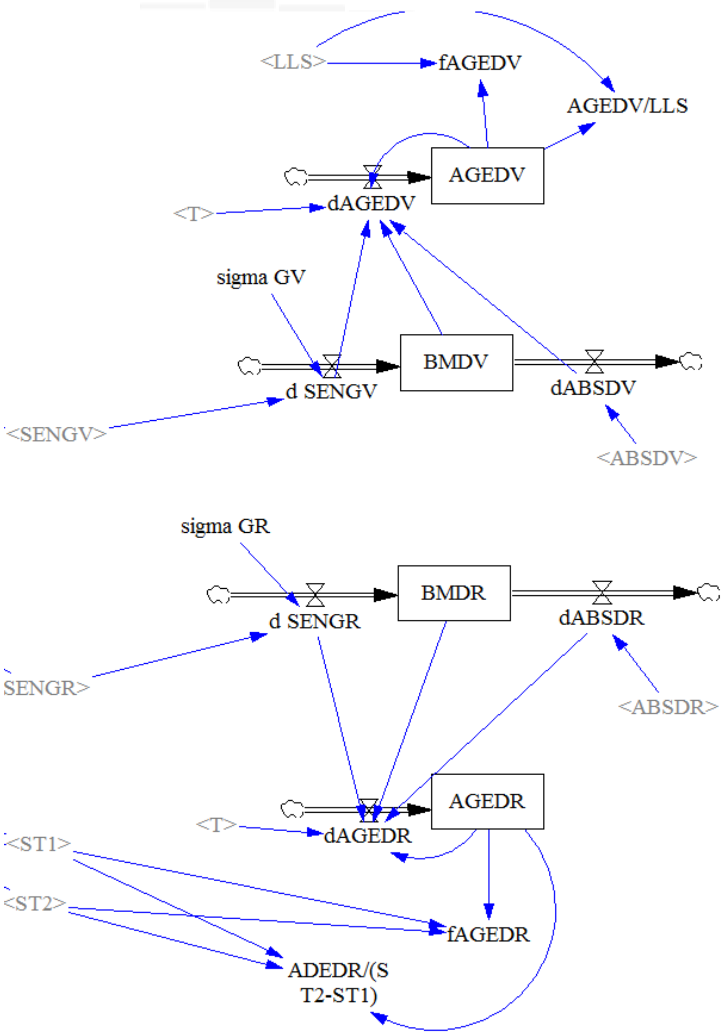
→ **as a compartment!**

4. Ageing of green vegetative/green reproductive compartment



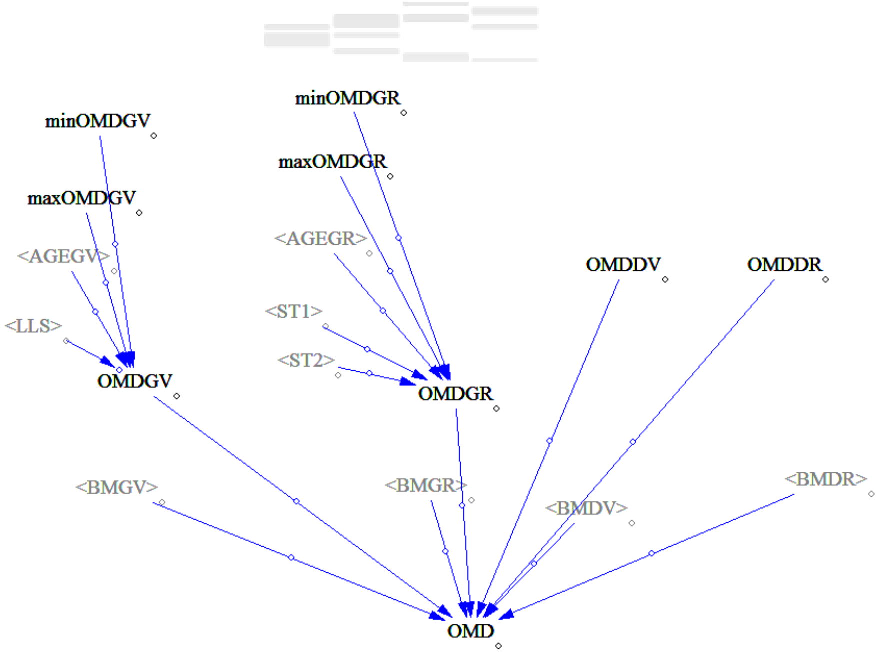
- Then we add the Age of both compartments and make the links between the variables

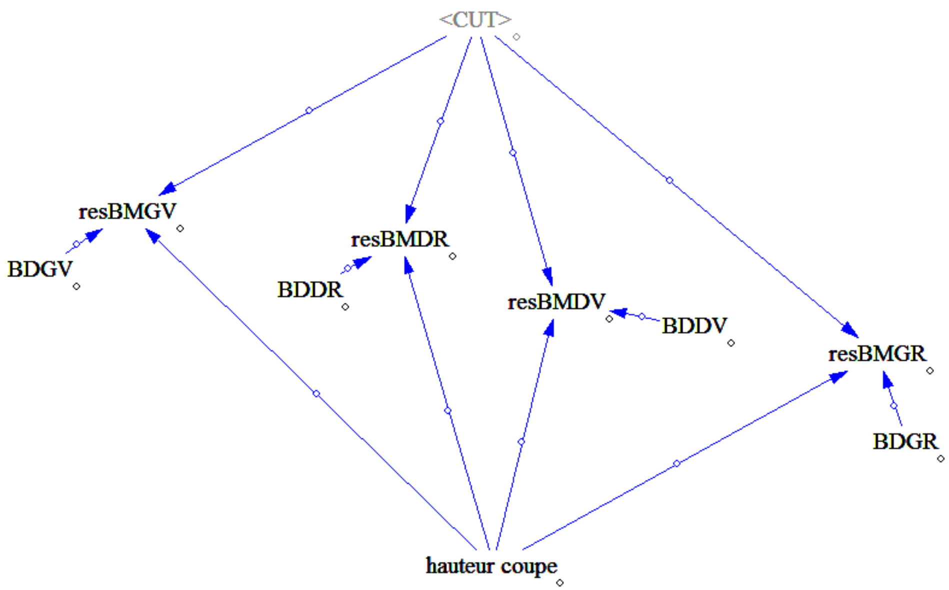
5. Development of the model for dead compartments



- Same approach as for green compartments

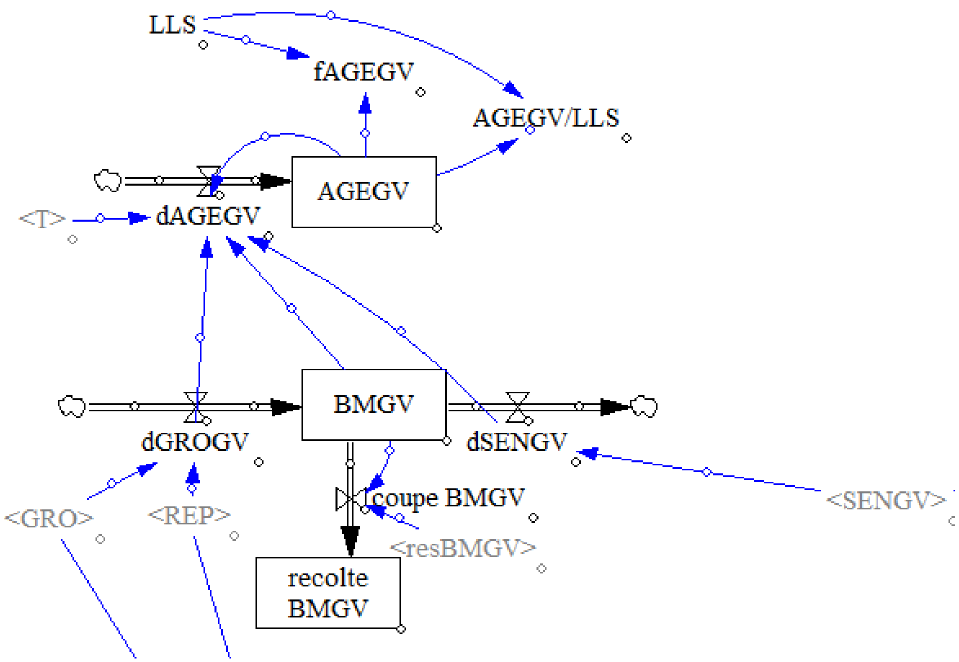
6. Sward digestibility and cutting (1/2)

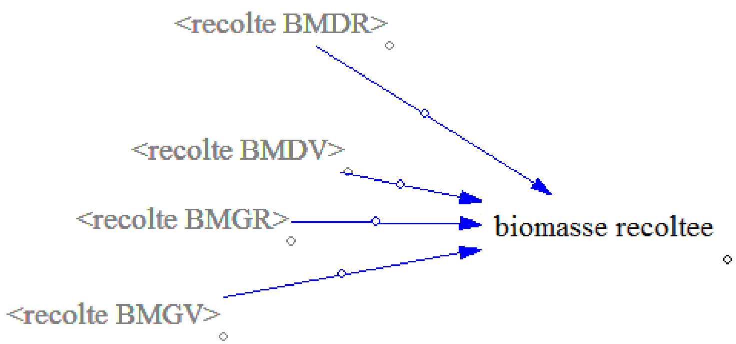




- Digestibility: linked to the age and weighted average
- Residual biomass: linked to cutting height and sward density

6. Sward digestibility and cutting (2/2)

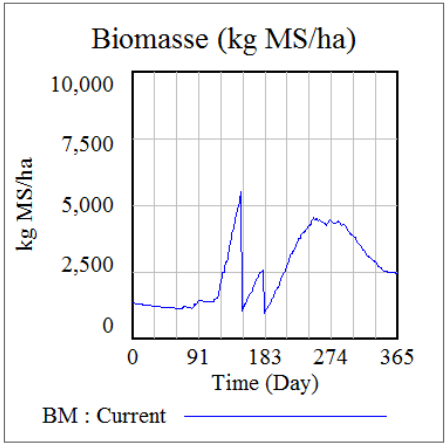


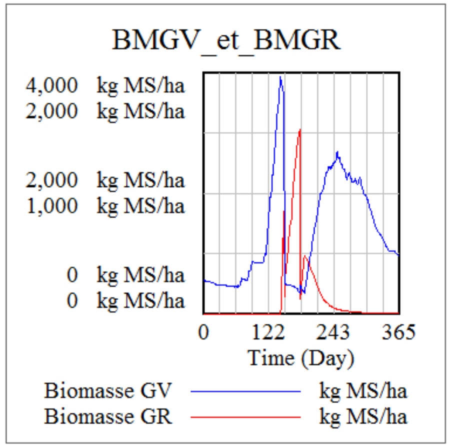


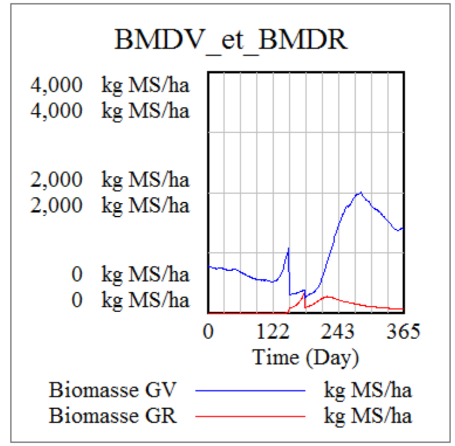
- Harvested biomass: inflow when occurrence of cutting for each compartment

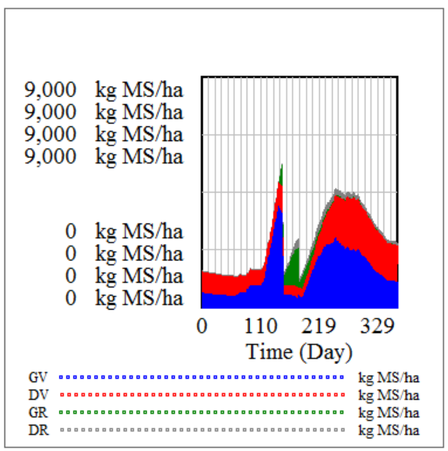
- Total harvested biomass: sum of all compartments

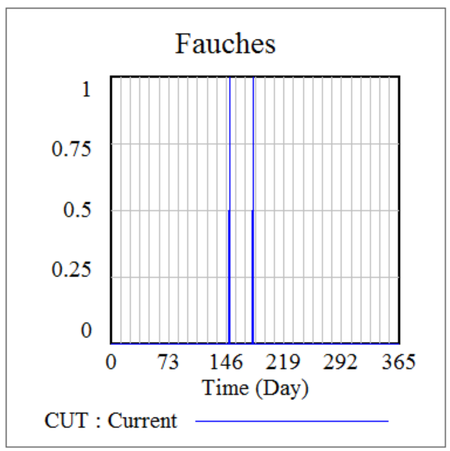
7. Simulation of results

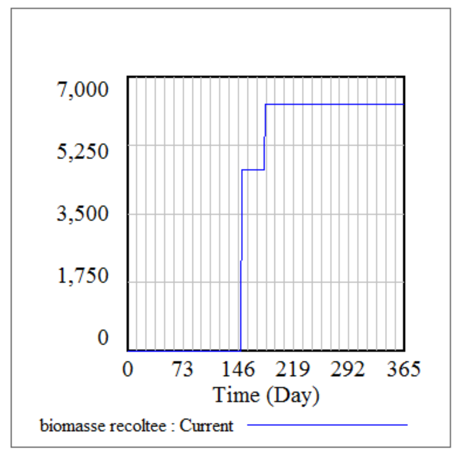


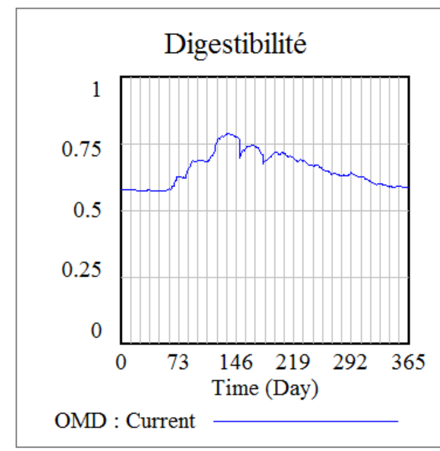












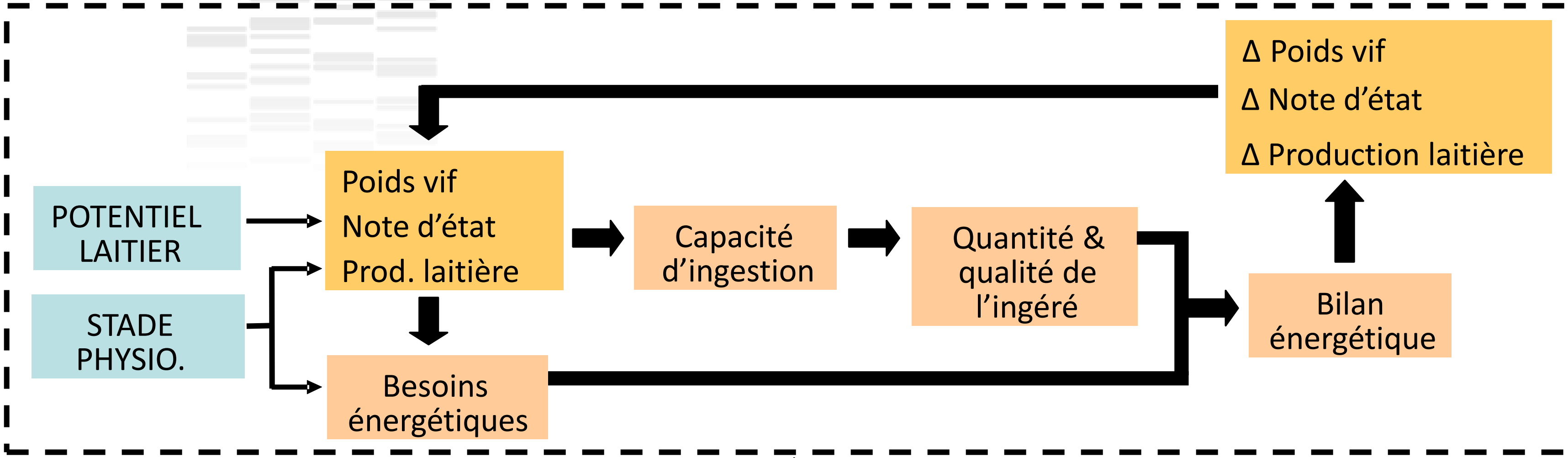
General remarks on the implementation using VenSim

- Create and save as many versions as necessary (here for the course → 18 versions)
- Check and run all the versions: graphs for each version / variable
- Use the different views to make your diagram clear, in particular useful to have a specific view for the graphs as results
- Only use lookup to input data with Vensim PLE

What are the modelling limits?

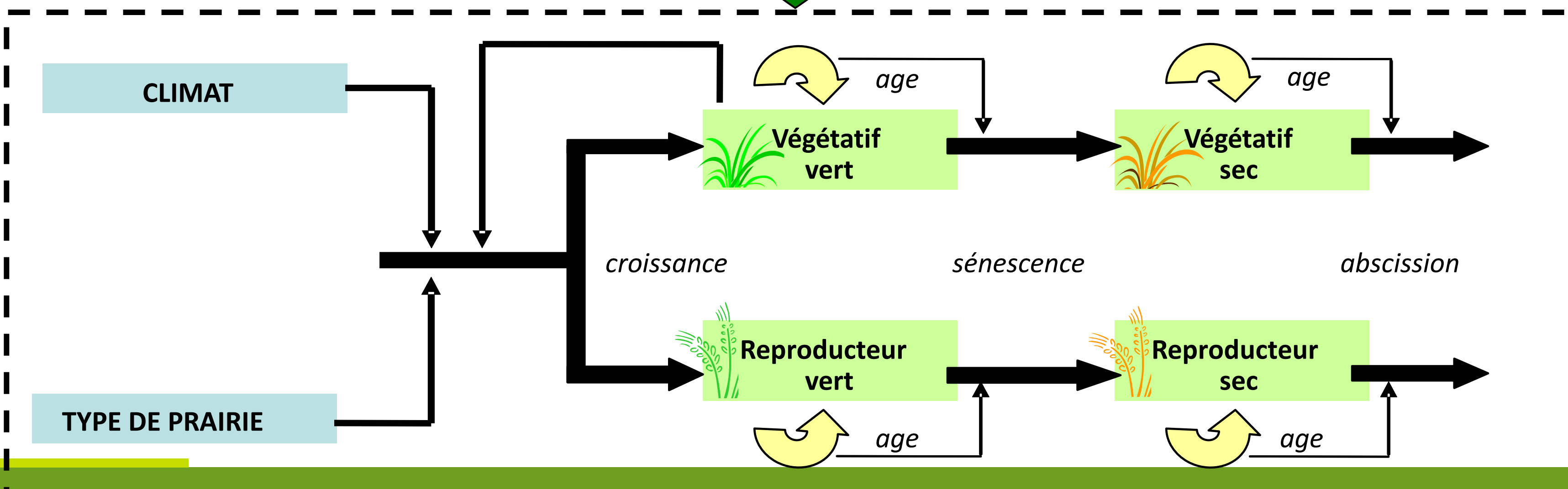
- Doesn't account for the variation of the abundance of functional groups in response to climate and management
- Species interactions (competition for resources) are neglected
- Doesn't consider root compartments
- The cutting height used to simulate cutting is fixed (5 cm above ground level)

Coupling with a ruminant livestock model



(Jouven et al., 2007)

Comportement de sélection
Limitation ingestion selon la biomasse



(Jouven et al., 2006)