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To cite this version:

Florence Garcia-Launay, Anne-Isabelle Graux. How implementing a model with Vensim PLE ? – example of the ModVege model. Master. Module " Analyses systémiques Méta-analyse et Modélisation ", France. 2017. hal-02790709

HAL Id: hal-02790709
https://hal.inrae.fr/hal-02790709v1

Submitted on 5 Jun 2020

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

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Agrocampus Ouest
TD modélisation
Rennes, France –Septembre 2017

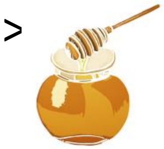
Maintaining grasslands is important

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

Provisioning

- Fodder =>

- Pollen =>



Cultural

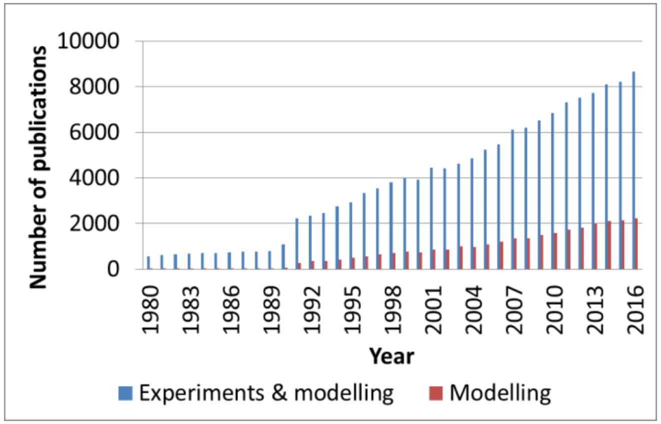
- Landscape maintenance & quality
- Recreation & tourism
- Quality of life

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

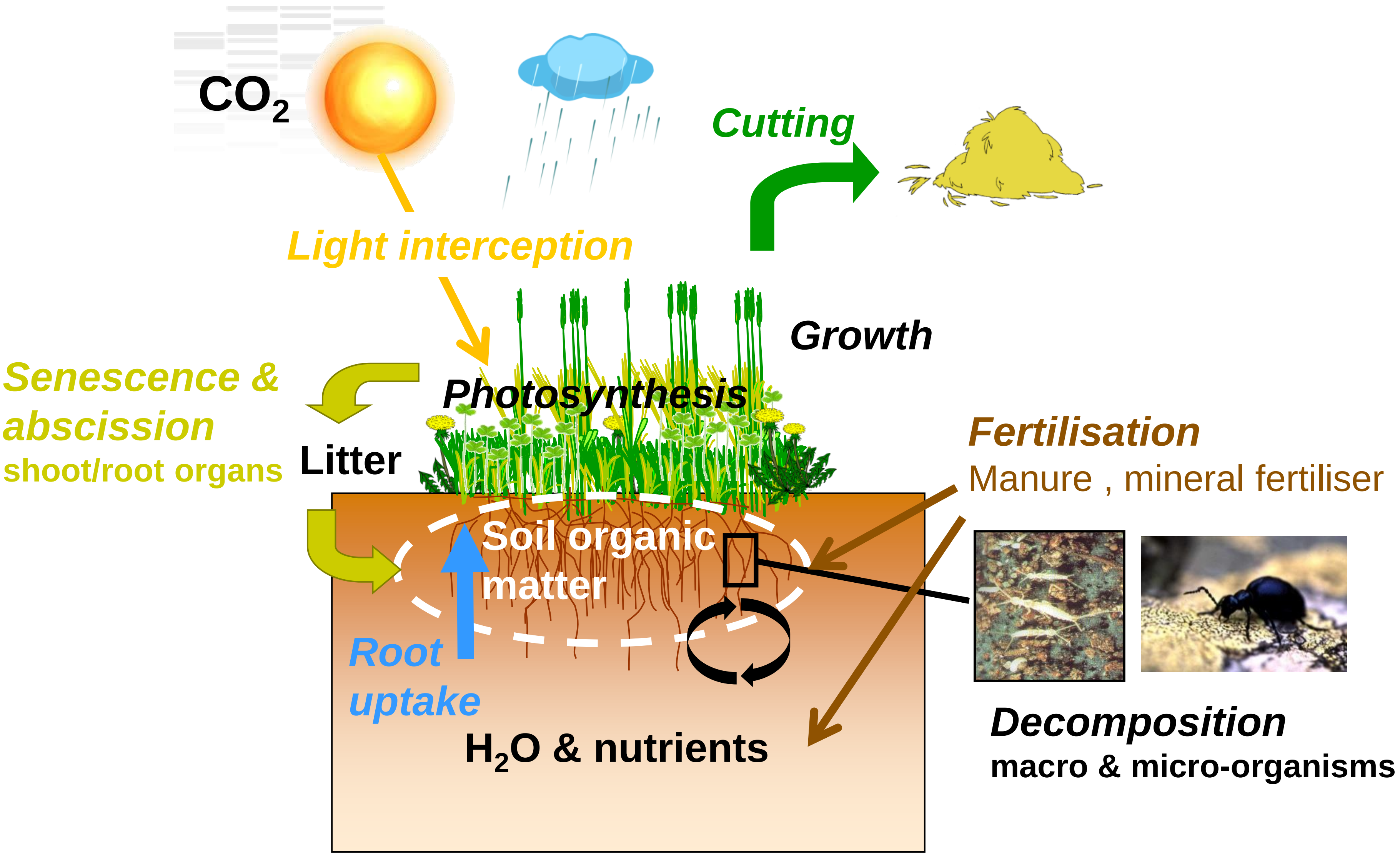
	Rich/fertile sites	Poor/infertile sites
Frequent defoliation	**Group A** *Ex: Lolium perenne, Holcus lanatus* High SLA High digestibility Short leaf lifespan Early reproductive growth & flowering	**Group C** *Ex: Festuca rubra, Agrotis capillaris* Low SLA Medium digestibility Long leaf lifespan Late 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**

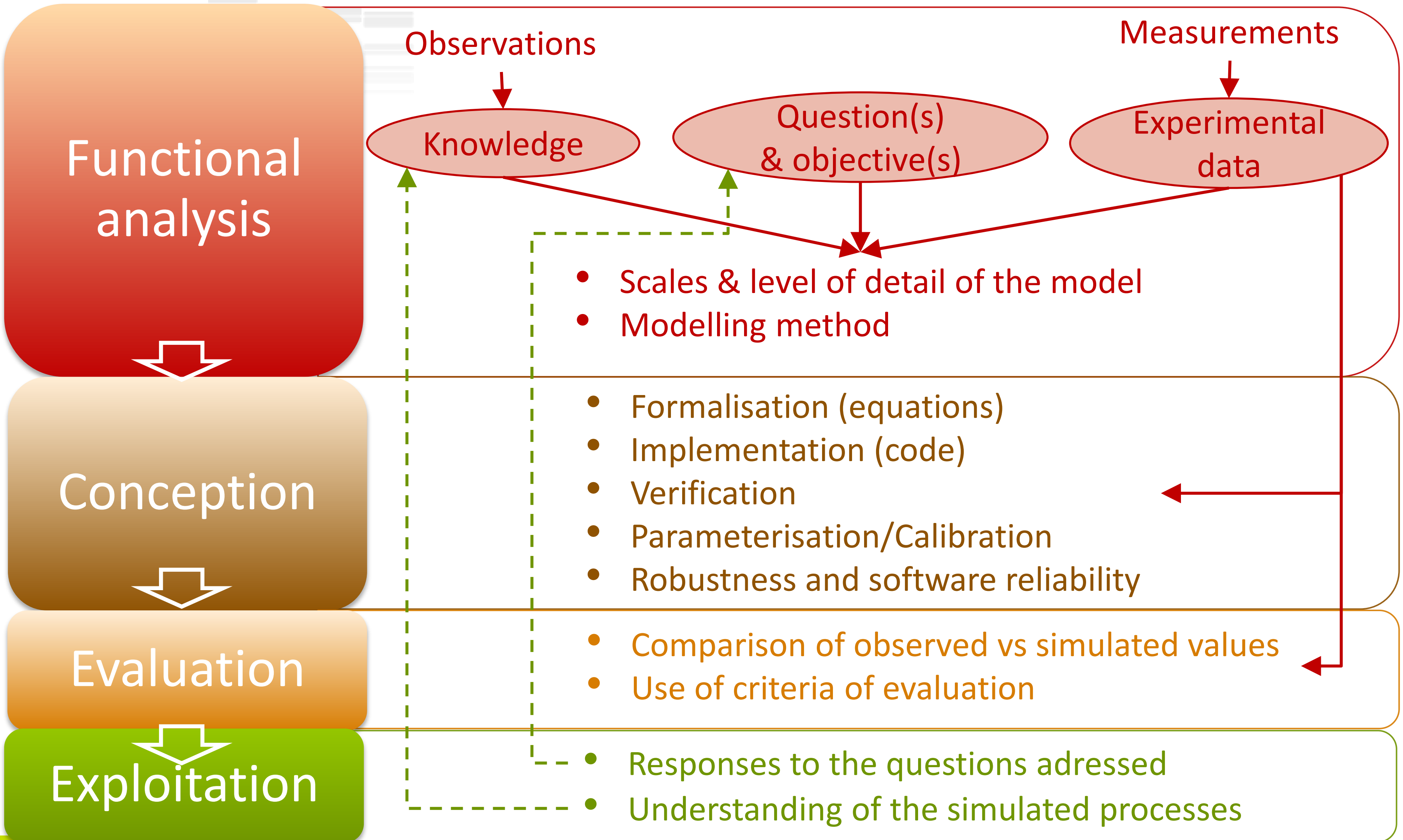
How it works?



CO_2
Cutting
Light interception
Growth
Senescence &
abscission
shoot/root organs
Photosynthesis
Litter
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

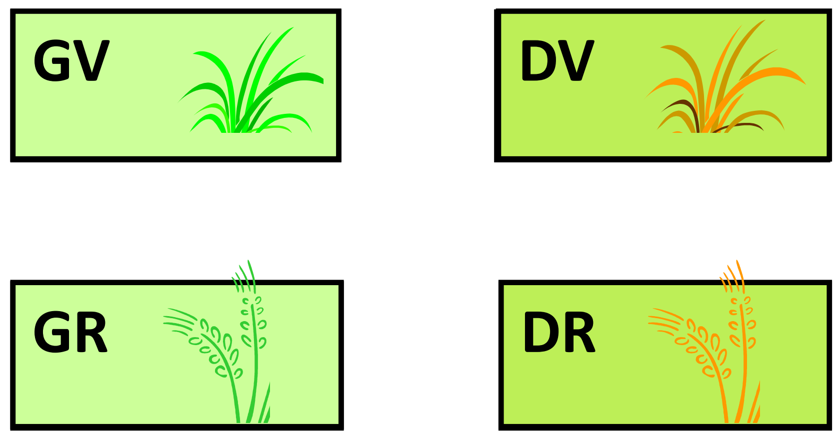
Jouven et al., 2006. Grass and Forage Science

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**)

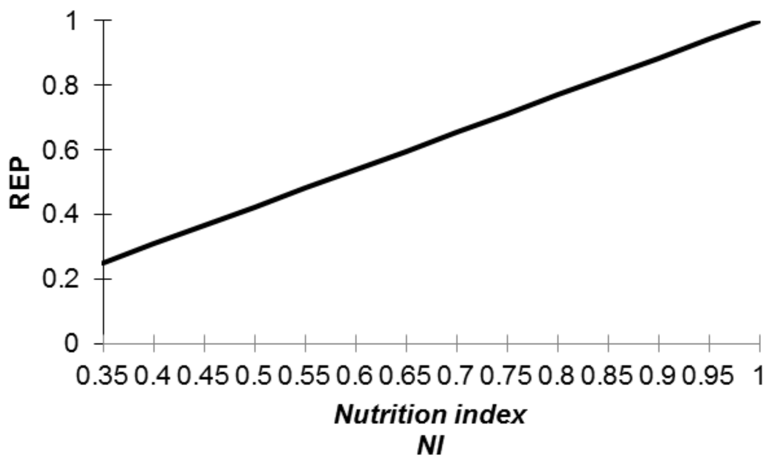
Partitioning of growth between vegetative and reproductive green comparments

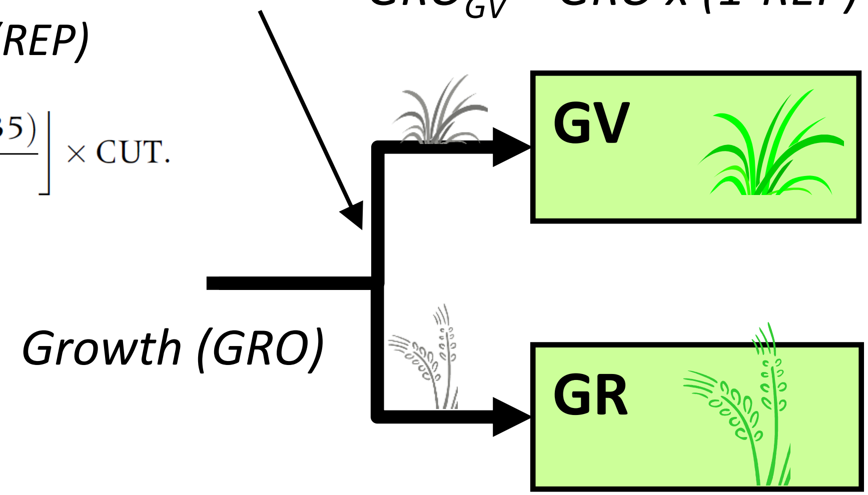
During the reproductive growth, growth is distributed between GV & GR = Reproductive function *(REP)*

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

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

Else REP = 0





$$GRO_{GR} = GRO \times REP$$

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

Structural component

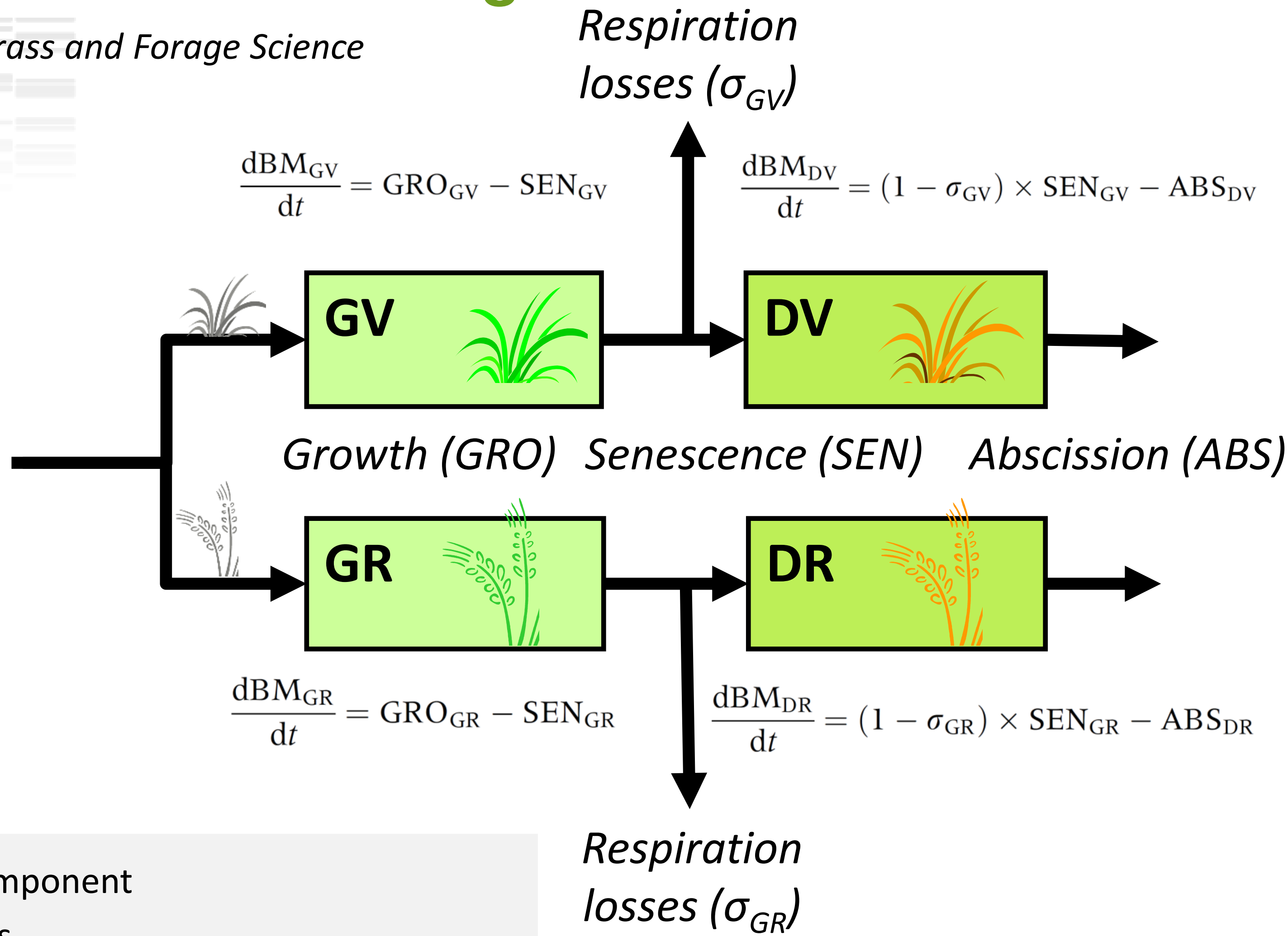
Biomass flows

Ageing functions

Direct & feedback effects of variables on flows

Calculation of the standing biomass

Jouven et al., 2006. Grass and Forage Science



Structural component

Biomass flows

Ageing functions

Direct & feedback effects of variables on flows

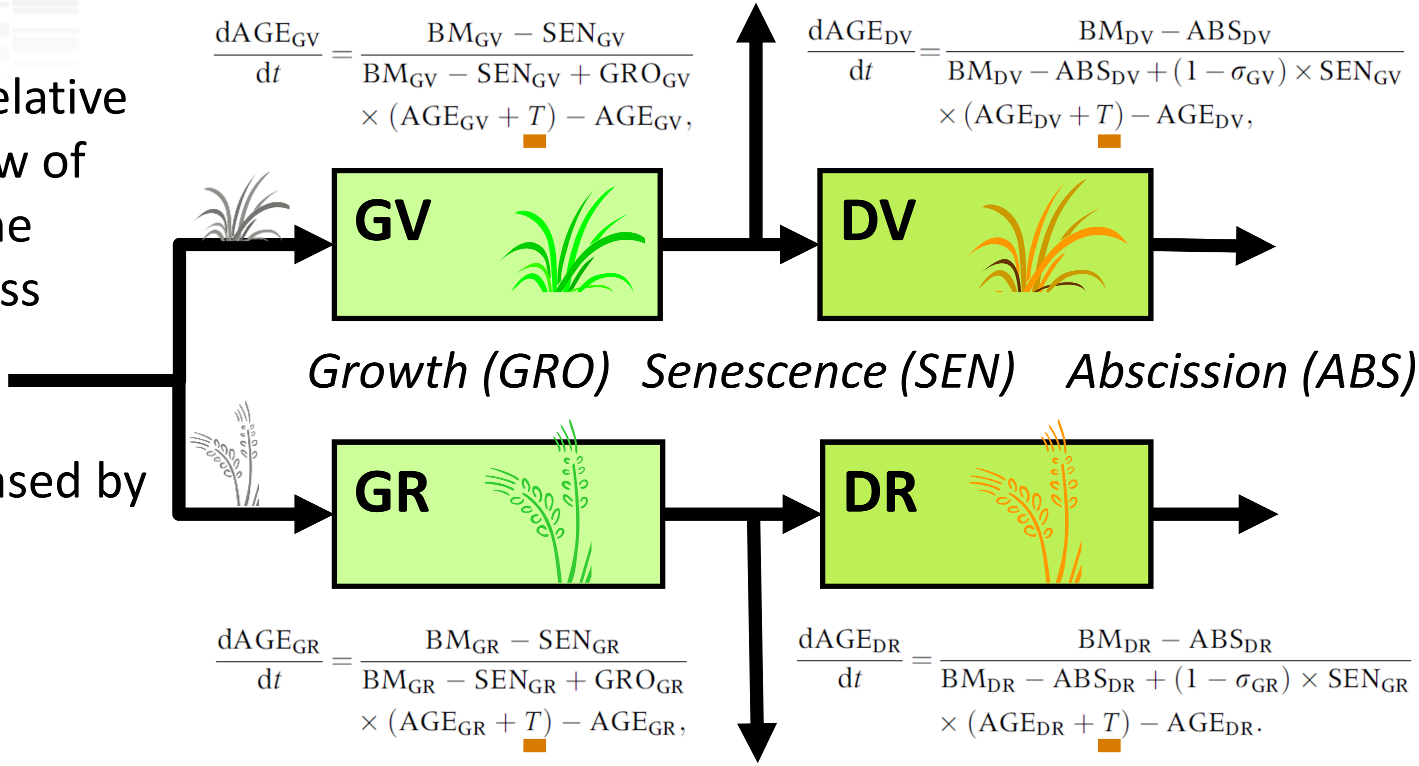
Calculation of the age

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)

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

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



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

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

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

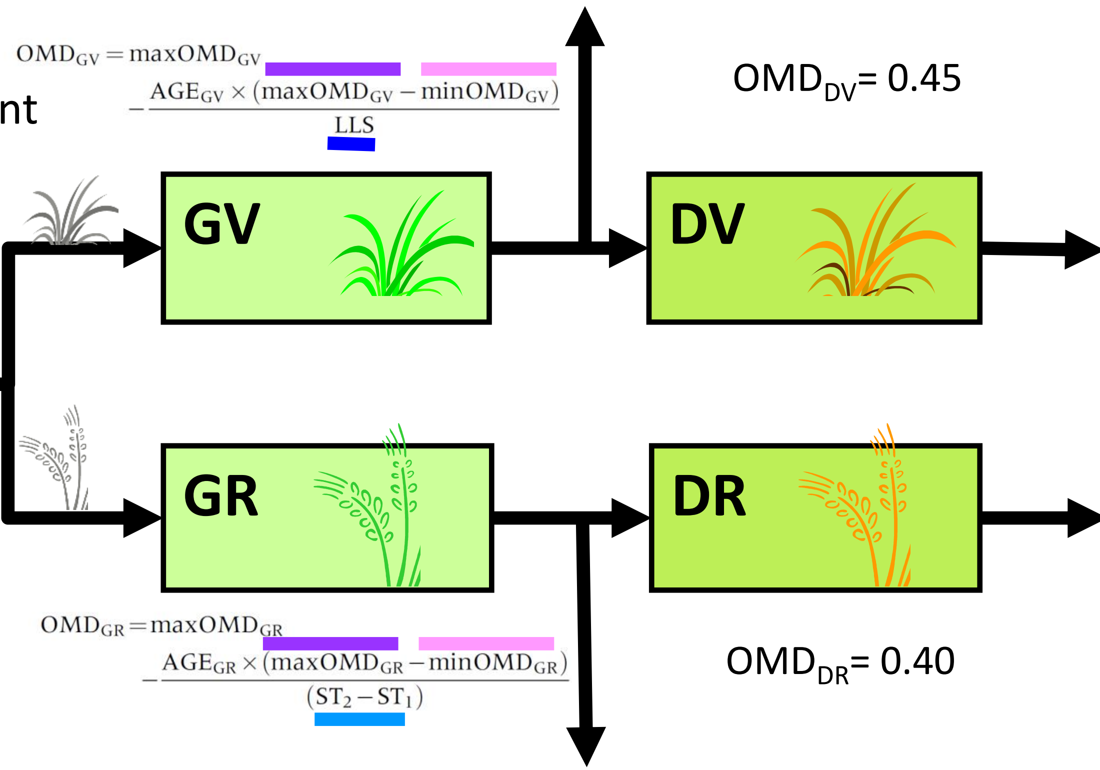
Calculation of the organic matter digestibility

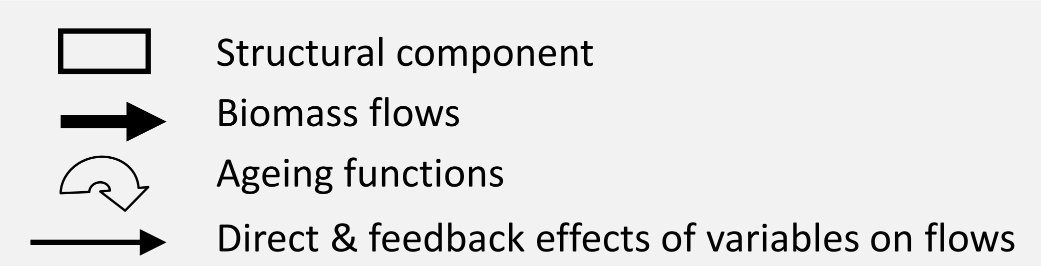
Jouven et al., 2006. Grass and Forage Science

- 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)

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

Incident photosynthetically active radiation

Radiation use efficiency (constant)

Leaf area index

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

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

Specific leaf area (constant)

GV biomass

Percentage of laminae in GV (constant)

Calculation of growth functions

- ***Limitation by environmental variables***

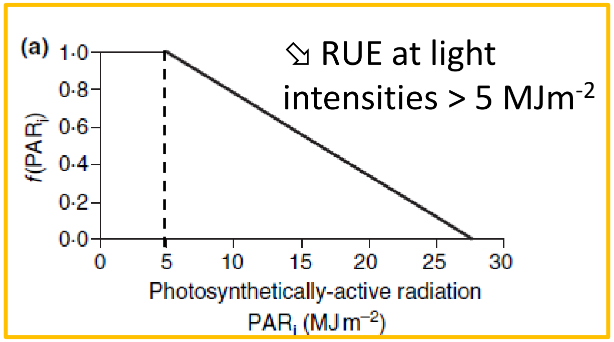
$$ENV = NI \times f(PAR_i) \times f(T) \times f(W)$$

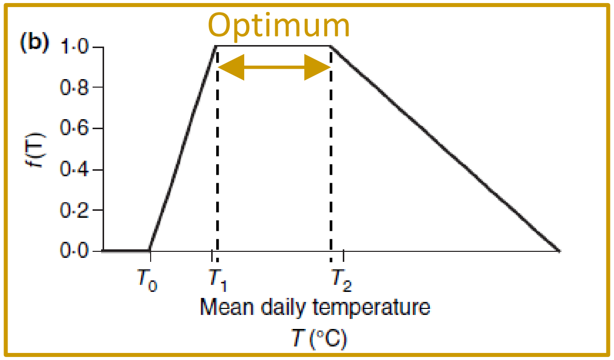
Nutrition index (site specific, constant)

Influence of PAR_i

Influence of temperature

Influence of water availability





- Water stress (W)

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

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

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

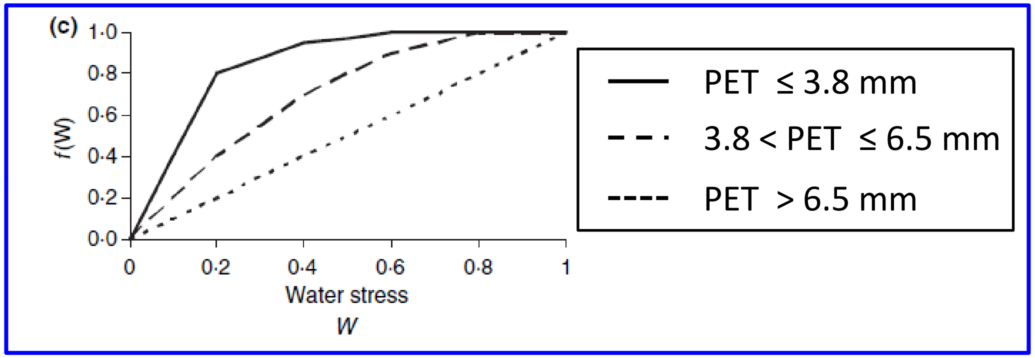
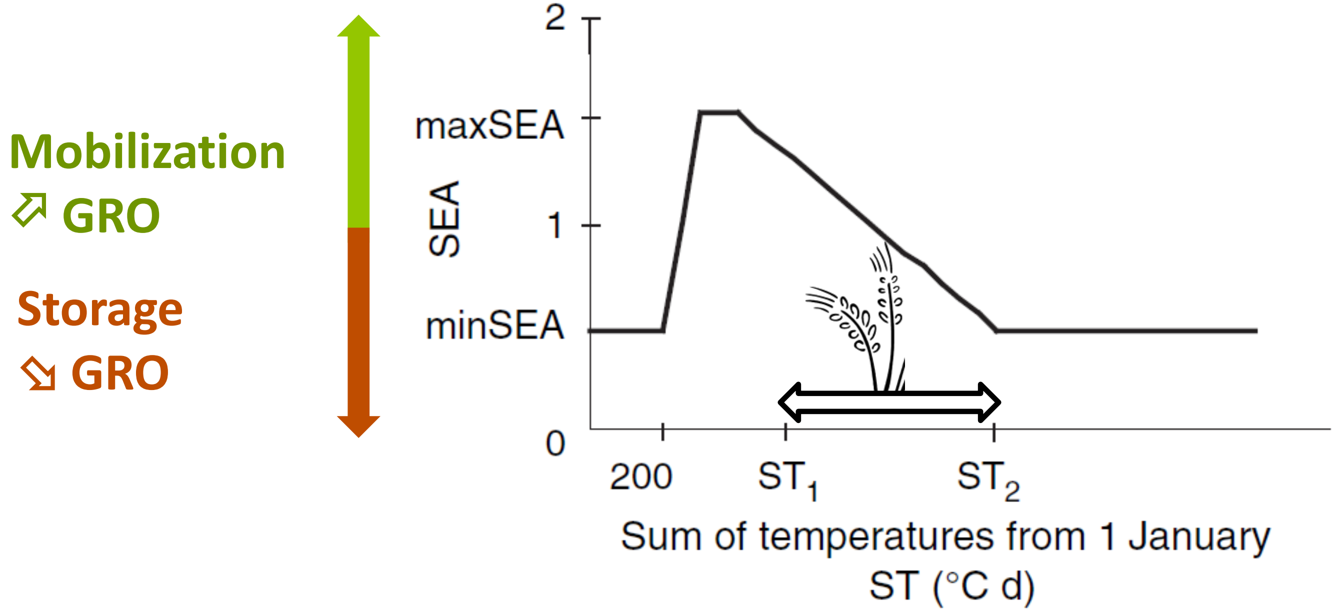


Figure 2 Threshold functions representing growth limitation

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 $0 \le T \le T_0$

$$SEN_{GV} = K_{GV} \times BM_{GV} \times T \times f(AGE_{GV}) \text{ if } T > T_0$$

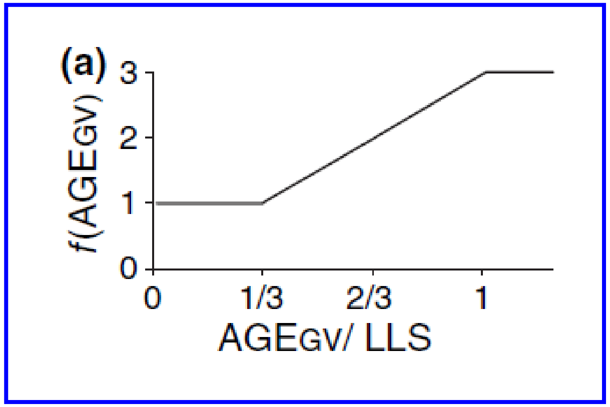
and similarly for compartment GR

and

$$SEN_{GV} = K_{GV} \times BM_{GV} \times |T| \text{ if } T < 0,$$

and similarly for compartment GR.

(Freezing effect)

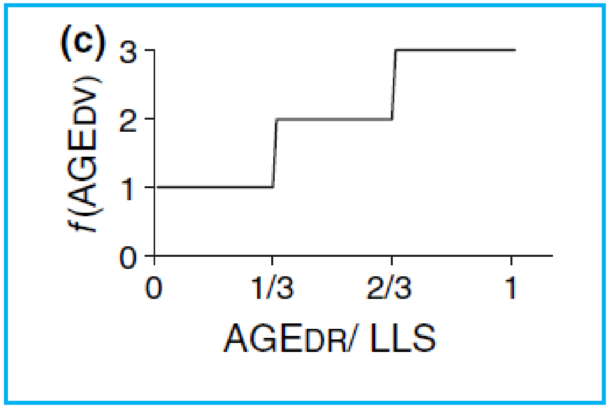


- ***Abscission of dead compartments***

if $T > 0$,

$$ABS_{DV} = Kl_{DV} \times BM_{DV} \times T \times f(AGE_{DV}) \text{ and,}$$

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

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

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

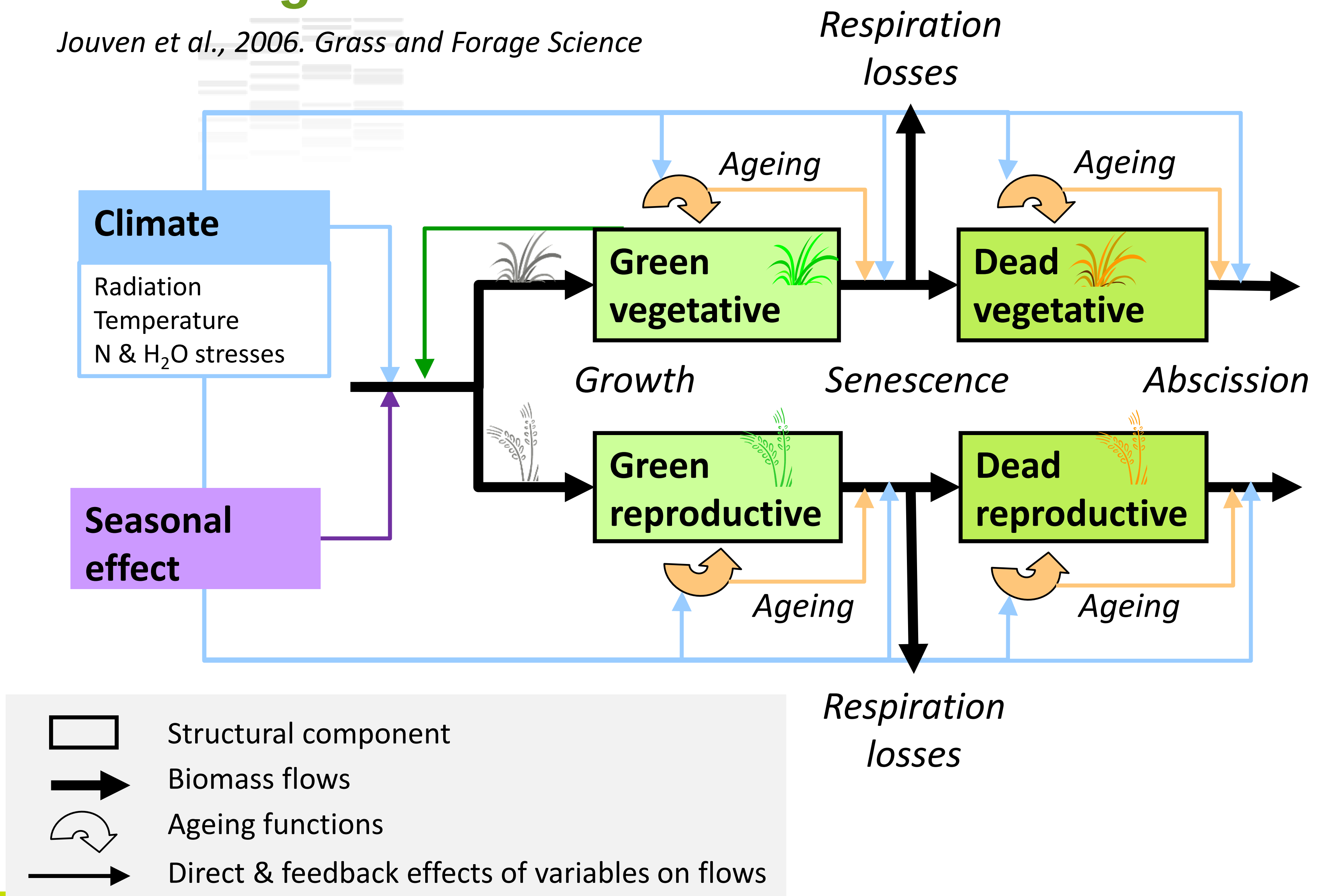
$$hBM_{GV} = BM_{GV} - resBM_{GV} \text{ and similarly for compartments GR, DV, DR}$$

- ***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.

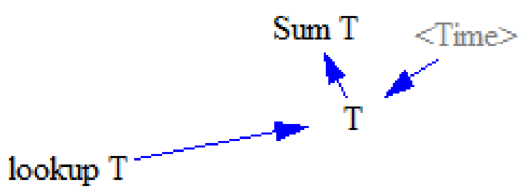
Model implementation using VenSim

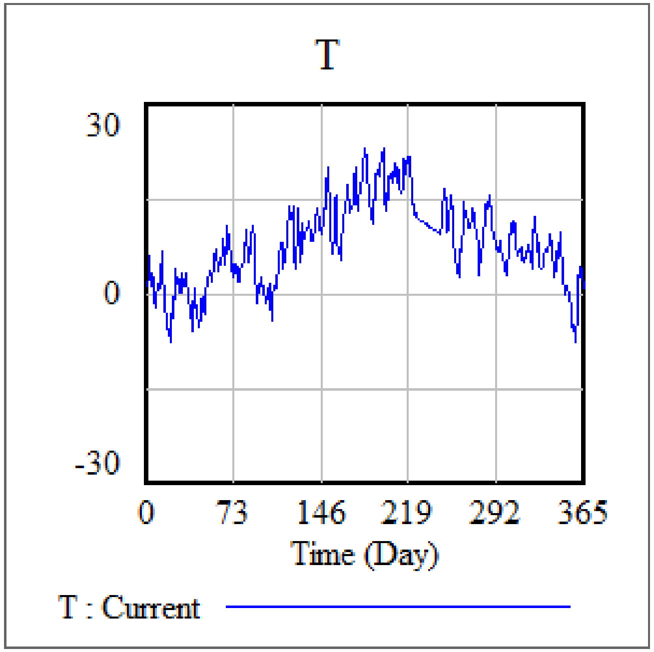
- ***A methodology***

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?



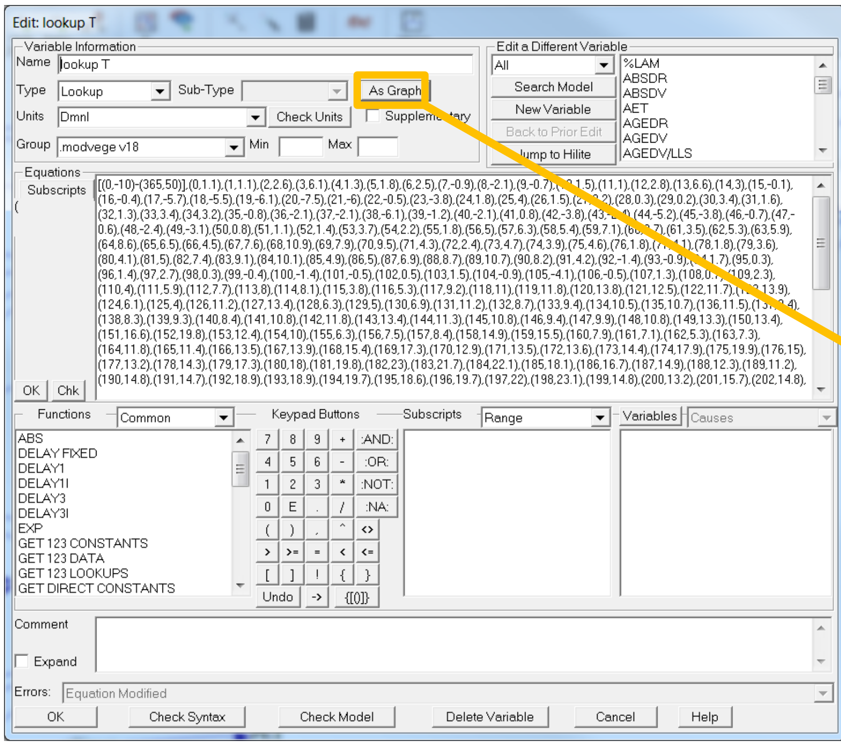


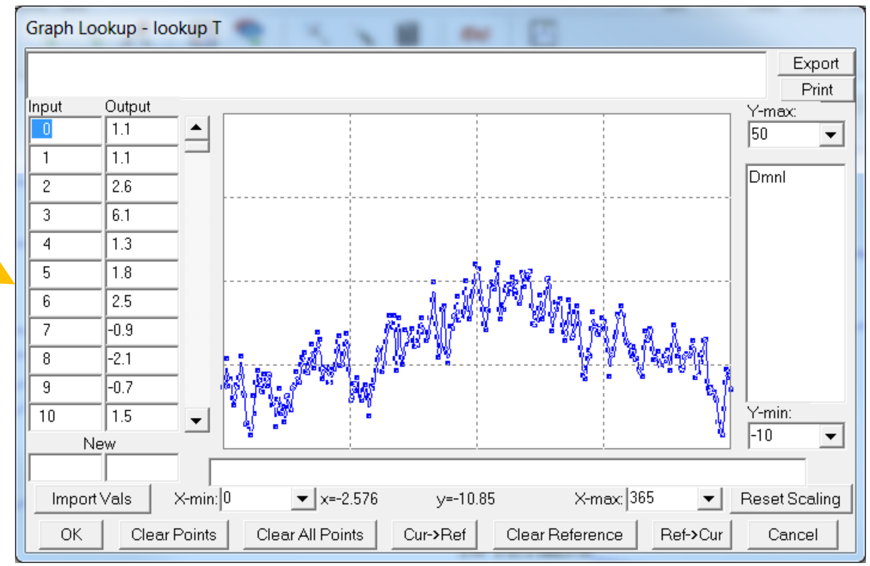
To input data use a lookup variable with the Vensim PLE version

→ the sum of temperatures

1. Growth limitations functions

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



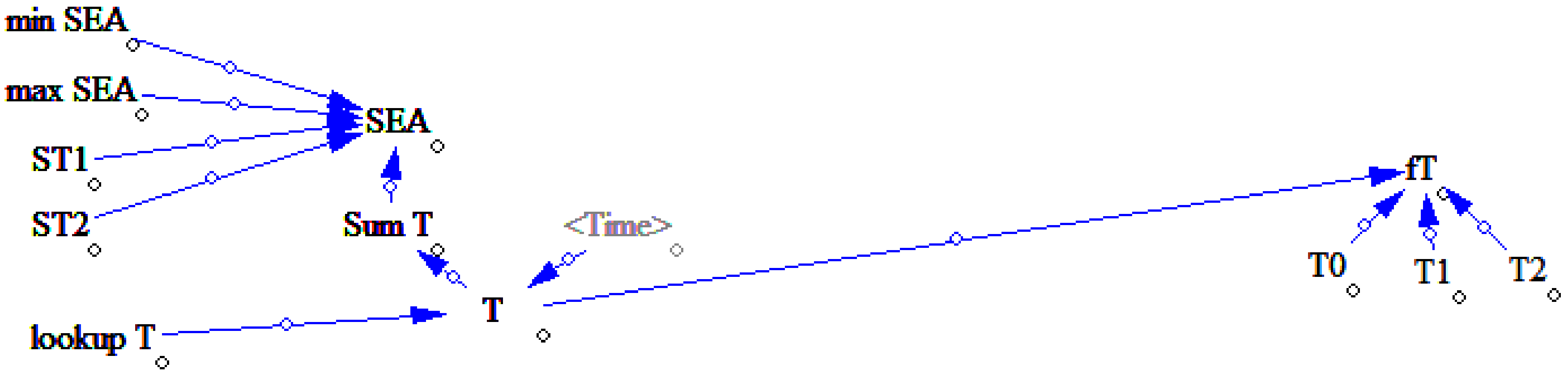


→ A Excel spreadsheet available to build and paste large input datasets (e.g. climate data)

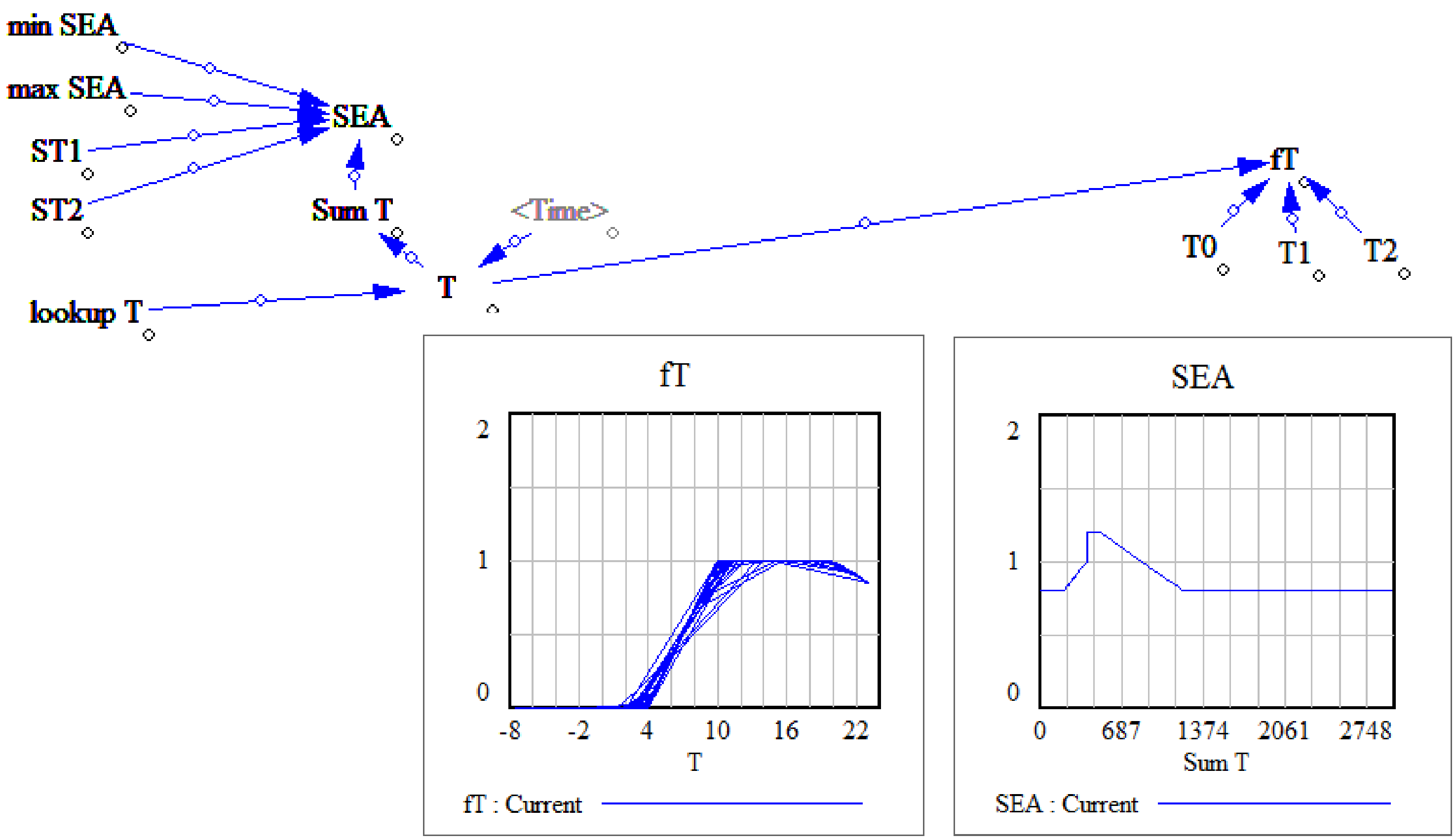
1. Growth limitations functions

- 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**



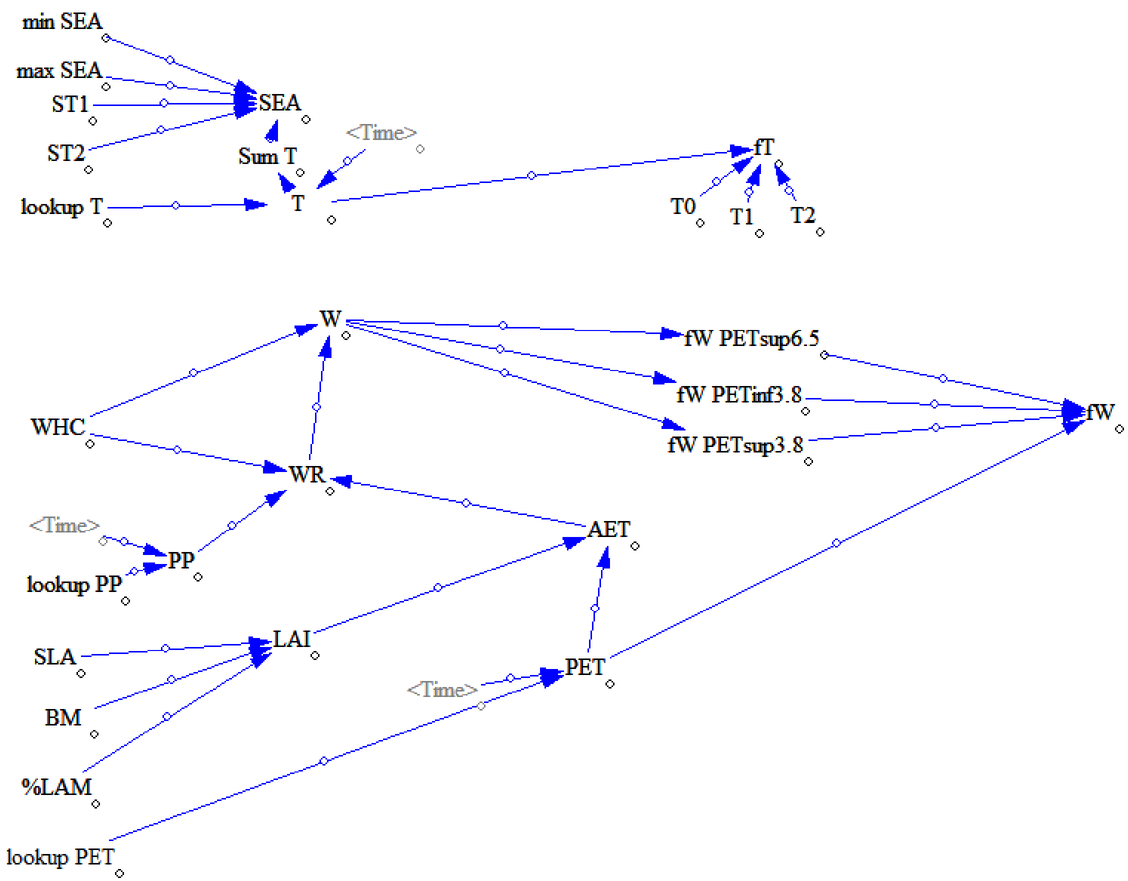
1. Growth limitations functions

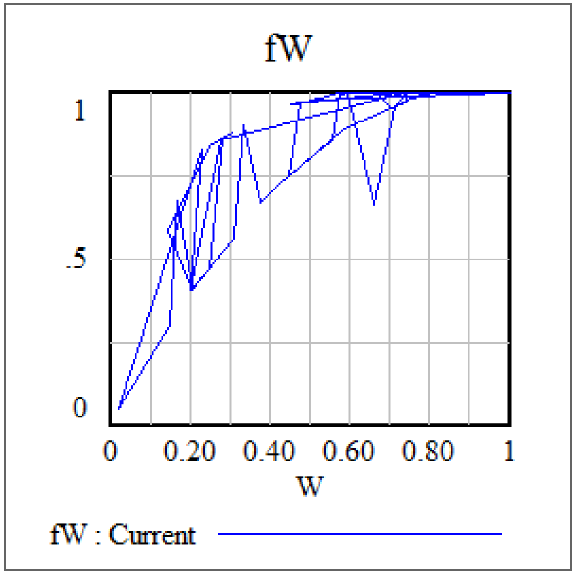


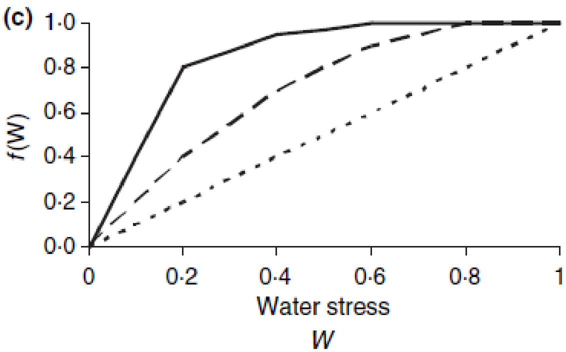
- **Check appropriate behaviour gradually** at each step with figure(s)

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

1. Growth limitations functions

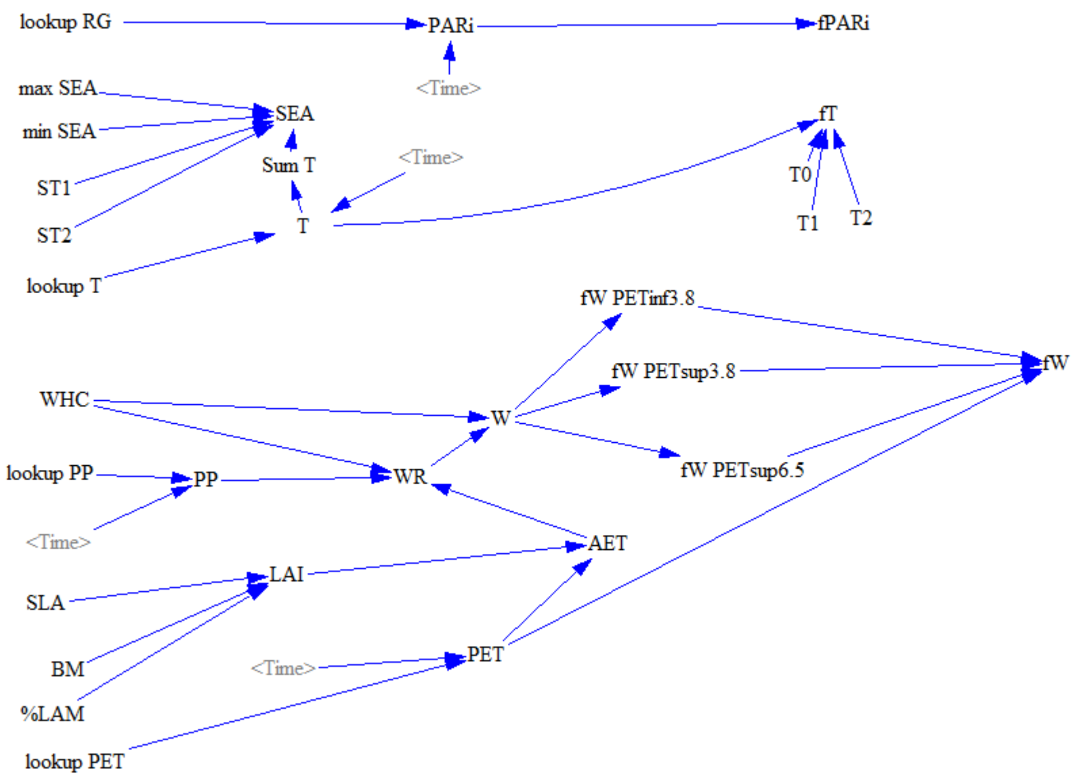


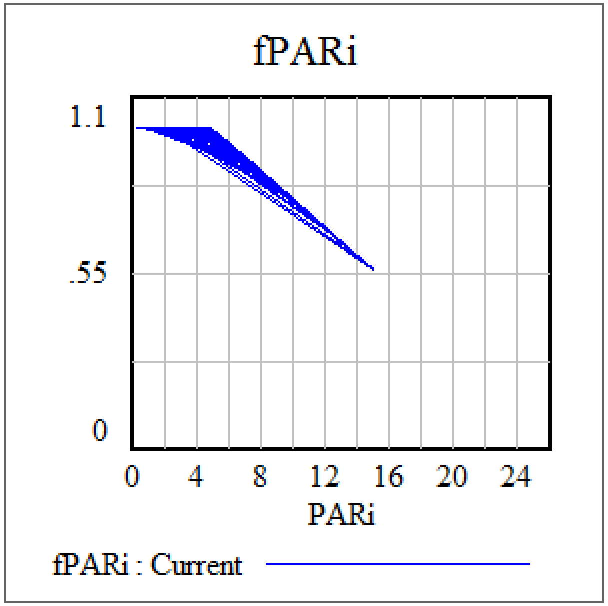




- Add the calculation of the leaf area index (LAI), and the effect of water stress on the function for limitation of growth : f(W)

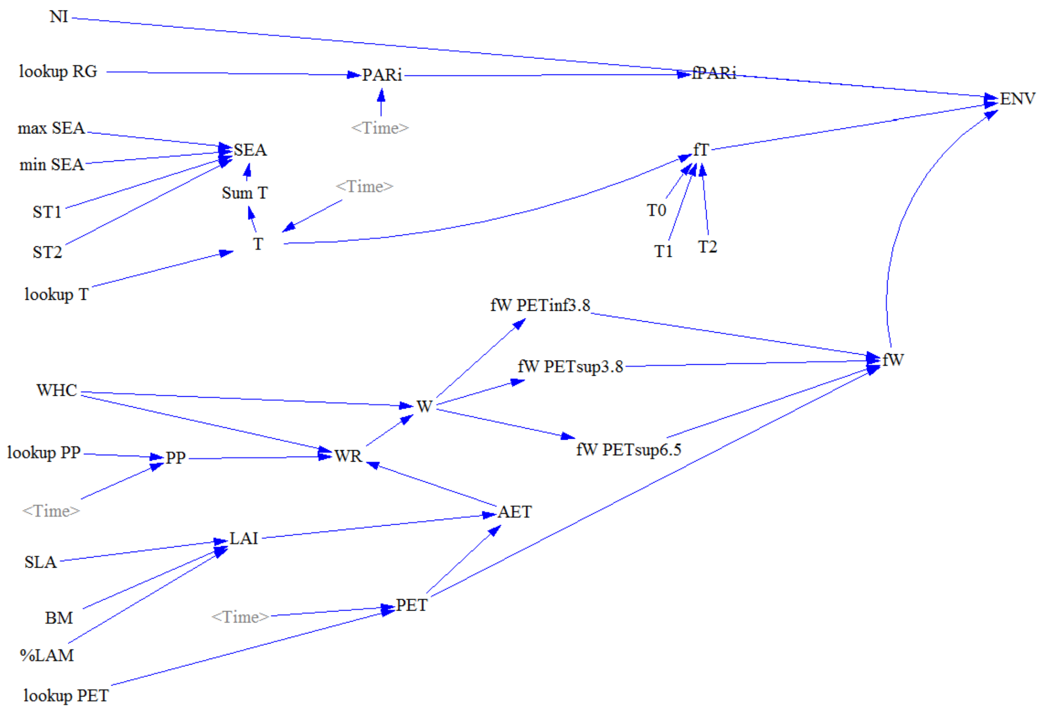
1. Growth limitations functions

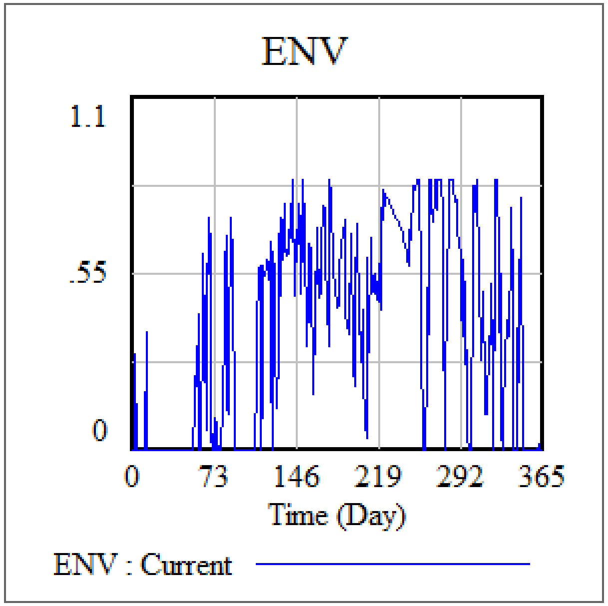




- The effect of the photosynthetically active radiation

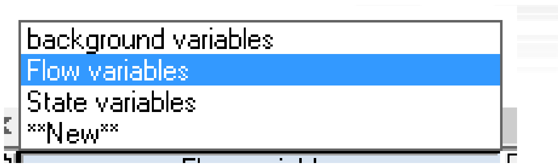
1. Growth limitations functions

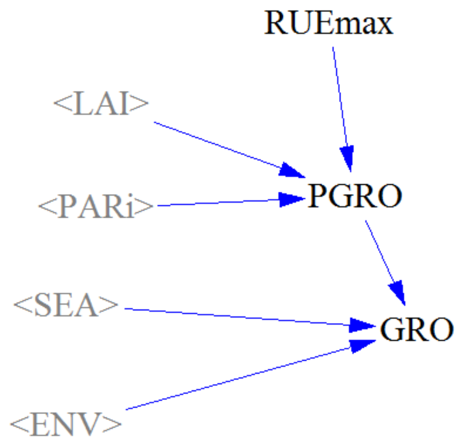


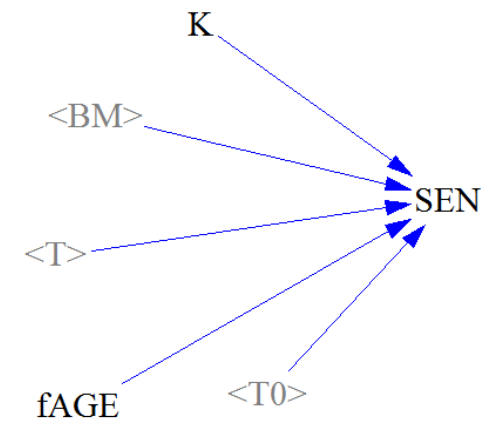


- We end up with this part → we obtain the equation for the environmental limitation of growth
- All this part in one view in Vensim → next new view

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

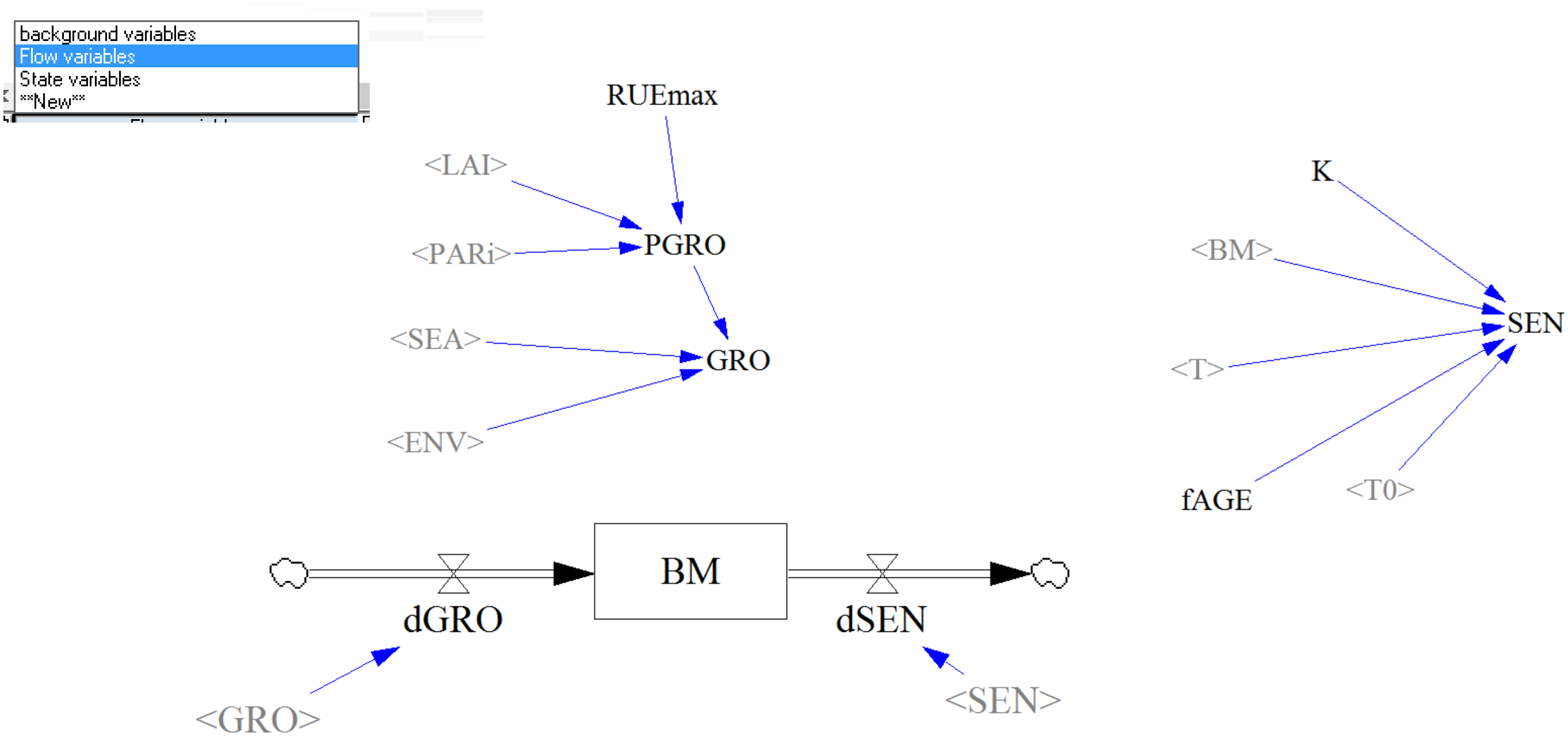






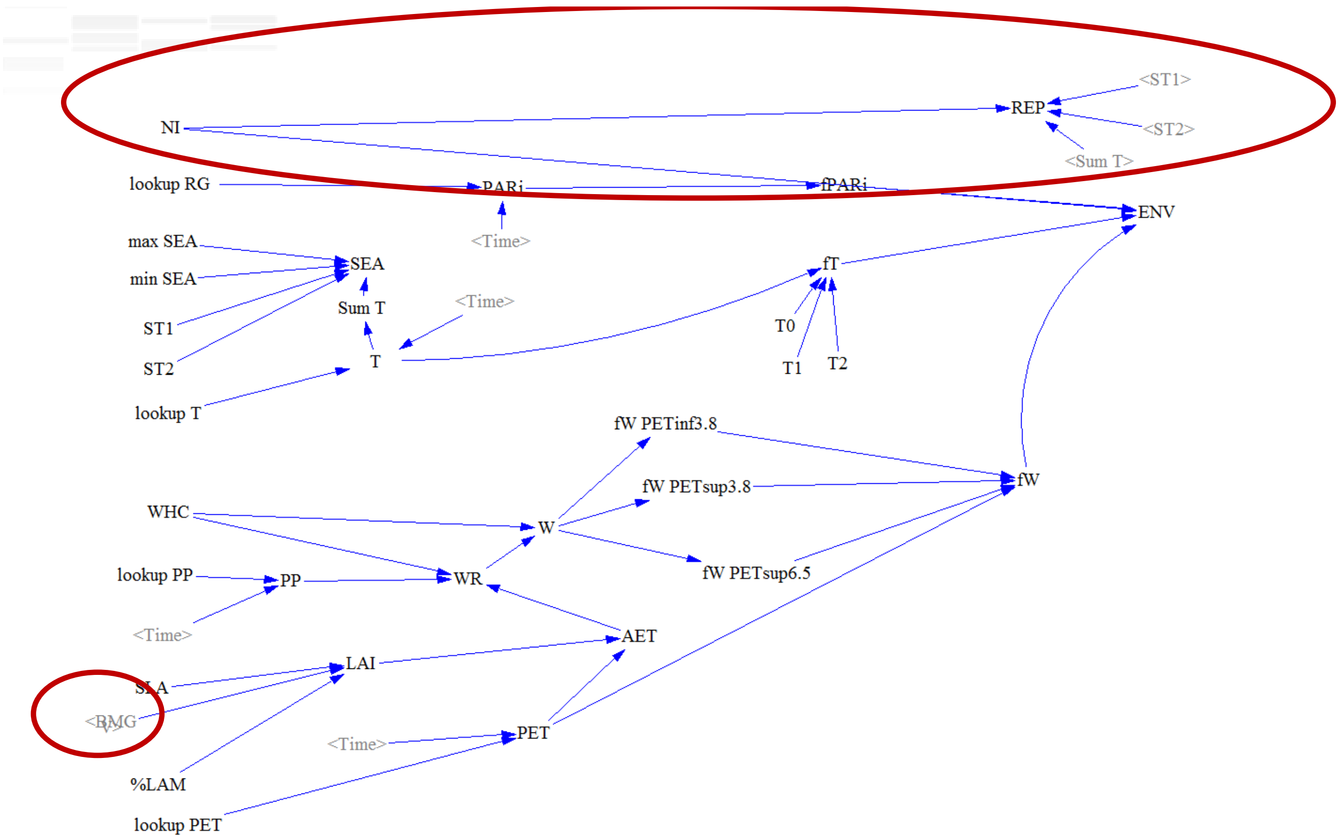
- We first try to implement protential growth, growth and senescence using some temporary variables

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



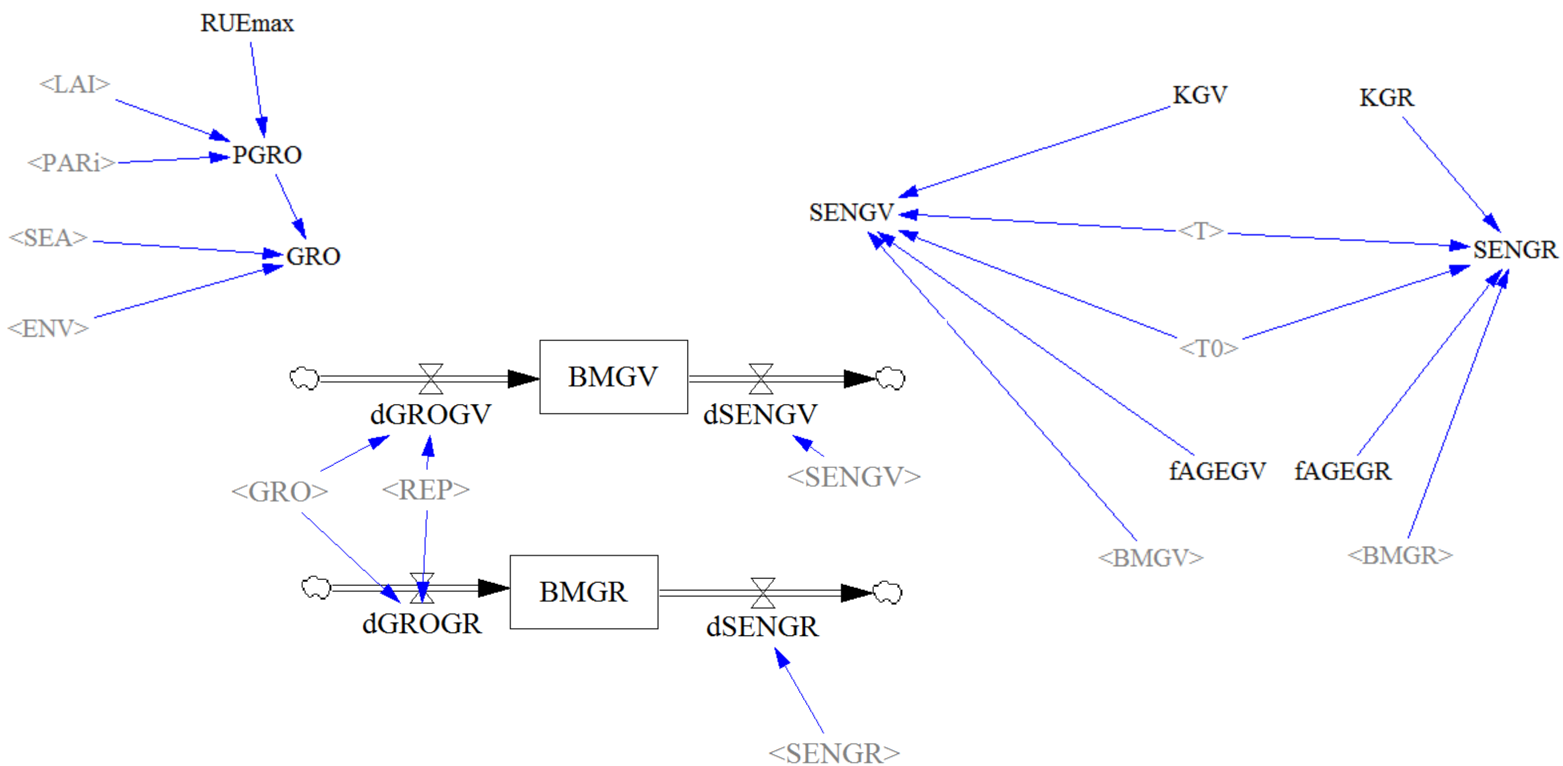
- and we implement a generic biomass compartment (without considering the GR, GV, DR, DV…)

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

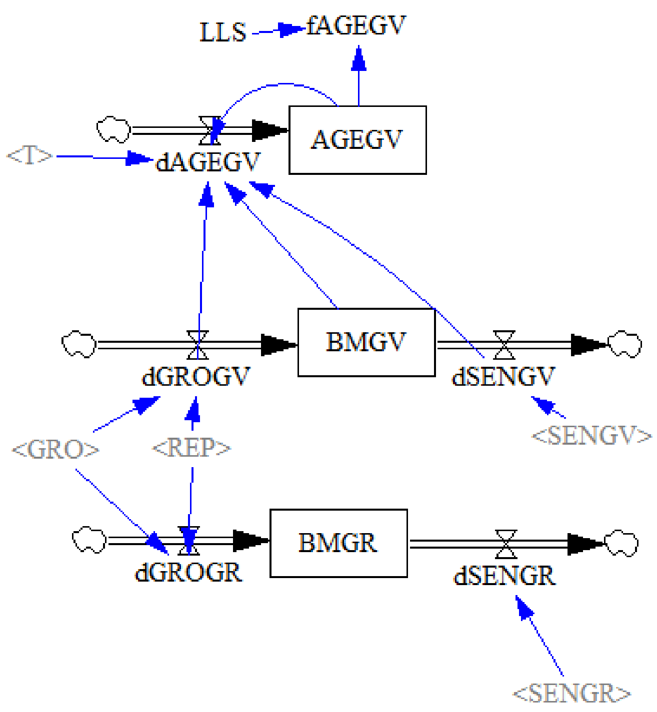
3. Reproductive function and differenciation of green vegetative/green reproductive compartment



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

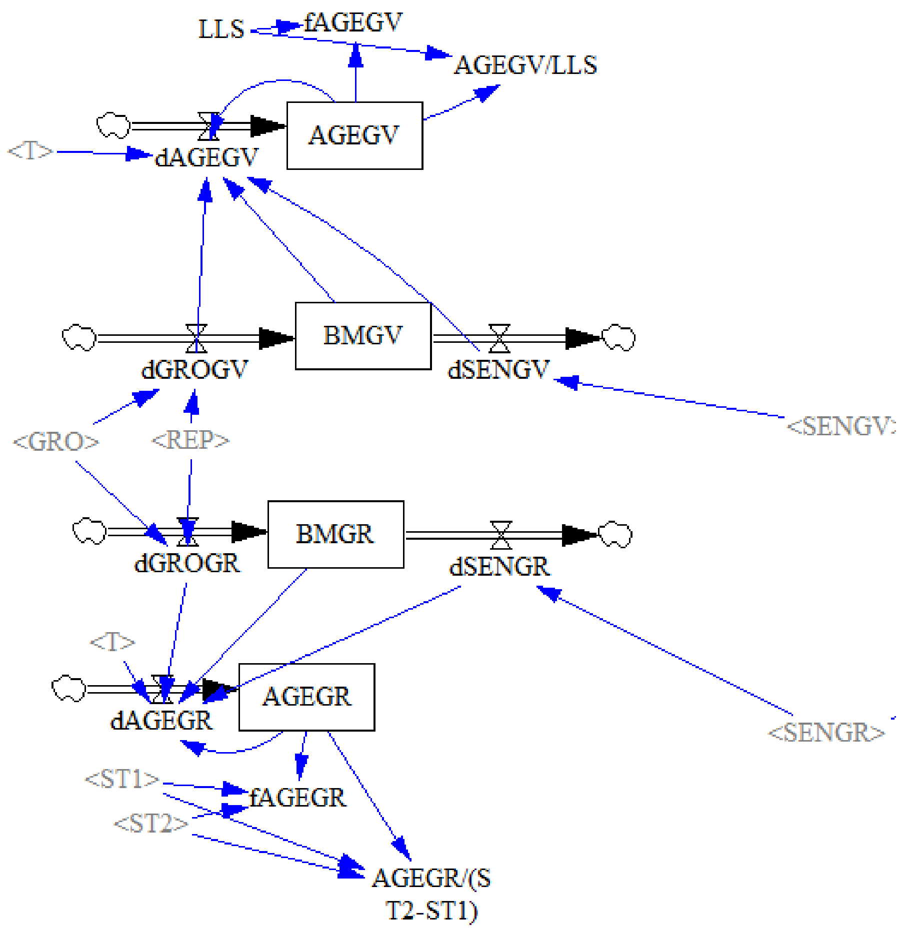
4. Ageing of green vegetative/green reproductive compartment

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



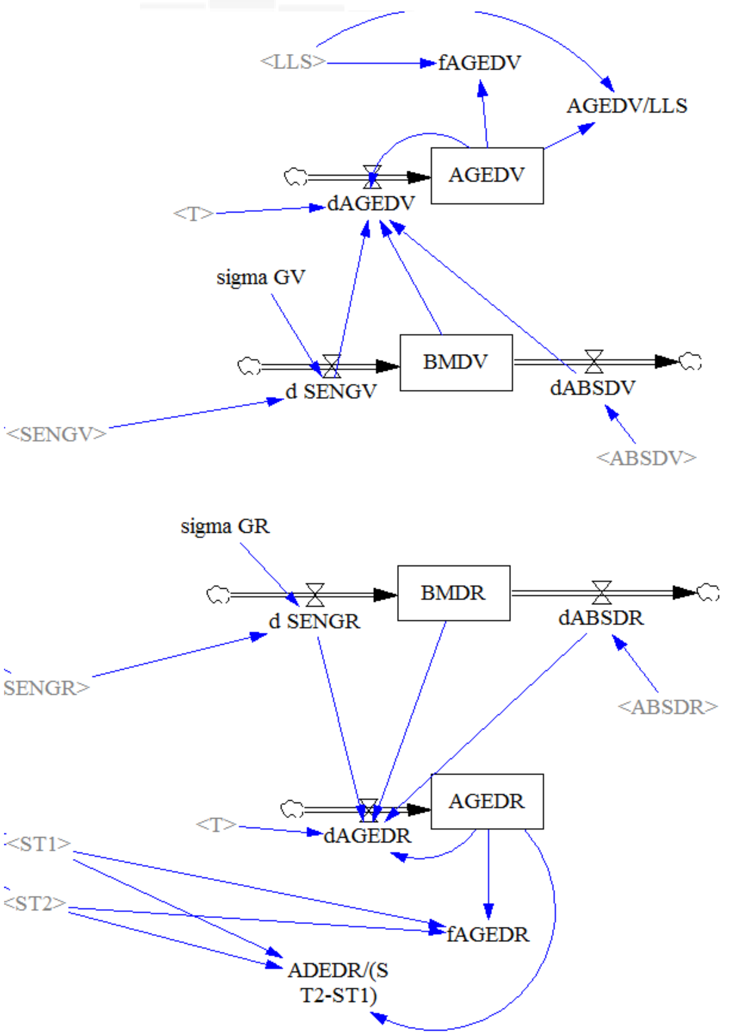
→ **as a compartment!**

4. Ageing of green vegetative/green reproductive compartment



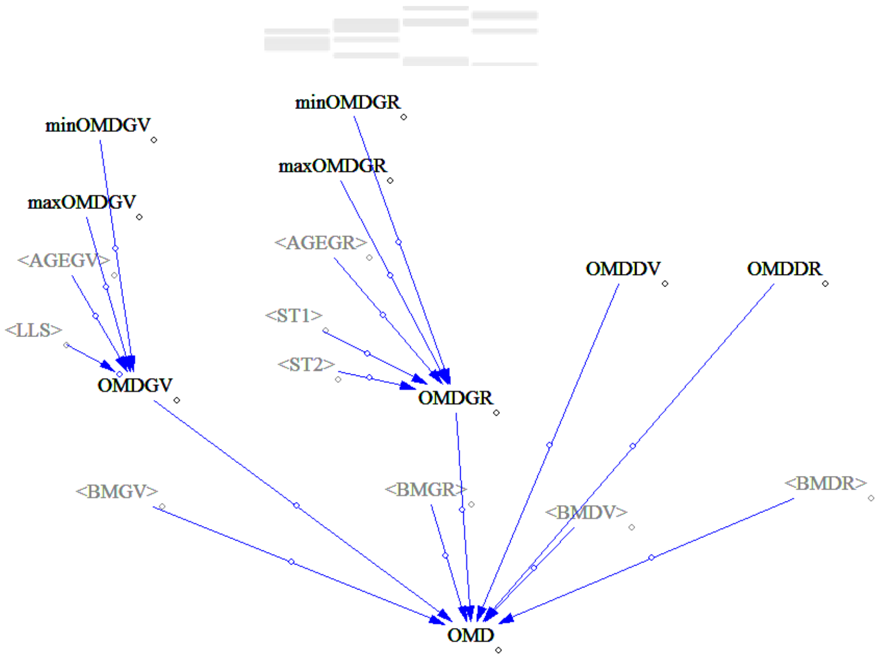
- Then we add the Age of both compartments and make the links between the variables

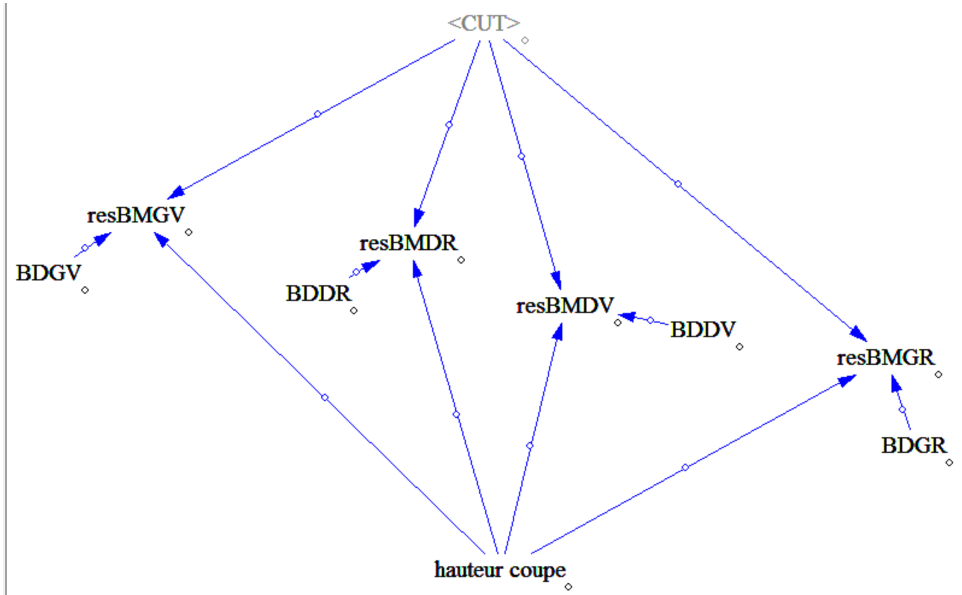
5. Development of the model for dead compartments



- Same approach as for green compartments

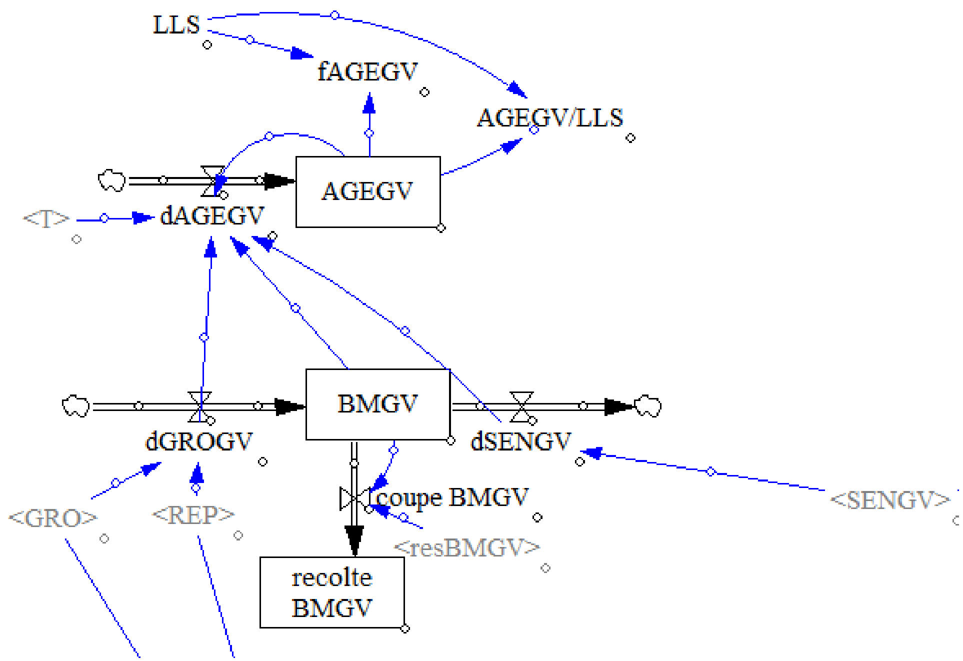
6. Sward digestibility and cutting (1/2)

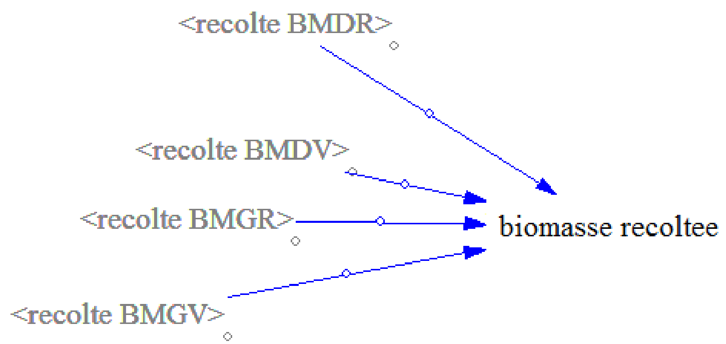




- Digestibility: linked to the age and weighted average
- Residual biomass: linked to cutting height and sward density

6. Sward digestibility and cutting (2/2)

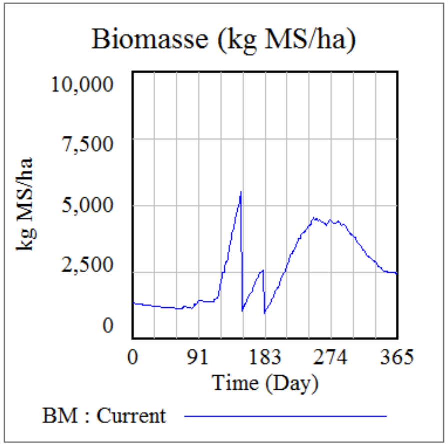


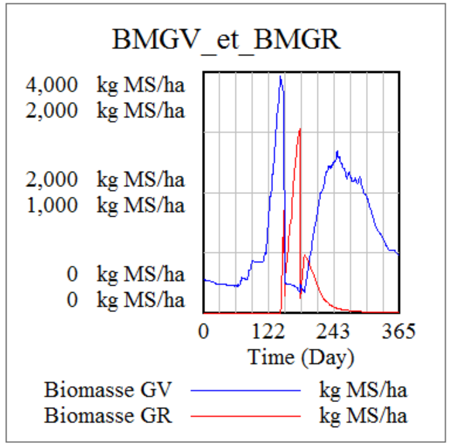


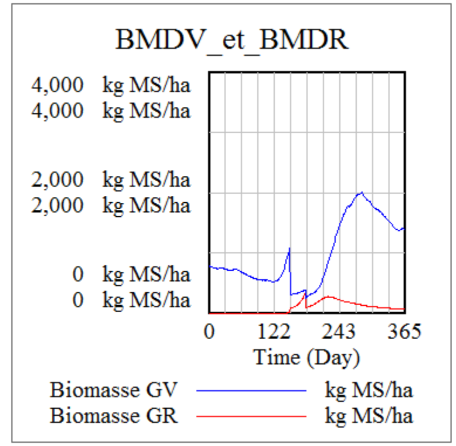
- Harvested biomass: inflow when occurrence of cutting for each compartment

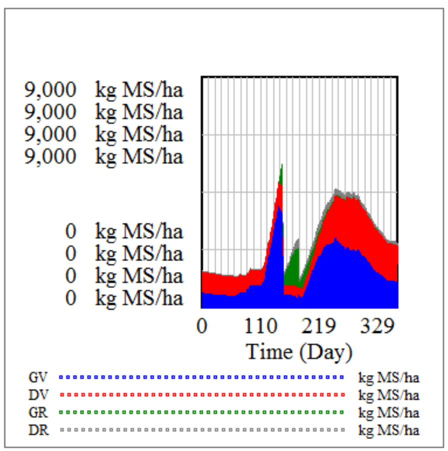
- Total harvested biomass: sum of all compartments

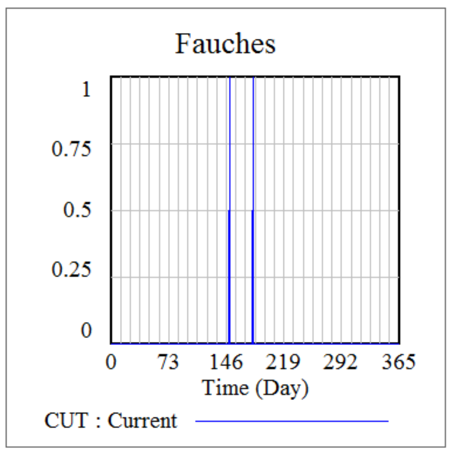
7. Simulation of results

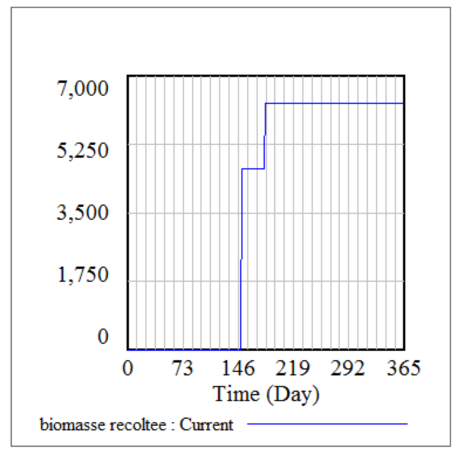


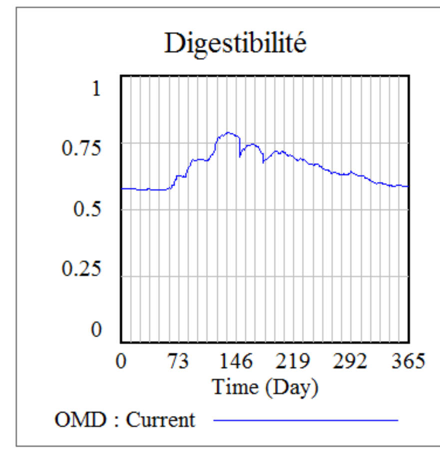












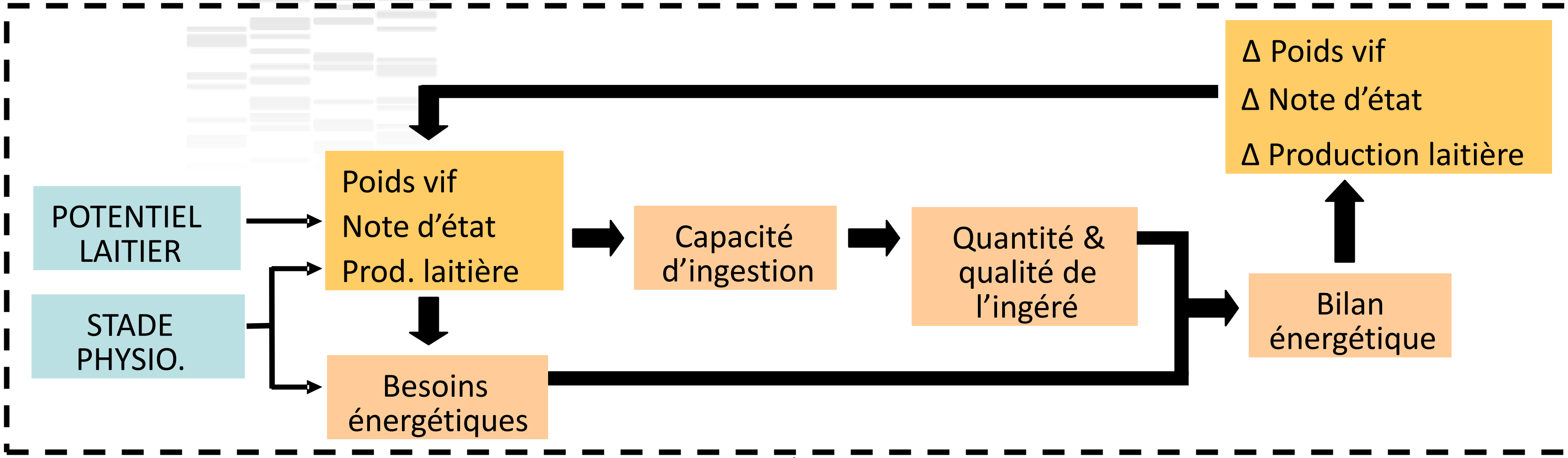
General remarks on the implementation using VenSim

- 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)

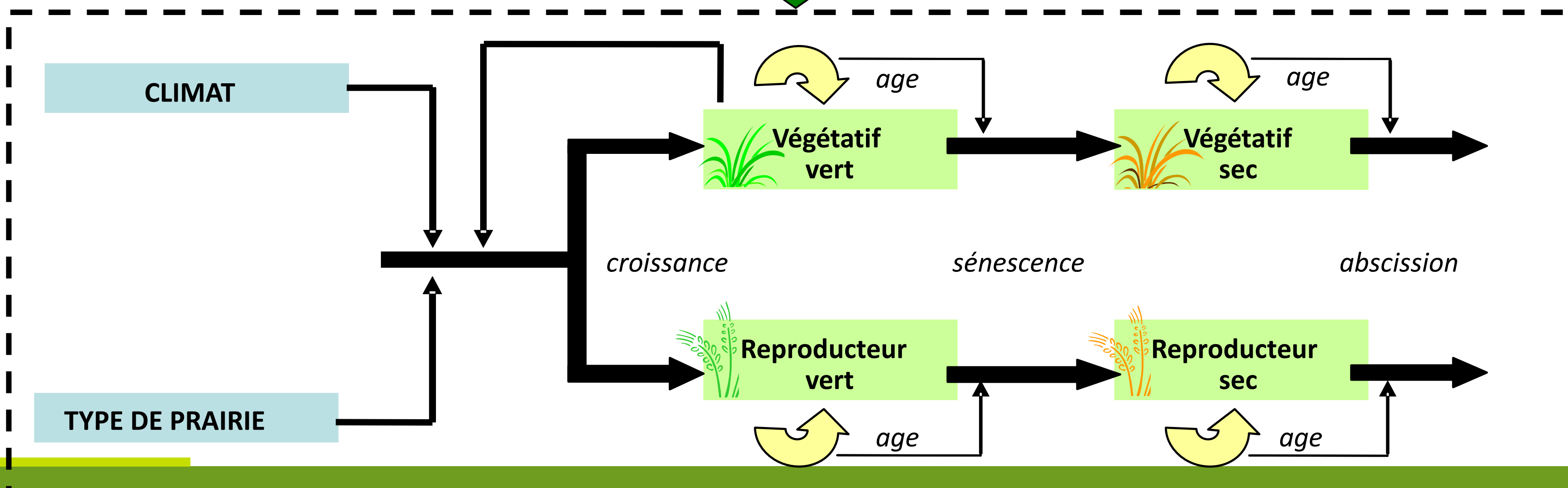
Coupling with a ruminant livestock model



(Jouven et al., 2007)

Comportement de sélection

Limitation ingestion selon la biomasse



(Jouven et al., 2006)