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

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How implementing a model with Vensim PLE ?

– example of the ModVege model

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

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



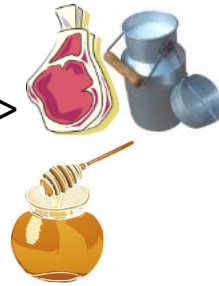
Maintaining grasslands is important



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

Provisioning

- Fodder =>
- Pollen =>



Cultural

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

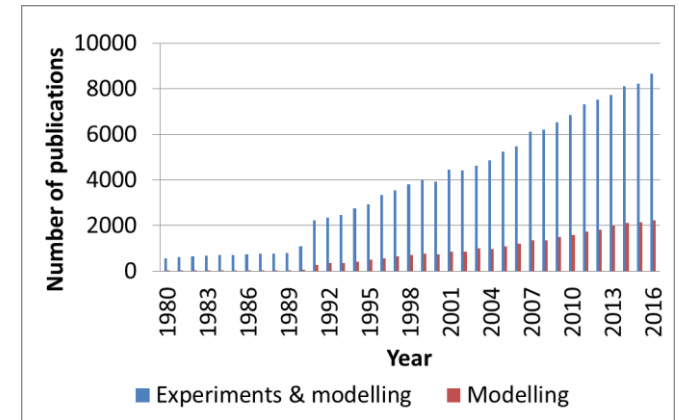
Regulation

- 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 addressing **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

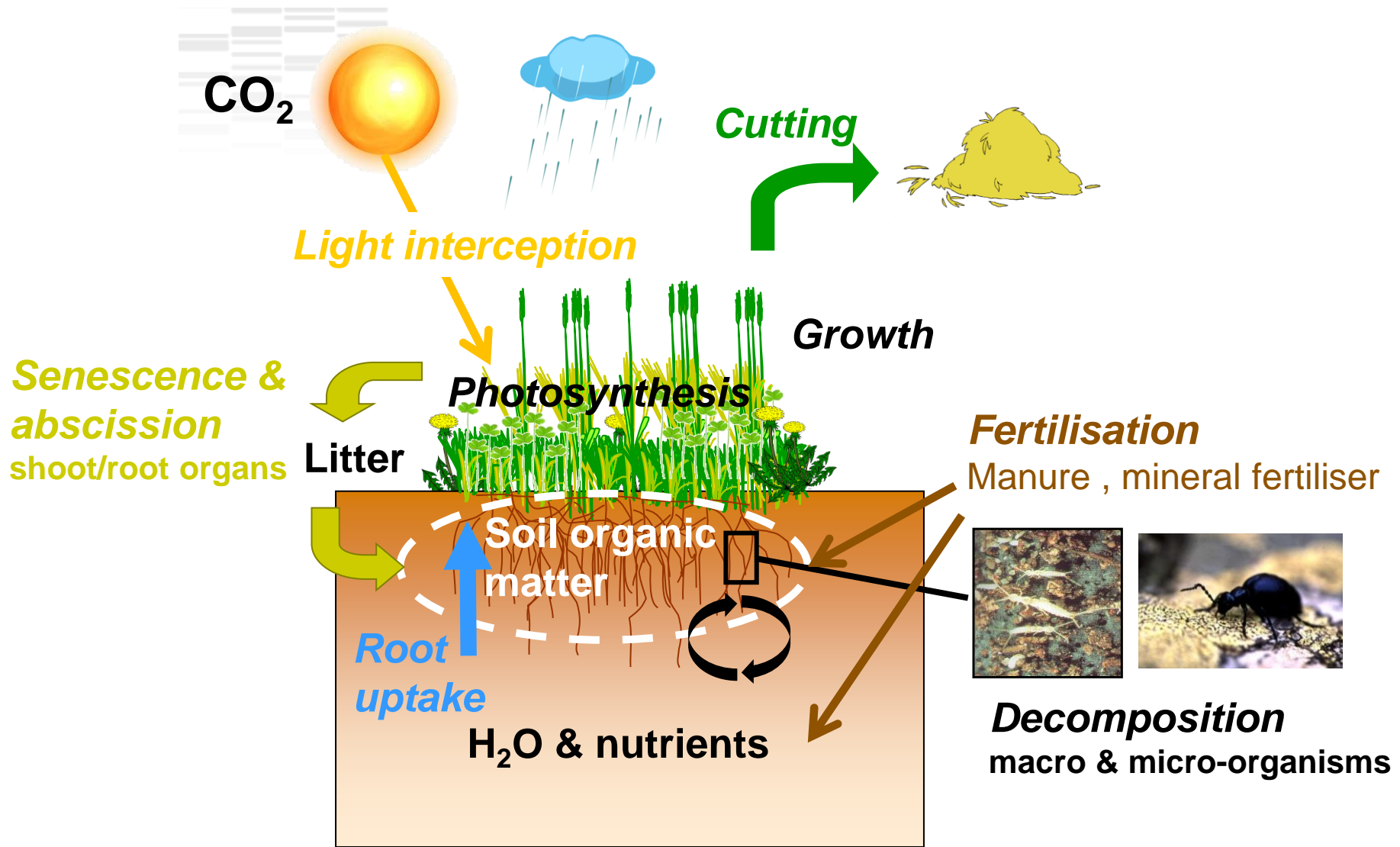
	Rich/fertile sites	Poor/infertile sites
Frequent defoliation	<p>Group A</p> <p><i>Ex: Lolium perenne, Holcus lanatus</i></p> <p>High SLA High digestibility Short leaf lifespan Early reproductive growth & flowering</p>	<p>Group C</p> <p><i>Ex: Festuca rubra, Agrotis capillaris</i></p> <p>Low SLA Medium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

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

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

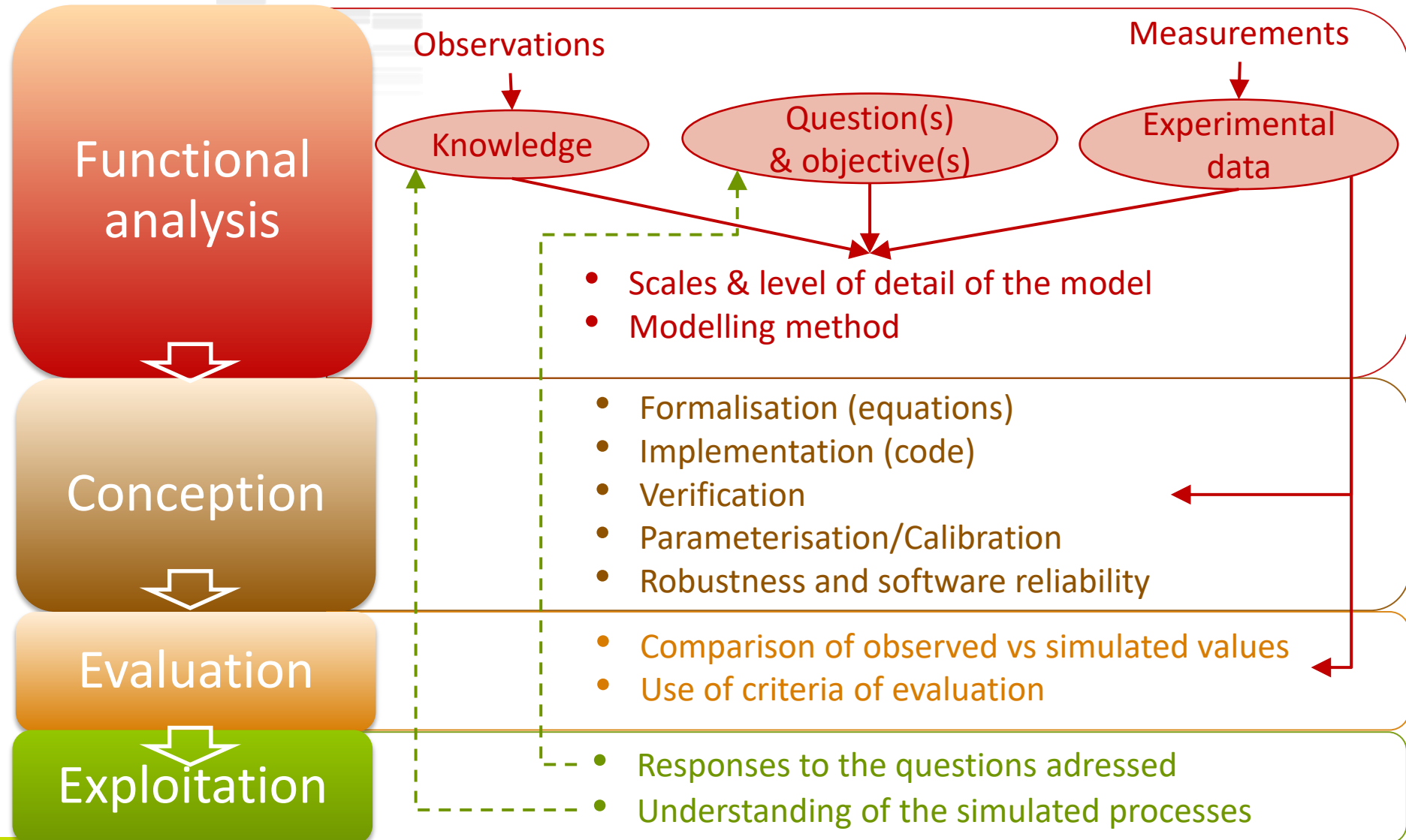
=> Useful to **simplify model parameterisation** and account for **functional diversity**

How it works?



The modelling approach : 4 steps

Adapted from Coquillard & Hill, 1997 and 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 compartmentation

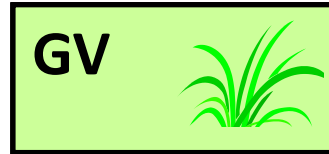
Jouven et al., 2006. *Grass and Forage Science*



Sward heterogeneity

= **4 structural shoot compartments**

Green (G)

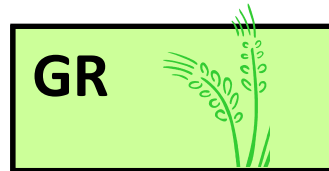


Dead (D)



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**)

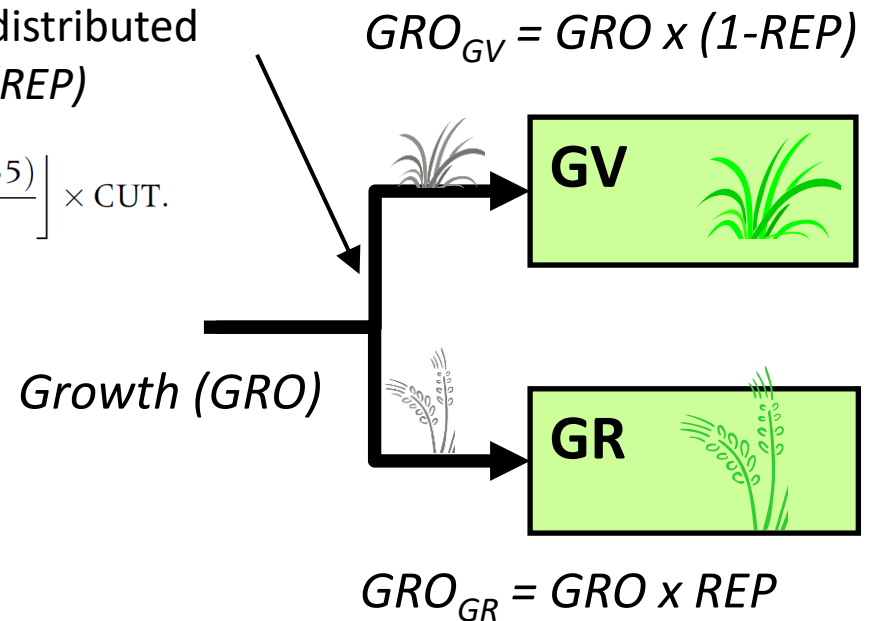
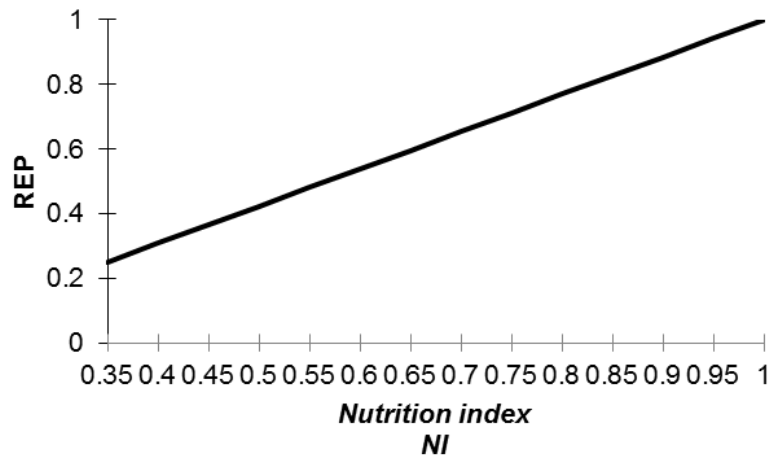
GV compartment **+1 state variable** : leaf area index (**LAI**)

Partitioning of growth between vegetative and reproductive green compartments

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

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

Else $\text{REP} = 0$

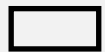
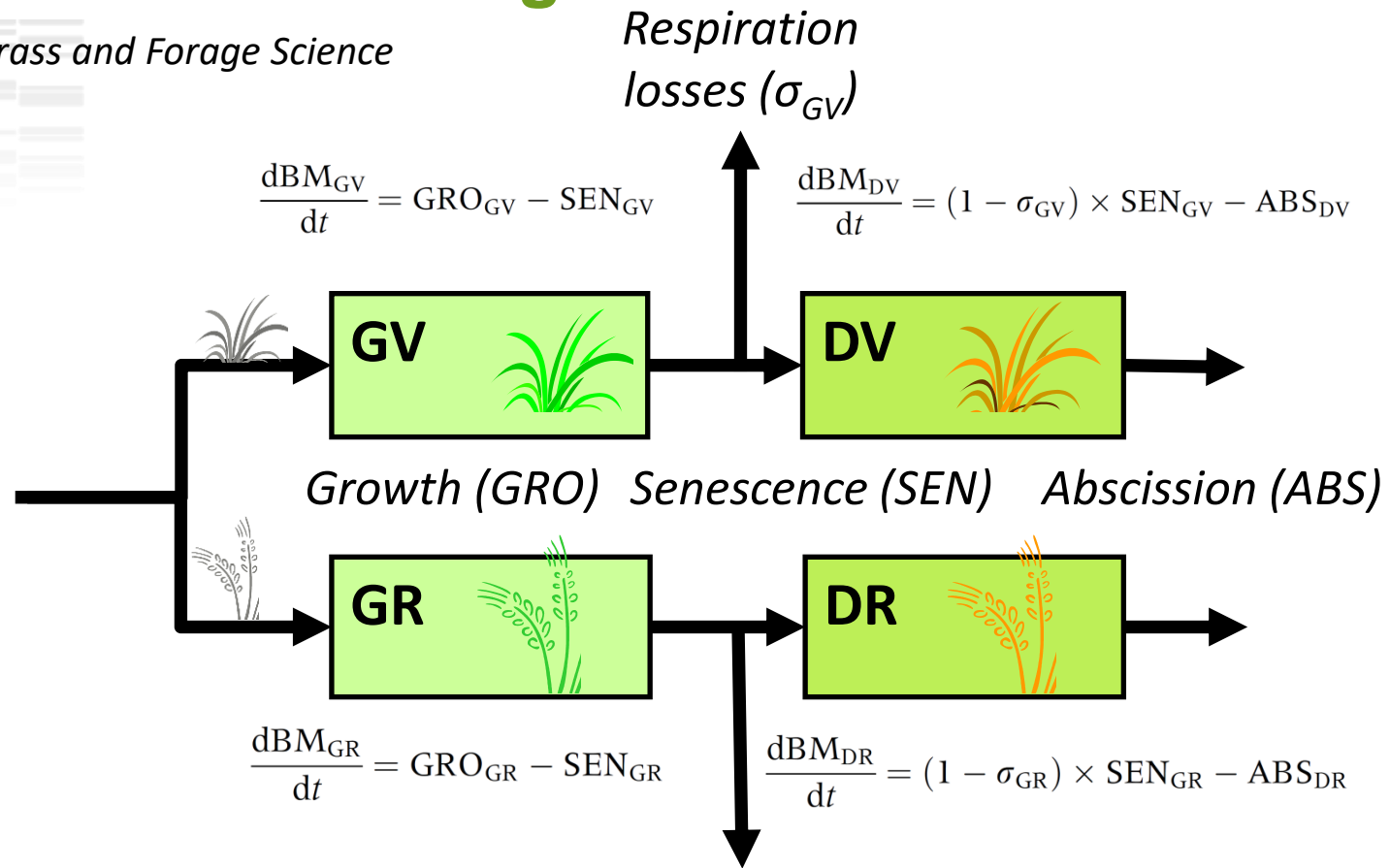


- If a cut occurs during the reproductive period, reproductive growth is stopped ($\text{REP} = 0$)
- Only 1 cycle of reproductive growth is modeled

- 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



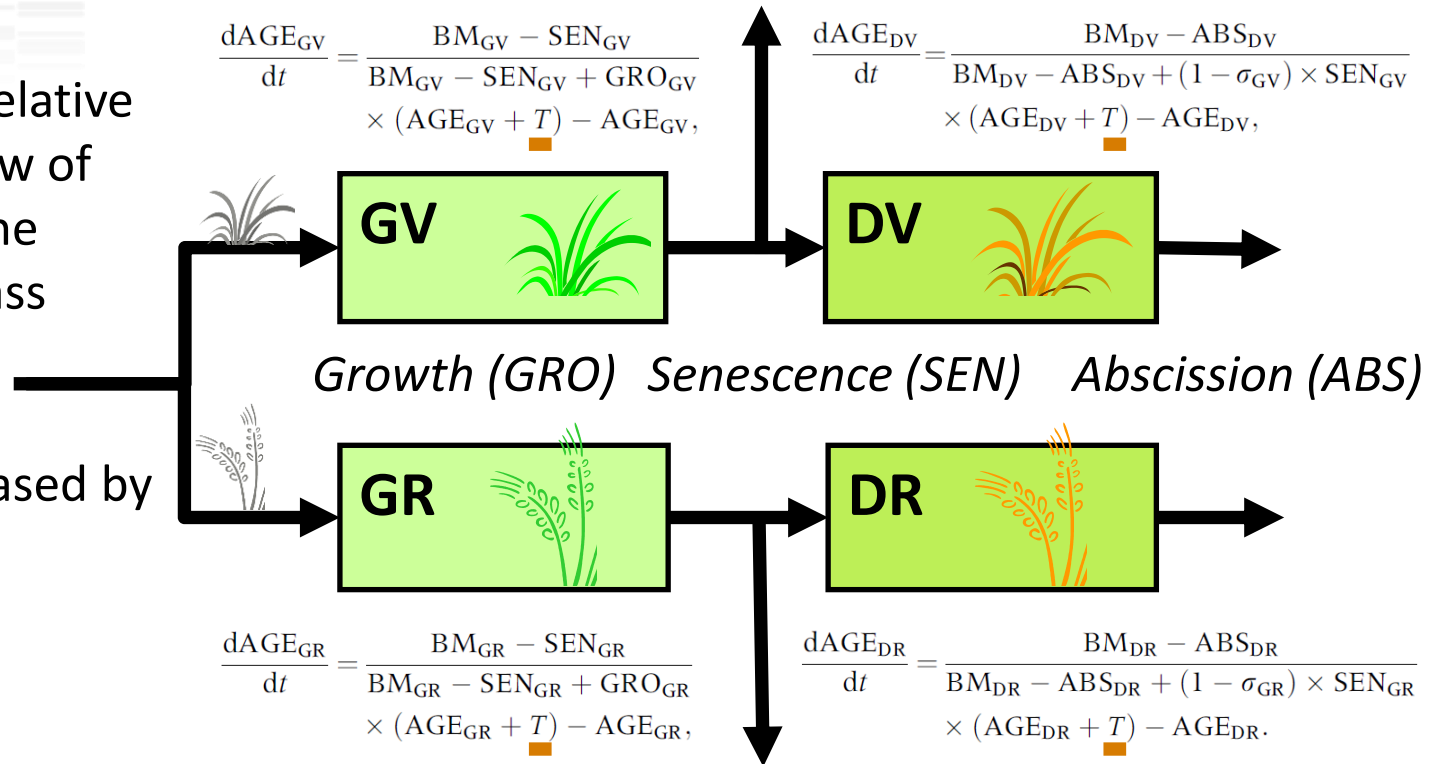
Direct & feedback effects of variables on flows

Calculation of the age

Jouven et al., 2006. Grass and Forage Science

- Age can \nearrow or \searrow 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)



Structural component



Biomass flows



Ageing functions

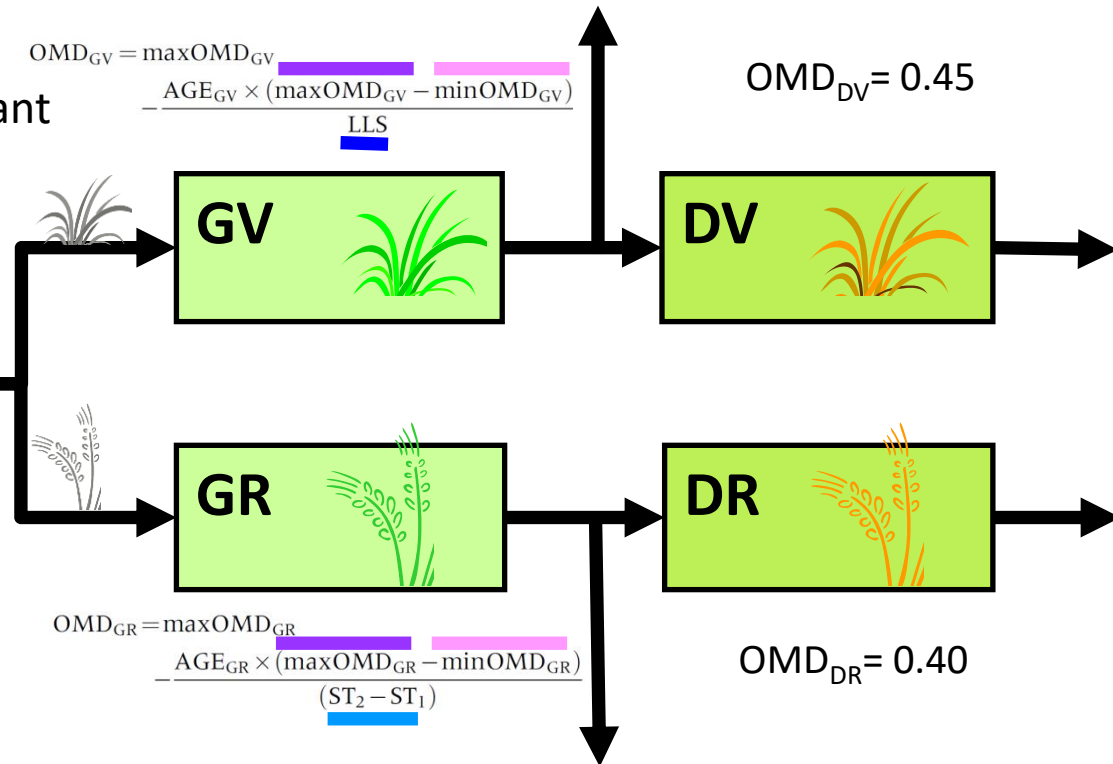






Direct & feedback effects of variables on flows

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



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

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

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

Nutrition index (site specific, constant)

Influence of PAR_i

Influence of temperature

Influence of water availability

● Water stress (W)

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

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

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

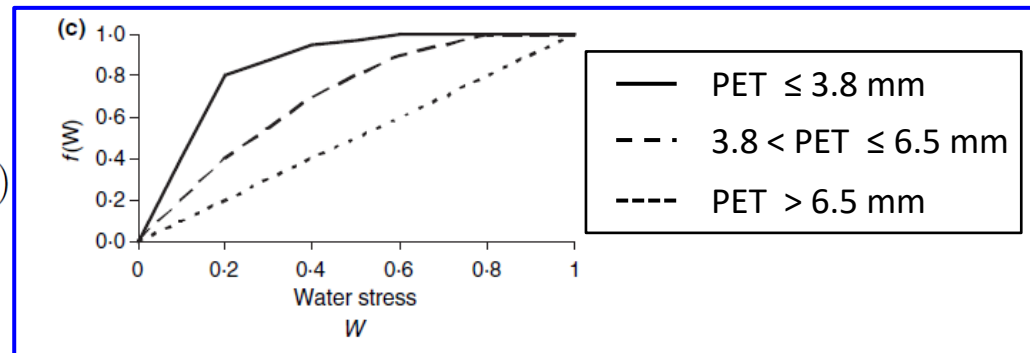
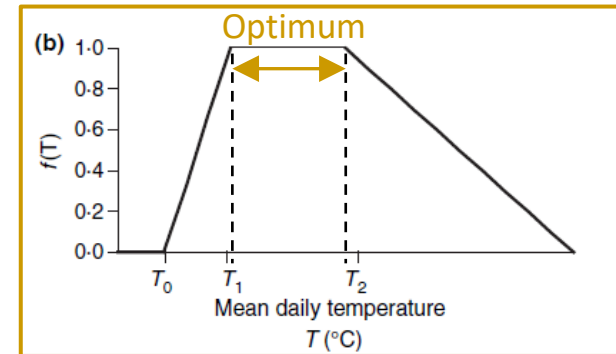
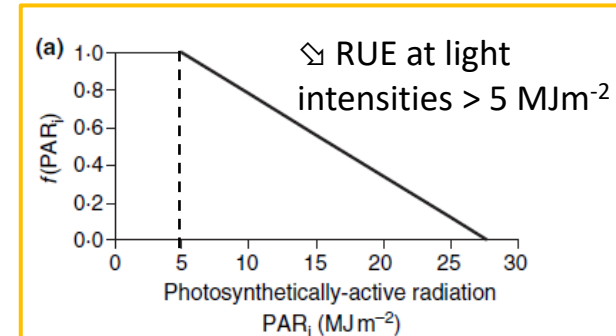


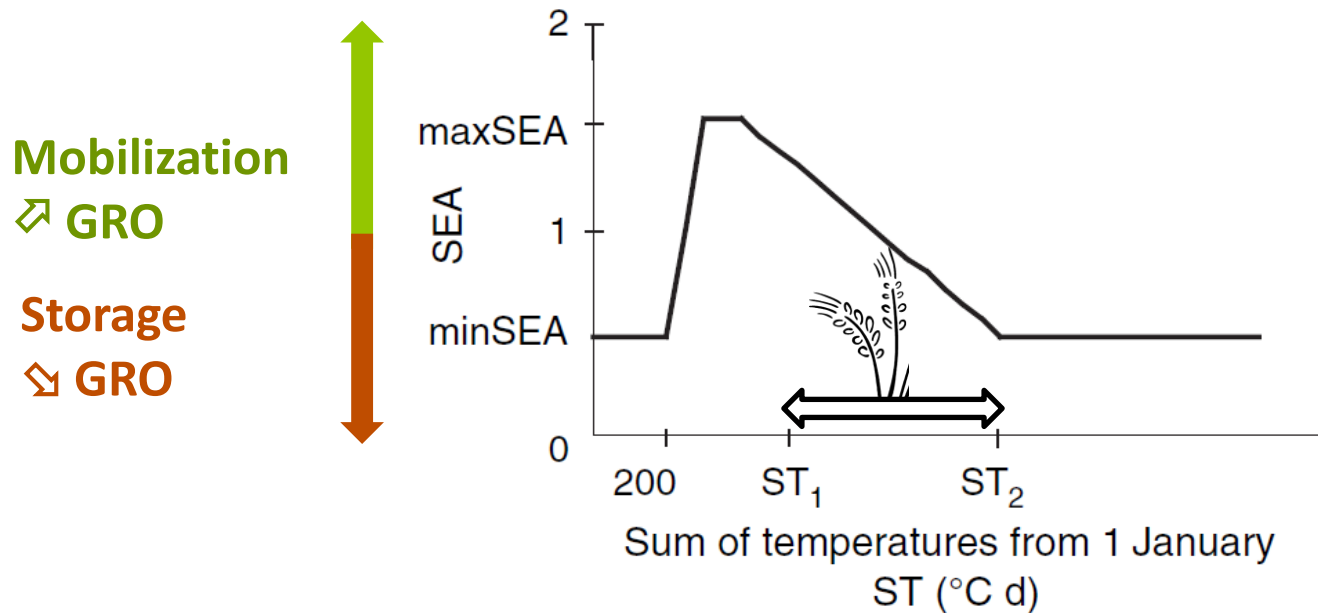
Figure 2 Threshold functions representing growth limitation

Calculation of growth functions

■ *Seasonal pattern of storage/mobilisation of reserves*

● Empirical function (SEA)

- $ST < 200^{\circ}\text{C d}$ (winter) = minimum (minSEA)
- $ST_{1-200} < ST < ST_{1-100}$ (growth) : ↗ to a maximum (maxSEA)
- $ST_{1-100} < ST < ST_2$ (summer) : ↘
- $ST > ST_2$ (after the end of reproductive growth) = minSEA



Calculation of senescence & abscission functions

■ **Senescence of green compartments**

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

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

and similarly for compartment GR

and

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

and similarly for compartment GR.

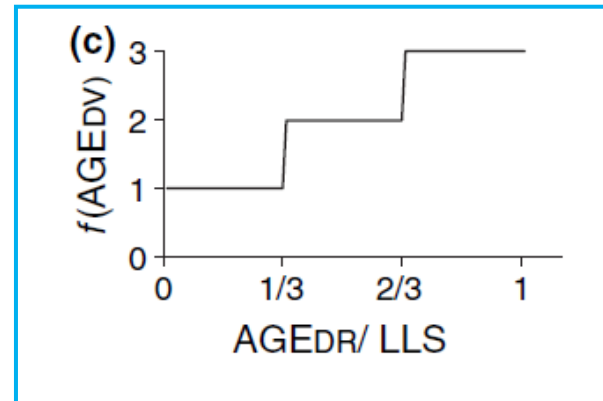
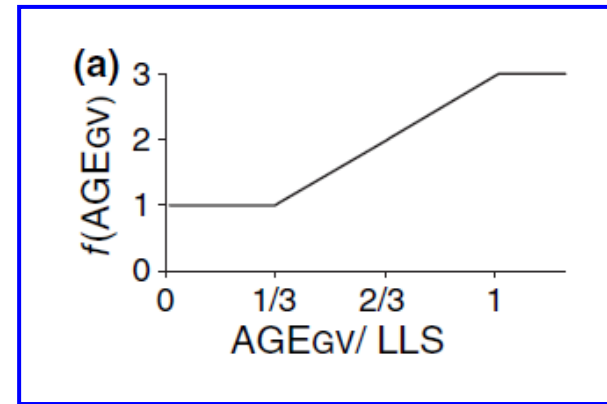
(Freezing effect)

■ **Abscission of dead compartments**

if $T > 0$,

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

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

$$\text{resBM}_{\text{GV}} = 0.05 \times 10 \times \text{BD}_{\text{GV}} \text{ and, similarly,}$$

for compartments GR, DV and DR

■ *Harvested biomass in each structural component*

$$\text{hBM}_{\text{GV}} = \text{BM}_{\text{GV}} - \text{resBM}_{\text{GV}} \text{ and similarly}$$

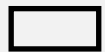
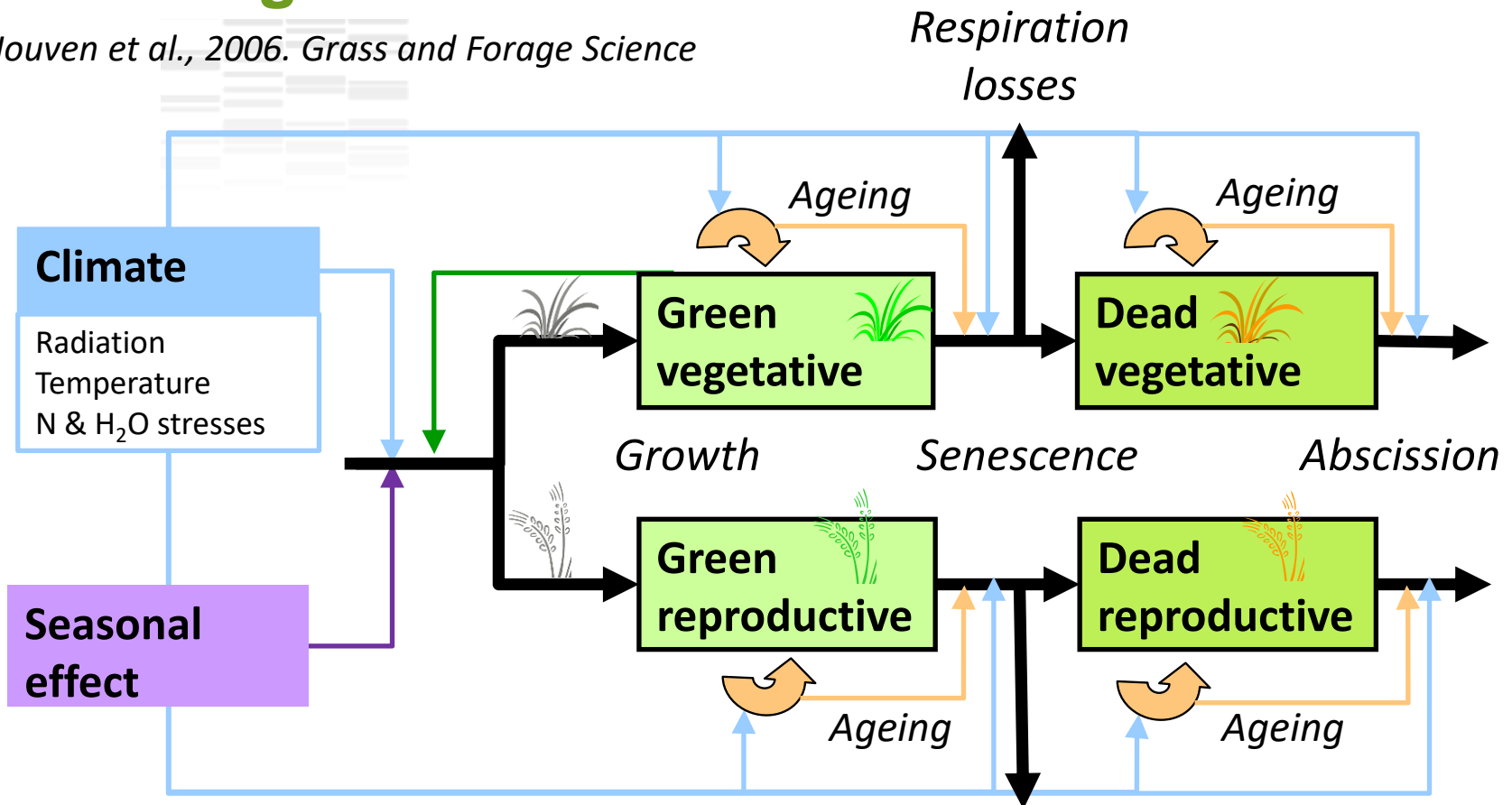
for compartments GR, DV, DR

■ *Total harvested biomass*

$$\text{hBM} = \text{hBM}_{\text{GV}} + \text{hBM}_{\text{GR}} + \text{hBM}_{\text{DV}} + \text{hBM}_{\text{DR}}$$

Flow diagram of the model

Jouven et al., 2006. Grass and Forage Science



Structural component



Biomass flows



Ageing functions



Direct & feedback effects of variables on flows

Respiration losses

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				Sources
	A	B	C	D	
SLA (m ² g ⁻¹)	0.033	0.025	0.022	0.019	Cruz <i>et al.</i> (2002)
%LAM	0.68	0.68	0.68	0.68	Louault <i>et al.</i> (2005)
ST ₁ (°C d)	600	700	850	1000	Ansquer <i>et al.</i> (2004);
ST ₂ (°C d)	1200	1350	1550	1850	Louault <i>et al.</i> (2005)
maxSEA	1.20	1.30	1.40	1.50	Bausenwein <i>et al.</i> (2001);
minSEA	0.80	0.70	0.60	0.50	Thornton <i>et al.</i> (1993, 1994)
LLS (°C d)	500	800	900	1400	Ansquer <i>et al.</i> (2004)
maxOMD _{GV}	0.90	0.90	0.85	0.75	Terry and Tilley (1964); Demarquilly
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 <i>et al.</i> (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 <i>et al.</i> (1995);
					Ginane <i>et al.</i> (2003)
BD _{GR} (g DM m ⁻³)	300	300	200	150	Louault <i>et al.</i> (2005)
BD _{DR} (g DM m ⁻³)	150	150	300	450	

SLA, specific leaf area; %LAM, percentage of laminae; ST₁ and ST₂, 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 <i>et al.</i> (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 <i>et al.</i> (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.

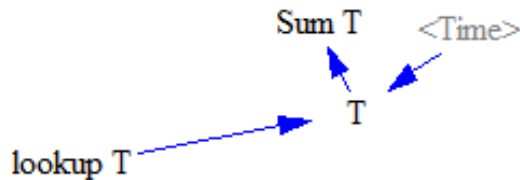
Model implementation using VenSim

■ *A methodology*

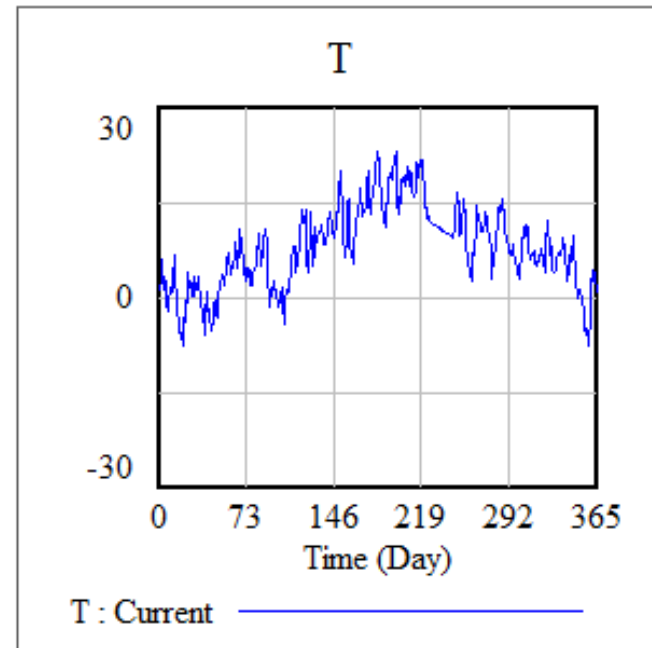
1. Growth limitation functions
2. Growth and senescence flows for one (green) compartment, biomass
3. Reproductive function and differentiation of green vegetative/green reproductive compartment
4. Ageing of green vegetative/green reproductive compartment
5. Same for dead compartments
6. Sward digestibility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

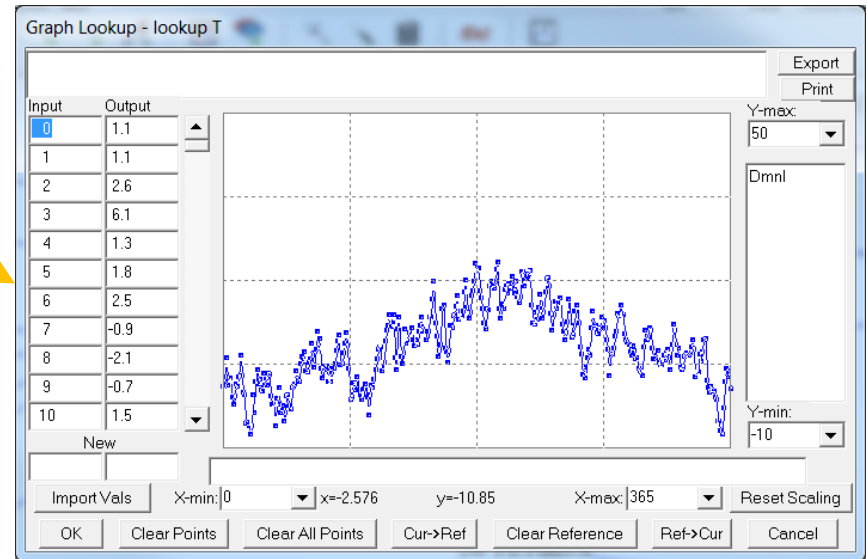
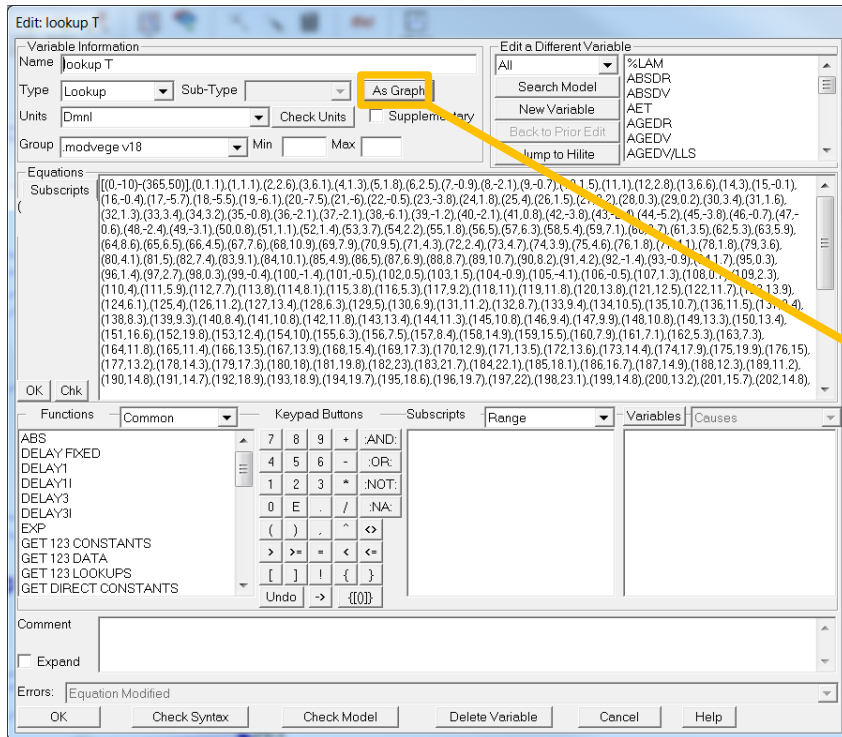


→ the sum of temperatures

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)

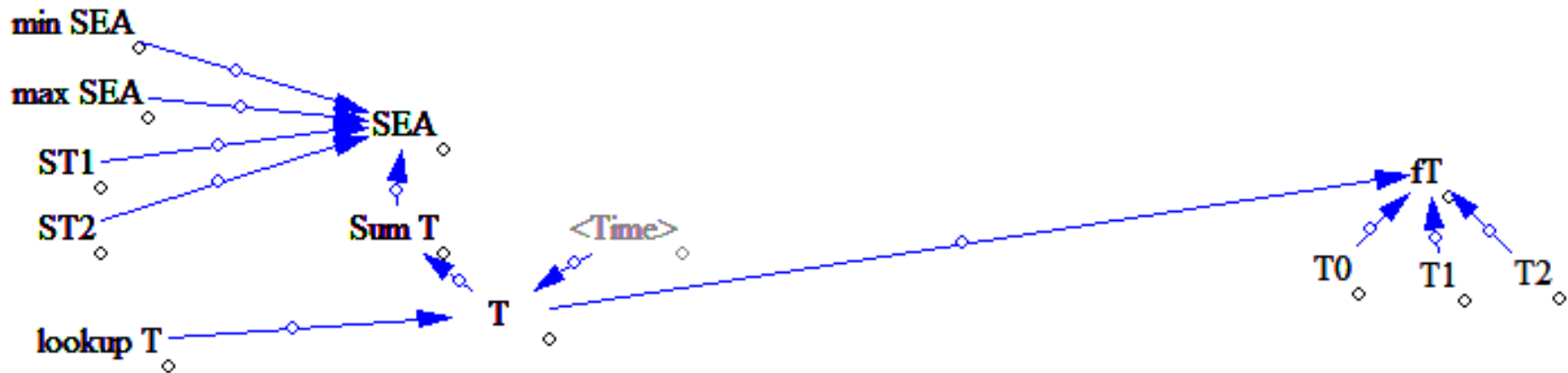
How implementing a model with VenSim PLE ?
– example of the ModVege model

1. Growth limitations functions

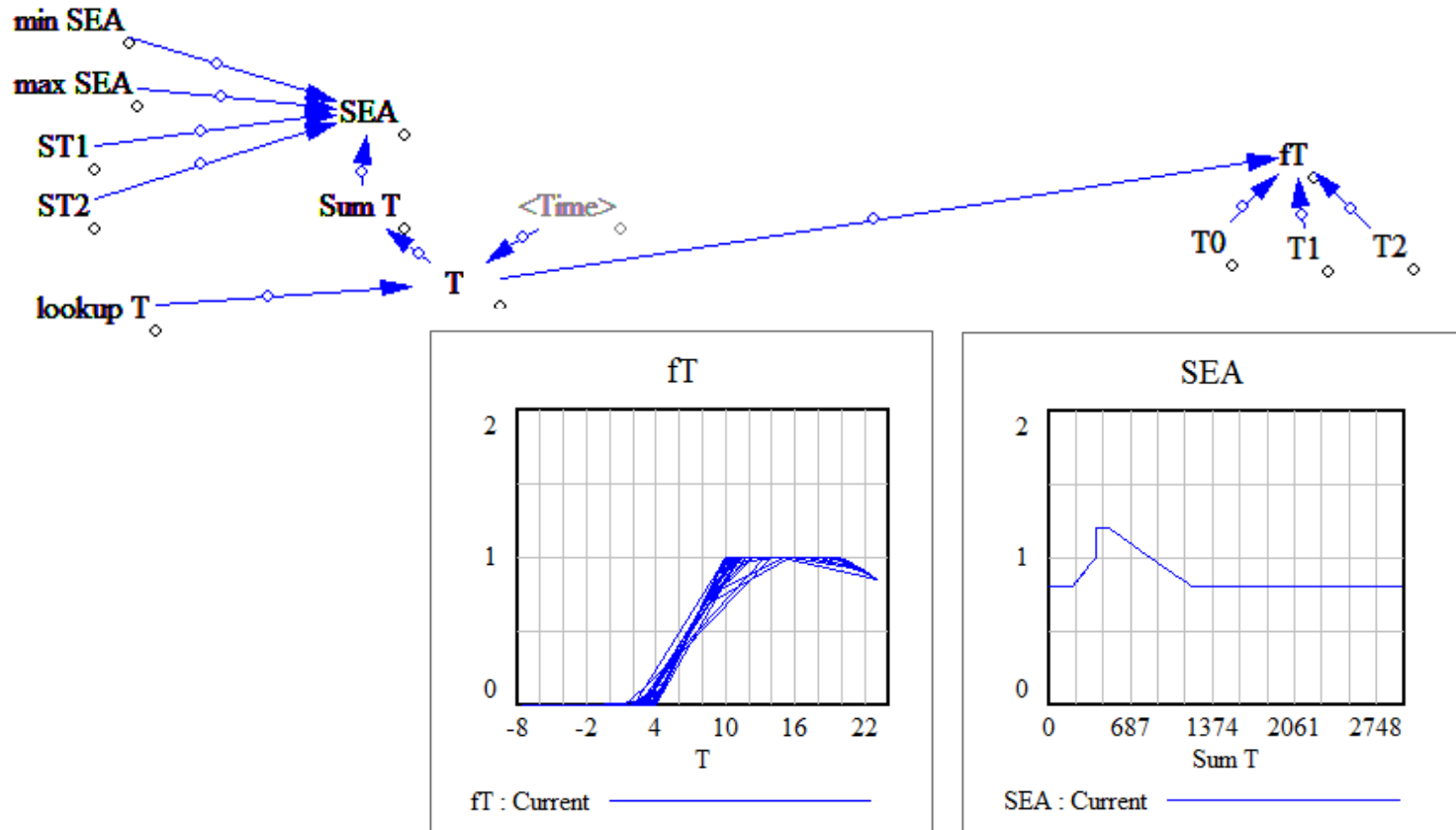


- Then, choose to represent « **basic** » **explanatory variables**, which will not be dependent on many other ones

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

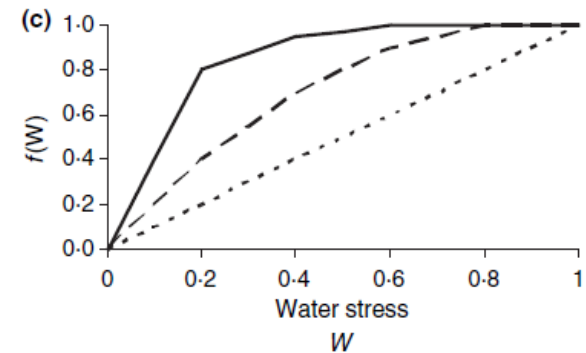
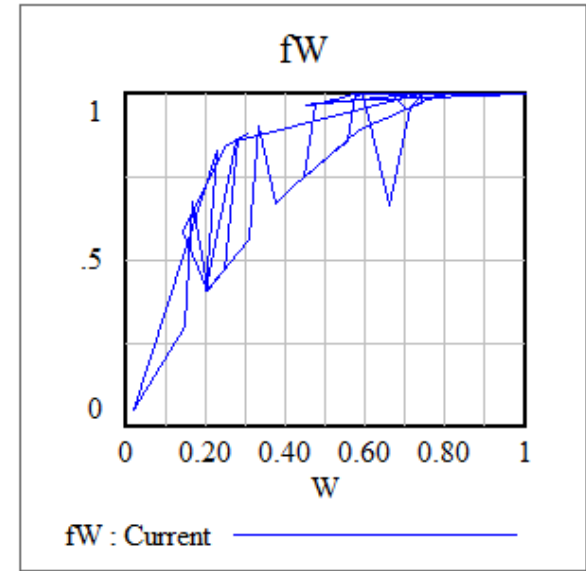
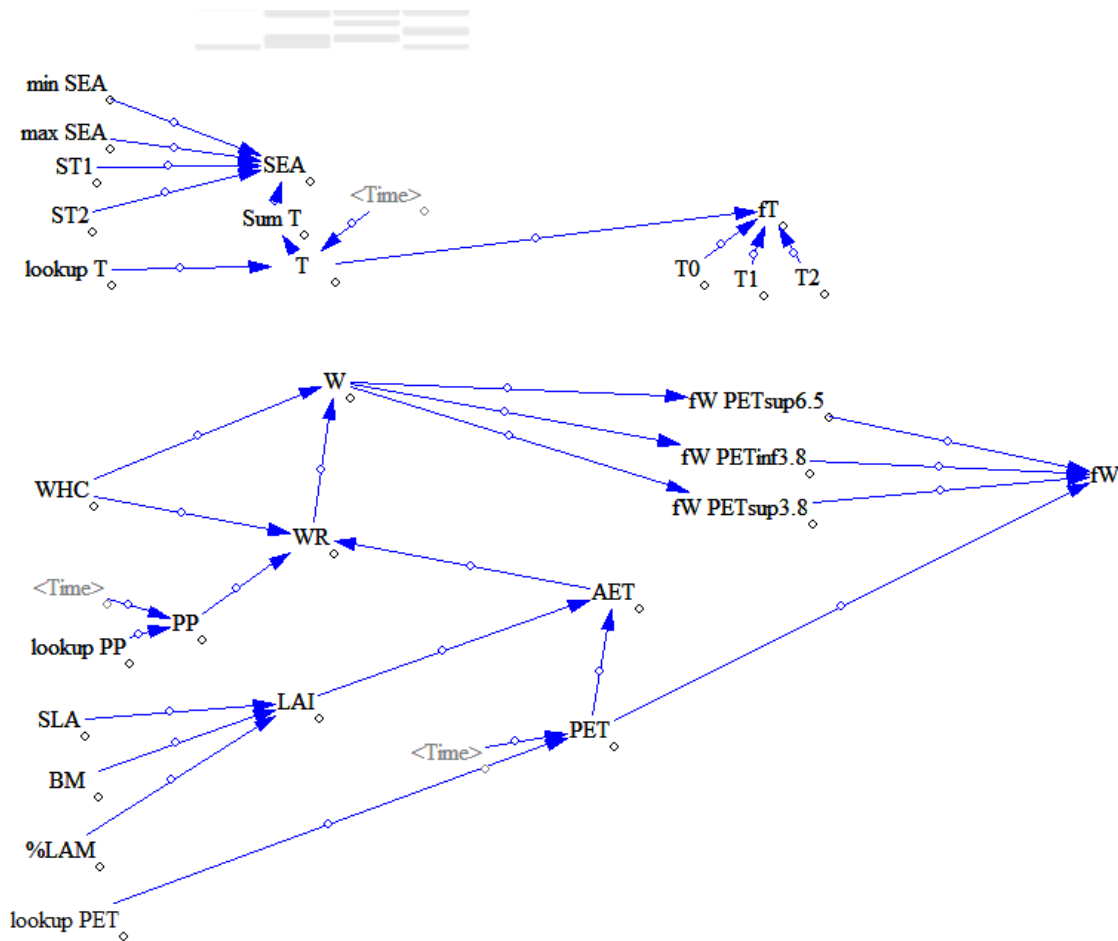


1. Growth limitations functions



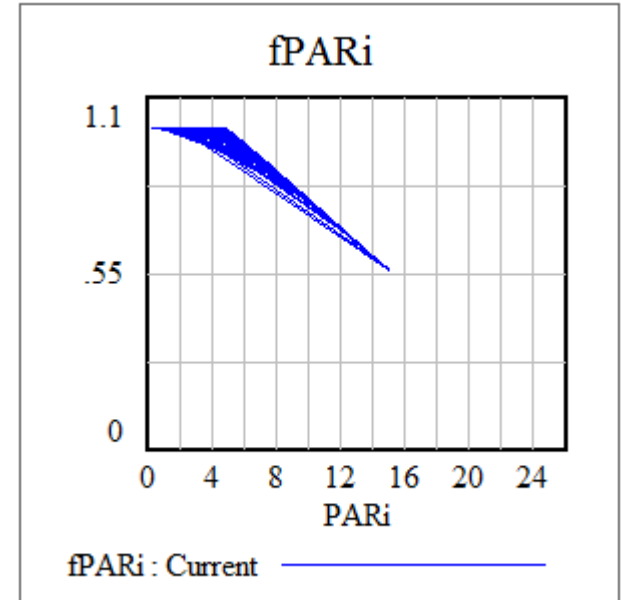
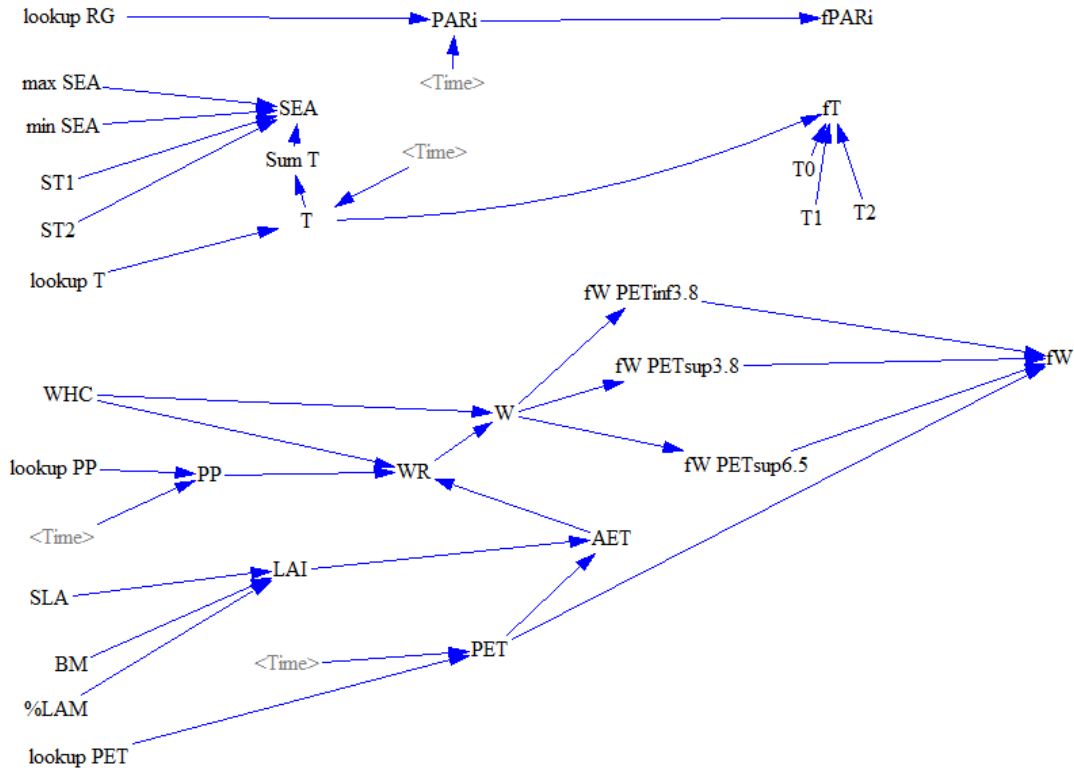
- Check appropriate behaviour gradually at each step with figure(s)
→ look at the paper, what do you think about these graphs?

1. Growth limitations functions



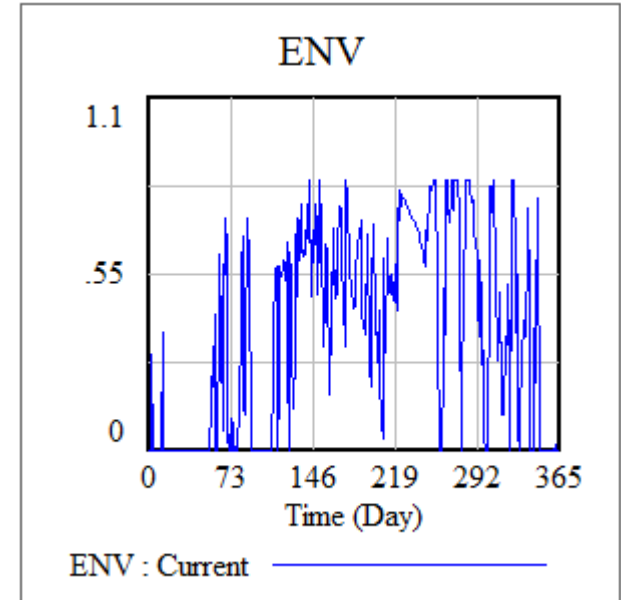
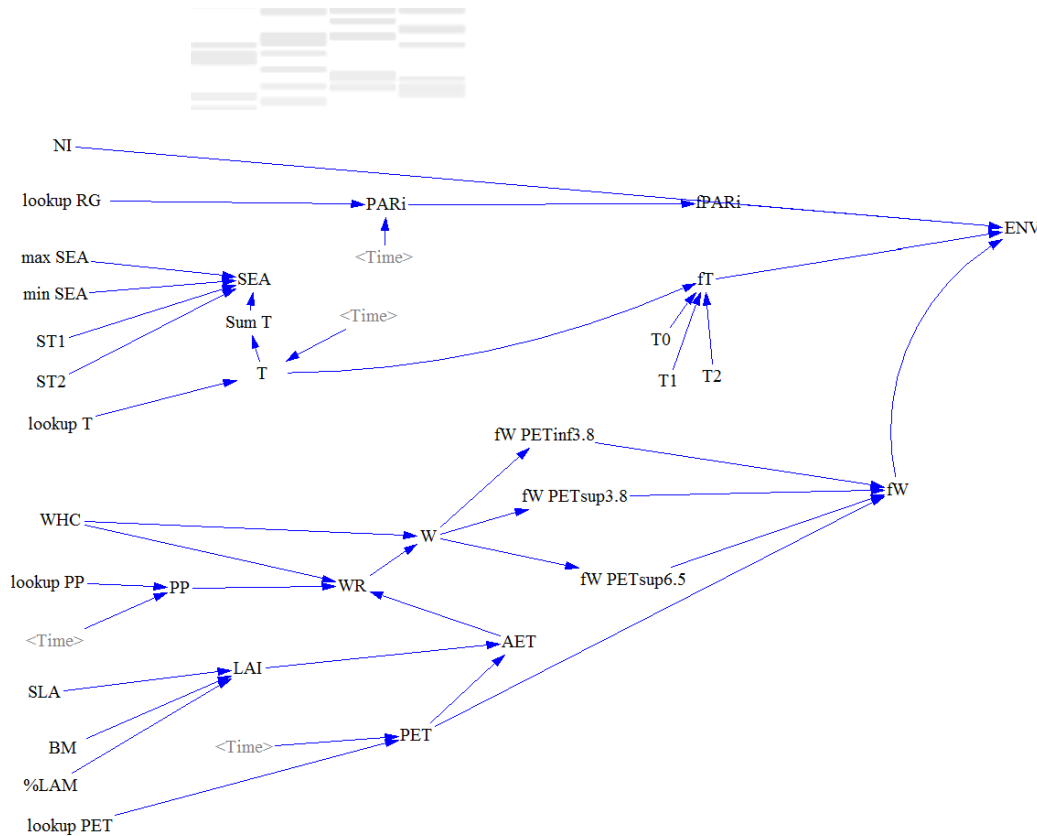
- Add the calculation of the leaf area index (LAI), and the effect of water stress on the function for limitation of growth : $f(W)$

1. Growth limitations functions



- The effect of the photosynthetically active radiation

1. Growth limitations functions

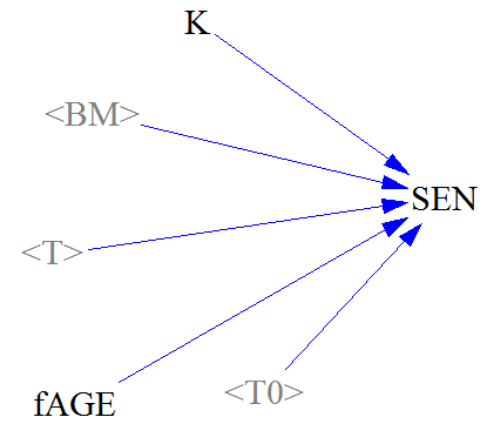
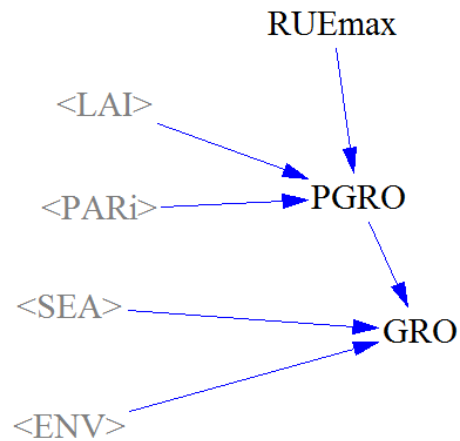


- We end up with this part → we obtain the equation for the environmental limitation of growth
- All this part in one view in Vensim → next new view



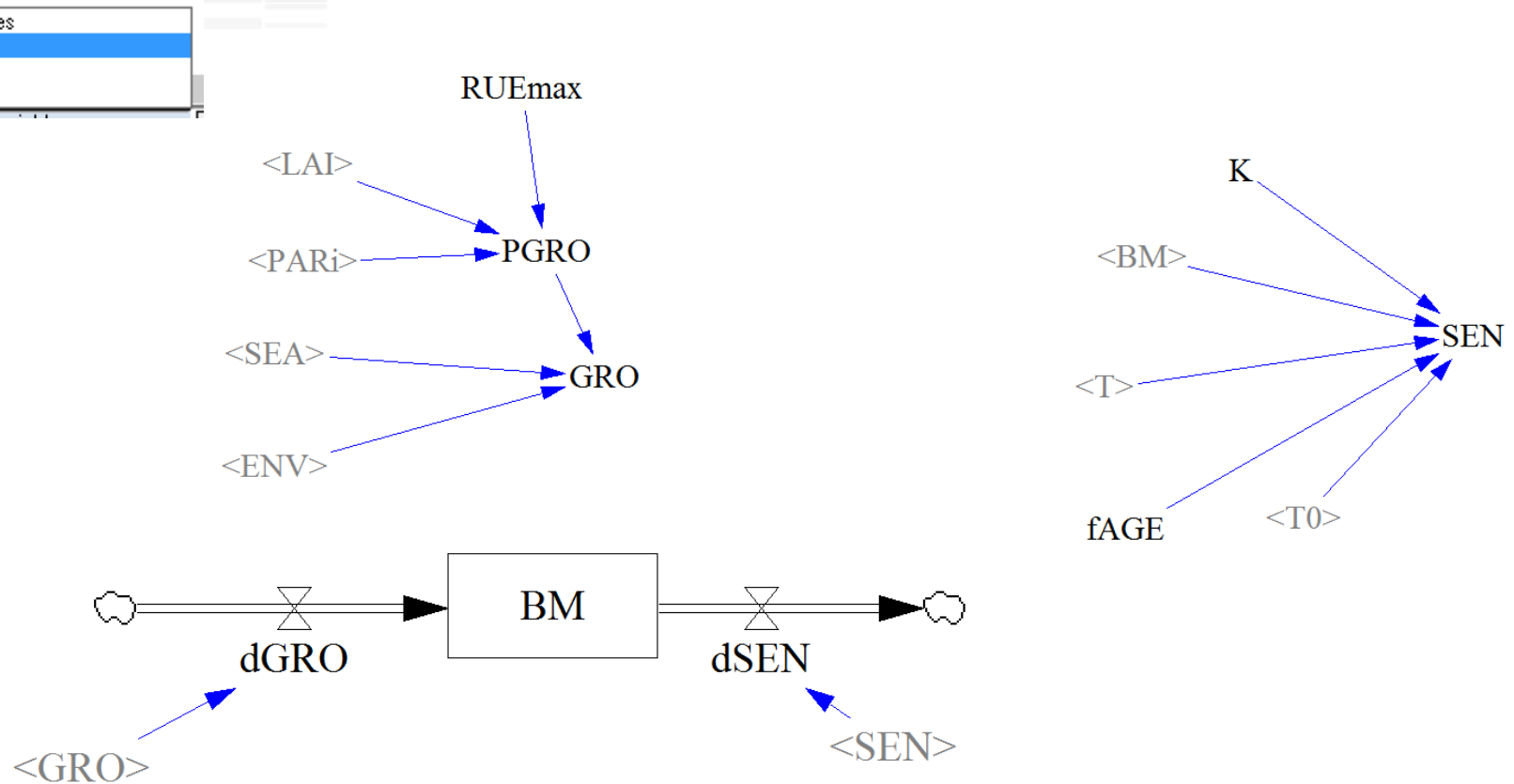
2. Growth and senescence flows for one (green) compartment, biomass

background variables
Flow variables
State variables
New



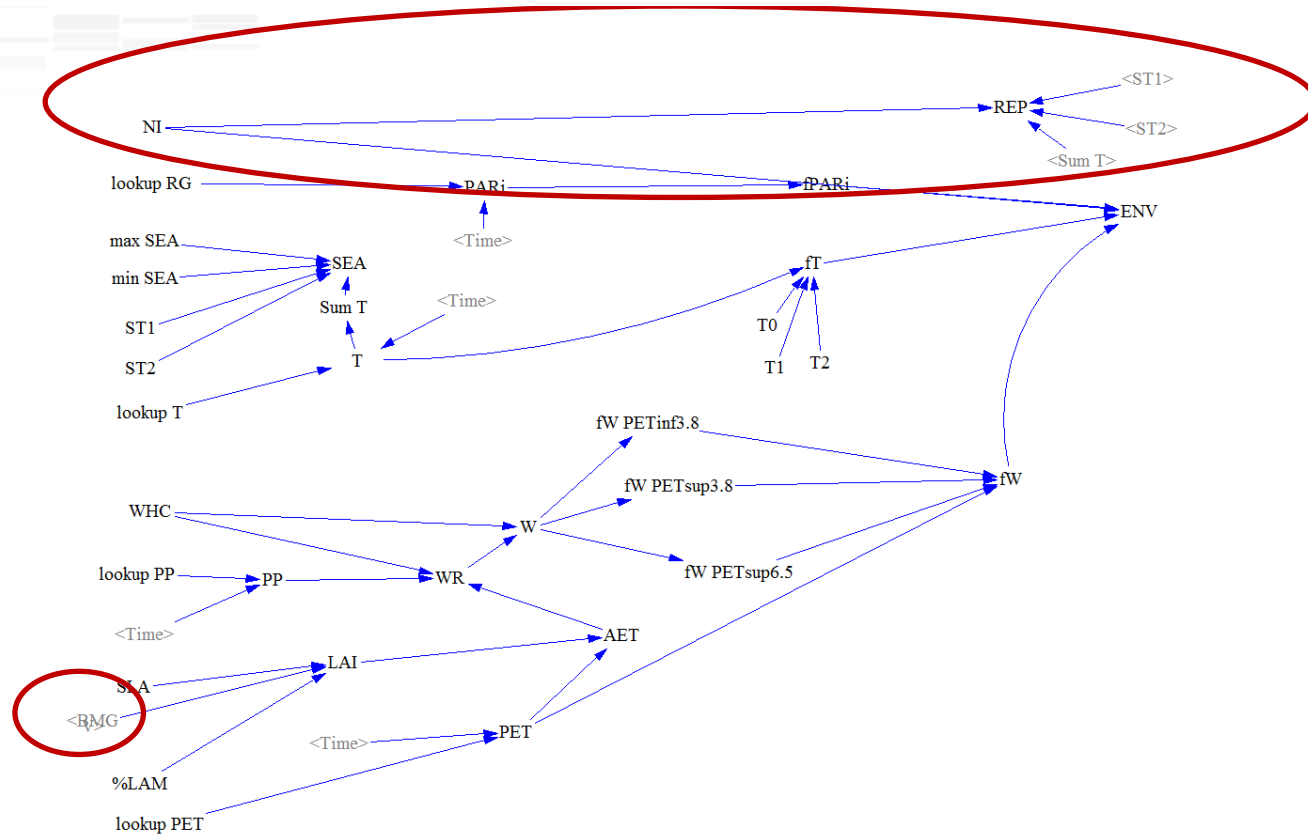
- We first try to implement protential growth, growth and senescence using some temporary variables

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



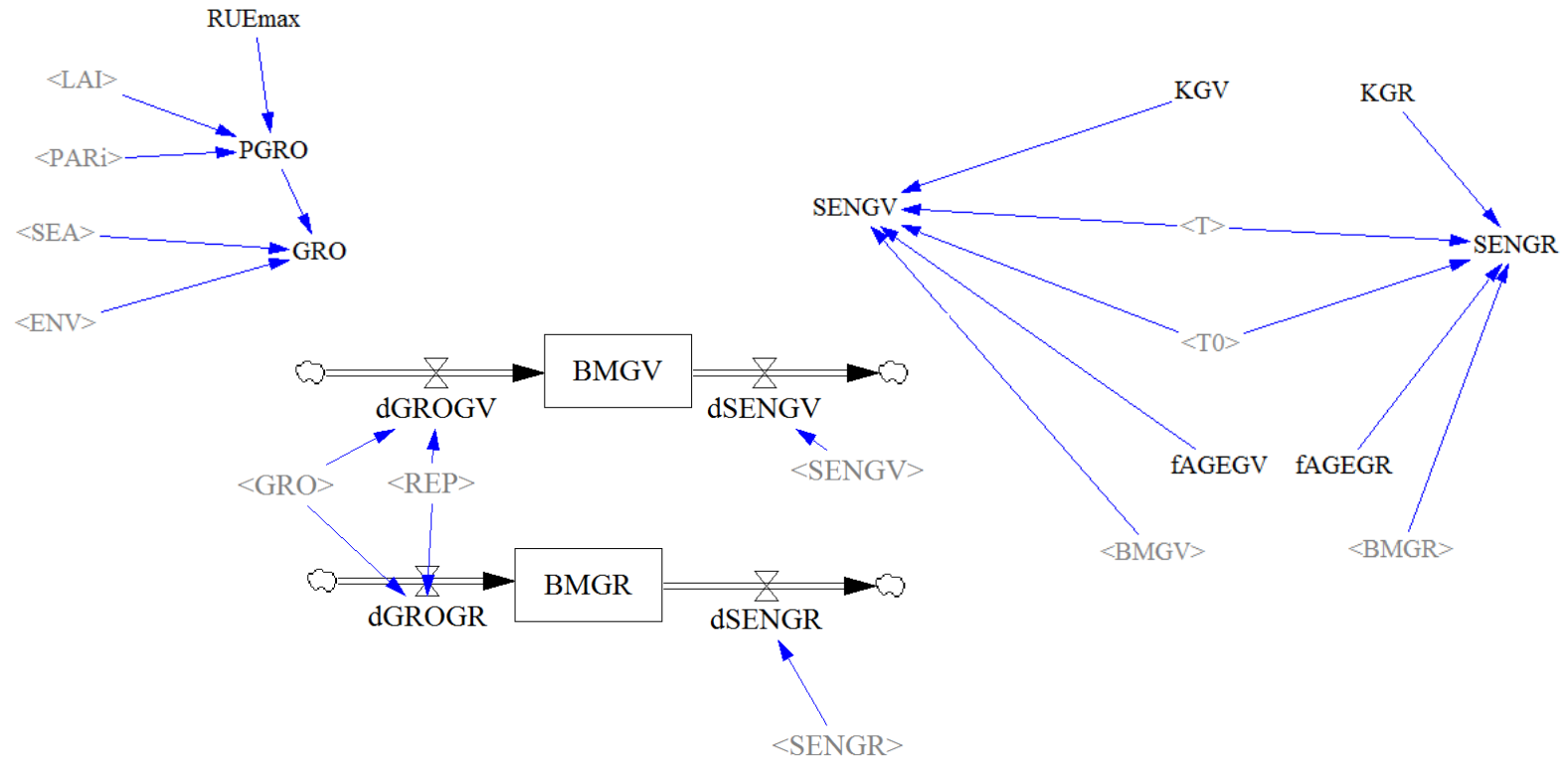
- and we implement a generic biomass compartment (without considering the GR, GV, DR, DV...)

3. Reproductive function and differentiation 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

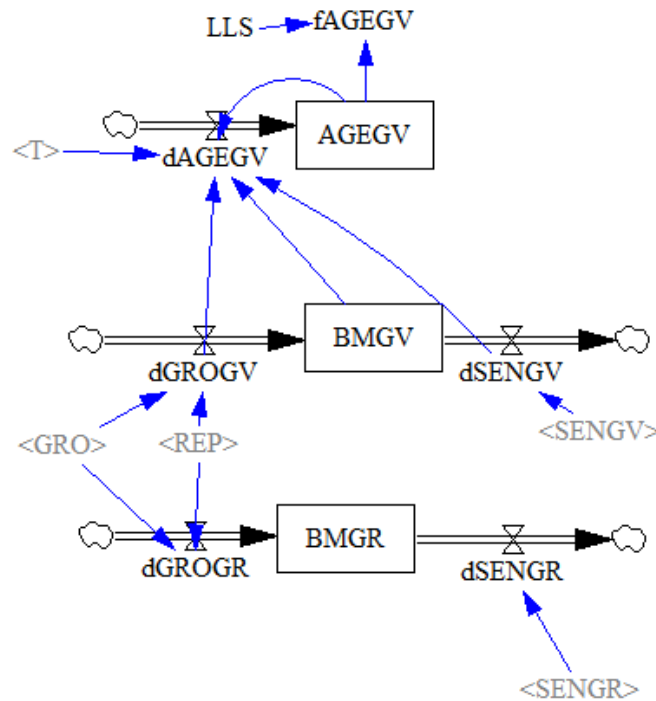
3. Reproductive function and differentiation of green vegetative/green reproductive compartment



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

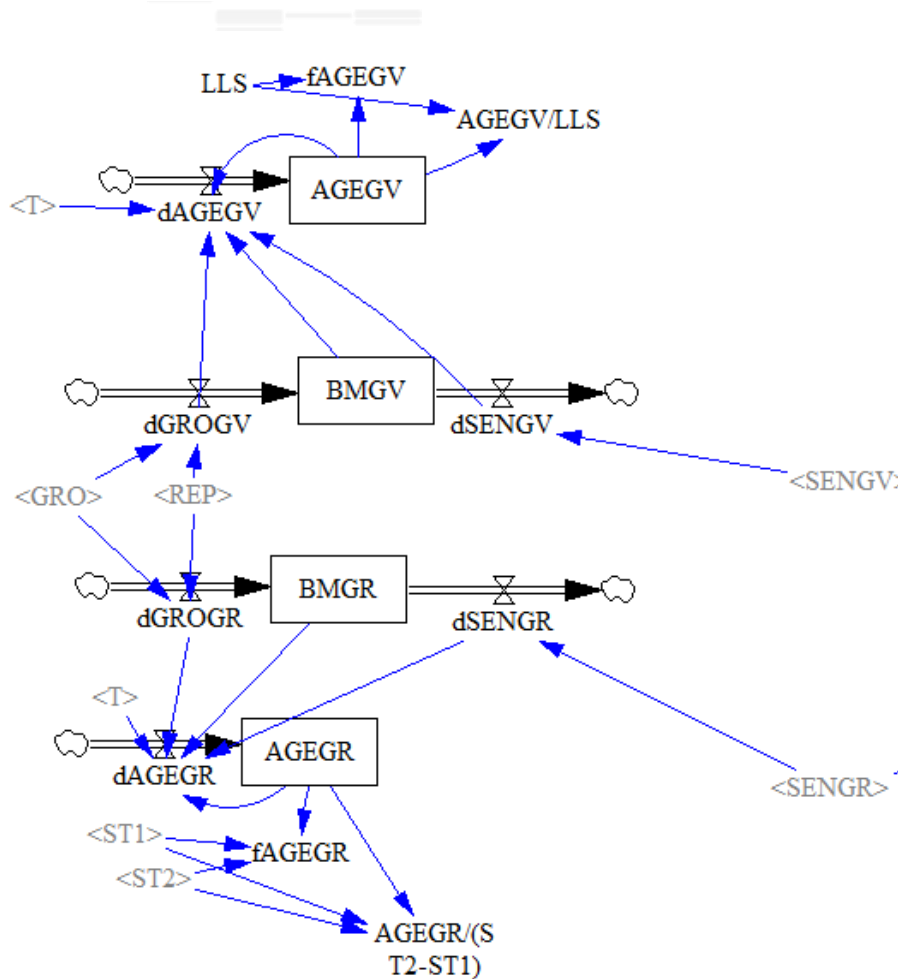
4. Ageing of green vegetative/green reproductive compartment

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



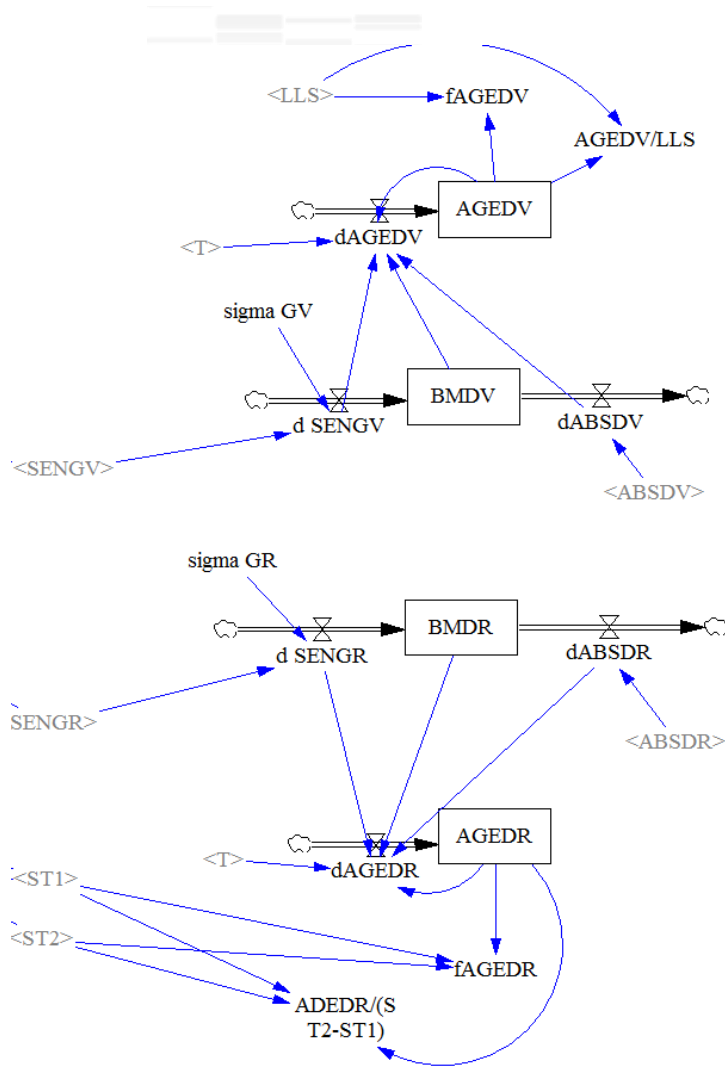
→ as a compartment!

4. Ageing of green vegetative/green reproductive compartment



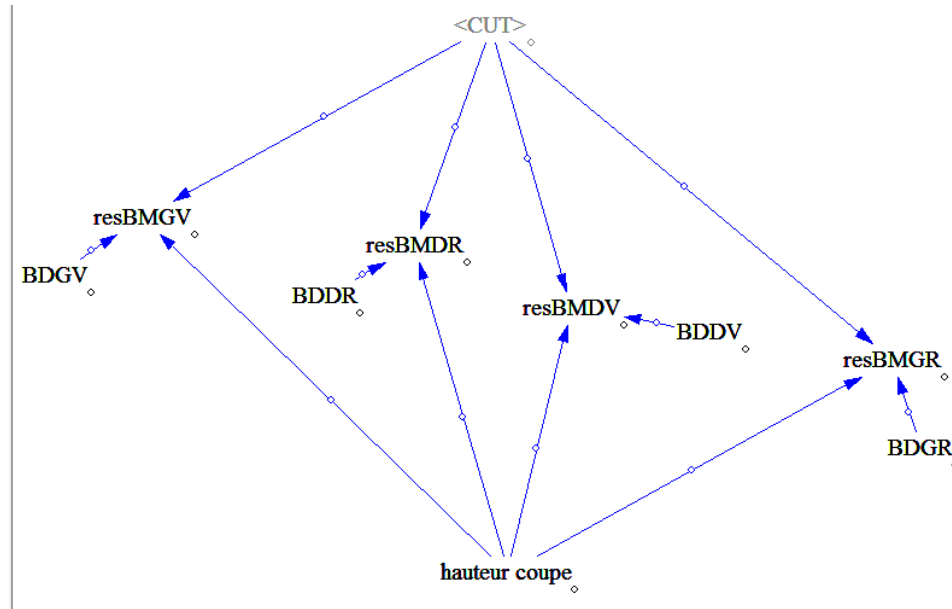
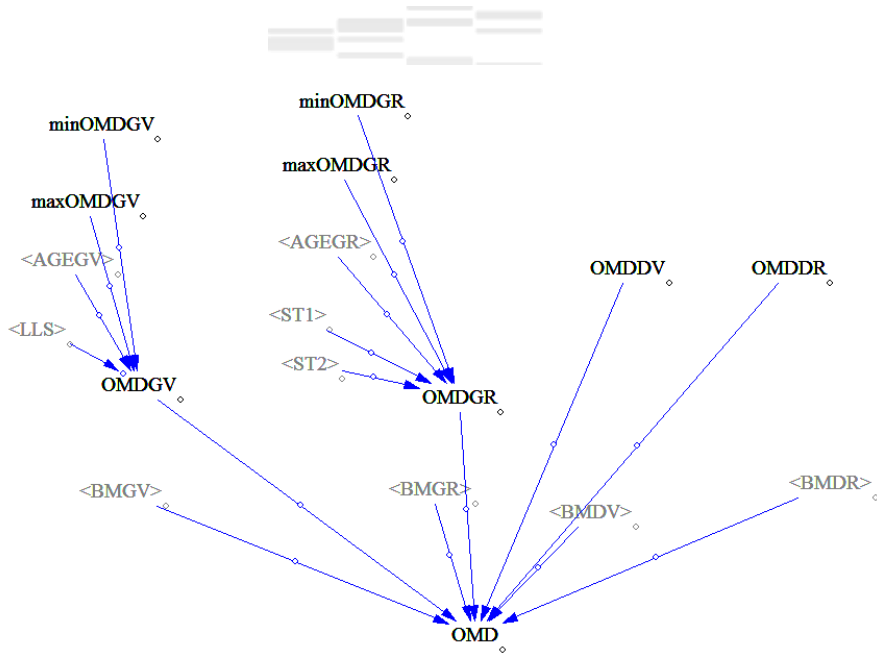
- Then we add the Age of both compartments and make the links between the variables

5. Development of the model for dead compartments



- Same approach as for green compartments

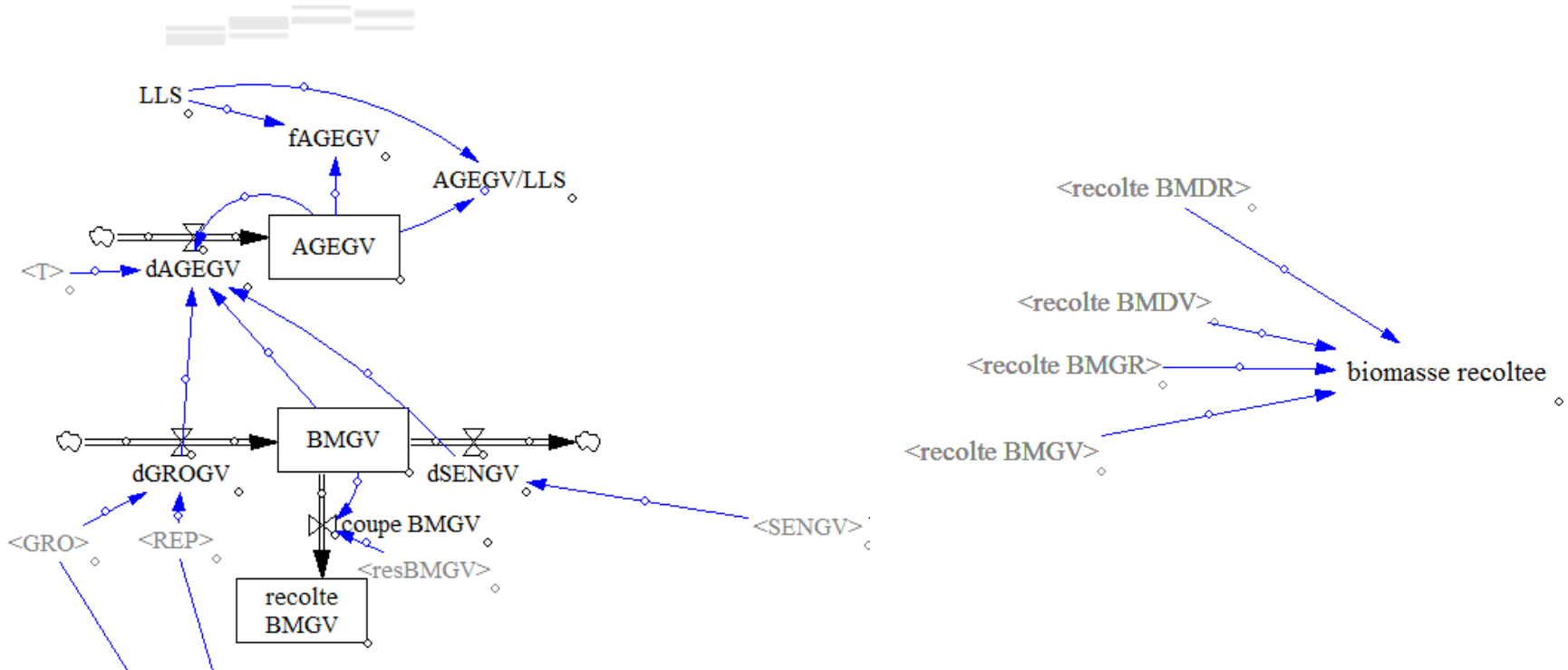
6. Sward digestibility and cutting (1/2)



- Digestibility: linked to the age and weighted average

- Residual biomass: linked to cutting height and sward density

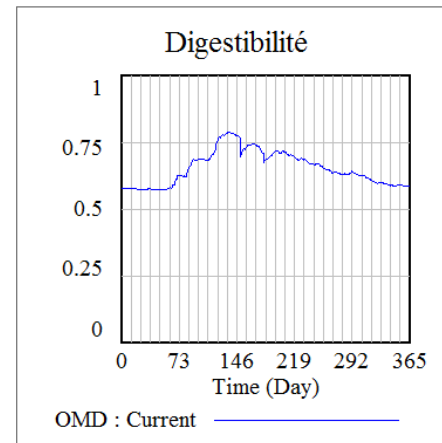
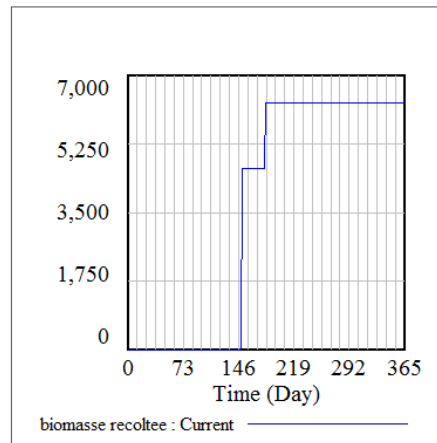
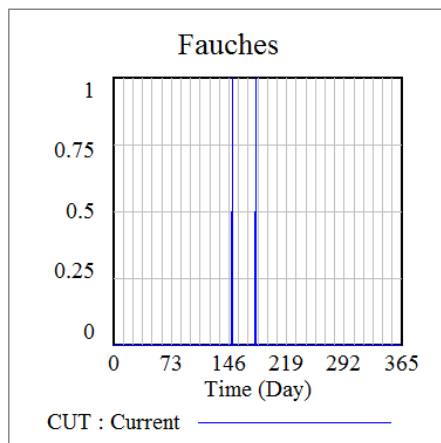
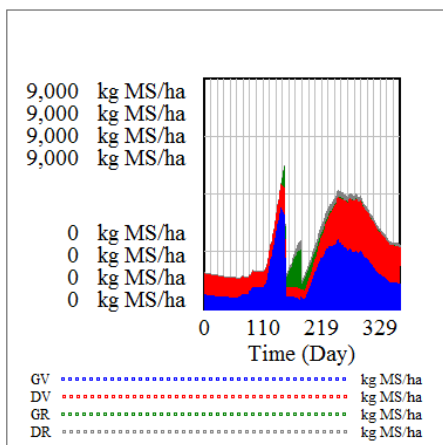
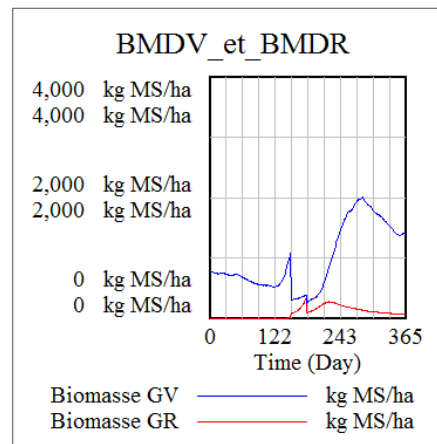
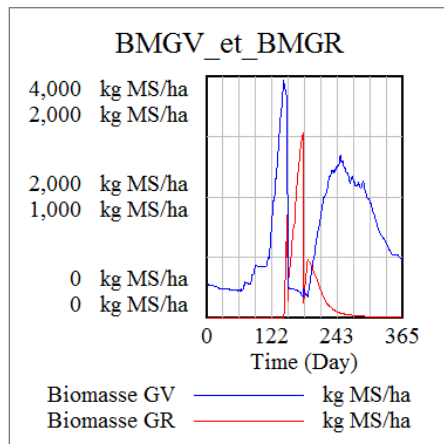
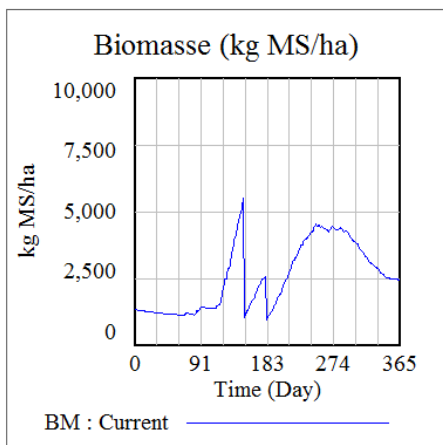
6. Sward digestibility and cutting (2/2)



- 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



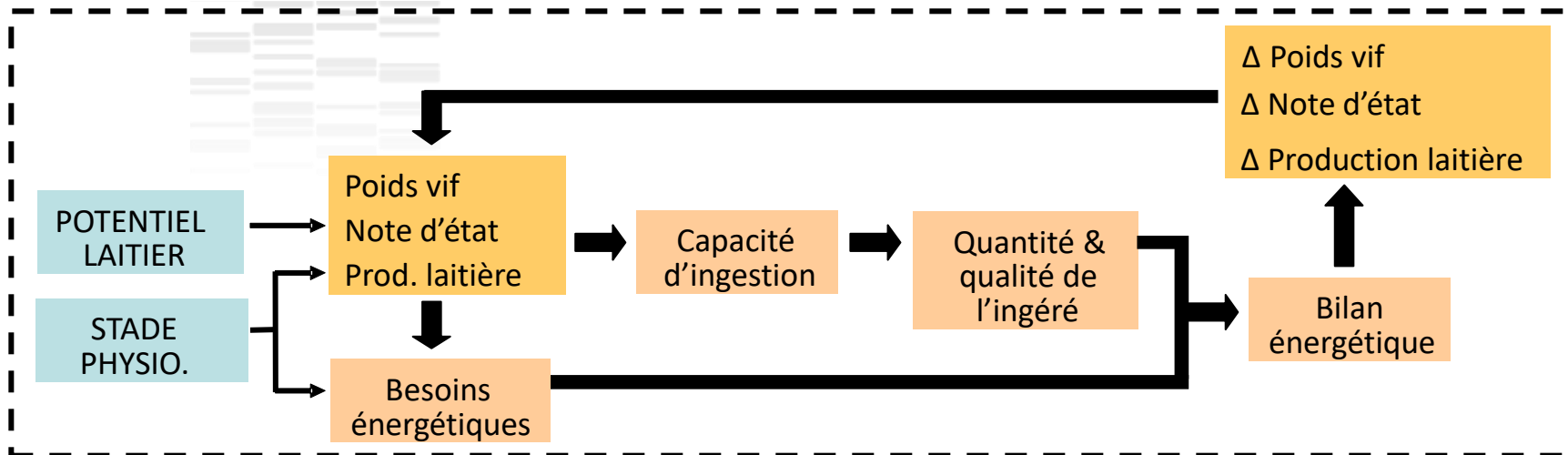
- Create and save as many versions as necessary (here for the course → 18 versions)
-  ■ Check and run all the versions: graphs for each version / variable
- Use the different views to make your diagram clear, in particular useful to have a specific view for the graphs as results
- Only use lookup to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

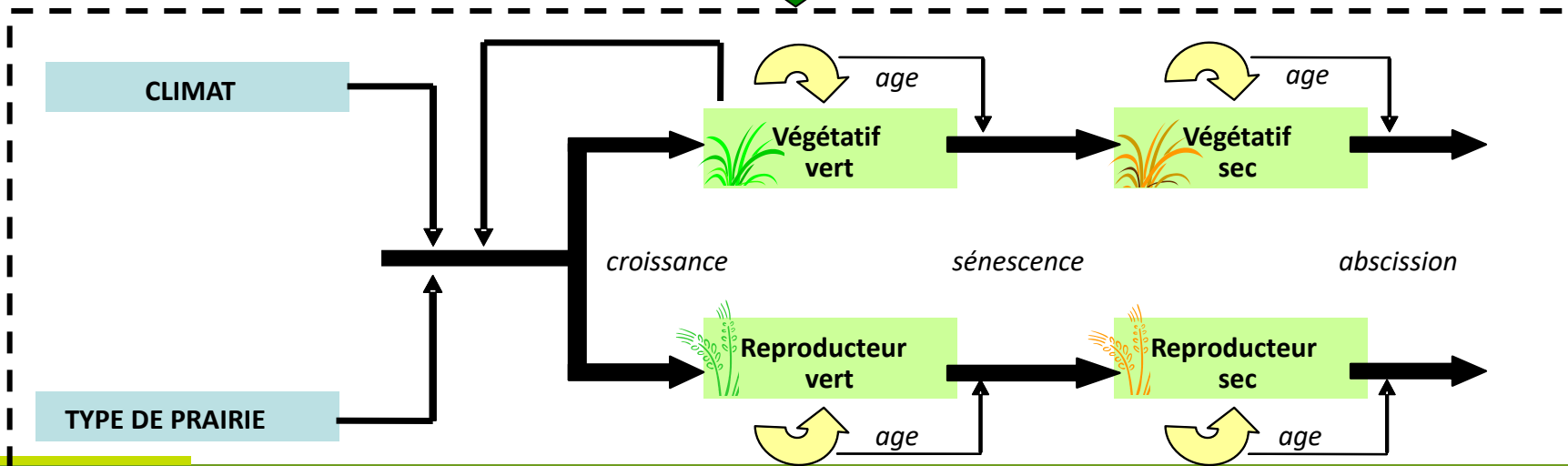
Coupling with a ruminant livestock model



(Jouven et al., 2007)



Comportement de sélection
Limitation ingestion selon la biomasse



(Jouven et al., 2006)