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

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Maintaining grasslands is important

**Provisioning**
- Fodder =>
- Pollen =>

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

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

Different grasslands that serve different benefits for people

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

<table>
<thead>
<tr>
<th>Frequent defoliation</th>
<th>Rich/fertile sites</th>
<th>Poor/infertile sites</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group A</strong></td>
<td><em>Ex: Lolium perenne, Holcus lanatus</em></td>
<td><strong>Group C</strong></td>
</tr>
<tr>
<td></td>
<td>High SLA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High digestibility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Short leaf lifespan</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Early reproductive growth &amp; flowering</td>
<td></td>
</tr>
<tr>
<td><strong>Group B</strong></td>
<td><em>Ex: Dactylis glomerata, Arrhenaterum elatius</em></td>
<td><strong>Group D</strong></td>
</tr>
<tr>
<td></td>
<td>Medium SLA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High digestibility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Long leaf lifespan</td>
<td></td>
</tr>
</tbody>
</table>

*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 implementing a model with VenSim PLE?**

– example of the ModVege model
How it works?

Senescence & abscission shoot/root organs

Light interception

Photosynthesis

Litter

Growth

CO₂

Cutting

Fertilisation
Manure, mineral fertiliser

Root uptake

Soil organic matter

H₂O & nutrients

Decomposition
Macro & micro-organisms

How implementing a model with VenSim PLE?
– example of the ModVege model
The modelling approach: 4 steps

Adapted from Coquillard & Hill, 1997 and Hirooka, 2010

Functional analysis

Observations

Knowledge

Question(s) & objective(s)

Measurements

Experimental data

- Scales & level of detail of the model
- Modelling method

Conception

- Formalisation (equations)
- Implementation (code)
- Verification
- Parameterisation/Calibration
- Robustness and software reliability

Evaluation

- Comparison of observed vs simulated values
- Use of criteria of evaluation

Exploitation

- Responses to the questions addressed
- Understanding of the simulated processes

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

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

Jouven et al., 2006. Grass and Forage Science

Sward heterogeneity
= 4 structural shoot compartments

Green (G)

Dead (D)

GV

DV

GR

DR

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)

How implementing a model with VenSim PLE ?
– example of the ModVege model
Partitioning of growth between vegetative and reproductive green compartments

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

If $ST_1 \leq ST \leq ST_2$

$$REP = \left[ 0.25 + \frac{(1 - 0.25) \times (NI - 0.35)}{1 - 0.35} \right] \times CUT.$$  

Else $REP = 0$

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

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

$GRO_{GR} = GRO \times REP$

How implementing a model with VenSim PLE ?
- example of the ModVege model
Calculation of the standing biomass

Jouven et al., 2006. Grass and Forage Science

\[
\frac{dB_{M_{GV}}}{dt} = GRO_{GV} - SEN_{GV}
\]

\[
\frac{dB_{M_{DV}}}{dt} = (1 - \sigma_{GV}) \times SEN_{GV} - ABS_{DV}
\]

\[
\frac{dB_{M_{GR}}}{dt} = GRO_{GR} - SEN_{GR}
\]

\[
\frac{dB_{M_{DR}}}{dt} = (1 - \sigma_{GR}) \times SEN_{GR} - ABS_{DR}
\]

Growth (GRO)  Senescence (SEN)  Abscission (ABS)

Respiration losses (\(\sigma_{GV}\))

Respiration losses (\(\sigma_{GR}\))

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

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

Jouven et al., 2006. Grass and Forage Science

- Age can depend 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).

Equations:

\[
\frac{d\text{AGE}_{GV}}{dt} = \frac{\text{BM}_{GV} - \text{SEN}_{GV}}{\text{BM}_{GV} - \text{SEN}_{GV} + \text{GRO}_{GV} \times (\text{AGE}_{GV} + T) - \text{AGE}_{GV}},
\]

\[
\frac{d\text{AGE}_{DV}}{dt} = \frac{\text{BM}_{DV} - \text{ABS}_{DV}}{\text{BM}_{DV} - \text{ABS}_{DV} + (1 - \sigma_{GV}) \times \text{SEN}_{GV} \times (\text{AGE}_{DV} + T) - \text{AGE}_{DV}},
\]

\[
\frac{d\text{AGE}_{GR}}{dt} = \frac{\text{BM}_{GR} - \text{SEN}_{GR}}{\text{BM}_{GR} - \text{SEN}_{GR} + \text{GRO}_{GR} \times (\text{AGE}_{GR} + T) - \text{AGE}_{GR}},
\]

\[
\frac{d\text{AGE}_{DR}}{dt} = \frac{\text{BM}_{DR} - \text{ABS}_{DR}}{\text{BM}_{DR} - \text{ABS}_{DR} + (1 - \sigma_{GR}) \times \text{SEN}_{GR} \times (\text{AGE}_{DR} + T) - \text{AGE}_{DR}}.
\]

Symbols:

- GV: Growth
- DV: Senescence
- GR: Abscission
- DR: Direct & feedback effects of variables on flows

Structural component:
- Biomass flows
- Ageing functions

How implementing a model with VenSim PLE?
- Example of the ModVege model
Calculation of the organic matter digestibility

Jouven et al., 2006. Grass and Forage Science

- OMD of dead compartments is constant
- OMD of green compartments
  - \( \preceq \) 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

\[
\begin{align*}
\text{OMD}_G &= \max\text{OMD}_G - \frac{\text{AGE} \times (\max\text{OMD}_G - \min\text{OMD}_G)}{\text{LLS}} \\
\text{OMD}_D &= \min\text{OMD}_D
\end{align*}
\]

How implementing a model with VenSim PLE?
- example of the ModVege model
Calculation of growth functions

- **Shoot growth (GRO)**

  \[ \text{GRO} = \text{PGRO} \times \text{ENV} \times \text{SEA} \]

- **Leaf area index (LAI)**

  \[ \text{LAI} = \text{SLA} \times \frac{\text{BM}_{GV}}{10} \times \%\text{LAM} \]

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

- **Actual growth**

\[ \text{PGRO} = \text{PAR}_i \times \text{RUE}_{\text{max}} \times [1-\exp(-0.6 \times \text{LAI})] \times 10 \]

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

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

How implementing a model with VenSim PLE? – example of the ModVege model
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 \( WR = \max(0, \ WR + PP - AET) \)

  and \( AET = \min\left[\frac{PET \times LAI}{3}\right] \).

Figure 2: Threshold functions representing growth limitation

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

How implementing a model with VenSim PLE ?
– example of the ModVege model
Calculation of senescence & abscission functions

- **Senescence of green compartments**

  \[ \text{SEN}_{GV} = 0 \text{ if } 0 \leq T \leq T_0 \]

  \[ \text{SEN}_{GV} = K_{GV} \times BM_{GV} \times T \times f(AGE_{GV}) \text{ if } T > T_0 \]

  and similarly for compartment GR

- **Abscission of dead compartments**

  \[ \text{ABS}_{DV} = K_{1, DV} \times BM_{DV} \times T \times f(AGE_{DV}) \text{ and,} \]

  similarly, for compartment DR.

(Freezing effect)
Calculation of the harvested biomass

- **Residual biomass after cutting**

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

  \[
  \text{resBM}_{GV} = 0.05 \times 10 \times \text{BD}_{GV}
  \]

  and, similarly, for compartments GR, DV and DR

- **Harvested biomass in each structural component**

  \[
  \text{hBM}_{GV} = \text{BM}_{GV} - \text{resBM}_{GV}
  \]

  and similarly for compartments GR, DV, DR

- **Total harvested biomass**

  \[
  \text{hBM} = \text{hBM}_{GV} + \text{hBM}_{GR} + \text{hBM}_{DV} + \text{hBM}_{DR}
  \]
Flow diagram of the model

Jouven et al., 2006. Grass and Forage Science

Climate
- Radiation
- Temperature
- N & H₂O stresses

Seasonal effect

How implementing a model with VenSim PLE?
- Example of the ModVege model

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

<table>
<thead>
<tr>
<th>Functional trait</th>
<th>Value for functional group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>SLA (m² g⁻¹)</td>
<td>0.033</td>
</tr>
<tr>
<td>%LAM</td>
<td>0.68</td>
</tr>
<tr>
<td>ST₁ (°C d)</td>
<td>600</td>
</tr>
<tr>
<td>ST₂ (°C d)</td>
<td>1200</td>
</tr>
<tr>
<td>maxSEA</td>
<td>1.20</td>
</tr>
<tr>
<td>minSEA</td>
<td>0.80</td>
</tr>
<tr>
<td>LLS (°C d)</td>
<td>500</td>
</tr>
<tr>
<td>maxOMDGV</td>
<td>0.90</td>
</tr>
<tr>
<td>minOMDGV</td>
<td>0.75</td>
</tr>
<tr>
<td>maxOMDGR</td>
<td>0.90</td>
</tr>
<tr>
<td>minOMDGR</td>
<td>0.65</td>
</tr>
<tr>
<td>BDᵥG (g DM m⁻³)</td>
<td>850</td>
</tr>
<tr>
<td>BDᵥR (g DM m⁻³)</td>
<td>500</td>
</tr>
<tr>
<td>BDᵥR (g DM m⁻³)</td>
<td>300</td>
</tr>
<tr>
<td>BDᵥR (g DM m⁻³)</td>
<td>150</td>
</tr>
</tbody>
</table>

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.

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

Jouven et al., 2006. Grass and Forage Science

- **Common to all groups**

<table>
<thead>
<tr>
<th>Functional trait</th>
<th>Value</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_{GV} )</td>
<td>0.4</td>
<td>Ducrocq (1996)</td>
</tr>
<tr>
<td>( \sigma_{GR} )</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>( T_0 ) (°C)</td>
<td>4</td>
<td>Schapendonk et al. (1998)</td>
</tr>
<tr>
<td>( T_1 ) (°C)</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>( T_2 ) (°C)</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>( K_{GV} )</td>
<td>0.002</td>
<td>Ducrocq (1996)</td>
</tr>
<tr>
<td>( K_{GR} )</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>( K_{LV} )</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>( K_{LR} )</td>
<td>0.0005</td>
<td></td>
</tr>
<tr>
<td>( OMD_{DV} )</td>
<td>0.45</td>
<td>Garcia et al. (2003a; b)</td>
</tr>
<tr>
<td>( OMD_{DR} )</td>
<td>0.40</td>
<td></td>
</tr>
</tbody>
</table>

\( \sigma_{GV} \) and \( \sigma_{GR} \) 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; \( K_{LV} \) and \( K_{LR} \), 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

How implementing a model with VenSim PLE ?
– example of the ModVege model
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: \( f(W) \)

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

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

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

How implementing a model with VenSim PLE? – example of the ModVege model
6. Sward digestibility and cutting (1/2)

- Digestibility: linked to the age and weighted average

- Residual biomass: linked to cutting height and sward density

How implementing a model with VenSim PLE? – example of the ModVege model
6. Sward digestibility and cutting (2/2)

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

- Total harvested biomass: sum of all compartments

How implementing a model with VenSim PLE? – example of the ModVege model
# 7. Simulation of results

**How implementing a model with VenSim PLE?**

– example of the ModVege model

---

**Biomasse (kg MS/ha)**

<table>
<thead>
<tr>
<th>Time (Day)</th>
<th>0</th>
<th>91</th>
<th>183</th>
<th>274</th>
<th>365</th>
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<tbody>
<tr>
<td>Biomasse GV</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Biomasse GR</td>
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<td>0</td>
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**BMGV_et_BMGR**

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<td>Biomasse GR</td>
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**BMDV_et_BMDR**

<table>
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<th>Time (Day)</th>
<th>0</th>
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<th>243</th>
<th>365</th>
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<tbody>
<tr>
<td>Biomasse GV</td>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Biomasse GR</td>
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**Fauches**

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<th>146</th>
<th>219</th>
<th>292</th>
<th>365</th>
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<tr>
<td>GM</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>DR</td>
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<td>0</td>
<td>0</td>
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**Digestibilité**

<table>
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<th>146</th>
<th>219</th>
<th>292</th>
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**Science & Impact**

.042
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., 2006)

Bilan énergétique

Δ Poids vif
Δ Note d'état
Δ Production laitière

Poids vif
Note d'état
Prod. laitière

Capacité d’ingestion

Quantité & qualité de l’ingéré

Bilan énergétique

POTENTIEL LAITIER

STADE PHYSIO.

Besoins énergétiques

POTENTIEL LAITIER

Note d'état
Prod. laitière

Capacité d’ingestion

Quantité & qualité de l’ingéré

Bilan énergétique

STADE PHYSIO.

(Jouven et al., 2007)

Comportement de sélection
Limitation ingestion selon la biomasse

CLIMAT

Végétatif

Végétatif

Reproducteur

Reproducteur

age

age

age

age

croissance

sénescence

abscession

TYPE DE PRAIRIE

INRA

SCIENCE & IMPACT