Development and evaluation of the herd dynamic milk (HDM) model with focus on the individual cow component

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Supplementary Material S1: Feeding, bcs change and milk production of the dairy cow

The intake and the requirement of the animal is based on the model GrazeIN all the equation and justification are described in (Delagarde et al., 2011a, Delagarde et al., 2011b, Faverdin et al., 2011). The calculation of the intake and intake at grazing is fully describe in (Delagarde et al., 2011a, Faverdin et al., 2011) and won’t be re describe here. The only differences are that the MPprot (equation 20 is (Faverdin et al., 2011)) is replaced by the TheoMY (equation X and Y) and that the UFL_mob (equation 19 in (Faverdin et al., 2011)) is replaced by the actual BCSloss of the previous day in the HDM.

Requirement of the animal

Supplementary Equation S1: $UFL_{req} = Growth Re q + Gest Re q + Maint Re q$

Supplementary Equation S2: $Growth Re q = 3.25 - 0.08 \times Age$

with Age in months,

Supplementary Equation S3: $Gest Re q = 0.00072 \times BW_{calf} \times e^{0.116 \times \frac{GestD}{7}}$

With $BW_{calf}$ the BW of the calf at birth and $GestD$ the day in gestation of the cow (Linked with the Gest requirement the BW of the cow increase of $GestReq/4.5$)

Supplementary Equation S4: $Maint Re q = (0.041 \times BW^{0.75}) \times Coeff_{-req}$

with $Coeff_{-req}$ equal to 1.2 at grazing and 1.1 for indoor feeding (Faverdin et al., 2010).

Energetic interaction:

Supplementary Equation S5: $E = 6.3 \times %C^2 - 0.017 \times UFL_{int} + 0.002 \times UFL_{ing}^2$

with $%C$ the percentage of concentrate in the diet and $UFL_{int}$ the quantity of UFL ingested during the day in UFL.

Grummer et al. (1995) has shown that for the first eight weeks of the lactation for a primiparous cow, growth rate is substantially reduced with most of the energy consumed directed toward milk production. Taking this into account, it has been assumed that during the eight first weeks of lactation, the growth of the younger cow
slows down, therefore, there is a requirement for a coefficient to be multiplied to the growth requirement of the animal:

Supplementary Equation S6: \[ \text{growth\_coefficient} = \frac{\text{nb\_day\_in\_milk}}{7 \times 8} \]

with \text{nb\_day\_in\_milk} the number of days in milk of the cow, 7 the number of days per week and 8 the eight weeks involved in the reduction of the growth rate.

**UFL balance:**

Supplementary Equation S7:

\[ \text{UFLbalance} = 0.3 \times \text{UFL}_{\text{int}_{p-2}} + 0.7 \times \text{UFL}_{\text{int}_{p-3}} - (\text{UFL\_Req} + \text{MY} \times 0.44) - E \]

If the cows are dry the UFL balance is calculated with a MY equal to 0, the requirement due to milk is set at 0.

**BW and BCS change in case of negative energy balance:**

Supplementary Equation S8: \[ \text{BCSchange} = \frac{\text{UFLbalance}}{250} \]

Supplementary Equation S9: \[ \text{BWchange} = \frac{\text{UFLbalance}}{3.5} \]

With the \text{BCSchange} in unit of BCS.

**BW and BCS change in case of positive energy balance:**

Supplementary Equation S10: \[ \text{BCSchange} = \text{UFLbalance} \times \left( 0.0034 - \frac{0.000004}{e^{-1.325 \times \text{BCS}}} \right) \]

Supplementary Equation S11: \[ \text{BWchange} = \frac{\text{UFLbalance}}{4.5} \]

For every day, the \text{BCSpool} is calculated as the actual \text{BCSpool} from previous day minus the \text{BCSchange} taking into account an upper bound limit of 0 and a lower bound limit of the \text{theoMOBmax} (the \text{theoMOBmax} is always negative).

Equation to go from actual milk yield to standard milk yield:

Supplementary Equation S12: (Faverdin et al., 2010)

\[ \text{MY} = \frac{\text{actualMY} \times (0.44 + 0.0055 \times (\text{FC} - 40) + 0.0033 \times (\text{PC} - 31)}}{0.44} \]

with \text{actualMY} the non corrected milk yield in kg, FC and PC the fat and protein content in gram per kg of non corrected milk.
Supplementary Material S2: Fertility calculation

Interval between two heat event: \( N(22.75,3.17) \) (Brun-Lafleur, 2011)

Calculation of the return in heat:

\[ N(47.9-5.7*(2.63-\text{BCScalv}),27.4) \] days after calving (Pryce et al., 2001)

The percentage of foetal death is set at 3% (abortion) (Brun-Lafleur et al., 2013) the rate of late embryonic death is set at 20% (Cutullic et al., 2011).

Supplementary Table 1: Description of the different percentage and coefficient used to calculate the percentage of change of recalving (RC) after artificial insemination (AI) for the dairy cow (taking into account the fact that to be inseminate the farmer need to have seen that the cow was in heat its depending on the heat detection level which is an input)

<table>
<thead>
<tr>
<th>Description</th>
<th>percentage</th>
<th>modification</th>
<th>reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>First AI RC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic percentage for parity 1 to 3</td>
<td>44</td>
<td></td>
<td>(Inchaisri et al., 2010)</td>
</tr>
<tr>
<td>parity bigger than 3</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>parity 2 and 3 inseminate between DIM 40-60</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>parity bigger than 3 between DIM 40-60</td>
<td>31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>other AI RC</td>
<td>basic percentage</td>
<td>42 to 49</td>
<td>(Dillon et al., 2003, Inchaisri et al., 2010)</td>
</tr>
<tr>
<td>Overall</td>
<td>occur between DIM 21 and 40</td>
<td>x 2/3</td>
<td>(McDougall et al., 2012)</td>
</tr>
<tr>
<td></td>
<td>occur before DIM 21</td>
<td>x 1/2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>last calving ease of 3</td>
<td>x 0.64</td>
<td></td>
</tr>
<tr>
<td></td>
<td>non Holstein cow</td>
<td>+10%</td>
<td></td>
</tr>
</tbody>
</table>

Supplementary Material S3: Calving calculation:

Percentage of chance to have twin: 1% for parity 1, 3.8% for parity 2, 4.9 for parity 3 and more.

Supplementary Table S2: Percentage of the different calving ease score depending on cow and calf parameters (Lombard et al., 2007, Mee et al., 2011):

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parity 1</td>
<td>48.8%</td>
<td>32.3%</td>
<td>18.9%</td>
</tr>
<tr>
<td>Parity 2</td>
<td>70.6%</td>
<td>22.5%</td>
<td>6.9%</td>
</tr>
<tr>
<td>Single calf</td>
<td>65.9%</td>
<td>23.4%</td>
<td>10.7%</td>
</tr>
<tr>
<td>Twin</td>
<td>44.3%</td>
<td>44.3%</td>
<td>12.4%</td>
</tr>
<tr>
<td>Female calf</td>
<td>67%</td>
<td>24.8%</td>
<td>8.2%</td>
</tr>
<tr>
<td>Male calf</td>
<td>60%</td>
<td>26.5%</td>
<td>13.4%</td>
</tr>
</tbody>
</table>
Furthermore, if the previous calving had a calving ease score of 3 the probability of a score of 1 is unchanged the probability of a score of 2 is multiplied by 1.65 the probability of a score of 3 is multiplied by 2.9 (the actual percentage are recalculated after).

Supplementary Material S4: Creation of the new calf

BW of the calf at calving (consider that the BW of the calf at calving will depend on the sum of the gestation requirement during the year with an average calf weight at calving of 42):

\[
\text{Supplementary Equation S13: } \text{base} = \sum_{k=0}^{\text{DIG}} \frac{0.00072 \times 42 \times e^{0.116 \times k}}{4.5}
\]

if it’s a heifer the base is reduce of 5 kg.

If there is twin the base is reduce of 5.

Finally the BW of the calf at calving will be: \( \text{BW} = N(\text{base},1) - 5 \)

The BW of the cow is changed in accordance by deleting twice the BW of the calf (only 1.5 if it’s twins).

The calf genetic index is calculated as it’s mother genetic index multiply by 1.02 plus \( N(0,1) \).

Supplementary Material S5: Death of the animals

The basic percentage of stillbirth is set at 2 (can be changed). This percentage is multiply by 1.7 for a primiparous cow, by 2.3 if the calving ease score is 2, 15.4 if the calving ease score is 3, 2.7 is there is twin, 1.4 if the calf is a male (Lombard et al., 2007).

Supplementary Table S3: Annual probability of death depending on the parity (Miller et al., 2008):

<table>
<thead>
<tr>
<th>Parity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base % death</td>
<td>2.05</td>
<td>2.66</td>
<td>3.72</td>
<td>4.38</td>
<td>4.83</td>
<td>5.78</td>
<td>5.92</td>
<td>6.40</td>
</tr>
</tbody>
</table>

Supplementary Table S4: Multiplicatif coefficient for the probability of death depending on the month of the year (Miller et al., 2008):

<table>
<thead>
<tr>
<th>Month</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>coeff</td>
<td>1.00</td>
<td>1.10</td>
<td>1.07</td>
<td>0.99</td>
<td>0.95</td>
<td>1.05</td>
<td>1.13</td>
<td>1.01</td>
<td>0.90</td>
<td>0.89</td>
<td>0.98</td>
<td></td>
</tr>
</tbody>
</table>

Coefficient multiplied by 1.81 if the last calving ease was of 3.
Those coefficients are the annual percentage of death. It is considered that half of the “chances” occur the day of calving.

**Supplementary Material S5: Calf and heifer feeding and growing**

The hypothesis is made that the calf (0 to 91 days) are growing of 600g per day.

The intake capacity of the heifer (IC) is calculated as (Agabriel and Meschy, 2010):

Supplementary Equation S14: $IC = 0.035 \times BW^{0.9}$

Calculation of the actual forage intake (iterative process) for more information/explanation (Agabriel and Meschy, 2010):

Supplementary Equation S15: $A = 1 - (1.26 \times (avFVfor - 0.85)^{0.84}$

With $avFVfor$ the average fill value of the forage intake

Supplementary Equation S16: $D = \frac{1}{avFVfor} - A$

Supplementary Equation S17: $B = \frac{avFVfor}{2.04 \times D}$

Supplementary Equation S18: $K = avFVfor \times D \times e^{\frac{B}{0.7}}$

Supplementary Equation S19: $Sg = \frac{0.86}{avFVfor} \times \left(1 - K \times e^{\frac{-B}{1-%C}}\right)$

$Sg$: the concentrate substitution rate

%C percentage of concentrate (between 0-1)

Supplementary Equation S20: $forageIntake = \frac{(IC-Qc\times Sg)}{avFVfor}$

$Qc$ quantity of concentrate

Growth:

Supplementary Equation S21: $dailyGrowth = \left(\frac{UFLIntake^{\text{GestReq}}-GestReq}{BBW^{0.75}}\right)^{0.0336} - 0.045^{1.457}$

With UFL intake the ufl intake

With GestReq the UFL requirement for gestation (Supplementary Equation S3).
**Supplementary Table S5: Comparison of the impact of the increase of 1kg of concentrates per cow per day in the model to the actual impact shown in published studies on the daily milk production of a dairy cow**

<table>
<thead>
<tr>
<th>Time of the lactation</th>
<th>Model output (kg of milk/day/cow)</th>
<th>Literature output (kg of milk/day/cow)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Early lactation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(lactation weeks 1-16)</td>
<td>0.75-1.38</td>
<td>0.54-0.88 (McEvoy et al., 2008)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.51-1.18 (Gill and Kaushal, 2000)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.92-1.08 (Roche et al., 2007)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5-1.3 (Kennedy et al., 2003)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.95-1.35 (Kennedy et al., 2007)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.50-1.63 (Delaby et al., 2003)</td>
</tr>
<tr>
<td><strong>Mid lactation</strong></td>
<td>0.5-1.45</td>
<td>0.7-1.1 (Robaina et al., 1998)</td>
</tr>
<tr>
<td>(lactation weeks 17-25)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Late lactation</strong></td>
<td>0.2-0.65</td>
<td>0.5-1 (Kennedy et al., 2003)</td>
</tr>
<tr>
<td>(lactation weeks 26-39)</td>
<td></td>
<td>0.42-1.39 (Delaby et al., 2001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Whole lactation</strong></td>
<td>0.5-1.12</td>
<td>0.63-1.63 (Fulkerson et al., 2008)</td>
</tr>
<tr>
<td>(lactation weeks 1-39)</td>
<td></td>
<td>0.76-1.1 (Bargo et al., 2002)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.39-0.75 (Reis and Combs, 2000)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.33-0.9 (McCarthy et al., 2007)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.23-1.06 (Roche et al., 2006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.18-0.5 (Horan et al., 2005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.76-1.09 (Tozer et al., 2004)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.60-1.57 (Delaby et al., 2003)</td>
</tr>
</tbody>
</table>
References


Cutillic E, Delaby L, Gallard Y and Disenhaus C 2011. Dairy cows’ reproductive response to feeding level differs according to the reproductive stage and the breed. animal 5, 731-740.


