A mechanistic model to explore potential beef production of cattle breeds in contrasting climates

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Aart van der Linden, Simon Oosting, Gerrie van de Ven, Martin van Ittersum, Imke de Boer
Introduction (1)

[Graph showing the increase in human population and meat production from 1950 to 2060, with projections for 2030 and 2050.

Source: FAOSTAT (2013)
Introduction (2)

How to increase meat production?

1. Increase number of animals
2. Increase production per animal (intensification)

How much meat can be produced more per animal?
Production ecological concepts

Potential

Defining factors

Breed

Climate

Limited

Limiting factors

Water

Nutrients

Actual

Reducing factors

Pests

Diseases

Weeds

Production

Van Ittersum and Rabbinge, 1997; Van de Ven et al, 2003
Introduction (4)

- Potential production: Genotype, Climate, and G x C
- Animal models
  - Either genotype or climate are not included
    - Genotype + Empirical climate correction (THI)
  - Mechanistic growth models $\rightarrow$ genotype
  - Mechanistic thermoregulation models $\rightarrow$ climate
Research objective

To assess and explore potential beef production

To develop a mechanistic model that simulates potential production
Overview methodology

1. Modelling growth defined by genotype
2. Modelling growth defined by climate
3. Integration of genotype and climate
Methods (1) Genotype

- Net energy (NE) for growth
Methods (2) Genotype

- Example composition muscle tissue
  - Water 77.2 %
  - Ash 1.3 %
  - Protein 21.0 % (23.8 MJ kg\(^{-1}\))
  - Lipid 0.5 % (39.6 MJ kg\(^{-1}\))

\[
E_m(t) = \frac{dM}{dt} \times (0.210 \times 23.8 + 0.005 \times 39.6)
\]
Methods (3) Genotype

- **Net energy (NE) for growth**
  - Protein accretion efficiency: 54% (NE → NE accr.)
  - Fat accretion efficiency: 74% (NE → NE accr.)

- **NE for maintenance**
  - $EBW^{0.75} \times 311 \text{ kJ day}^{-1}$

- **NE for pregnancy and milk production**

- **NE for physical activity**

- **Energy for digestion and absorption** = Heat incr. of feeding (HIF)
  - Different for feeds (Chandler, 1994)
  - 30-70% of ME (Armstrong and Blaxter, 1956)
Methods (4) Genotype

\[ ME_{tn}(t) = (NE_{growth}(t) + NE_{maintenance}(t) + NE_{physical\ activity}(t) + \\
NE_{gest.\ tot.}(t_c) + NE_{milk}(t_p)) \times (1 + \left(\frac{fr.HIF}{1-fr.HIF}\right)) \]
Methods (4) Climate
Methods (5) Climate

\[ H_{\text{metabolism}} + H_{\text{solar}} = H_{\text{resp}} + H_{\text{sweating}} + H_{\text{LWR}} + H_{\text{convection}} \]

Adaptation to climate

Weather data

- Respiration (T, RH)
- Sweating (T, RH, ws)
- LWR (T, cloudiness)
- Convection (T, ws)

Solar radiation

McGovern and Bruce, 2000
Methods (6) Climate

Cena and Monteith (1975)
Methods (7) Climate

For given weather conditions: maximum heat release vs. minimum heat release

Solar radiation = 25000 kJ m$^2$ (soil); wind speed = 0.5 m s$^{-1}$; RH = 90%; cloudiness = 2 Ω; total weight Charolais: 950 kg
Methods (8) G x C interaction

\[ H_{metabolism} + H_{solar} = H_{resp} + H_{sweating} + H_{convection} + H_{LWR} \]

- Minimum \( H_m \)
- Maximum \( H_m \)

Heat release (W m\(^{-2}\))

Genotype \( \frac{ME_m - NE_{accr.}}{\text{Genotype}} = H_m \)

Climate

Heat generation (W m\(^{-2}\))

Shivering, fat used

\( H_m < \text{minimum } H_m \)
Methods (8) G x C interaction

\[ H_{\text{metabolism}} + H_{\text{solar}} = H_{\text{resp}} + H_{\text{sweating}} + H_{\text{convection}} + H_{LWR} \]

- **Heat release** (W m\(^{-2}\))
- **Heat generation** (W m\(^{-2}\))

Minimum \( H_m \leq H_m \leq \text{maximum } H_m \)

\[ ME_m - NE_{\text{accr.}} = H_m \]
Methods (8) G x C interaction

\[ H_{\text{metabolism}} + H_{\text{solar}} = H_{\text{resp}} + H_{\text{sweating}} + H_{\text{convection}} + H_{\text{LWR}} \]

- **Minimum** \( H_m \)
- **Maximum** \( H_m \)

Heat generation (W m\(^{-2}\))

\[ ME_m - NE_{\text{accr.}} = H_m \]

Heat release (W m\(^{-2}\))

Body heats up when \( H_m > \text{maximum } H_m \)
Methods (9) Feed digestion

- Adopted a feed digestion model
  - Includes a number of feeds
  - ‘Potential’ barley-hay diet
    - No limits to digestion capacity
  - Degradation and passage rates
  - Higher rumen fill → higher passage rate

$100 \text{ Megajoule } ME_m \text{ day}^{-1} = \text{? kg DM feed day}^{-1}$

Chilibroste et al, 1997
Methods (10) Upscaling to herd level

Potential production; from individual to herd

Reproductive cow

- Calf 1
- Calf 2
- Calf 3
- Calf 4

Milk consumption
Pregnancy
Milk production
Results (1) Potential production

Charolais cow, Ethiopia, free grazing

- Heat release (W m⁻²)
- Cow weight (kg)

- Max. heat release
- Min. heat release
- Gen. maintenance
- Gen. growth
Results (2)

Boran cow, Ethiopia, free grazing

- Max. heat release
- Min. heat release
- Gen. maintenance
- Gen. growth

Heat release (W m$^{-2}$) vs. Cow weight (kg)
Results (3)

- Charolais bull, France

2.2 years
Results (4)

- Charolais cow, France

6 years
Results (5)

- Charolais cow, France
Results (6)

Scenarios for modelling potential beef production

- Charolais breed
- 4 climates:
  - Wageningen, The Netherlands
  - Charolles, France
  - Arba Minch, Ethiopia
  - Invercargill, New Zealand
- Cattle housed in stables
- Barley-hay diet
- No death of cattle, fertility = 100%
- 4 calves per cow
## Results (6) Charolais

<table>
<thead>
<tr>
<th>Herd</th>
<th>Netherlands</th>
<th>France</th>
<th>New Zealand</th>
<th>Ethiopia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reproductive</td>
<td>Pot. beef prod. ¹</td>
<td>83.5</td>
<td>74.3</td>
<td>86.9</td>
</tr>
<tr>
<td></td>
<td>FCR²</td>
<td>38.3</td>
<td>41.6</td>
<td>37.5</td>
</tr>
</tbody>
</table>

¹ kg beef per cow per year  
² Feed Conversion Ratio  
³ kg beef per calf per year  
⁴ kg beef cow + calves per year
Preliminary conclusions

- First quantitative application of the production ecological principles to animals.
- Model simulations show that potential production of cattle is greater in a climate to which the breed is adapted than a sub-optimal climate.
Thank you!

www.yieldgap.org
www.wageningenur/en/basis
Boran in New Zealand