Alternative strategies for improving feed efficiency and sustainability

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Funding was provided by Agriculture and Food Research Initiative Competitive Grant no. 2011-68004-30340 from the USDA National Institute of Food and Agriculture.

Outline and goals

Outline
1. Defining feed efficiency.
2. Breeding for optimal production and body size.
3. Using residual feed intake to further improve efficiency.

Goal: to spur the discussion about what kind of cow we want in the future

Ever-Green-View, 2/15/2010
2790 #F, 2140 #P in 365 d
The modern dairy cow is a different beast!

- We have been altering cattle genetics for 9000 years.
- Most selection was made based on animal’s own phenotype.
- Population genetics (>1937) accelerated the progress.
- We made a lot of progress based on looks and a few numbers.
- Modern dairy cows are taller, thinner, and less muscular, and they have bigger udders.
- Today we have data. Lots of it.

Feed efficiency is a complex trait.

Foods consumable by humans

Foods not consumable by humans

Non-food usable energy sources, fertilizers, and other chemicals

Environmental pollutants

- climate impacts
- farm profitability
- ecosystem services
- soil erosion and conservation
- imported oil
- rural aesthetics
- rural sociology
- food quality and healthfulness
- food security
- animal behavior and well-being
- efficiency of the beef industry

This is too complicated to use!
The basics of feed efficiency

Gross Energy of Feed

Energy lost as feces, gas, urine, and heat for metabolizing feed

Net Energy of Feed

Energy lost as heat for maintenance

Energy captured as milk or body tissue

Gross feed efficiency is the percentage of feed energy captured in milk and body tissues. To improve gross feed efficiency:

1. Increase the conversion of GE to NE
2. Increase milk production relative to maintenance.

Increased productivity in the past has resulted in increased efficiency

Our focus to increase milk yield has increased feed efficiency indirectly through the dilution of maintenance.

Gross feed efficiency < 10%

Gross feed efficiency ~ 20%

CO2/milk = 3.7

CO2/milk = 1.4
Efficiency increases from the “Dilution of Maintenance”

As cows eat more and produce more per day, a smaller percentage of the food they eat is used for maintenance and a greater percentage is converted to product.

The dilution of maintenance: past vs future

A cow at 4X has NE intake at 4X its NE for maintenance.

As productivity increases, gross efficiency increases but the incremental advantage diminishes. In addition, as cows eat more, they digest feed less efficiently, so this curve plateaus at ~5X.
**Optimal production per unit BW based on current data**

\[ \text{GEff} = -0.098 + 0.13 \times \text{MM} - 0.0094 \times \text{MM}^2 \]

High producing cows per unit BW are more efficient. The returns in efficiency from more milk are diminishing, but not as much as current NRC suggests!

**Is there an optimal milk production and body size?**

Feb 15, 2010: Wisconsin cow Ever-Green-View My 1326-ET became the national milk production record holder, at 4 yr 5 mo. of age. She produced a 365-day record of 72,200 lbs of milk, with 2,790 lbs of fat and 2,140 lbs of protein.

*If a cow produces this much, I don’t care if she weighs 2000 lb!*
The dilution of maintenance: milk vs cow size

Whether we get more milk with the same BW or the same milk with a smaller BW, the cow is operating at a higher level and efficiency increases (but maybe not much).

Maintenance requirement – what is it?

- NRC 2001: 0.08 x Metabolic BW
- Birnie et al., 2000: 0.084 to 0.113 x MBW depending on BCS
- Moraes et al, 2015: 0.086 to 0.115 x MBW depending on decade
- Tempelman et al., 2015: 0.11 to 0.17 x MBW depending on research farm

Maintenance for lactating cows varies with level of milk, body weight, and body condition score.
Holsteins are getting larger!

• Of current proven AI bulls in 2007, 62% were >1SD for stature and 3% were <1SD. (Anderson, 2007)

• Because of the 2014 base change, current AI bulls look average for stature, but “average” for Holsteins jumped 0.8 stature points in the last 2 years!
• Larger, more angular cows have more health problems. (Hansen, 2000)

➢ Why select for cows that look like they can produce more milk when we can directly select for more milk?

Jerseys vs Holsteins

A comparison of the environmental impact of Jersey compared with Holstein milk for cheese production

J. L. Capper and R. A. Cady†

<table>
<thead>
<tr>
<th></th>
<th>Jersey</th>
<th>Holstein</th>
<th>H/J</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Wt, lb</td>
<td>1000</td>
<td>1500</td>
<td>150%</td>
</tr>
<tr>
<td>Maint Reqt, Mcal/day</td>
<td>7.9</td>
<td>10.7</td>
<td>135%</td>
</tr>
<tr>
<td>Life Maint Reqt, Mcal/day</td>
<td>13</td>
<td>18</td>
<td>141%</td>
</tr>
<tr>
<td>Milk, lb/day</td>
<td>46</td>
<td>64</td>
<td>139%</td>
</tr>
<tr>
<td>Milk Energy, Mcal/day</td>
<td>18</td>
<td>22</td>
<td>119%</td>
</tr>
<tr>
<td>Life Cheese Yield, Mcal/day</td>
<td>28</td>
<td>33</td>
<td>118%</td>
</tr>
<tr>
<td>Life Multiple of Maintenance</td>
<td>3.2</td>
<td>2.8</td>
<td>89</td>
</tr>
</tbody>
</table>

Feed intake was not measured.
Jerseys vs Holsteins

Impact of milk yield, herd size, and feed efficiency on economic change between and within California dairies from 2006 through 2010. L. Rodriguez1, G. Bethard2, D. Tomlinson1, and M. McGilliard3. 1Zinpro Corporation, Elk Grove, CA, 2G & R Consulting, Blacksburg, VA, 3Virginia Tech, Blacksburg.

- Feed efficiency and profitability were similar for top Jersey and Holstein herds.

- Published data is lacking to decide if feed efficiency is actually different between the breeds.

- Holsteins better produce almost twice as much milk more protein and fat, or they will be less efficient than Jerseys! Both breeds should focus on production per unit BW.

Genetic (upper right) and non-genetic (lower left) correlations and heritabilities (diagonal) for efficiency traits on 5700 Holsteins. Lu et al., 2015

<table>
<thead>
<tr>
<th></th>
<th>MilkE</th>
<th>MBW</th>
<th>DMI</th>
<th>Gross Eff.</th>
<th>IOFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>MilkE</td>
<td>0.37 ±0.03</td>
<td>0.06 ±0.06</td>
<td>0.66 ±0.04</td>
<td>0.66 ±0.08</td>
<td>0.97 ±0.01</td>
</tr>
<tr>
<td>MBW</td>
<td>0.22 ±0.04</td>
<td>0.51 ±0.03</td>
<td>0.45 ±0.05</td>
<td>-0.28 ±0.06</td>
<td>0.02 ±0.07</td>
</tr>
<tr>
<td>DMI</td>
<td>0.56 ±0.02</td>
<td>0.37 ±0.03</td>
<td>0.38 ±0.03</td>
<td>-0.11 ±0.04</td>
<td>0.54 ±0.06</td>
</tr>
<tr>
<td>Gross Eff.</td>
<td>0.39 ±0.02</td>
<td>-0.03 ±0.01</td>
<td>-0.19 ±0.02</td>
<td>0.13 ±0.00</td>
<td>0.70 ±0.05</td>
</tr>
<tr>
<td>IOFC</td>
<td>0.85 ±0.01</td>
<td>0.17 ±0.04</td>
<td>0.34 ±0.03</td>
<td>0.77 ±0.01</td>
<td></td>
</tr>
</tbody>
</table>

Selection against body size will enhance feed efficiency but not milk income per cow. Selection for milk increases both.
**Summary for body size and efficiency**

Liu et al., 2015. Body weight.
- For 5700 Holsteins, body weight was not genetically correlated with milk energy per day. The genetic correlation of body weight with gross feed efficiency was -0.3.

Manzanilla-Pech et al., 2015. Stature.
- For 1900 US Holsteins, stature was not genetically correlated with milk energy/day. The genetic correlation of stature with gross feed efficiency was -0.7 and with residual feed intake was +0.4.

➢ Selecting for bigger, taller cows does not increase milk.
➢ Selecting for bigger, taller cows decreases feed efficiency.

**Other considerations in the size debate**

- Milk solids yield (income per cow) is more important than size.
- Feed efficiency and profitability must be considered on a whole-farm basis.
- Smaller cows need less space so could have more cows per farm.
- Management time per cow is about the same.
- Bigger cows and their bull calves have more salvage value.
- Smaller cows might have fewer health problems.
- Smaller cows might handle heat stress better.
- Bigger cows might need less digestible diets (large herbivores can digest fiber better than small ones).
The basics of feed efficiency

To improve efficiency:
1. Increase the conversion of GE to NE
2. Increase milk production relative to maintenance.

Residual feed intake (RFI) = “unjustified” feed intake

\[
\text{Observed DMI} = \mu + b_1 \times \text{MilkEnergy} + b_2 \times \text{BW}^{0.75} + b_3 \times \Delta \text{BodyEnergy} + \text{cohort} + \text{RFI}
\]

The heritability of RFI is 0.17, based on 4900 Holsteins from North America and Europe. (Tempelman et al., 2015)
RFI is a repeatable trait

- Diet: high starch vs high fiber
- Climate conditions
- Lactation number
- Lactation stage
- Heifer vs cow

Selecting genotypes today that are more efficient should provide more efficient cows in the future, even if they are on higher fiber diets in a hotter climate.

Traditional breeding values are based on daughter performance, but feed efficiency data are not available. Perhaps genomics can help.

2 sets of 30 chromosomes, with 3 billion base pairs per set.
Selection for RFI based on Single Nucleotide Polymorphisms (SNP)

- Genomics enables us to select for new traits and make decisions earlier on old ones.
- The SNP itself may have no biological effect, but it is linked to the DNA around it. If allele T is associated with a desirable trait, we can select for T and against C.
- Each single SNP may not have much effect, but additive effects of 1000s of SNP might.

SNP: 1 2 3 4 5 6 7...78000
Genotype: 1 1 2 0 0 1 0... 2
Value: 0 2 3-3 0 0 8... -1
gPTA: 0 2 6 0 0 0... -2 Sum = 650

Preliminary genomic analysis for traits related to feed efficiency (2900 cows)
The mean and estimates of genetic variance (VarG), proportion of phenotypic variance accounted for by SNP (Mh²), and Pi, such that 1-Pi represents the proportion of SNP fitted in the genome wide association analyses.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Mean</th>
<th>VarG</th>
<th>Mh²</th>
<th>Pi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter intake, kg/d</td>
<td>22</td>
<td>1.5</td>
<td>0.26</td>
<td>0.93</td>
</tr>
<tr>
<td>Milk energy output, Mcal/d</td>
<td>27</td>
<td>3.3</td>
<td>0.22</td>
<td>0.91</td>
</tr>
<tr>
<td>Metabolic BW</td>
<td>119</td>
<td>23</td>
<td>0.38</td>
<td>0.92</td>
</tr>
<tr>
<td>BW change, kg/d</td>
<td>0.39</td>
<td>0.17</td>
<td>0.02</td>
<td>0.98</td>
</tr>
<tr>
<td>Residual feed intake, kg DM/d</td>
<td>0</td>
<td>0.27</td>
<td>0.14</td>
<td>0.91</td>
</tr>
</tbody>
</table>

Spurlock et al., 2014; Results were similar with 4900 cows. Lu et al., 2017; Hardie et al., submitted
Genomic Selection

Animals could be selected for specific SNP or for the summation of 1000s of SNP.

Reference populations require continual updating.

Preliminary genomic results of efficiency traits for North American bulls. (Yao et al., 2016)

- Breeding values for 16,000 Holstein AI bulls in North America were predicted from a reference population of 3,500 cows.
- 57,000 SNP markers per animal were analyzed.
- Heritabilities were similar to what we previously reported.
- A “Feed_Saved” trait was calculated based on RFI and BW. Selection for this trait looks promising.
- Feed saved/yr
  \[ = -(\text{RFI} + 2.1 \text{ lb per extra lb BW}) \]
- Reliability of EBV for RFI = 0.29

BV ranged from -2200 to +2200 lb/lactation.
Genomic selection for RFI can work

- Genomic Breeding Values for RFI were developed in growing heifers. Cows that were identified as being more efficient based on these GEBV did in fact need less feed to make milk. (Davis et al., 2014)

- Australia is now using genomic breeding values for RFI in combination with breeding values for smaller BW per unit milk in a “Feed Saved” index

- Netherlands is now using Genomic Breeding Values for DMI.

| Net Merit (NM$) – Selection Index | 1971 | 2010 | 2014 | 2019?
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk Yield</td>
<td>52</td>
<td>0</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>Fat Yield</td>
<td>48</td>
<td>19</td>
<td>22</td>
<td>15</td>
</tr>
<tr>
<td>Protein Yield</td>
<td>16</td>
<td>20</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Productive Life</td>
<td>22</td>
<td>19</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Somatic Cell Score</td>
<td>-10</td>
<td>-7</td>
<td>-8</td>
<td></td>
</tr>
<tr>
<td>Udder Composite</td>
<td>7</td>
<td>8</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Feet/legs Composite</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Body Size Composite</td>
<td>-6</td>
<td>-5</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>Daughter Pregnancy Rate</td>
<td>11</td>
<td>7</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Cow Conception Rate</td>
<td>-</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heifer Conception Rate</td>
<td>-</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calving Ability</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Unjustified Feed Intake</td>
<td></td>
<td></td>
<td></td>
<td>-18</td>
</tr>
</tbody>
</table>
**Summary on selection for efficiency**

- To increase total feed efficiency and profitability, we want cows that eat and produce at a higher multiple of maintenance.

- We need to stop breeding for large cows just because they look nice. Instead we should breed for cows that produce more milk solids per unit of BW.

- In the near future, we will select directly for feed efficiency, using genomic breeding values for RFI in combination with breeding values for smaller BW per unit milk in a “Feed Saved” index.

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**Managing for greater feed efficiency**

Ad lib TMR feeding has helped increase milk production but decreased the focus on individual cow needs.

Feeding cows to meet their potential without overfeeding is key.

Grouping cows by feed needs improves feed efficiency and profitability, but grouping requires more work for management.

The farm team must work together and strategize:  
*How can we promote production and efficiency of feed use?*
Should milk/feed be a goal in feeding?

- Each nutrient class also alters feed intake and partitioning between body stores and milk, and thus efficiency.
- These effects cannot be modeled. We must assess what is happening on the farm!
- Diets that increase feed efficiency may not increase profits!

<table>
<thead>
<tr>
<th>Nutrient Class</th>
<th>GE (kcal/g)</th>
<th>Starch (kcal/g)</th>
<th>Protein (kcal/g)</th>
<th>Fat (kcal/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>NE</td>
<td>1-2</td>
<td>~2</td>
<td>~2</td>
<td>4-6</td>
</tr>
</tbody>
</table>

depends on digestion, gas, and urine losses

Optimal feeding through a lactation cycle

- Intake limited mostly by gut distention
- Intake limited by metabolic controls
- Extra fiber
- Minimum fiber/high starch
- Digestible fiber
- Low starch
- High CP and RUP
- low CP and RUP
- Expensive supplements
- Cheap feeds

GOALS

<table>
<thead>
<tr>
<th>GOALS</th>
<th>Optimal health</th>
<th>Maximal milk</th>
<th>Successful breeding</th>
<th>Optimal condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight</td>
<td>Intake limited by metabolic controls</td>
<td>Intake limited mostly by gut distention</td>
<td>Milk yield</td>
<td></td>
</tr>
<tr>
<td>DM intake</td>
<td>Extra fiber</td>
<td>-Minimum fiber/high starch</td>
<td>Low starch-----</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>------Digestible fiber---------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-high CP and RUP--------------------------</td>
<td>low CP and RUP--</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Expensive supplements</td>
<td>Cheap feeds</td>
<td></td>
</tr>
</tbody>
</table>

Days in milk

-60 0 60 120 180 240 300

-53rd Florida Dairy Production Conference
- Gainesville, FL, April 20, 2017
**Nutritional grouping**

In a survey of 400 farms, Contreras-Govea et al. (2015) found the 2 major constraints to nutritional grouping were:
- “It makes things too complicated”
- “Low diets decrease milk yield”

Dairy feeding goals:
- develop diets that meet needs for fresh, peak, and maintenance groups using published data
- use supplements, metabolic modifiers, feed additives, and cheap feeds to improve efficiency within groups
- make rules based on milk and BCS for moving cows and design systems to track cows
- develop protocols for feeding an extra diet
- consider computer feeders for high cows within a group
- track cow responses and make decisions based on them

**Maintenance diets**

- Several studies show this works! (Oba and Allen, 1998; Ipharraguerre et al., 2002; Voelker and Allen, 2003; Bradford and Allen, 2004; Boerman et al., 2015)
- Use high quality forages (digestible fiber) as the base.
- Drop the starch to 10-20%.
- Use slowly fermenting starch sources (ground dry corn).
- Include high fiber byproduct feeds at 20-30%.
- Consider fat if the price is right
- Drop %CP 2 units to increase N efficiency and save money.
- Drop out expensive ingredients that are most effective for the high group.
- Pay attention to prices! The goal is to increase income over feed costs in the short run and health in the long run!
**Take-home points.**

Point 1: Efficient cows produce a lot of milk for their size!
Point 2: Efficient cows efficiently convert feed to net energy.

What can we do?
- Breed for milk and moderate reductions in cow size.
- Feed and manage for high production over the lactation (one diet cannot do this).
- Consider selecting for low RFI or “Feed Saved” when it becomes available.

**We want more than just efficiency**

Our goal is a cow that efficiently converts feed to milk
- has high GE to NE (low RFI) because of greater digestibility, greater % of DE to NE, or lower maintenance
- efficiently captures (partitions) lifetime NE to product because she operates at a high multiple of maintenance
- is profitable (high production dilutes out farm fixed costs)
- has minimal negative environmental impacts

AND
- is healthy and thrives through the transition period
- yields products of high quality and salability
- is fertile and produces high-value offspring
- is adaptable to different climates and diets
- can use human-inedible foods, pasture, and cheap feeds
- can digest feeds better
- requires less protein and phosphorus per unit of milk
- has a good disposition and looks happy to the general public