Managing cows to improve feed efficiency and sustainability

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Feed efficiency is a complex trait.

Foods consumable by humans

- Human-consumable milk and beef

Foods not consumable by humans

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

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

- Heat Energy

- Wastes

- Products that are not consumable by humans

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!
Defining feed efficiency

No single metric for feed efficiency is adequate.

• Milk to Feed Ratio
• Gross energetic efficiency - (Milk E + Gain E)/Feed E
• $milk per $feed
• Income over feed cost   – use for all decisions! (farm basis)
• Residual feed intake    – use for breeding decisions!
The basics of feed efficiency

Gross Energy of Feed → Net Energy of Feed → Energy captured as milk or body tissue

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

To improve efficiency:
1. Increase the conversion of GE to NE
2. Increase milk production relative to maintenance.
She is more productive and efficient!

- Dairy cows today produce a lot more milk and they use feed more efficiently to make it!
- Genomics and reproductive technologies are changing things even faster.
Efficiency increased 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. However, the incremental advantage in efficiency diminishes.
Production and Efficiency: Data from 5000 cows

\[ GE = -0.098 + 0.13 \times MM - 0.0094 \times MM^2 \]

High producing cows are more efficient. The returns in efficiency from more milk are diminishing.

Arouja et al, unpublished
Is there a limit to efficiency?


- examined 1,038 complete energy balance records from 284 Holstein cows in 40 studies conducted from 1963 to 1995 at the Beltsville USDA Energy Metabolism Unit to determine if maintenance requirements and partial efficiencies of energy use changed over time.

<table>
<thead>
<tr>
<th></th>
<th>Decade</th>
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<tr>
<td></td>
<td>1963-73</td>
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<tr>
<td>Heart rate</td>
<td>69</td>
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<tr>
<td>BW, kg</td>
<td>610</td>
</tr>
<tr>
<td>ME/GE</td>
<td>0.56</td>
</tr>
<tr>
<td>NEm, Mcal/kgBW^0.75</td>
<td>0.072</td>
</tr>
<tr>
<td>Milk NE / ME</td>
<td>0.60</td>
</tr>
<tr>
<td>Theoretical maximum efficiency (MilkE/GE)</td>
<td>0.34</td>
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</table>
Is there an optimal cow size for feed efficiency?

Whether we get more milk with same BW or same milk with smaller BW, the cow is operating at a higher multiple of maintenance and efficiency increases a little.
**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

A higher maintenance requirement means cows needs to make more milk relative to BW to dilute it out.

Using the higher coefficients:
- Optimal milk for 750-kg cow is >80 kg instead of >50 kg.
- Optimal BW for 50 kg of milk drops <650 kg.
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>
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<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

- 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>
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<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>
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<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>
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<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.
New TPI slows the rate of increase in stature of our cows.

New TPI has less relationship with stature than Old TPI.
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.
• Smaller cows might be better in a grazing system.
• Bigger cows might need less digestible diets (large herbivores can digest fiber better than small ones).
• Taller cows might be more of a problem than thicker cows.
The basics of feed efficiency

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

In genetics, we want genotypes than produce more milk and that eat less than average to do it.

In nutrition, we should usually focus on getting cows to eat more.
Residual feed intake (RFI) = “unjustified” feed intake

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

Cows with negative RFI (and high milk) are more efficient.
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.
Managing for greater feed efficiency and profits

1. Feed efficiency is useful on farms, but the financial return to each feed is what matters most.
   • Some expensive feeds, such as fats, may increase feed efficiency but not be worth the cost. Many high fiber feeds will decrease feed efficiency but be worth feeding anyway.

2. Feeding cows to meet their potential without overfeeding is key.
   • Ad lib TMR feeding has increased milk production but decreased the focus on individual cows. Nutritional grouping can help.
We want animals that give more milk per unit feed, but when designing diets, income over feed cost is what matters!
Balancing nutrients to enhance efficiency

- Nutrients interact to alter digestion and metabolism.
- Nutrients also alter feed intake and partitioning between body stores and milk, and thus efficiency.
- Responses to diet changes can be modeled but they must be monitored on farm!
- Efficiency does not equal profitability.
Supplements that Increase costs may not give more income. Management that increases intake almost always does.
Greater intake is still generally an advantage

Based on 5000 cows, Arouja et al, unpublished

We want animals that eat less and are more efficient than expected based on level of production (low RFI), but eating more is still generally desirable

How can we feed cows to promote production and meet their nutrient needs without overfeeding?
So how should we design diets?

• We cannot measure all of the characteristics of feeds that are critical in balancing rations.

• We cannot accurately predict animal responses.

• But we can be precise using mathematical equations!

• Precision gives the false impression of accuracy.

• Models often lure people into wasting time getting the numbers perfect on a computer screen.

• *We need to monitor cows not computer monitors!*

• *Great rations require more than ration software!*
Accuracy vs Precision

Accuracy is how close the model answer is to the true value. Precision is repeatability of the model and how many significant figure there are. In modeling, it is easy to be precise, but being accurate is much harder.

Example: NRC2001 usually says methionine supplements are needed, but the cows often show no response.

It is better to be vaguely right than exactly wrong.

- Carveth Read, 1898
Getting caught up in numbers

Maintenance and physical work

Milk

NEL is difficult to predict and CP is not all useful.

Responses are more important than requirements.

Feed

Crude Protein

Net Energy

NEL
Thinking through Digestion and Metabolism

**Feed**
- Fiber
- Starches/sugars
- Proteins
- Lipids

**Appetite**

**Nutrient Partitioning (pulls)**

**Body tissues**

**Maintenance and physical work**

**Milk**

- Feed
- Nutrient Partitioning (pulls)
- Appetite

- **feces**
- **urine**

- **lipids**
- **amino acids**
- **glucose**
- **acetate**
- **ketones**
- **Ac, Prop, But**

- **Milk**
- **Body tissues**
- **Maintenance and physical work**

- **Thinking through Digestion and Metabolism**
Options for feed chemicals

Escape:
Small dense particles, bypass proteins, some starch

Ferment:
Most starch, sugar, half the fiber

Lost at methane or urea:
some fiber, some degraded protein

Incorporated into microbes:
most degraded protein

Flushed after time:
half the fiber

Fermented to acetate, propionate, or butyrate and absorbed

Escape before fermenting
Flushed when mostly finished fermenting
Incorporated into microbes and flushed
What controls feed intake?

Hypothalamus
- Hunger center
- Satiety center

Ad libitum feed intake

Chemical feedback signals

Hepatic vagus signals

Metabolic set point not met!

Restrict feed intake

Gastric distention feedback signals

Cow eats to meet its metabolic set point
Feed intake decreases with increased diet forage NDF content

Allen, 2000, J. Dairy Sci. 83:1598
What is the optimal NDF level?

First 3 weeks postpartum → ++
High inclusion of short fiber feeds → +++
High inclusion of rapidly-fermented starch → +
  +← Rumen buffers
Grain fed in 1 or 2 meals per day → ++
  +← Excellent quality control in feeding management
Hepatic oxidation theory of intake regulation

Oxidation of compounds such as glucose, propionate, or fatty acids increases ATP and NADH and causes satiety by signals through the efferent vagus nerve.
Increased ruminal starch digestion can depress DMI of lactating cows

Allen, 2000, J. Dairy Sci. 83:1598

Grains differing in ruminal degradation
Summary of regulation of voluntary feed intake

- Mechanisms controlling energy intake and partitioning are:
  - Multiple, entwined, and inseparable
  - Affected by diet and physiological state
- The liver is likely an important sensor of energy status:
  - Stimulates and inhibits eating
  - Integrates short and long-term appetite mechanisms
- Brain feeding centers integrate all signals and dominant mechanisms controlling intake
- Accurate predictions of feed intake are useful in designing diets but very difficult to achieve.
Strategies to maximize dry matter intake

1. Feed a diet with **adequate protein** to stimulate mammary pull.
2. Provide a **comfortable** environment, especially at the feed bunk.
3. Ensure **fresh, palatable** feed is available whenever a cow wants to eat (need bunk space and no bare bunks!)
4. Strive for a consistent rumen environment!
5. Use biology of feed intake to feed optimal diets.
6. Consider feeding partial or even total mixed rations.
7. **Monitor** intake or eating behavior to fine-tune the diet.
Hormones of nutrient partitioning

Feed nutrients

Rapidly available nutrient pool (blood)

Liver

Kidney

Urine

Feces

Maintenance

Heat

Mammary gland

Adipose tissue

Muscle

Uterus

Milk

I = insulin
G = glucagon
GH = growth hormone
IGF = insulin-like growth factor-I
Effect of starch on milk production

- Starch: 
  - Less filling
  - Lower rumen pH

- Propionate: 
  - More liver energy
  - More CLA

- Glucose: 
  - More blood insulin
  - Milk

- Milk: 
  - Body stores

- Feed intake: 
  - (+)
  - (-)
How might this alter nutrient partitioning in a lactating cow?
**Effect of bm3 corn silage on intake and production of dairy cows fed low or high NDF diets**

<table>
<thead>
<tr>
<th></th>
<th>29% NDF</th>
<th>38% NDF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bm3</td>
<td>control</td>
</tr>
<tr>
<td>Corn grain, % DM</td>
<td>26</td>
<td>29</td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>24.7</td>
<td>23.9</td>
</tr>
<tr>
<td>3.5% FCM, kg/d</td>
<td>35.6</td>
<td>34.3</td>
</tr>
<tr>
<td>BW gain, kg/d</td>
<td>1.10</td>
<td>0.79</td>
</tr>
</tbody>
</table>

Significance, $P$

- NDF: $<0.001$
- CS: 0.02
- NDFxCS: NS
- NS

Oba and Allen, 2000, J. Dairy Sci. 83:1333
Response varied by production level

Bradford and Allen, 2004 J. Dairy Sci 87:3800

Difference (HM - DG) in FCM yield (kg/d)

FCM yield (kg/d)

$r^2 = 0.19$

$P = 0.02$
Production and DMI response to forage NDF

Voelker et al., 2002, J. Dairy Sci. 85:2650

32 cows, crossover design

Treatments:
44% forage, 24% NDF, 34% starch
67% forage, 31% NDF, 23% starch

Preliminary milk yield: ~20 – 60 kg/d
Intermediate diet

Marginal feed efficiency: FCM/DMI
> ~45 kg/d FCM: 2.2
< ~40 kg/d FCM: 0
**Milk Yield for Treatments by Preliminary Milk**

\[ y = 0.94x + 0 \]
\[ R^2 = 0.75 \]
\[ P < 0.01 \]

\[ y = 0.65x + 9 \]
\[ R^2 = 0.56 \]
\[ P < 0.01 \]

*Boerman et al., 2013*

**In high cows, high starch increased milk yield, milk/feed, and IOFC.**

**In low cows, high soyhulls gave similar milk yield, similar milk/feed, less BW gain, and greater IOFC.**
**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., 2015a; Boerman et al., 2015b)
- 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!
Optimal feeding through a lactation cycle

**GOALS**

- Optimal health
- Maximal milk
  - Successful breeding
  - Optimal condition

**Intake**

- Limited by metabolic controls
- Limited mostly by gut distention

**Extra fiber**

- Minimum fiber/
  - high starch
  - Low starch
  - Digestible fiber

**Expensive supplements**

- high CP and RUP
  - low CP and RUP

**Cheap feeds**

- DM intake

**Body weight**

- Milk yield
**Problems with one ration**

Early to mid lactation cows
- decreased feed intake and lower energy diet = less NEL
- inadequate NEL for maximum milk and efficiency
- more body fat loss
- delayed conception

Mid to late lactation cows
- too much starch results in excess body fat gain
- fatter cows have more problems in following lactation
**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
Are the cows actually eating the diet on paper?

Communication and respect are essential.

The person mixing the feed is one of the most important people on the farm! Make sure they understand exactly what to do and that they want to do it well.

If we cannot get the diet on paper translated to the cow, a computer model is worthless.

Find the right balance for time on the computer versus time on the farm with the people and the cows.

How often have you seen problems by quick farm observations?
Choose feeds based on actual $ return, not milk/feed.

- Feed efficiency is not an end in itself for most farms.
- The financial return to dietary change for the farm is what matters! Profit might increase with a cheaper ration even though milk per feed decreases. Profit might decrease with expensive rations even though milk per feed increases.
- Treatment responses can be misleading for mixed groups.
- Grouping cows by production level allows allocation of feeds to cows that will benefit the most.
- **Computer models cannot accurately predict responses. Feed intake and cow responses (including body condition changes) must be measured to determine if diet changes are returning a profit!**
Strategies to maximize profits for lactating cows:

• Don’t focus too much on feed costs—be wary of cheap feeds, use expensive supplements wisely.
• Let cows, not computer models, decide the best diets.
• Make sure diets on paper are actually fed and eaten.
• Minimize daily variation in feeds by planning, carefully managing inventory, and monitoring %DM of wet feeds.
• Strategize monthly to enhance feed intake
• Emphasize cow comfort and health, esp. for fresh cows
• Group cows by requirements and feed multiple TMR
• Evaluate responses when changes are made
  • Expensive “Production boosters” better produce results
  • “Cheap alternatives” better not be costly mistakes
  • Monitor milk yield, energy intake, body condition, and behavior
Summary

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

What can we do?

• Breed for milk and moderate reductions in cow size.
• Select for low RDI or DMI or “Feed Saved” someday.
• Group and feed according to nutritional needs.
• Feed and manage for high production.
• Feed to enhance GE to NE ???

The farm team must work together and strategize to promote production and efficiency!