Early Life Nutrition for Growth, Health, and Future Production

James K. Drackley
Professor of Animal Sciences
University of Illinois at Urbana-Champaign

Why do we feed what we do – and when?

Nutrients required by calves
• Water
• Energy
• Protein
• Minerals
• Vitamins

Nutrient requirements of calves
• Maintenance
  – Basal functions
  – Body temperature
  – Immune or stressor challenges
• Growth
  – Bone and muscle dominate (protein)

Standards for calf performance:
1. Mortality less than 5% (> 24 hours old)
2. Morbidity (treatments) rates:
   Diarrhea: < 25%
   Respiratory disease: < 10%
3. Double birth weight by 56 days
   41 kg birth weight \( \rightarrow \) 82 kg @ 56 days
   Requires average daily gain = 0.73 kg/day

Why the emphasis on early growth rate?
Why the emphasis on early growth rate?

- We are in the food production industry. Our production machinery is a collection of individual, highly sophisticated bioreactors (cows). These units take approximately 24 months to bring into service.
- Our business is converting human-inedible feed into high-quality human food. In all things we do, therefore, efficiency (output / input) should be a major metric:
  - We use milk / feed DM intake for cows...
  - For calves, why don’t we use:
    - Cost per unit BW gain
    - Gain / feed DM intake
    - Gain in milk / change in investment cost per heifer

What other manufacturing business would focus only on cost/day, without considering the effect on efficiency and profitability?

Healthy rapid growth begins at birth

Maternity pen management

Healthy calves and efficient growth depends on excellent colostrum management

Colostrum: Nature’s first food

- Single most important management factor for calf health and survival
  - 31% of heifer deaths preventable by improved colostrum management (Wells et al., 1996)
- Rich first source of nutrients

Important Concepts for Colostrum Management

- Quickly
- Quantity
- Quality
- Cleanliness

Get colostral antibodies to intestine before environmental bacteria!
Colostrum: More than just antibodies...

- Single most important management factor for calf health and survival
- Rich first source of nutrients
- But also the “gatekeeper” for growth... and future production?

Colostrum and the “lactocrine effect”

- Role of the non-nutrient and non-Ig substances in colostrum
- Milk-borne bioactive factors may have immediate and long-term effects on animal
  - peptide and steroid hormones
  - growth factors
  - cytokines
  - microRNA

Bartol et al., 2008

Colostrum enables calf to use the added nutrients from more milk

- Purchased male calves were fed either intensified early nutrition or conventional milk replacer.
- Average daily gain (ADG) through 5 wk compared in calves with adequate (Good; >1000 mg/dL) vs. inadequate (Poor; <1000 mg/dL) blood IgG concentration

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control Poor</th>
<th>Intensified Poor</th>
<th>Control Good</th>
<th>Intensified Good</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>21</td>
<td>17</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>IgG, mg/dL</td>
<td>558</td>
<td>609</td>
<td>1793</td>
<td>2036</td>
</tr>
<tr>
<td>ADG, kg/d</td>
<td>0.53</td>
<td>0.63a</td>
<td>0.50</td>
<td>0.74b</td>
</tr>
</tbody>
</table>

a-b P < 0.05. Interaction, P < 0.07

Osorio et al., 2009 (unpublished)

Water: the most important, and most neglected, nutrient

Colostrum enables calf to use the added nutrients from more milk

Milk-fed calves need free water

- Milk or MR bypasses rumen, whether fed by nipple or bucket
- Need supplemental water to enter rumen and support microbial environment
- For 1 kg starter intake, need 4 L water intake
  - Inadequate water = less starter intake
  - = Decreased growth

The Milk Feeding Stage
In the beginning...

- Calves are born with the digestive machinery to use milk, and only milk, as their source of nutrients.
- Not calf starter, not forage, not non-milk milk replacers
- Ability to use non-milk ingredients develops over the first 3 weeks
- Ability to use forage takes several weeks

Mother Nature’s feeding program

- Cows’ milk: 25 – 26% protein (dry solids basis)
- Feeding rate: > 2x the “conventional” feeding rate of milk replacers (1 – 1.5 kg solids vs. ~ 0.5 kg), spread over 6 – 12 meals
- First solid feed: High-quality fresh grass (easily fermented in developing rumen)
- Weaning: gradually, at 6 to 10 mo vs. 4 to 8 wk

What happens if you leave a “modern” Holstein calf with the cow?

Calves gain weight about 3 times faster

1.04 kg/d vs. 0.36 kg/d

Body weight (kg)

Calf age (days)

~ 6 L/day

~ 4 L/day

Flower and Weary, 2001

Are we feeding enough milk for growth and health?

The best innovation in calf feeding in recent years: 3-L and 4-L nursing bottles!

- Why have we always dictated how much calves eat by bottle size or milk replacer scoop size or milk replacer bag weight?
- Shouldn’t we design feeding programs and equipment to meet the calf’s needs?

Improved nutrient requirement equations based on NRC (2001), now used in AMTS.

Energy and protein for 50-kg calf (thermoneutral conditions), based on the “Cornell - Illinois” equations:

<table>
<thead>
<tr>
<th>ADG (kg/d)</th>
<th>DMI (% BW)</th>
<th>ME (Mcal/d)</th>
<th>CP (g/d)</th>
<th>CP (% of DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>1.08</td>
<td>2.33</td>
<td>97</td>
<td>18.1</td>
</tr>
<tr>
<td>0.4</td>
<td>1.34</td>
<td>2.88</td>
<td>155</td>
<td>23.2</td>
</tr>
<tr>
<td>0.6</td>
<td>1.62</td>
<td>3.48</td>
<td>214</td>
<td>26.5</td>
</tr>
<tr>
<td>0.8</td>
<td>1.89</td>
<td>4.12</td>
<td>272</td>
<td>28.9</td>
</tr>
<tr>
<td>1.0</td>
<td>2.22</td>
<td>4.78</td>
<td>331</td>
<td>29.9</td>
</tr>
</tbody>
</table>

(ME lower, CP higher than NRC) Van Amburgh and Drackley, 2005
Increasing milk replacer intake increases ADG and gain:feed of calves

- Bartlett, 2001

<table>
<thead>
<tr>
<th>Intake of milk replacer (26% CP)</th>
<th>10% BW</th>
<th>14% BW</th>
<th>18% BW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average daily gain (kg)</td>
<td>0.55</td>
<td>0.71</td>
<td>0.81</td>
</tr>
</tbody>
</table>

* No effect on composition of gain

Impact of cold stress on maintenance requirements

- Maintenance of 45-kg calf requires:
  - 0.52 kg of milk replacer powder at −1 °C vs. 0.38 kg of powder at 16 °C
  - If amount fed is insufficient health will suffer

Energy and protein supply

- Must be in correct proportion to each other
- Energy intake is primarily determined by the amount of milk or replacer fed
- Protein intake is affected both by amount fed and the protein content in the milk replacer

Body protein deposition increases in proportion to dietary protein intake

- Bartlett et al., 2006

Whole-body protein and fat deposition vary inversely as dietary protein increases

- Crude protein in milk replacer (%)
- Gain of protein or fat (g/d)

Calves fed at 14% of BW; Initial ME intakes were equal.

Data from Bartlett et al., 2006

How did we decide that 4 L of milk per day was the right amount to feed calves?

- Management decision to limit milk or milk replacer to 8 to 10% of body weight
- Designed to promote early intake of starter and allow early weaning
- Starter intake provides minor contribution to nutrient intake until ~ week 2 of life
- Growth is proportional to starter intake
In conventional systems growth is directly proportional to starter intake

Until starter intake increases, calves fed conventionally are hungry
- Increased vocalization
  - 31.4 vs. 5.0 calls per day for calves fed 5 L vs. 8 L of milk daily (Thomas et al., 2001)
- More active (restless)
  - More unrewarded visits to feeder
  - More competitive displacement of other calves from feeder
  - More time standing (1 h greater for calves fed 10% of BW than for those fed ad libitum) (De Paula Vieira et al., 2008)

Feeding more milk replacer increases early growth of calves, proportional to amount consumed

Feeding the right protein to energy ratio in milk replacer results in increased frame size, not fattening

Potential economic impacts of better early nutrition
- Capitalize on rapid early growth potential
  - Most efficient weight and height increase
- Decrease days to breeding and first calving
- Improve health
- Improve future productivity

Areas of potential economic advantage for greater milk feeding programs
Evidence for production benefit with more milk fed across other studies

- Many data sets exist where milk yield was reported along with alterations in pre-weaning feeding program
- Most studies were conducted with small numbers of cattle because of cost and logistics of managing multi-year studies

Meta analysis of effect of increased milk during early life (difference of >75% in early milk intake) on subsequent milk yield

<table>
<thead>
<tr>
<th>Effect on 1st lact. milk, kg</th>
<th>SE, kg</th>
<th>Lower limit, kg</th>
<th>Upper limit, kg</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>435</td>
<td>117</td>
<td>205</td>
<td>664</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

(Odds ratio of effect was 2.1 times greater for increased milk intake)

Better early nutrition improves health

Calves fed on high plane of nutrition better withstand a Cryptosporidium parvum challenge

Differences in first-lactation milk due to increased early milk or MR intake

<table>
<thead>
<tr>
<th>Study</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foldager and Krohn, 1994</td>
<td>+1,405 kg</td>
</tr>
<tr>
<td>Foldager et al., 1997</td>
<td>+520 kg</td>
</tr>
<tr>
<td>Bar-Peled et al., 1997</td>
<td>+454 kg</td>
</tr>
<tr>
<td>Ballard et al., 2005</td>
<td>+700 kg @ 200 DIM</td>
</tr>
<tr>
<td>Shamay et al., 2005</td>
<td>+981 kg</td>
</tr>
<tr>
<td>Pollard et al., 2007</td>
<td>+836 kg</td>
</tr>
<tr>
<td>Raeth-Knight, 2009</td>
<td>+716 kg</td>
</tr>
<tr>
<td>Terré et al., 2009</td>
<td>+624 kg</td>
</tr>
<tr>
<td>Morrison et al., 2009</td>
<td>−91 kg</td>
</tr>
<tr>
<td>Moallem et al., 2010</td>
<td>+732 kg</td>
</tr>
<tr>
<td>Davis-Rincker et al., 2011</td>
<td>+416 kg</td>
</tr>
<tr>
<td>Stamey et al. unpublished</td>
<td>+14 to +126 kg</td>
</tr>
<tr>
<td>Flockhart et al. unpublished</td>
<td>+414 to +578 kg</td>
</tr>
<tr>
<td>Kiezebrink et al., 2015</td>
<td>−25 kg</td>
</tr>
</tbody>
</table>

How do we increase milk solids intake?
Strategies for increased milk intake
• Feed more per feeding
• Increase number of feedings daily
• Increase solids concentration (<18%) of milk replacers
• Fortify pasteurized milk with a balancer
• Use an automated calf feeder

If feeding milk, it should be pasteurized on-farm!
• Particularly if using waste milk
• Your “babies” – most vulnerable animal on farm
• Proven benefit to growth and health

Milk vs. milk replacers

Content of metabolizable energy (ME) in liquid feeds and predicted calf growth

<table>
<thead>
<tr>
<th>Feed</th>
<th>ME (Mcal/kg DM)</th>
<th>Expected ADG (kg)a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole milk</td>
<td>5.37</td>
<td>0.40</td>
</tr>
<tr>
<td>Milk replacer 22/10</td>
<td>4.25</td>
<td>0.22</td>
</tr>
<tr>
<td>Milk replacer 22/19</td>
<td>4.80</td>
<td>0.29</td>
</tr>
<tr>
<td>Milk replacer 20/20</td>
<td>4.82</td>
<td>0.30</td>
</tr>
</tbody>
</table>

For 41-kg calf fed at 10% BW (12.5% solids) or approximately 4 L of liquid daily (NRC, 2001)

Implications:
Calves fed milk replacer are underfed both energy and protein relative to those fed equal volumes or weights of whole milk.
- Calves fed 4 L of milk replacer receive about 10% less energy (ME) than calves fed 4 L whole milk.

This does NOT mean that milk replacer is poor quality or inferior.

High-quality milk replacers provide similar growth if energy and protein intakes are equal.

Methods
• 18 calves assigned to 3 treatment groups (n = 6)
• Treatments designed to vary only in source of energy at similar ME and CP intakes:
  - Moderate-fat conventional milk replacer (CMR), fed at 14% BW
  - High fat milk replacer (HFMR), fed at 11.65% BW
  - Whole milk (Milk), fed at 11.65% BW
Analyzed composition (DM basis) of conventional (CMR) or high fat (HFMR) milk replacers and whole milk

<table>
<thead>
<tr>
<th>Component</th>
<th>CMR</th>
<th>HFMR</th>
<th>Milk</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP, %</td>
<td>22.3</td>
<td>25.4</td>
<td>25.4</td>
</tr>
<tr>
<td>Fat, %</td>
<td>21.4</td>
<td>27.4</td>
<td>27.1</td>
</tr>
<tr>
<td>Lactose, %</td>
<td>49.1</td>
<td>40.1</td>
<td>41.9</td>
</tr>
<tr>
<td>Ash, %</td>
<td>7.2</td>
<td>7.1</td>
<td>5.6</td>
</tr>
<tr>
<td>Gross energy, Mcal/kg</td>
<td>5.1</td>
<td>5.6</td>
<td>5.6</td>
</tr>
</tbody>
</table>

*Total fatty acids / 0.90

100 - CP - fat - ash (NRC, 2001)

Intakes by calves fed conventional or high fat milk replacer or whole milk

<table>
<thead>
<tr>
<th>Variable</th>
<th>Diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeding rate, %BW</td>
<td>CMR</td>
</tr>
<tr>
<td></td>
<td>HFMR</td>
</tr>
<tr>
<td></td>
<td>Milk</td>
</tr>
<tr>
<td></td>
<td>SE</td>
</tr>
<tr>
<td>Initial ME intake, Mcal/d</td>
<td>3.63</td>
</tr>
<tr>
<td></td>
<td>3.56</td>
</tr>
<tr>
<td></td>
<td>3.62</td>
</tr>
<tr>
<td></td>
<td>0.19</td>
</tr>
<tr>
<td>Initial CP intake, g/d</td>
<td>177</td>
</tr>
<tr>
<td></td>
<td>181</td>
</tr>
<tr>
<td></td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Initial FA intake, g/d</td>
<td>152</td>
</tr>
<tr>
<td></td>
<td>176</td>
</tr>
<tr>
<td></td>
<td>164</td>
</tr>
<tr>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Initial lactose intake, g/d</td>
<td>389</td>
</tr>
<tr>
<td></td>
<td>286</td>
</tr>
<tr>
<td></td>
<td>288</td>
</tr>
<tr>
<td></td>
<td>24</td>
</tr>
<tr>
<td>Mean DMI, kg/d</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>0.10</td>
</tr>
</tbody>
</table>

* CMR vs. HFMR and milk (P < 0.05)

Growth of calves fed conventional or high fat milk replacers or whole milk

<table>
<thead>
<tr>
<th>Variable</th>
<th>Diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeding rate, %BW</td>
<td>CMR</td>
</tr>
<tr>
<td></td>
<td>HFMR</td>
</tr>
<tr>
<td></td>
<td>Milk</td>
</tr>
<tr>
<td></td>
<td>SE</td>
</tr>
<tr>
<td>ADG, kg/d</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>0.09</td>
</tr>
<tr>
<td>Gain:feed</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>0.03</td>
</tr>
<tr>
<td>Days with FS &gt;2</td>
<td>9.7</td>
</tr>
<tr>
<td></td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>3.9</td>
</tr>
</tbody>
</table>

* CMR vs. HFMR and milk (P < 0.05)

Effect of energy source (fat vs. lactose) on average daily gain of calves fed equal amounts of energy and protein

Conclusions

- Lactose promotes greater lean tissue growth than does fat in preruminant calves.
- Growth was generally similar between whole milk and high-fat milk replacer.
- If milk replacer and milk are fed in amounts to supply equal energy, growth is similar.
Advantages of milk replacers

- Biosecurity without cost and labor of pasteurization
- Quality control
- Consistency
- Convenience

Accuracy and consistency are critical

- Volume
  - Correct for feeding program goals
- Concentration
  - 10-15% solids, consistent day to day
- Temperature
  - At mixing (follow manufacturer instructions)
  - When calf drinks (~39°C)
- Quality and nutritional balance

Key management aspects for early growth

- Colostrum program
- Supplemental water
- Milk or appropriate milk replacer; proper mixing
- Starter/weaning management
- Post-weaning nutrition

Weaning: The “other” transition period

- A critical stage of calf’s life and subject to many stressors
- Changes in diet, environment, and social structure

  - Growth slumps, behavioral stress, more disease

Increasing milk or milk replacer intake delays starter intake

- Maximum total DM intake is 2.0 to 2.5% of BW
- High rates of milk or milk replacer substitute for starter intake
Higher rates of milk feeding decrease preweaning starter intake

Effects of diet on rumen development
- Milk and hay do little to develop rumen epithelium (papillae)
- Grain (starter) or fresh grass (sugars) are key to development of rumen papillae via VFA production°C
- Papillae development can occur by 3-4 wk of age with good starter management
- Process takes ~3 wk no matter when start

Insufficient rumen development (starter intake) before weaning decreases nutrient digestibility after weaning

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Low</th>
<th>High</th>
<th>Difference, %</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent digestibility, %</td>
<td>77.4</td>
<td>71.8</td>
<td>-5.6</td>
<td>0.009</td>
</tr>
<tr>
<td>DM</td>
<td>77.1</td>
<td>71.6</td>
<td>-5.5</td>
<td>0.01</td>
</tr>
<tr>
<td>CP</td>
<td>34.7</td>
<td>20.3</td>
<td>-14.4</td>
<td>0.02</td>
</tr>
<tr>
<td>NDF</td>
<td>75.6</td>
<td>69.8</td>
<td>-5.8</td>
<td>0.007</td>
</tr>
</tbody>
</table>

But, proper nutritional management during and after weaning prevents the weaning slump

At wk 35:
- 366 kg vs 351 kg

Cowles et al., 2006
Stamey et al., 2012
Terré et al., 2007
Osorio et al., 2012
Meeting the nutrient requirements of calves around weaning

Starter concentrates provide less energy per unit solids than milk
- Lower digestibility than milk solids
- Efficiency of use of ME from VFA and milk endproducts not greatly different.
- Differences in digestibility mean that:
  - ME of starter is ~65 to 70% of ME in milk replacer (NRC, 2001)
  - Growth will be ~2/3 of that on equal DM from milk replacer.

Starter dry matter intake (DMI) required to support various rates of gain in weaned calves

<table>
<thead>
<tr>
<th>BW (kg)</th>
<th>ADG (g/d)</th>
<th>Starter required (kg/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>600</td>
<td>1.53</td>
</tr>
<tr>
<td>60</td>
<td>800</td>
<td>1.90</td>
</tr>
<tr>
<td>80</td>
<td>600</td>
<td>1.80</td>
</tr>
<tr>
<td>80</td>
<td>800</td>
<td>2.18</td>
</tr>
</tbody>
</table>

Based on starter containing 3.1 Mcal ME/kg DM (NRC 2001)

Pre-weaning starter intake determines post-weaning starter intake

\[ y = 0.0009x - 0.0244 \]
\[ R^2 = 0.732 \]
Pre-weaning starter intake determines post-weaning starter intake

\[ y = 0.0009x - 0.0244 \]

\[ R^2 = 0.732 \]

- 1.5
- 1
- 0.5
0
0.5
1
1.5
2
0 200 400 600 800 1000 1200 1400 1600 1800 2000

ADG weaning week, kg/d

Pre-weaning starter DMI, g/d

\~1.3 \text{ kg/d} \text{ starter intake}

Stamey et al., 2012

Older age at weaning improves success

\text{de Passilé et al., 2011}

Slower weaning improves starter intake

Sweeney et al., 2010

Should we feed forage to young calves?

First, let’s ask the calves
• If limit concentrates with free choice hay, calves don’t grow well.
• Hay is fermented and digested poorly in the young and developing rumen. Calves get “hay belly”, less concentrate intake.
• Hay is not necessary for development of rumen volume and ruminination.
• Hay does not reliably increase rumen pH.
• Therefore, don’t feed hay before weaning!
  – Unless calves are not bedded on straw or to prevent bloating on pelleted starter

**Summary of arguments *against* forages**

**Summary of arguments *for* forages**

• Calves “crave” forage fiber. Satisfies behavioral needs, prevents stereotypic behaviors (tongue rolling, mouthing objects, etc).
• Small amounts of hay increase starter intake and feed efficiency.
• Hay particles keep rumen papillae healthier and prevent abnormal growth.
• Therefore, feed small amounts of hay with concentrates before weaning!

---

<table>
<thead>
<tr>
<th>Forage</th>
<th>F:C</th>
<th>ADG (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>---</td>
<td>0.72c</td>
</tr>
<tr>
<td>Oat hay</td>
<td>8:92</td>
<td>0.93a</td>
</tr>
<tr>
<td>Barley straw</td>
<td>5:95</td>
<td>0.88a</td>
</tr>
<tr>
<td>Rye-grass hay</td>
<td>4:96</td>
<td>0.84ab</td>
</tr>
<tr>
<td>Corn silage</td>
<td>5:95</td>
<td>0.82ab</td>
</tr>
<tr>
<td>Alfalfa hay</td>
<td>14:86</td>
<td>0.76bc</td>
</tr>
</tbody>
</table>

Hay or straw chopped. Gain/feed was not different among diets.

From Castells et al., 2012
Forage to concentrate ratio selected by calves given free choice of both

<table>
<thead>
<tr>
<th>Forage</th>
<th>F:C</th>
<th>ADG (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>---</td>
<td>0.72c</td>
</tr>
<tr>
<td>Oat hay</td>
<td>8:92</td>
<td>0.93a</td>
</tr>
<tr>
<td>Barley straw</td>
<td>5:95</td>
<td>0.88a</td>
</tr>
<tr>
<td>Rye - grass hay</td>
<td>4:96</td>
<td>0.84ab</td>
</tr>
<tr>
<td>Corn silage</td>
<td>5:95</td>
<td>0.82ab</td>
</tr>
<tr>
<td>Alfalfa hay</td>
<td>14:86</td>
<td>0.76bc</td>
</tr>
</tbody>
</table>

For 1.5-kg total DM intake, forage intake would be 75 g/d for barley straw vs. 210 g/d for alfalfa hay.

Hay or straw chopped. Gain/feed was not different among diets.

Summary: Hay or not?
- Free-choice alfalfa hay decreases starter intake, which is most important for rumen development.
- Small amounts of grass hays or straw may increase starter consumption.
- Hay is not necessary for development of rumen volume and rumination.
- 5% chopped hay can be provided with starter if calves not bedded on straw or to prevent bloating on pelleted starter.
- Free choice hay should not be provided until > 4 weeks postweaning.

“Feeding more milk is too expensive, with little immediate benefit.”
- Cost or investment?
- We must move beyond cost per day for feeding calves.
- Think of:
  - Cost per pound of BW gain
  - Cost per day of life until enter milking herd
- Must be coordinated system…birth to heifer to lactating cow.

OMG, will you PLEASE wrap it up?!

Summary and Conclusions
- Higher protein milk replacers promote greater lean body growth if energy supply is adequate.
- Milk replacers and whole milk result in similar growth in calves if compared on an equal nutrient intake basis.
- Think cost per unit weight and frame increase; if implemented correctly will pay!
Thank you!

drackley@illinois.edu