Nutritional strategies related to sustainability and efficiency of the U.S. beef industry

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Producing Food with Animals: Sustainability, Efficiency, and Security in the U.S.

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U.S. Beef Industry

• Traditionally segmented
  • Cow-calf (purebred and commercial)
  • Stocker/backgrounding
  • Finishing phases
• Evolving into a total production system
  • Livestock and environmental stewardship
  • Economic sustainability
  • Social responsibility
U.S. Beef Industry

Consumer

Retailer

Packing Industry

Feedlot sector

Backgrounding sector

Commercial cow/calf

Seedstock
U.S. Land: 0.785 billion hectares

- 23.3% is water or federal land
- Non-federal land: 34.7% rangeland, 34.7% forest land, and 30.6% cropland
- Over 4.5 million metric tons of crop residues annually
- 37 kg of byproducts available for livestock for every 100 kg of plants grown for human food
Advantages of Ruminants

• About 35% of the U.S. land surface is rangeland.
• Ruminants can utilize the largest carbohydrate (CHO) source in the world and produce food and other products for man.
• Microbial digestion maintains the carbon cycle. Plants fix CO$_2$ and release O$_2$ (85 billions tons of CO$_2$ released each year from microbial fermentation).
Rumen Ecosystem

• Catabolic processes are collectively thought of as “fermentation”.
  – “Fermentation is the consequence of life without air” (Louis Pasteur).
  – VFA are fully reduced, energy dense compounds. Microbes grow and end products are absorbed.

• Anabolic processes are critical:
  – Supply of protein of relatively high biological value, from protein and NPN sources.
  – To meet the B-vitamin requirements of the host.
Advantages of Pregastric Fermentation

• More effective use of fermentation end-products including:
  – Volatile fatty acids, microbial protein, B vitamins

• Ability to detoxify some poisonous compounds
  – Oxalates, cyanide, alkaloids

• Undigested residues (OM) returned to the soil

• In wild animals, it allows animals to “eat and run”
Disadvantages of Pregastric Fermentation

• Inefficiencies in fermentation
  – Energy
    • Loss Amount (% of total caloric value)
      - Methane 5-8
      - Heat of fermentation 5-6
    • Relative efficiency is dependent on the diet NDF.
  – Protein
    • Some ammonia resulting from microbial degradation will be absorbed and excreted
    • 20% of the nitrogen in microbes is in the form of nucleic acids
• Ruminants are susceptible to acidosis and ketosis
• Ruminants are susceptible to toxins produced by rumen microbes
  – Nitrates → Nitrites
  – Urea → Ammonia
  – Nonstructural carbohydrates → Lactic acid
  – Tryptophan → 3-methyl indole
  – Isoflavonoid estrogens → Estrogen
## Forage use in Beef Production Systems

<table>
<thead>
<tr>
<th>Metric Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forage for Cows/Replacements</td>
</tr>
<tr>
<td>Forage for Calf Finishing</td>
</tr>
<tr>
<td>Grain for Calf Finishing</td>
</tr>
<tr>
<td>Total forage</td>
</tr>
<tr>
<td>Total feed</td>
</tr>
</tbody>
</table>

- **Beef Production is > 80% forage**
Feed Consumption in Beef Production Systems

<table>
<thead>
<tr>
<th>Feed Type</th>
<th>kg DM/kg CW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grazed forage</td>
<td>13.2</td>
</tr>
<tr>
<td>Harvested forage</td>
<td>5.1</td>
</tr>
<tr>
<td>Grain concentrate</td>
<td>2.6</td>
</tr>
<tr>
<td>Other feed</td>
<td>1.5</td>
</tr>
<tr>
<td>Total feed</td>
<td>22.3</td>
</tr>
</tbody>
</table>

- Beef Production is > 80% forage

(Rotz et al., 2019)
Humans vs. Ruminants

We’re only 10% human
Human microbiota to ruminants – polysaccharide utilization

- 70% of energy from microbial breakdown
- Mutualism
- Dietary polysaccharides that reach the large intestine impact microbial ecology

“Diet influences microbial community”

Nature Reviews Microbiology 6, 121-131 (February 2008)
Pyruvate Metabolism in the Gut

Lactate fermenter (Megasphaera elsdenii)
Lactate producers
PYRUVATE [3C]

Lactate fermenters
Fiber digesters
Starch and sugar fermenters

Oxaloacetate [4C]
GLUCOSE [6C]

Fiber digesters
Starch and sugar fermenters

Acrylate [3C]

Acetyl CoA [2C]

Ethanol [2C]

Fiber digesters
Starch digesters

Formate [1C]

Butyrate [4C]

Malate [4C]

Fiber digesters
Starch and sugar fermenters

Fumarate [4C]

Fiber digesters
Starch and sugar fermenters

Succinate [4C]

2H

CO₂

2H

4H

CO₂

ATP

2H

ATP

Propionate [3C]

Acetate [2C]
Key Points

- Polymers are converted to monomers and are phosphorylated
  - Enter different pathways
- Pathways are interconnected and make intermediates that feed back into glycolysis
- Glycolysis is key in microbial metabolism to produce pyruvate
- Pyruvate is used for VFA production
- VFA produced are metabolized by the host for energy
  - Acetate and butyrate – produce H₂
  - Propionate, lactate and ethanol – use H₂
Methane and VFAs

Moss et al. Annales De Zootechnie, 49: 231-253
Inter Species Hydrogen Transfer

Courtesy of Dr. Nagaraja et al. (Kansas State University)

Hydrogen sinks in the rumen

Research Question

Beef Production is > 80% forage

*Can dietary intervention be used to reduce methane in ruminants?*
Growing Study

- 120 steers, initial BW 300 ± 25 kg
- 84 d growing study

- Forage quality:
  - High (alfalfa/sorghum silage)
  - Low (cornstalks)

- Monensin: +/-

- MDGS type and level:
  - Normal vs. De-oiled
  - 0, 20, 40%

S.C. Fernando et al.
# Emissions: Forage x Mon.

## 40% De-Oiled MDGS

<table>
<thead>
<tr>
<th>Monensin</th>
<th>HQ +</th>
<th>HQ -</th>
<th>LQ +</th>
<th>LQ -</th>
<th>SEM</th>
<th>Forage</th>
<th>Mon.</th>
<th>Int.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄:CO₂</td>
<td>0.101&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.101&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.083&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.101&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.003</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Pesta et al. Unpublished data
Structuring – Forage Quality

*Bacteria*

Knoell et al. Unpublished data
Structuring – Forage Quality

Archaea

Knoell et al. Unpublished data
Metagenomic Analysis to Identify Microbial Pathways

Principle Component Analyses for all enzymes based on metagenomic shotgun analyses

Anthony-Babu et al.
Unpublished data
Metabolic differences in HQ and LQ forage diets

Ternary diagram for methane associated pathways

Anthony-Babu et al. Unpublished data
Metabolic differences in HQ and LQ forage diets

Anthony-Babu et al. Unpublished data
Key Points

- Production of methane within the rumen plays an important role in efficient substrate utilization.
- Decreasing methanogenesis needs to be coupled with efficient rumen function.
  - Re-cycling NADH using alternative pathways to methanogenesis.
- Dietary intervention is a viable strategy to reduce enteric fermentation by utilizing substrates that select for microbes that compete with methanogens for H$_2$.
- Whole rumen ecosystem needs to be considered.
Evaluating how a change in one segment impacts production and profit in multiple segments

- Seedstock producer
- Commercial cow/calf
- Backgrounding sector
- Feedlot sector
- Packing industry
- Retailer
- Consumer
Available corn residue
1950-2014

Assumes forage is 80% of corn yield, DM basis
Beef Cows
Future Direction

• Should we encourage farmers to integrate cows onto existing farmland?

• Why? Pasture is limited and total production per acre increases.
# Technologies

<table>
<thead>
<tr>
<th>Method</th>
<th>% Improvement in FE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implants</td>
<td>5 to 15%</td>
</tr>
<tr>
<td>Ionophores</td>
<td>4 to 8%</td>
</tr>
<tr>
<td>DFM</td>
<td>2 to 2.5%</td>
</tr>
<tr>
<td>β-adrenergic agonists</td>
<td>10 to 30%</td>
</tr>
</tbody>
</table>
Opportunities

• “Wide variation in environmental footprints found among individual production systems indicates that reductions can be made to improve overall sustainability.” (Rotz et al., 2019)
  – Will require improvements on individual operations
  – Decrease days on feed
  – Optimize use of fertilizer
  – More efficient use of solar and wind power for fencing and watering
  – Efficient use of water
Opportunities

- Increased understanding of GxExMxS
- Increased understanding of Genotype to Phenotype
- Emphasis on the use of precision management tools
- Place value of information flowing across segments of the industry
- Animal health and well being
- Consumer confidence and trust (social and product)
Conclusions

• Beef cattle rely on forages for production

• Diversity of microorganisms in the rumen allows for altering nutritional strategies to improve efficiency
  – Improve efficiency of forage utilization

• Byproducts and crop residue use important for competitive advantage

• Variation in environmental footprints indicate improvements should be individualized

• There is need for greater understanding of GxExMxS
From Pasture... To Plate
Beef cattle are well positioned

Turn forage into high quality protein