Carbohydrate Nutrition

Introduction
- Largest component of dairy rations
- CHO comprise 70 to 80% of ration DM
- Major source of energy for milk production
- One-third of milk solids is lactose
  - 4.9 lbs. of lactose in 100 lbs. milk

Microbial CHO Metabolism
- Fermentation Pathways
  - Structural CHO: acetate, butyrate
  - Nonstructural CHO: propionate, lactate, butyrate
  - Other endproducts: CO₂, NH₃
- Acetate
  - metabolized by peripheral tissues
  - fat precursor

Microbial CHO Metabolism
- Propionate
  - metabolized in liver
  - primary glucose (lactose) precursor
- Butyrate
  - metabolized in rumen wall
  - ketone body
  - fat precursor

CHO Fractions
- Fiber Carbohydrates
  - Cellulose
  - Hemicellulose
  - Lignin
- Non-fiber Carbohydrates
  - Starch
  - Sugars
  - Pectin
  - Organic Acids

Fiber CHO (FC)
- FC - plant cell walls
  - Cellulose (50 to 90% digestible)
  - Hemicellulose (20 to 80% digestible)
  - Lignin (Indigestible)
- Provide structural support and protection
- Fermented in the rumen - resistant to animal digestive enzymes
Detergent Fiber System

- Developed by Van Soest in 60's
- Partitions CHO based on insoluble acid and neutral detergent residue
- Neutral Detergent Fiber (NDF)
  - Cellulose, Hemicellulose, Lignin
- Acid Detergent Fiber (ADF)
  - Cellulose, Lignin

**NDF and Intake**

- NDF is related to the bulk density of diets
- It measures the components with the slowest rates of digestion
- As ration NDF increases, intake decreases
- As ration NDF declines below optimum, intake decreases

**Effect of Ration NDF on Intake**

Intake limited by excess fermentation (digestive upsets)

Intake limited by rumen capacity

Optimal NDF 27 to 32% DM

As milk yield increases, optimal NDF decreases.
As milk yield decreases, optimal NDF increases

15 17 19 21 23 25 27 29 31 33 35 37 39 41 43
% NDF

**Saliva Production**

- 36% during eating
- 46% during rumination
- 18% during rest
- >200 L produced/day
- 1.5 to 2.0 lbs. bicarbonate produced/day
- Short particle size ration
  - decrease eating time
  - decrease ruminating time
Effective NDF (eNDF)

- Particles longer than 10mm stimulate rumination
- Saliva and motility
- Recommended that eNDF exceed 21% NDF
- 70 - 75% of NDF should come from forage

Maintain healthy rumen and intake

Effective NDF (eNDF)

<table>
<thead>
<tr>
<th>Feed</th>
<th>NDF (% of DM)</th>
<th>eNDF (% of NDF)</th>
<th>eNDF (% of DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Silage, 3/8&quot;</td>
<td>45</td>
<td>81</td>
<td>36</td>
</tr>
<tr>
<td>Corn Silage, &lt;3/8&quot;</td>
<td>45</td>
<td>71</td>
<td>32</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>40</td>
<td>92</td>
<td>37</td>
</tr>
<tr>
<td>Brewers</td>
<td>49</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>Distillers</td>
<td>46</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Whole Cottonseed</td>
<td>52</td>
<td>100</td>
<td>52</td>
</tr>
<tr>
<td>Soy Hulls</td>
<td>66</td>
<td>34</td>
<td>22</td>
</tr>
<tr>
<td>Wheat Midds</td>
<td>35</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Non-fiber Carbohydrates (NFC)

- Sugars
- Starch
- Pectin - citrus and beet pulp
- Organic acids - fermented feeds
- NFC = 100 - %NDF - %CP - %Fat - %Ash
- Nonstructural CHO - lab determination
  - does not include pectin and organic acids

NFC and NSC of Feeds

<table>
<thead>
<tr>
<th>Feed</th>
<th>NDF (% of DM)</th>
<th>NFC (% of DM)</th>
<th>NSC (% of DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa Hay</td>
<td>43</td>
<td>22</td>
<td>13</td>
</tr>
<tr>
<td>Corn Silage</td>
<td>44</td>
<td>41</td>
<td>35</td>
</tr>
<tr>
<td>Corn</td>
<td>13</td>
<td>68</td>
<td>69</td>
</tr>
<tr>
<td>Beet Pulp</td>
<td>47</td>
<td>36</td>
<td>20</td>
</tr>
<tr>
<td>Barley</td>
<td>23</td>
<td>61</td>
<td>62</td>
</tr>
<tr>
<td>Soy hulls</td>
<td>67</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td>SBM</td>
<td>10</td>
<td>34</td>
<td>17</td>
</tr>
</tbody>
</table>

Composition of NFC Fraction

<table>
<thead>
<tr>
<th>Feed</th>
<th>Sugar</th>
<th>Starch</th>
<th>Pectin</th>
<th>VFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Silage</td>
<td>0</td>
<td>71</td>
<td>0</td>
<td>29</td>
</tr>
<tr>
<td>Barley</td>
<td>9</td>
<td>82</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Corn</td>
<td>20</td>
<td>82</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Beet Pulp</td>
<td>34</td>
<td>2</td>
<td>64</td>
<td>0</td>
</tr>
<tr>
<td>Soy hulls</td>
<td>19</td>
<td>19</td>
<td>62</td>
<td>0</td>
</tr>
<tr>
<td>SBM</td>
<td>28</td>
<td>28</td>
<td>44</td>
<td>0</td>
</tr>
</tbody>
</table>

NFC Recommendations

- Greatest milk yield - 35% DM
- Optimal range - 30 to 40% DM
- Depends on degradation rate
  - wheat, barley, high moisture corn
    - 30 to 35% DM
- NDF and NFC vary inversely
  - Balancing for one balances for the other
NFC Recommendations

- $r^2$ for NFC (% of DM) and milk yield = 0.04
- $r^2$ for NFC intake and milk yield = 0.40
- 1 lb increase in NFC intake resulted in a 2.4 lb increase in milk yield
- In the past, when grain and forage were fed separately, the rule of thumb was 2.5 lbs of grain per lb of milk

Ruminal Rates of NFC Degradation

<table>
<thead>
<tr>
<th>Grain Type</th>
<th>NFC</th>
<th>% Starch</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barely, rolled</td>
<td>56</td>
<td>58</td>
<td>High</td>
</tr>
<tr>
<td>Corn, course</td>
<td>76</td>
<td>70</td>
<td>Low</td>
</tr>
<tr>
<td>Corn, fine</td>
<td>76</td>
<td>70</td>
<td>Mod</td>
</tr>
<tr>
<td>Corn, wet-fine</td>
<td>76</td>
<td>70</td>
<td>High</td>
</tr>
<tr>
<td>Wheat, ground</td>
<td>70</td>
<td>65</td>
<td>HIGH</td>
</tr>
</tbody>
</table>

Digestibility of Grains

- Barley
  - Whole poorly digested
  - Must roll, crack, or grind
- Corn
  - Whole corn poorly digested
  - Rolling or cracking 25% increase
  - Dry ground 4 – 6 % > rolled or cracked
  - Steam-flaking > ground > rolled = cracked > whole
    - Steam-flaked corn – 28 lb/bu

Processing

- Degradability of starch – oats > wheat > barley > corn > sorghum
- Physical form – ground > cracked > whole
- Steam processing – flaking > rolling > ground
- Moisture – high moisture = steam flaking > dry

Protein Requirements

- Weight Gain
  - 20% protein
  - 0.3 lb crude protein/lb gain (200 lb calf)
  - 0.7 lb crude protein/lb gain (1000 lb heifer)
- Milk Production
  - 0.025 lb crude protein/% milk protein
  - 3.2 to 4.0% protein
- Maintenance
  - 0.06 to 0.08 lb crude protein/100 lb BW
Crude Protein (CP) System

- Feed CP = Kjeldahl N x 6.25

- Advantage
  - Easily determined from routine lab analysis

- Disadvantage
  - Assumes all proteins have similar ruminal degradabilities

Metabolizable Protein (MP) System

- Metabolizable Protein (MP) system introduced in 1985

- Two reasons for introduction
  - More information was available on degradability of feed protein
  - More information was available on microbial protein synthesis

Protein Fractions

1. Rumen Degradable Protein (RDP)
   - degraded to ammonia by microbes
   - incorporated into microbial protein
   - microbes pass to small intestine

2. Rumen Undegradable Protein (RUP)
   - pass from rumen to small intestine

Rumen Degradable Protein

- Best indicator is solubility
- not a perfect relationship
- soluble in borate-phosphate buffer
- Amino acid composition/positions
- Protein structure

Protein Supplements

<table>
<thead>
<tr>
<th></th>
<th>CP (%) DM</th>
<th>Soluble (%) CP</th>
<th>RDP (%) CP</th>
<th>RUP (%) CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brewers</td>
<td>30</td>
<td>4</td>
<td>34</td>
<td>66</td>
</tr>
<tr>
<td>Canola</td>
<td>40</td>
<td>32</td>
<td>63</td>
<td>37</td>
</tr>
<tr>
<td>CS Meal</td>
<td>46</td>
<td>20</td>
<td>57</td>
<td>43</td>
</tr>
<tr>
<td>Distillers</td>
<td>30</td>
<td>6</td>
<td>26</td>
<td>74</td>
</tr>
<tr>
<td>Fish Meal</td>
<td>68</td>
<td>21</td>
<td>41</td>
<td>59</td>
</tr>
<tr>
<td>48% SBM</td>
<td>55</td>
<td>20</td>
<td>65</td>
<td>35</td>
</tr>
</tbody>
</table>
Microbial Protein Synthesis

- Microbial growth is dependent upon amount of CHO fermented in the rumen
- Microbial crude protein (g/day) = 130 x kg TDN
- MCP is 80% true protein and 80% digestible
- 1 lb MCP provides 0.64 lb MP

Rumen Degradable Protein

- RDP = MCP (g/d) x 1.18
- “Protein Energy Uncoupling”
  - Occurs when either RDP or energy is deficient relative to the other
  - Excess RDP relative to energy is lost as NH₃
  - Excess energy relative to RDP results in less than optimal fermentation

Microbial Protein/RDP

- Microbial protein contribution is generally 65 to 70% of dietary CP
- Rumen available energy and RDP should match
- As a rule of thumb - half RDP should be soluble

Rumen Undegradable Protein

- Microbial protein peaks at 12 to 13% dietary CP
- 5 to 6% dietary CP must be supplied as RUP
- Rule of thumb - 30 to 35% of dietary CP provided as RUP

1500 lb Cow, 3.2% Milk Protein

- Common RUP Sources

<table>
<thead>
<tr>
<th>Source</th>
<th>CP (% DM)</th>
<th>RUP (% CP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood Meal</td>
<td>93</td>
<td>75</td>
</tr>
<tr>
<td>CG Meal</td>
<td>67</td>
<td>59</td>
</tr>
<tr>
<td>Feather Meal</td>
<td>86</td>
<td>70</td>
</tr>
<tr>
<td>Fish Meal</td>
<td>67</td>
<td>65</td>
</tr>
<tr>
<td>Prolak</td>
<td>72</td>
<td>66</td>
</tr>
<tr>
<td>Soy Plus</td>
<td>47</td>
<td>55</td>
</tr>
</tbody>
</table>
Rumen Undegradability

- Many RUP values were determined at maintenance intake
  - passage rate differs from 4 to 8%/hour
- Most RUP values determined by hanging dacron bags in rumen
  - simulate true rumen environment?
  - no chance for passage out of rumen

Santos and Huber

<table>
<thead>
<tr>
<th>RUP Source</th>
<th>Milk Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- 0 +</td>
</tr>
<tr>
<td>All plant proteins</td>
<td>6 28 9</td>
</tr>
<tr>
<td>All fish meals</td>
<td>0 16 7</td>
</tr>
<tr>
<td>Animal by-products</td>
<td>2 19 1</td>
</tr>
</tbody>
</table>

Lack of Response to RUP

- RUP replaces RDP to extent that RDP becomes deficient in rumen
- RUP sources heat-treated
  - Too much heat decreases intestinal digestibility
- Poor amino acid profile
  - Response to fish meal - excellent amino acid profile

Amino Acids

- Animals require amino acids not protein
- Methionine and Lysine considered limiting for milk production
  - Arg & His 3rd and 4th limiting
- Microbial protein closely mimics the amino acid profile of milk
  - natures perfect protein source

Amino Acid Profiles

<table>
<thead>
<tr>
<th></th>
<th>Met</th>
<th>Lys</th>
<th>Arg</th>
<th>His</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g/100 g AA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk</td>
<td>2.7</td>
<td>8.3</td>
<td>3.7</td>
<td>2.7</td>
</tr>
<tr>
<td>Microbes</td>
<td>2.7</td>
<td>7.9</td>
<td>5.1</td>
<td>2.0</td>
</tr>
<tr>
<td>Fish Meal</td>
<td>2.8</td>
<td>7.1</td>
<td>7.2</td>
<td>2.3</td>
</tr>
<tr>
<td>SBM</td>
<td>0.8</td>
<td>6.1</td>
<td>7.7</td>
<td>2.3</td>
</tr>
<tr>
<td>Prolak</td>
<td>1.6</td>
<td>6.1</td>
<td>5.8</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Goals of Ruminant Protein Nutrition

- Optimize efficiency of use of dietary CP
- Selection of feed proteins and NPN that provide types and amounts of rumen degradable protein (RDP)
  - Meet, but not exceed, N needs of rumen microbes for maximal synthesis of MCP
- Selection of feed proteins that provide types and amounts of digestible rumen undegradable protein (RUP)
  - Optimize amounts and profile of absorbed AA
Fat Nutrition

Introduction
- Several fatty acids are essential - usually provided in diet
  - common diet 2 to 3% fat
- Fat contains 2.25x more energy than carbohydrates
- Common fat sources - 2.65 Mcal NEL/lb

When to Use Fat
- Increase ration energy density
  - 1 lb ground corn = 0.88 Mcal NE
  - 1 lb animal/vegetable fat = 2.65 Mcal NE
- Alleviate heat stress
  - fat decreases heat production
- Improve reproductive performance
  - hormonal or improved energy balance

Problems with Fat
- Too much impairs fiber digestion
  - coating of fiber particles
  - toxic effect on microbes
- Fatty acids can be poorly digested
- Fat can reduce intake
  - physiological mechanism to maintain constant energy intake
  - reduced fiber digestibility
  - negative feedback from intestine

Reduced Fiber Digestion
- Unsaturated fatty acids depress fiber digestion more severely than saturated fatty acids
- Saturated = no double bonds
- Mono-Unsaturated = one double bond
- Polyunsaturated = two or more double bonds

Fatty Acid Digestibility
- Saturated fats less digestible than unsaturated fats
- Fully hydrogenated yellow grease
  - digestibility decreased from 68 to 47%
- Partially hydrogenated tallow
  - digestibility decreased from 78 to 50%
Fiber/Fat Interaction

- Slight impairment of ruminal fermentation when fat was added at 6% DM to 21% ADF diets vs 28% ADF
- Ruminal fermentation inhibited more when added to corn silage based rations

Milk Response to Added Fat

- Phase I
- Phase II
- Phase III

% Added Fat

How Much Fat to Add?

- 2 to 3% DM naturally in diet
- 3% DM from unprotected sources
  - whole oil seeds
  - animal/vegetable fats
- 1 to 2% DM from protected sources
  - Megalac
  - Energy Booster
- About 1.5 lbs for most cows (75 lbs milk)

Adding Unprotected Fat

- Added Fat (%DM) = (6 x ADF (%DM))/UFA (Jenkins)

Total Unsaturated Fatty Acids (UFA) Values for Fat Sources

<table>
<thead>
<tr>
<th>Fat Source</th>
<th>% UFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Booster</td>
<td>15</td>
</tr>
<tr>
<td>Megalac</td>
<td>50</td>
</tr>
<tr>
<td>Beef Tallow</td>
<td>45</td>
</tr>
<tr>
<td>Animal-Vegetable</td>
<td>52</td>
</tr>
<tr>
<td>Palm</td>
<td>53</td>
</tr>
<tr>
<td>Yellow Grease</td>
<td>71</td>
</tr>
<tr>
<td>Cottonseed</td>
<td>72</td>
</tr>
<tr>
<td>Soybean</td>
<td>85</td>
</tr>
<tr>
<td>Canola</td>
<td>90</td>
</tr>
</tbody>
</table>

Adding Unprotected Fat

Animal-Vegetable Example

- Added Fat (%DM) = (6 x ADF (%DM))/UFA
- Added Fat = (6 x 21)/52 = 2.4% DM
- DMI = 50 lbs
- Added fat = 50 x 0.024 = 1.2 lbs
- Protected Fat = 1.5 - 1.2 = 0.3 lbs
- Canola Oil 0.7 lbs
General Comments

- Fat protected by oil gland in whole seeds
  - soybeans, cottonseed
  - feed at higher levels than predicted by equation
  - successfully fed at 8 lbs/day
- Melting Points
  - Animal Fat = 105°F
  - Yellow Grease = 95 °F
  - Vegetable Oils = <32 °F

General Comments

- Cost
  - Tallow = $0.25/lb
  - Protected = $0.40/lb
- Whole Cottonseed
  - fat, protein, fiber
- Roasted Soybeans
  - fat, undegradable protein

Measuring Energy Content of Feeds

- Estimating TDN of Feeds
  - Truly digestible NFC (tdNFC) = 0.98 x (100 - [(NDF - NDIP) + CP + EE + Ash])
  - Truly digestible CP (tdCP) = CP x exp[-1.2 x (ADIP/CP)]
  - Truly digestible Fatty Acids (tdFA) = FA
  - Truly digestible NDF (tdNDF) = 0.75 x (NDF - NDIP - Lignin) x [1 - (Lignin/(NDF - NDIP))^{0.667}]

Estimating TDN of Feeds

- Estimating TDN of Feeds
  - TDN_{1x} = tdNFC + tdCP + (tdFA x 2.25) + tdNDF - 7
  - For animal products (protein):
    TDN_{1x} = Cpdigest x CP + (tdFA x 2.25) + 0.98 x (100 - CP - ASH - EE) - 7
  - For fat sources
    TDN_{1x} = (EE x 0.1) + [Fatdigest x (EE x 0.9) x 2.25]

Calculating Energy in Feeds

- DE_{ix} Mcal/kg = (tdNFC/100) x 4.2 + (tdNDF/100) x 4.2 + (tdCP/100) x 5.6 + (FA/100) x 9.4 - 0.3
- Discount = [(TDN_{ix} - [(0.18 x TDN_{1x}) - 10.3] x Intake)/TDN_{ix}]
  - 0 to 4 % unit decline as TDN increases from 60 to 78%
- ME_{p} = [1.01 x DE_{p} (Mcal/kg) - 0.45]
Effect of Intake Level on TDN

Net Energy of Feeds

- $\text{NE}_{\text{LP}}$ (Mcal/kg) = \[0.703 \times \text{ME}_p (\text{Mcal/kg}) - 0.19\]
- $\text{NE}_M = 1.37 \text{ ME} - 0.138 \text{ ME}^2 + 0.0105 \text{ ME}^3 - 1.12$
- $\text{NE}_G = 1.42 \text{ ME} - 0.174 \text{ ME}^2 + 0.0122 \text{ ME}^3 - 1.65$