Dairy Nutrition

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Ruminants (ovine and bovine species) are foregut fiber fermenters with multicompartment stomachs.

Digestion occurs primarily in the reticulorumen.
Ruminants are earth’s dominant herbivores, due in part to the evolution within this group of a mechanism utilizing microorganisms to digest plant components not susceptible to attack by ruminant enzymes.” (Hungate 1975)

Thus, we care for two reasons:

1- Ruminants are earth’s dominant herbivores in natural ecosystems

2- Human food economy depends on ruminants
Ruminant digestion – diet is high in cellulose, but ruminants cannot produce cellulase

1- Food is first chewed, then enters the rumen

2- The rumen is a specialized chamber for microbial fermentation, containing many bacteria, protozoa and fungi

a. rumen environment is quite uniform - anaerobic, high Temp. (30-40 degrees C), pH (5.5-7), constant substrate supply.

b. in the rumen, cellulolytic bacteria and protozoa hydrolyze cellulose to produce cellobiose and glucose.
Ruminant digestion

These sugars are then fermented, producing volatile fatty acids (acetic, propionic, and butyric), CO$_2$ and CH$_4$

Food passes from the rumen into the reticulum, where it is formed into small portions called ‘cuds’
Cuds are regurgitated into the mouth where they are chewed again – ‘rumination’

These solids are now finely divided and very well mixed with saliva; they are swallowed again, but this time the material enters the abomasum, an organ more like a true stomach, where ‘true’ digestion begins and continues into the small and large intestine
Diagram of the rumen and gastrointestinal system of a cow, showing the route of passage of food.
Ruminant digestion

Overall fermentation reaction:
cellulose $\rightarrow$ acetate, propionate, butyrate, $\text{CO}_2$, $\text{CH}_4$, $\text{H}_2\text{O}$

three main products that benefit the animal:

1- Volatile fatty acids: acetate, propionate, butyrate
   these pass through the rumen wall and are absorbed
   propionate – used for carbohydrate biosynthesis
   acetate, butyrate – used for energy and fat biosynthesis

2- Microbial cells – contributes protein to ruminant’s diet –
   probably the main source of protein. Many rumen bacteria can
   use urea as a sole N source; often part of cattle feed to promote
   protein synthesis (cheap meat)

3- Heat – important to the ruminant’s thermoregulation
Rumen microorganisms
Microbiology of the Rumen

• Relative stable population for a given feed (substrate)

• Microorganisms adapted to rumen environment

• Mostly obligate anaerobes
  – Bacteria - $10^{10}$ to $10^{11}$ cells/ml
  – Protozoa - $10^{5}$ to $10^{6}$ cells/ml
  – Fungi - $10^{3}$ to $10^{5}$ zoospores/ml
Rumen microorganisms

1- Bacteria
bacterial populations: $10^9$ to $10^{11}$/ml

highly specialized bacterial community

all are obligate anaerobes
specific groups specialize in the degradation of cellulose, starch, hemicellulose, sugar, fatty acids, proteins, fats

some autotrophically produce methane, acetate

many different bacterial genera
Rumen microorganisms

Cellulolytic rumen bacteria:

*Bacteriodes succinogenes* and *Ruminococcus albus*

Methanogens: *Methanobacterium ruminantium* (many others)

Composition varies:

- among different ruminants
- among different parts of the world
- when diet changes
Bacterial Adhesion to Plant Tissues

1. Transport of bacteria to fibrous substrate

2. Initial nonspecific adhesion  
   Electrostatic, hydrophobic, ionic on cut or macerated surfaces

3. Specific adhesion to digestible tissue  
   ligands or adhesins on bacterial cell surface

4. Proliferation of attached bacteria  
   Allows for colonization of available surfaces
Adherence of mixed rumen bacteria to plant material.

Protuberances from cells probably are binding factors.
Benefits of Bacterial Attachment

• If attachment prevented or reduced, digestion of cellulose greatly reduced
• Brings enzymes and substrate together in a good mixed system
• Protects enzymes from proteases in the rumen
• Allows bacteria to colonize on the digestible surface of feed particles
• Retention in the rumen to prolong digestion
• Reduces predatory activity of protozoa
Cellulose Digesting Bacteria

Predominant:

*Ruminococcus flavefaciens*
- Gram+ve cocci, usually in chains
- Ferments cellulose, cellobiose \& glucose
- Produces acetic, formic, succinic, some lactic \& H$_2$

*Fibrobacter succinogenes*
- Gram–ve rod
- Ferments cellulose, cellobiose \& glucose
- Produces acetic, formic \& succinic

*Ruminococcus albus*
- Gram–ve cocci
- Ferments cellulose, cellobiose, usually not sugars
- Produces acetic, formic, lactic, ethanol \& H$_2$

strict anaerobes
Tolerate narrow pH range (pH 6 to 7)
Attach to feed particles
Cellulose Digesting Bacteria

Secondary:

*Eubacterium cellulosolvens*  Numbers usually low in rumen
  Gram–ve rod
  Ferments cellulose & soluble sugars
  Produces mostly lactic acid

*Butirivibrio fibrisolvens*  Several strains in rumen
  Gram–ve curved rod
  Ferments cellulose (slow) & starch
  Produces formic, butyric & lactic acids, ethanol & $\text{H}_2$

Strict anaerobes
Tolerate narrow pH range  (pH 6 to 7)
Attach to feed particles
Nutrient Requirements of Cellulose Digesters

- Carbohydrates (source of energy)
- Branched chain volatile fatty acids
  - Isobutyric, isovaleric, 2-methylbutyric
  Needed for:
  - Synthesis of branched chain amino acids
  - Synthesis of branched chain fatty acids (phospholipids)
- CO$_2$
- Minerals (PO$_4$, Mg, Ca, K, Na, probably other trace minerals)
- Nitrogen
  - Mostly NH$_3$ rather than amino acids
- Biotin is stimulatory in pure cultures
Added sugar was a source of readily available energy from 0 to 24 h. Subsequent drop in pH after 24 h limited the rate of cellulose digestion after 36 h.
Hemicellulose Digesting Bacteria

Butrivibrio fibrisolvens

Prevotella ruminicola
  Gram–ve non motile rod
  Digests starch, hemicellulose
  Produces succinic, formic, acetic and some strains propionic

Eubacterium ruminantium
  Gram+ve non motile rod
  Ferments hemicell., cellobiose, dextrins, maltose, glucose, fructose, lactose, sucrose and 5-carbon sugars
  Does not digest starch and cellulose
  Produces lactic, formic, acetic & butyric acids

Ruminococcus flavefaciens

Ruminococcus albus
## Digestion of Forage Hemicellulose

### Pure cultures

<table>
<thead>
<tr>
<th>Species</th>
<th>Pre bloom</th>
<th>Late bloom</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. fibrisolvens</td>
<td>35.4/34.1</td>
<td>27.4/27.0</td>
</tr>
<tr>
<td>P. ruminicola</td>
<td>33.6/33.9</td>
<td>23.6/20.6</td>
</tr>
<tr>
<td>R. flavefaciens</td>
<td>44.6/10.1</td>
<td>23.6/0</td>
</tr>
<tr>
<td>F. succinogenes</td>
<td>62.1/0</td>
<td>28.7/0</td>
</tr>
<tr>
<td>R. albus</td>
<td>50.1/26.9</td>
<td>31.6/7.4</td>
</tr>
</tbody>
</table>

**Degradation/Utilization %**
**Pectin Digesting Bacteria**

*Lachnospira multiparus*
- Mostly gram–ve motile curved rod
- Ferments pectin, glucose, fructose, cellobiose & sucrose
- Xylan, cellulose & starch not fermented
- Produces acetic, formic, lactic, ethanol & $\text{H}_2$

Treponemes
- Anaerobic spiral organisms
- Ferment pectin, arabinose, inulin and sucrose
- Produces acetic and formic acids

*B. fibrosolvens*

*P. ruminicola*

*R. flavefaciens and R. albus* can degrade pectins but not ferment the end products
# Digestion of Forage Pectin

## Pure cultures

<table>
<thead>
<tr>
<th></th>
<th>Alfalfa Prebloom</th>
<th>Alfalfa Late bloom</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. fibrisolvens</td>
<td>67.5/57.3</td>
<td>54.4/53.1</td>
</tr>
<tr>
<td>P. ruminicola D31d</td>
<td>31.3/29.1</td>
<td>29.3/24.1</td>
</tr>
<tr>
<td>P. ruminicola 23</td>
<td>36.7/36.6</td>
<td>29.5/27.3</td>
</tr>
<tr>
<td>R. flavefaciens</td>
<td>70.5/30.4</td>
<td>54.3/26.6</td>
</tr>
<tr>
<td>L. multiparus</td>
<td>62.9/50.4</td>
<td>56.6/45.8</td>
</tr>
</tbody>
</table>

**Degradation/Utilization %**
Starch Digesting Bacteria

*Streptococcus bovis*

- Gram+ve spherical to ovoid in shape
- Hydrolyzes starch and ferments glucose
- Produces lactic acid, acetic, formic & ethanol
  - 80 to 85% of CHO fermented converted to lactic acid
- Tolerates low pH <5.0 and does not require low oxidation-reduction potential
- Rapid growth at low pH
- Low numbers in the rumen of hay-fed animals & numbers remain low in grain adapted animals
- If too much starch is available to animals not adapted: pH drops, growth of *S. bovis* increases, production of lactic acid increased, further decrease in pH, loss of lactic acid utilizers (*Megasphaera elsdenii*), lactic acid accumulates, further decrease in pH, all resulting in acute lactic acidosis
Starch Digesting Bacteria

*Ruminobacter amylophilus*
Gram–ve non motile rod, some are coccoid to oval in shape
Ferments starch & maltose  Does not use glucose or cellobiose
Produces acetic, formic, succinic & ethanol

Nutritional interdependence
- Medium containing starch, glucose and cellobiose
- Inoculated with *R. amylophilus, M. elsdenii* & *R. albus*
  Initially only *R. amylophilus* grows but when growth stops
  cells undergo autolysis releasing amino acids
  *M. Elsdenii* requires branched chain amino acids can grow
  *M. Elsdenii* produces branched chain fatty acids required
  by *R. albus* that can now grow
Starch Digesting Bacteria

*Succinomonas amylolytica*
- Gram–ve motile rod
- Hydrolyzes starch and ferments dextrins, maltose & glucose
- Produces succinic acid and small amounts of acetic and propionic

*Selenomonas ruminantium*
- Gram–ve motile curved rod
- Hydrolyzes starch and ferments soluble CHO
- Produces lactic, acetic & propionic, formic, butyric & $\text{H}_2$
- Also produces an intracellular polysaccharide that is used when available energy is low

*B. fibrisolvens*

*P. ruminicola*
Sugar Utilizing Bacteria

*Succinivibrio dextrinosolvens*
- Gram –ve helicoidal rod
- Ferments sugars but does not hydrolyze starch, cellulose or xylans
- Produces succinic and acetic, formic & lactic

*Eubacterium ruminantium*
- Gram+ve non motile rod
- Ferments glucose, cellobiose and fructose
- Produces lactic, formic, acetic and butyric acids
Veillonella alcalescens  
Gram–ve coccus  
Does not ferment sugars but does ferment lactate  
Produces propionic and acetic acids

Megasphaera elsdenii  
Gram–ve coccus  
Ferments lactate, sugars, glycerol and some amino acids  
Produces propionic, acetic, butyric, valeric, caproic acids & H₂  
Increase in numbers during adaptation to grain
Methanogens

\[ \text{CO}_2 + 2 \text{H}_2 \rightarrow \text{CH}_4 + 2 \text{H}_2\text{O} \]

Formic acid

* Methanobrevibacter ruminantium
  - Gram+ve non motile coccobacilli
  - Requires a low oxidation-reduction potential

* Methanomicrobium mobile
  - Gram–ve rod
  - Uses formic, CO\(_2\) and H\(_2\)

* Methanosarcina barkeri

* Methanobacterium formicicum
  - Have been isolated from the rumen but thought to be of less importance
Acetogenic Bacteria

Reduce CO₂ at expense of hydrogen

\[ 2 \text{CO}_2 \rightarrow \text{CH}_3\text{COOH} + 2 \text{H}_2\text{O} \]

Bacteria present in rumen and hind gut of several species

Do not compete with methanogens for hydrogen
\[ \text{H}_2 \text{ threshold 100 times greater} \]
Only of significance if methanogens inhibited
If active would conserve energy loss from the fermentation

Fact they are present in the rumen indicates they might use other substrates
Rumen microorganisms

2- Protozoa

primarily ciliates
obligate anaerobes
$10^5$ to $10^6$ / ml
some degrade cellulose, starch, carbohydrates

Ruminant digests protozoa – thus, some protein contribution to ruminant’s diet probably easier for ruminant to digest than bacteria
Rumen Protozoa

Isotricha
Starch, glucose, fructose, pectin

Dasytricha
Starch, glucose, maltose, cellobiose

Entodinium
Starch, maltose
Less use of cellobiose, sucrose & glucose

Diplodinium
Starch, pectin, maltose, glucose, sucrose
Cellulose not always hydrolyzed

Epidinum
Starch, hemicellulose, cellobiose, sucrose, maltose
Cellulose digested

Ophryoscolex
Pectin, starch
Moderate digestion of cellulose
Role of Protozoa in the Rumen

- Digestion and fermentation
  - Carbohydrates and proteins
- Ingest bacteria and feed particles
- More of a digestive process.
- Engulf feed particles and digest CHO, proteins and fats.
- Produce volatile fatty acids, CO$_2$, H$_2$ & NH$_3$
- Make a type of starch (amylopectin) that is digested by the animal.
Rumen microorganisms

3- Fungi

Initially thought to be a flagellated protozoa.
Five genera of fungi have been found in the rumen:

- Neocallimastix
- Piromyces
- Caecomyces
- Orpinomyces
- Anaeromyces

Anaerobic flagellated organisms
Life cycle includes motile zoospores and non motile vegetative form
Zoospores attach to feed particles followed by encystment and germination
Counts range from $1.5 \times 10^3$ to $1.5 \times 10^6$ per g rumen contents
Fungi can degrade cellulose, starch, xylan, hemicellulose & pectin
Some evidence of esterases that free CHO from lignin
Ferments cellobiose, maltose, sucrose, glucose, fructose & xylose

Role of Rumen Fungi

Digestion of wheat straw leaves in pure culture

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>DM, %</td>
<td>45.2</td>
<td>42.3</td>
<td>30.1</td>
</tr>
<tr>
<td>Cellulose, %</td>
<td>58.1</td>
<td>50.4</td>
<td>39.4</td>
</tr>
<tr>
<td>Hemicellulose, %</td>
<td>52.3</td>
<td>55.0</td>
<td>39.6</td>
</tr>
<tr>
<td>Pectin, %</td>
<td>20.5</td>
<td>47.3</td>
<td>16.3</td>
</tr>
</tbody>
</table>

Role of the fungi not clearly established in mixed cultures with bacteria. Bacteria seem to inhibit the fungi.
## Composition of Rumen Microorganisms

<table>
<thead>
<tr>
<th></th>
<th>Bacteria</th>
<th>Protozoa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen, %</td>
<td>7.8</td>
<td>6.4</td>
</tr>
<tr>
<td>CHO %</td>
<td>15.5</td>
<td>38.1</td>
</tr>
<tr>
<td>Lipids, %</td>
<td>10.1</td>
<td>9.1</td>
</tr>
<tr>
<td>Ash, %</td>
<td>16.8</td>
<td>6.4</td>
</tr>
</tbody>
</table>
Feeds
Chemistry of Feed Dry Matter

1. Organic
   - Carbohydrates
     - Fiber (Cellulose, hemicellulose)
     - Pectin, fructans, β-glucans (NSP)
     - Starch
     - Free sugars
   - Lignin and other phenolics
   - Proteins (amino acids)
   - Lipids (sol. substances as vitamins)
   - DNA & RNA

2. Inorganic (Ash)
Carbohydrates

Importance
Make up 60% to 70% of diet
Major source of energy

1. Microbes
   Energy for microbes: Metabolism, Growth, Protein synthesis

2. Animal
   End products of the fermentation
   Digestible CHO escaping the rumen
Carbohydrates

Classification:

- Nonstructural (NSC)
  Cell contents – storage

- Structural (SC)
  Cell walls
# Plant Carbohydrates

## Cell Content
- Sugars
- Starches
- Fructans
- Organic acids

## Cell Wall
- Pectins
- β-glucans
- Hemicelluloses
- Cellulose

- Mammalian enzymes which digest starch and sucrose (limited in ruminants)

- Microbes digest the plant polysaccharides
Secondary cell wall would develop
Cellulose

cellulose
Pectins less in grass than legumes.
Hemicellulose greater in grass than legumes.
Hemicellulose and cellulose increase with maturity.
Lignin

• Not a carbohydrate – does not contain sugars
• Large phenolic three-dimensional polymers in secondary cell walls
• Attach with hemicellulose and pectins
• Not digested in the rumen
• Negative relationship usually observed between lignin and digestibility of Cell Walls
Feed Evaluation - Chemical

- Sample feed
  - Need representative sample

- Proximate analysis (Weende procedure)
  - Moisture - Residue is dry matter
    - Oven dry
      Volatile components will be lost
      Overheating causes reactions of carbohydrates with proteins and changes solubility of carbohydrates
    - Freeze dry
  
  - Organic matter
    - Burn at 550°C - Residue is ash
Feed Evaluation - Chemical

- Crude protein
  - Kjeldahl N x 6.25
- Ether extract
  - Lipids, waxes, pigments, fat soluble vitamins
  - Extract with ether or hexane
- Crude fiber
  - Cellulose, hemicellulose, lignin
  - Boil in dilute acid and then dilute alkali, dry, weigh, ash (Wt loss is crude fiber)
- Nitrogen-free extract
  Starch & Sugars + Other
  \[ \text{NFE} = 100 - (\text{moisture} + \text{ash} + \text{crude fiber} + \text{protein} + \text{ether extract}) \]

Acid and sodium hydroxide used for crude fiber dissolve some cellulose, hemicellulose and lignin in cell walls which then are included in NFE.
CHO analysis in feeds

- Soluble (NFE) and non-soluble CHO (crude fibre).

- Weende method for CF determination.

-Van Soest determination or fractionation of CF.
Fiber analysis - Detergent solutions
(Van Soest)

Forage

(Neutral detergent solution, pH 7)

Soluble
Cell contents
Starch & Sugars
(Pectin, β-glucans & fructans)
Soluble proteins
Lipids
Organic acids

Insoluble
Cell walls (NDF)
Hemicellulose
Cellulose
Lignin
Insoluble proteins
Insoluble minerals (dirt)
Neutral Detergent Soluble (NDS)

- 98% potentially digestible in the rumen
- Rapidly fermented in the rumen
- Diverse group and not easily measured directly in feeds
- Not all digested by mammalian enzymes
Neutral Detergent Soluble (NDS)

Pectins
Galactans
β-glucans
Fructans

Not digested by mammalian enzymes
Rapidly fermented in the rumen (Sol. fibers)
  • 20 to 40% per hour
  • Produces mostly acetic acid – no lactate
  • Some byproduct feeds high in these soluble fibers will be more rapidly fermented than predicted from starch and free sugars
Fiber analysis - NDF

Cell walls
Hemicellulose
Cellulose
Lignin
Insoluble proteins
Insoluble minerals (dirt)
Fiber analysis - Detergent solutions (Van Soest)

NDF (Insoluble residue)
(Acid detergent solution, CTAB)

Soluble
Hemicellulose
Protein

Insoluble (ADF)
Cellulose
Lignin
Insoluble minerals (soil)
Acid detergent insol N (ADIN)

ADIN is unavailable protein - not digested in rumen or intestines
Acid detergent fiber (ADF)

Or

Boiling with

- $\text{H}_2\text{SO}_4 \ (72\%)$
  - Cellulose dissolve
  - Lignin + Ash
  - Ashing
  - Ash

Boiling with

- $\text{KMnO}_4 \ (\text{pH} \ 3)$
  - Cellulose
  - Ash
  - Ashing
  - Ash
Acid detergent fiber (ADF) was the best chemical predictor of *in vivo* DDM for both corn and sorghum silages.

ADF concentration accounted for 80% of the variation in digestibility of sorghum silages and 61% of the variation in digestibility of corn silages.

More than half of the variation in digestibility of these silages was also accounted for by calculated cellulose and by crude fiber (CF) concentration.
- Permanganate lignin accounted for 74% of the variation in digestibility of sorghum silages but only 23% of the variation in corn silage digestibility.

- Inclusion of crude protein concentration did not improve the digestibility prediction potential of ADF, CF, or the other chemical methods.
Carbohydrate Fractions in Feeds
Carbohydrate Fractions in Feeds

- Alfalfa hay
- Alfalfa silage
- Citrus pulp
- Soy hulls
- Wheat mids

% of DM

- NDF
- Organic acids
- Sugars
- Starch
- Sol fiber
Nutrition of Lactating Cows

• To provide lactating dairy cows adequate nutrition is challenging and complex
Nutrition of Lactating Cows

Period post-calving most important

- Hard to provide adequate nutrition
  - Milk yield is high
  - Intake is limited
    - Cow uses her body fat and protein to provide for the nutrients not taken in by her daily ration
  = Negative Energy Balance
Energy Supply to Dairy cattle

VFA 70%
Microbial cells 10%
Digestible unfermented feed 20%

Concentration of VFA in the rumen = 50 to 125 µM/ml
# Amino Acid Supply to Dairy Cattle

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein in microbial mass</td>
<td>65%</td>
</tr>
<tr>
<td>Undegraded feed proteins</td>
<td>30%</td>
</tr>
<tr>
<td>Recycled endogenous proteins</td>
<td>5%</td>
</tr>
</tbody>
</table>

Amino acid balance of microbial mass is superior to that from undegraded feed proteins when corn-based diets are fed.
Nutrition of Lactating Cows

• Cows nutritional needs vary during different stages of her production cycle
  – Optimize milk yield
  – Prevent metabolic disorders

• Water and Energy are the limiting nutrients in a dairy ration
Nutrition of Lactating Cows

- **Body Condition Score**
  - Used to monitor nutrition, reproduction, and health programs
Nutrition of Lactating Cows

• **Body Condition Score**
  – May help to group cows according to BCS and lactation stage
The Transition Cow
Nutrition of Transition Cows

Transition period: the time comprising 3-4 weeks before to 2-4 weeks after calving.

Proper management of dry cows should be thought of as an investment in the next lactation.

One of the major nutritional objectives should be to control clinical milk fever, subclinical hypocalcemia, metritis and retained placenta.

Mineral nutrition is key: as mineral concentrations in cells and tissues need to be maintained within narrow limits. Deficiencies and excesses can lead to health/metabolic disorders and reduced performance. Major economic impact.
The Science of Dietary Cation-Anion Difference (DCAD)

- DCAD is expressed as the difference between cations and anions: (Na+K) - (Cl+S)

- Most dry cow rations have a DCAD of +50 to +300 mEq/kg

**Cations:** positively charged electrolytes: Na, K, Ca, Mg

**Anions:** negatively charged electrolytes: Cl, S, P

- Strongest ionic effect on acid-base balance is: K, Na, Cl, S

Calculation in Milliequivalents (mEq)

- Predicts whether a diet will evoke an acidic or alkaline response
The Science of Dietary Cation-Anion Difference (DCAD)

- Introduction of cations (K, Na) into the diet creates a mild metabolic alkalosis – alkaline diet.

- Readily absorbable dietary cations (K, Na) alkalinize the blood and interfere with parathyroid hormone function resulting in hypocalcemia.

- Metabolic alkalosis reduces tissue responsiveness in both skeletal and renal tissue to PTH, resulting in reduced conversion of 1,25-(OH)D₃ to the active form 1,25-dihydroxycholecalciferol or vitamin D₃, disrupting calcium homeostasis (Goff & Horst 1997).
The Science of Dietary Cation-Anion Difference (DCAD)

- Introduction of anions (Cl, S) into the diet creates a mild metabolic acidosis – acidic diet.

- Inflow of anions: bone & kidney release of CO$_3$ (buffer), bone Ca & P mobilization, Ca pooling on bone surface and increased blood Ca levels.

- Metabolic acidosis stimulates PTH, vitamin D synthesis and bone Ca mobilization.

- Decreasing the DCAD during the last 3 weeks prior to parturition alters acid-base status improving Ca homeostasis by increasing PTH responsiveness and markedly reducing hypocalcemia (Moore 2000, Goff 2003, Joyce 1997).
The Science of Dietary Cation-Anion Difference (DCAD)

-A DCAD of -15 meq/100 g is usually effective in preventing most cases of hypocalcemia and other disorders (Moore 1997).

- Water quality and water DCAD are very important

- Urine pH helps to determine the right level of anions to add to the diet.

- Target Urine pH; 6.2 to 6.8

- Do not go below a urine pH of 5.3 as you may cause metabolic acidosis
Thank You !!