What are the Five Most Important Things to Measure in Hay Crops?

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Introduction

- Most important measurements affect either
  - Economic value
  - Nutritional value in meeting animal requirements

- Selecting most important is not simple
  - Type of animal fed
  - Proportion in the total diet
  - Nutrient that is most limiting
Introduction

- Will restrict discussion to hay crops fed to dairy cows
- Hay crops fed at significant proportion in the ration (>20%)
- Evaluate small proportion (<10%) of hay crops differently
  - High quality hay crops that are fed as “top-dress” or “cow candy” to stimulate extra intake
  - Straw fed to improve rumen function
Introduction

- Hay crops (>20% of the diet) are fed primarily as a source of energy
  - Therefore measurements affecting feed energy value are most important
- Hay crops also have value as fiber or "roughage" that optimizes ruminal fermentation and fiber digestion
- Crude protein (CP) also adds value in some circumstances
Objectives

- Identify five (or more) analytical measurements that are important in evaluating hay crops for dairy cows
- Describe the rationale for selecting each measurement
- Discuss future measurements that may change what is most important
Dry Matter (DM)

- DM is the non-water fraction of a feed that contains required nutrients
  - Although water is a nutrient, in feeds it provides no value that cannot be supplied by drinking water

- DM is measured by drying feeds in an oven
  - Really measures loss of weight during drying
  - Volatile acids, sugars, alcohols, urea, bicarbonate can also disappear
  - There are methods for measuring only $\text{H}_2\text{O}$
Dry Matter (DM)

- We buy, sell and feed on an “as-is” basis that contains the water in the feed
- But only the DM in feeds contains the valuable nutrients
  - We have to adjust economic value based on the DM
  - One ton of hay with 92% DM contains 1840 lb of DM
  - One ton of hay with 88% DM contains 1760 lb of DM
  - The 80 lb difference will feed several cows/d
Dry Matter (DM)

- Nutrients and price are often expressed on some type of “DM basis” to standardize the dilution of water in the feed
  - 100% DM – most common and removes all water – called the “DM basis”
  - 90% DM – roughly equivalent to “air-dry” hay or concentrates
    - A hay with 40% NDF on a DM basis contains 36% NDF on a 90% DM basis
    - Not generally useful – recommend 100% DM basis
Ash
(Total Mineral Matter)

- Ash contributes no energy value to hay crops (forages are fed to supply energy)
- Ash is inorganic material in feeds
  - Only a small portion is minerals that are required by animals
- Ash consists of minerals in plants
  - Alfalfa contains 9-11% ash
  - Grasses contain 7-9% ash
- Ash also comes from soil contamination
Ash (Total Mineral Matter)

- Prediction equations based on fiber account for part of the effect of ash on energy values
  - Leg: $\text{NEL}_{3X} = 2.323 - 0.0216 \times (\%\text{NDF})$
  - Grass: $\text{NEL}_{3X} = 2.860 - 0.0262 \times (\%\text{NDF})$
  - Lower intercept for Leg (2.323) reflects the higher ash content of legumes
- These equations only partly adjust NEL for soil contamination in NDF
Organic Matter (OM) (OM = 100 – Ash)

- Although ash is measured, it is OM that is important
- Only OM contributes energy to the cow
- Digestible OM (dOM) as a % of DM is highly correlated with energy value of feeds
  - European feed evaluation systems have used dOM “d value” for many years
  - We should consider this direct approach
    - Only limitation is accounting for high-energy fat in feeds – not important in hay crops
Fiber is the primary measurement for hay crops
- It measures the component in feeds that is the most difficult to digest
- Fiber is a nutritional concept we try to measure chemically
  - For ruminants, fiber is the slowly or incompletely digested matter in feeds that occupies space in the gastrointestinal tract (insoluble fiber)
  - Soluble fiber is important in simple-stomached animals, but is easily fermented in the rumen
Rumen Is Designed To Slow Passage of Fiber

Cow’s Rumen is an Engineering Marvel!

- Cows swallow large particles
- Large particles float to the top of the rumen and are regurgitated and rechewed
- Rumination reduces particle size and digestion increases density
- After rumination, dense small particles sink into the liquid and pass out
Amiylase-treated NDF (aNDF)

- There are several published “NDF” methods
  - Original NDF (sulfite & no amylase)
  - ND Residue = NDR (amylase & no sulfite)
  - aNDF = (amylase + sulfite)

- Soil contamination affects aNDF results
  - Soil is not soluble in neutral detergent
    - Can increase aNDF by 2 to 5 %-units
  - Recommend using aNDFoM (ash-free aNDF)
    - Important when aNDF is limiting in the ration
    - Corrects Non-fiber Carbohydrate (NFC) calculation
      \[ NFC = 100 - \text{ash} - \text{CP} - \text{Fat} - \ \text{aNDFoM} \]
Amylase-treated NDF (aNDF)

- **Reasons why aNDF is important**
  - Can limit intake in early lactation
  - Affects total DM or OM digestibility
  - Defines the minimum fiber requirement

- **Cow production**
  - Assume Availability is 100% (clean bunk ??)
  - Metabolic efficiency is relatively constant
  - Intake X Digestibility = 75 to 85% of variation in cow productivity = best index of feed nutritive value
    - NVI => RFV = Intake (~ NDF) X Digestibility (~ ADF)
    - Index concept is not bad – Predictions of factors need improvement
Amylase-treated NDF (aNDF)

- Intake regulation in animals – aNDF affects intake
  - When fed high-energy, low-fiber diets, animals eat to meet their energy demand
  - When fed low-energy, high-fiber diets, animals eat to the limit of their fill (fiber processing capacity)

- Mertens observed that cows maximize production when eating 1.2% of BW/d as NDF
  - As NDF content goes up, intake goes down
  - Source of the RFV equation using NDF

- Too much fiber
  - Lowers intake and digestibility
  - Reduces energy intake and animal performance
Amylase-treated NDF (aNDF)

- aNDF determines total digestibility
- Partitions feeds into fractions with distinctly different digestibility (Van Soest, 1967)
  - Neutral detergent fiber (aNDF)
    - True digestibility of aNDF (NDFD) is incomplete
    - Digestibility is variable and must be measured
  - Neutral detergent solubles (NDS = 100 – NDF)
    - .98 true digestibility
    - 12.9% endogenous loss per unit of DMI
    - Constant across most feeds when fed to animals at maintenance levels of intake (1X)
Amylase-treated NDF (aNDF)

- Simple summative equation can predict DM digestibility (Van Soest, 1967)
  - $DMD_{1X} = \text{digNDF} + \text{digNDS} - \text{Endog.Loss}$
  - $DMD_{1X} = \text{dNDF} + \text{dNDS} - \text{EL}$
  - $DMD_{1X} = \text{NDFD} \times \text{NDF} + 0.98 \times \text{NDS} - 12.9$
    - Because $\text{NDS} = 100 - \text{NDF}$
  - $DMD_{1X} \% = \text{NDFD} \times \text{NDF} + 0.98 \times [100 - \text{NDF}] - 12.9$

- DM digestibility is primarily a function of NDF and NDFD
Amylase-treated NDF (aNDF)

- DM digestibility is a function of NDF and NDFD
  - NDFD is not a constant, so simple equations are flawed
    - TDN$_{1X}$ = 86.2 – 0.513*NDF
    - TDN$_{1X}$ = 84.2 – 0.598*ADF
    - ADF equations are generally better than NDF equations
    - ADF digestibility is lower and more constant than NDFD
  - NDFD is a function of plant cutting, maturity and lignin
Amylase-treated NDF (aNDF)

- Variability in NDFD indicates why direct measurement of in vitro NDF digestibility (IVNDFD) is important
  - All forage characteristics (including lignin) that affect microbial fermentation are assessed
- In vitro digestibility requires a source of ruminal fluid
  - Donors vary (diet and time of collection)
- IV methods vary
  - Size of grind of sample
  - Time of fermentation
  - Fermentation vessel
  - Buffers and extraction methods
## Prediction of digestible DM

(dDM = NDFD * NDF + .98 * NDS – 12.9)

<table>
<thead>
<tr>
<th>Component</th>
<th>Corn Grain</th>
<th>Corn Silage</th>
<th>Grass Hay</th>
<th>Cereal Silage</th>
<th>Alfalfa Hay</th>
</tr>
</thead>
<tbody>
<tr>
<td>aNDF, % of DM</td>
<td>9.0</td>
<td>45.0</td>
<td>50.0</td>
<td>55.0</td>
<td>40.0</td>
</tr>
<tr>
<td>Fractional NDFD</td>
<td>0.50</td>
<td>0.58</td>
<td>0.64</td>
<td>0.58</td>
<td>0.46</td>
</tr>
<tr>
<td>Digestible NDF, % of DM</td>
<td>4.5</td>
<td>26.2</td>
<td>32.1</td>
<td>31.6</td>
<td>18.6</td>
</tr>
<tr>
<td>NDS, % of DM</td>
<td>91.0</td>
<td>55.0</td>
<td>50.0</td>
<td>45.0</td>
<td>60.0</td>
</tr>
<tr>
<td>Digestible NDS, % of DM</td>
<td>89.2</td>
<td>53.9</td>
<td>49.0</td>
<td>44.1</td>
<td>58.8</td>
</tr>
<tr>
<td>True dDM</td>
<td>93.7</td>
<td>80.1</td>
<td>81.1</td>
<td>75.7</td>
<td>77.4</td>
</tr>
<tr>
<td>Endogenous DM loss</td>
<td>-12.9</td>
<td>-12.9</td>
<td>-12.9</td>
<td>-12.9</td>
<td>-12.9</td>
</tr>
<tr>
<td>Apparent dDM&lt;sub&gt;1x&lt;/sub&gt;</td>
<td>80.8</td>
<td>67.2</td>
<td>68.2</td>
<td>62.8</td>
<td>64.5</td>
</tr>
</tbody>
</table>
Amylase-treated NDF (aNDF)

- aNDF affects ruminal function
- Too little fiber – minimum fiber requirement
  - Increases chronic acidosis – impairs ruminal function
  - May promote fattening – propionic acid production
  - Low fiber diets can be fed for short periods (90-120 days) – feedlot diets are terminal!
Physically effective NDF (peNDF)

- Minimum fiber effect is related to both chemically measured aNDF and its physical form (particle size)
  - Fiber’s “chewing effect” or “ruminal mat effect”
- Finely ground fiber loses its ability to meet the minimum fiber requirement
  - Particles passing through a 1.18-mm sieve appear in the feces and do not stimulate chewing (1.18 mm is the width of particles)
  - peNDF is the fiber in the diet that is retained on a 1.18-mm sieve (vigorous vertical shaking)
Energy Values or Digestibility

- Estimated energy values of feeds are needed by most ration formulation systems
  -digestible DM (dDM)
  -digestible OM (dOM)
  -Total Digestible Nutrients (TDN)
  -Net Energy of Lactation (NEL)

- Typically calculated from fiber contents
  - $\text{TDN}_{1X} = 86.2 - 0.513 \times \text{NDF}$
  - $\text{TDN}_{1X} = 84.2 - 0.598 \times \text{ADF}$
Energy Values or Digestibility

- Equations come from a variety of sources, many of which are unknown and most are quite old (generated 30-50 years ago).
- Energy values generated from a single fiber analyses contain no new information.
- Prefer that calculated values not be included in hay crop analysis reports – aren’t really analytical results!!
Energy Values or Digestibility

- Summative equations using aNDF and IVNDFD combine two measurements and provide additional information.
- In vitro dOM and dDM provide direct measurements of digestibility that provides additional information.
- An index combining intake estimated from NDF (like in RFV) and direct measurement of dOM would be the best indicator of animal productivity.
  - NDF and dOM provide relatively independent bits of nutritional information.
Crude Protein (CP)

- When high quality and relatively economical sources of protein are available, the CP of hay crops has limited economic or nutritional value
  - Amino acid quality of hay crop protein is not as high as protein supplements
  - True digestibility of protein is high (.90-.98)
  - CP in hay is less soluble than in silage
  - Dehydrated and pelleted hay crops are less soluble than hays
Crude Protein (CP)

- Heated proteins can complex with carbohydrates forming Maillard products
  - Heating in stacks when hay moisture is too high (>20%)
  - Dehydrating hay crops
  - Pelleting and cubing hay crops

- Toasted brown hay crops with sweet caramel or tobacco aroma should be tested for heat-damaged protein
  - Acid detergent Insoluble CP (ADICP)
Digestion Kinetics
Measurements of the Future

- Digestion has 3 components
  - Lag phase
  - Rate phase (of the potentially digestible fraction)
  - Asymptote or plateau phases determines the maximal extent of digestion and Indigestible fiber
Take-Home Message
Most Important Measurements

- DM
- Ash / OM
- ANDF or ANDFom (NDS or NDSom)
  - pNDF – physical particle size measurement
- Digestibility
  - IVNDFD – use with summative equation
  - dOM measured directly by in vitro methods
  - Index of intake X digestibility
- CP – ADICP and soluble CP
- Future of hay crop analysis is digestion kinetics
Factors Influencing NDF Digestibility: Intrinsic Plant and Feed Characteristics

Questions?

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Amylase-treated NDF (aNDF)

- aNDF indicates the space (volume) occupied that limits intake by fill
- Fiber particles are hollow – rigid plant cell wall occupies more space than its mass indicates
  Van Soest (1994) hotel theory for the filling effect of fiber

© micro.magnet.fsu.edu/cells/plantcell.html
Amylase-treated NDF (aNDF)

- Fiber is defined by the method
  - Chemical method
    - Crude fiber (CF) – cellulose + some lignin
    - Acid Detergent Fiber (ADF) – cellulose + lignin
    - Neutral Detergent Fiber (NDF) = insoluble fiber contains hemicellulose + cellulose + lignin
  - Enzymatic Methods
    - Total Dietary Fiber = soluble + insoluble fiber
NDF-Energy Intake System
Intake and Digestibility Effects of aNDF

![Graph showing the relationship between DM Intake (% BW/d) and Ration NDF (% DM). The graph includes zones for too little fiber, feasible ration, and too much fiber. There are markers for different feed intake levels: 20 kg FCM/d, 30 kg FCM/d, 40 kg FCM/d, and 50 kg FCM/d.]