A. Definition of Forage Quality

1. Importance of Understanding Forage Quality of Alfalfa

2. Plant-Animal Complex

Describe Quality of Alfalfa Hay

- Forage Quality Testing
- Intake
- Digestibility
- Efficiency
- Anti-quality Factors

Potential Intake

Digestibility

Efficiency

Anti-quality factors
3. **Routine Analytical Test Terms**

   a. **Dry matter (DM)** is the percentage of feed that is not water. Hay and other feeds must be expressed on a dry matter basis to determine if a daily ration meets the animal's nutrient requirements.

   b. **Moisture** is the percentage of the sample that is water.

   c. **Crude protein (CP)** is determined by measuring total nitrogen in a sample and multiplying by 6.25. CP is a mixture of true protein and non-protein nitrogen.

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**Fig. 2 Laboratory Apparatus for Fiber Analysis**

[Diagram of Laboratory Apparatus for Fiber Analysis]

- Cold water line
- Glass reflux condenser
- Ceramic plates with heating coil
- Refluxing Apparatus
- Filtering Manifold
- Hot water
- 50 ml sintered glass crucibles
- Vacuum line
d. **Neutral detergent fiber (NDF)** is the percentage of fiber in a forage sample which is not soluble in neutral detergent solution. It is the residue left after boiling in neutral detergent solution. It is called aNDF if amylase and sodium sulfite are used during the extraction (this is a recommended procedure). NDF in alfalfa represents the indigestible and slowly digestible components in plant cell walls (cellulose, hemicellulose, lignin, and ash). It includes acid detergent fiber (except pectin) plus hemicellulose. NDF represents the cell wall and is only partially digestible by animals. 100 - NDF equals cell solubles which are highly digestible by animals. NDF is inversely related to voluntary intake; as NDF increases intake declines.

![Neutral detergent fiber analysis](image)

**Fig. 3** Neutral detergent fiber analysis

- captures ...
- cellulose
- hemicellulose
- lignin
- acid insoluble ash
- cutin
- cell solubles
- sugars
- protein
- starch
- NPN
- fat
- pectin

e. **Acid detergent fiber (ADF)** is the percentage of fiber in a forage sample which is insoluble in a weak acid. It is the residue remaining after boiling a forage sample acid detergent solution. ADF contains cellulose, lignin and silica, but not hemicellulose. It often is used to calculate digestibility, TDN and/or NE\textsubscript{L}.

![Acid detergent fiber analysis](image)

**Fig. 4** Acid detergent fiber analysis

- captures ...
- cellulose
- lignin
- acid insoluble ash
- cutin
- cell solubles
- hemicellulose

f. **Acid detergent lignin (ADL)** is the percentage of plant material which is insoluble in 72 percent sulfuric acid. This analysis is performed sequentially on ADF residue. Treatment with 72 % sulfuric acid dissolves cellulose. Ashing the residue will determine the crude lignin fraction including cutin. Permanganate lignin procedure separates cutin and lignin. Lignin reduces digestibility and has been used to predict digestibility.

![Acid detergent lignin analysis](image)

**Fig. 5** Acid detergent lignin analysis

- captures ...
- cellulose
- lignin
- acid insoluble ash
- cutin
- cell solubles
- hemicellulose

f. **Acid detergent insoluble nitrogen (ADIN)** is nitrogen in acid detergent fiber residue. ADIN greater than 15 % of nitrogen is an indication of heat damage. Formation of ADIN is also called non-enzymatic browning (because hay or silage turns brown) or the Maillard reaction. Should be expressed as a percent of the dry matter.
Calcium (Ca) and Phosphorus (P) are minerals analyzed by many analytical techniques including atomic adsorption, flame photometry, and plasma emission spectrometry are used to estimate Ca:P ration in alfalfa. Neither test estimates the mineral's availability within the animal.

4. Routine Predicted Test Terms

a. Digestible dry matter (DMD) is the portion of the dry matter in a feed that is digested by animals at a specified level of intake. Called in vivo DMD if determined by feeding animals in a digestion trial. There is no laboratory method for measuring DMD directly; it is often estimated by measuring in vitro digestibility, in situ digestibility, near infrared reflectance spectroscopy, or calculated from % ADF. National alfalfa hay quality standards established in 1978 recommended the following equation:

\[
\text{% DMD} = 88.9 - (\% \text{ ADF} \times 0.779)
\]

b. Dry matter intake (DMI) is an estimate of the relative amount of forage an animal will eat when only forage is fed. DMI is determined from NDF by the following equation:

\[
\text{DMI as a % of body weight} = \frac{120}{\text{Forage NDF (of DM)}}
\]

NDF of 40% = _____% of body weight

3% body weight for 1200 lb cow is _______ lb predicted voluntary forage intake

d. Net energyL (lactation) (NE_L) is a more comprehensive measure of energy than TDN. An estimate of the energy value of a feed used for maintenance plus milk production during lactation and for maintenance plus the last two months of gestation for dry, pregnant cows. Energy is expressed megacalories (Mcal) per 100 pounds of feed DM. NE_L is used to formulate energy needs in dairy cattle diets. NE_L is calculated from TDN.

e. Total Digestible Nutrients (TDN) is the sum of crude protein, fat (multiplied by 2.25), non-structural carbohydrates, and digestible NDF.

\[
\text{TDN} = \text{NFC} \times 0.98 + \text{CP} \times 0.93 + \text{FA} \times 0.97 \times 2.25 + 0.75 \times \left(\frac{\text{NDF} \times \text{IVNDFD}}{100}\right) - 7
\]

TDN is often estimated by calculation from ADF. The formulas for Calculating TDN vary by region and nutritionist, see tables 1 to 5. Equations cited in the National Forage Testing Association Forage Testing Manual.

e. Relative feed value (RFV) is an index used to rank cool season grass and legume forages based on combining digestibility and intake potential. Calculated from ADF and NDF. The higher the RFV, the better the quality. It is used to compare varieties, match hay/silage inventories to animals, and to market hay.

\[
\text{RFV index} = \frac{(\text{Intake potential} \times \text{Digestible Dry Matter})}{\text{Constant}}
\]

\[
\text{RFV index} = \left(\frac{120}{\text{NDF}}\right) \times \left(88.9 - (0.779 \times \text{ADF})\right) / 1.29
\]
f. **Relative Forage Quality Index (RFQ).** Relative forage quality index replaces RFV index as the forage quality index, ranking forages based on potential digestible dry matter intake (RFQ_{legume}, legume-grass mixtures and RFQ_{grass}). Prediction of TDN via a summative equation replaces the prediction of DDM from % ADF.

\[
RFQ \text{ index} = \frac{(d\text{Intake Potential} \times d\text{TDN})}{\text{Constant}}
\]

\[
RFQ = (\text{DMI, % of BW}) \times (\text{TDN, % of DM})/1.23
\]

5. **New Test Terms**

a. **Digestible Neutral Detergent Fiber (dNDF)** is the portion of the neutral detergent fiber digested by animals at a specified level of feed intake. The dNDF of feeds may be determined by *in vivo* feeding trials or estimated by lignin analysis, *in vitro* or *in situ* digestibility, or by near infrared reflectance spectroscopy analysis. dNDF is expressed as a percent of dry matter. NDFD is a calculated value expressing dNDF as a percent of NDF content.

b. **In situ Digestibility** is digestibility determined by incubation of a ground alfalfa sample in a porous nylon bag within rumen of an animal for a fixed time period.

c. **Rumen Undegraded Protein.** That portion of the protein not digested in the rumen. While often called *bypass protein, escape protein,* or *undegraded protein. Rumen undegraded protein* is the preferred term.

d. **Total nonstructural carbohydrates (TNC)** is a measure of the starch and sugar in alfalfa. It has a lower value than nonfibrous carbohydrates because NFC contains compounds other than starch and sugars.

e. **Rumen Degraded Protein.** That portion of total protein that is degraded to ammonia in the rumen.

f. **Non-fibrous carbohydrate (NFC)** is an estimate of the rapidly available carbohydrates in alfalfa (primarily starch and sugars). This value is calculated from one of the following equations: 
\[
\text{NFC} = 100\% - (\text{CP}\% + \text{NDF}\% + \text{EE}\% + \text{Ash}\%) \text{ or if corrected for NDFCP, NFC} = 100\% - (\text{CP} + (\text{NDF} - \text{NDFCP}) + \text{EE} + \text{Ash}).
\]

g. **Milk per acre and milk per ton** are estimated from Excel 5.0 spreadsheet called MILK2000, which estimates milk per ton of forage dry matter as a forage quality index, Undersander et al. 1993. MILK2000 uses forage analyses (crude protein, NDF, *in vitro* NDF digestibility, starch, and non-fiber carbohydrate) to estimate energy content using a modification of the NRC (2001) summative approach and DM intake from NDF (Mertens, 1978) and *in vitro* NDF digestibility (Oba and Allen, 1999) to predict milk production per ton of forage DM. Forage dry matter yield multiplied times milk per ton of forage dry matter provides an estimate of milk produced per acre. Consult [http://www.uwex.edu/ces/forage/pubs/milk2000.htm](http://www.uwex.edu/ces/forage/pubs/milk2000.htm).
B. Application of Fiber Tests

Plant fiber, mostly cell-wall material, provides structure, rigidity, and protection for plants. It is not digested by mammalian enzymes, but can be partially digested by rumen microorganisms. The fiber and non fiber (cell solubles) composition of mid bloom alfalfa is shown in Fig. 5. The cell wall portion of this alfalfa sample contains cellulose (26%), hemicellulose (11%) and lignin (9%). The cell wall is determined by and NDF test (46%). Acid detergent fiber contains cellulose and lignin. Hemicellulose equals NDF-ADF (46-35 = 11%). These complex carbohydrates in the cell wall are only partially digested by animals; and, the ADF test is the best predictor of digestibility. The remaining part of the sample, 100% - NDF%, is cell solubles (100 - 42 = 58%).

Fig. 5  **Fiber composition of mid-bloom alfalfa hay.**

![Fiber composition of mid-bloom alfalfa hay](image)

Alfalfa Grass Composition

Fig. 6  **Fiber Composition: Alfalfa vs Orchardgrass**

![Fiber Composition: Alfalfa vs Orchardgrass](image)
Table 1. Prediction Equations from Midwest

<table>
<thead>
<tr>
<th>Forage Type</th>
<th>Equation</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legume and Grass</td>
<td>%DDM = 88.9 - (0.779 x ADF)</td>
<td>Rohweder, Barnes and Jorgensen, J. Anim. Sci. 68:403</td>
</tr>
<tr>
<td>Corn Silage</td>
<td>%TDN = 87.84 - (.70 x ADF)</td>
<td>Schmidt et al., Agron. J. 68:403</td>
</tr>
<tr>
<td>Shelled Corn</td>
<td>%TDN = 92.22 - (1.535 x ADF)</td>
<td>Pennsylvania State</td>
</tr>
<tr>
<td></td>
<td>NEL (Mcal/lb) = 0.905 - (0.0026 x ADF)</td>
<td>Source: NRC, Dairy Update, 1989</td>
</tr>
<tr>
<td>TDN conversion to NEL</td>
<td>NEL (Mcal/lb) = (TDN x 0.01114) - 0.054</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Prediction equations from Pennsylvania State

<table>
<thead>
<tr>
<th>Forage Type</th>
<th>Equation</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legumes</td>
<td>%TDN = 4.898 + (89.796 x NE\textsubscript{L})</td>
<td>Pennsylvania State</td>
</tr>
<tr>
<td></td>
<td>ENE (Mcal/100 lb) = NE\textsubscript{L} x 82.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NE\textsubscript{L} (Mcal/lb) = 1.044 - (0.0119 x ADF)</td>
<td></td>
</tr>
<tr>
<td>Mixed Forages</td>
<td>%TDN = 4.898 + (89.796 x NE\textsubscript{L})</td>
<td>Pennsylvania State</td>
</tr>
<tr>
<td></td>
<td>ENE (Mcal/100 lb) = NE\textsubscript{L} x 82.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NE\textsubscript{L} (Mcal/lb) = 1.0876 - (0.0127 x ADF)</td>
<td></td>
</tr>
<tr>
<td>Grasses</td>
<td>%TDN = 4.898 + (89.796 x NE\textsubscript{L})</td>
<td>Pennsylvania State</td>
</tr>
<tr>
<td></td>
<td>ENE (Mcal/100 lb) = NE\textsubscript{L} x 82.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NE\textsubscript{L} (Mcal/lb) = 1.0876 - (0.0127 x ADF)</td>
<td></td>
</tr>
<tr>
<td>Corn Silage</td>
<td>%TDN = 31.4 + (53.1 x NE\textsubscript{L})</td>
<td>Pennsylvania State</td>
</tr>
<tr>
<td></td>
<td>ENE (Mcal/100 lb) = NE\textsubscript{L} x 82.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NE\textsubscript{L} (Mcal/lb) = 1.044 - (0.0124 x ADF)</td>
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<tr>
<td>Sorghum, Small Grain Forages</td>
<td>%TDN = 4.898 + (89.796 x NE\textsubscript{L})</td>
<td>Pennsylvania State</td>
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<td>ENE (Mcal/100 lb) = NE\textsubscript{L} x 82.6</td>
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<tr>
<td></td>
<td>NE\textsubscript{L} (Mcal/lb) = 0.7936 - (0.00344 x ADF)</td>
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</tbody>
</table>

\(\text{NE}_L\) (Mcal/lb) = \(\text{TDN} \times 0.01114\) - 0.054

### Table 3. Equations from Western Region

**Alfalfa**

\[
\%\text{TDN} = 82.38 - (0.7515 \times \text{ADF}) \\
\text{NEL (Mcal/lb)} = 0.8611 - (0.00835 \times \text{ADF})
\]


### Table 5. Prediction equations from D.R. Mertens (personal communication)

**Legumes**

\[
\%\text{TDN}_{m} = 86.2 - (0.513 \times \text{NDF}) \\
\text{NEL (Mcal/lb)} = 1.054 - (0.0098 \times \text{NDF})
\]

\[
\%\text{TDN}_{m} = 84.2 - (0.598 \times \text{ADF}) \\
\text{NEL (Mcal/lb)} = 1.011 - (0.0113 \times \text{ADF})
\]

**Grasses**

\[
\%\text{TDN}_{m} = 105.2 - (0.667 \times \text{NDF}) \\
\text{NEL (Mcal/lb)} = 1.297 - (0.119 \times \text{NDF})
\]

\[
\%\text{TDN}_{m} = 97.6 - (0.974 \times \text{ADF}) \\
\text{NEL (Mcal/lb)} = 1.120 - (0.0159 \times \text{ADF})
\]

### Table 4. Prediction Equations from New York State

**Grasses**

\[
\%\text{TDN} = 34.9 + (53.1 \times \text{NEL}) \\
\text{ENE (Mcal/lb)} = \text{NEL} \times 0.826 \\
\text{NEL (Mcal/lb)} = 1.085 - (0.0150 \times \text{ADF})
\]

**Legumes**

\[
\%\text{TDN} = 29.8 + (53.1 \times \text{NEL}) \\
\text{ENE (Mcal/lb)} = \text{NEL} \times 0.826 \\
\text{NEL (Mcal/lb)} = 1.044 - (0.0123 \times \text{ADF})
\]

**Mixed Forages**

\[
\%\text{TDN} = 32.4 + (53.1 \times \text{NEL}) \\
\text{ENE (Mcal/lb)} = \text{NEL} \times 0.826 \\
\text{NEL (Mcal/lb)} = 1.044 - (0.0131 \times \text{ADF})
\]

**Complete Feed**

\[
\%\text{TDN} = 95.88 - 0.911 \times \text{ADF} \\
\text{ENE (Mcal/lb)} = 1.0123 - (0.01432 \times \text{ADF}) \\
\text{NEL (Mcal/lb)} = 0.866 - (0.007 \times \text{ADF})
\]

**Grain mix**

\[
\%\text{TDN} = 81.41 - (0.48 \times \text{ADF}) \\
\text{ENE (Mcal/lb)} = 0.9002 - (0.0084 \times \text{ADF}) \\
\text{NEL (Mcal/lb)} = [(\text{TDN} \times 0.0245) - 0.12] \times 0.454
\]

**Ear Corn**

\[
\%\text{TDN} = 99.72 - (1.927 \times \text{ADF}) \\
\text{ENE (Mcal/lb)} = \text{TDN} \times 1.025 \\
\text{NEL (Mcal/lb)} = 0.94 - (0.008 \times \text{ADF})
\]

**Shell Corn**

\[
\%\text{TDN} = 92.22 - (1.535 \times \text{ADF}) \\
\text{ENE (Mcal/lb)} = \text{TDN} \times 0.01053 \\
\text{NEL (Mcal/lb)} = 0.94 - (0.008 \times \text{ADF})
\]

**Corn Silage**

\[
\%\text{TDN} = 31.4 + (53.1 \times \text{NEL}) \\
\text{ENE (Mcal/lb)} = \text{NEL} \times 0.826 \\
\text{NEL (Mcal/lb)} = 0.94 - (0.008 \times \text{ADF})
\]