Importance of Fiber and Digestibility Analysis to Predict Animal Performance©

David R. Mertens
Mertens Innovation & Research LLC
Retired (2010) Dairy Scientist, U.S. Dairy Forage Research Center

Objectives

- Give you some background and current thinking on NDF and its digestibility as tools for feed evaluation, particularly for alfalfa
- Leave you with 5-6 ideas that help you understand and use the concepts of fiber and its digestibility for feed evaluation
- Generate 5-6 more concepts that may need more explanation
  - *Take notes for questions during the panel discussion*

Feed Evaluation for Animal Performance

- Performance = Availability X Intake X Digestibility X Metabolism X Usage
- If we assume that adequate feed is available then
  - *Performance = Intake of Net Energy/d = Intake X Digestibility X Metabolism X Usage*
  - *But Metabolism and Usage for a give type of animals varies little*
  - *And fecal losses of energy are the largest losses after consumption*
- For practical feed evaluation we are interested in the two factors that explain the most variation in digestible dry matter (dDM) or Total Digestible Nutrient (TDN) intake
  - *Intake explains 70-75% of variation in performance*
  - *Digestibility explains 15-25% of variation in performance*
  - *So Intake X Digestibility are the key factors of feed evaluation for animal performance*
  - *If we can estimate intake and digestibility we can effectively predict animal performance*

Feed Evaluation for Animal Performance – Intake

- Unfortunately, feed intake is a complicated mechanism (Mertens, 1994) which is related to
  - *characteristics of the forage and the diet in which it is fed,*
  - *the animal and*
  - *the feeding situation (management and environment)*
- In feed evaluation, we try to estimate the intake potential of a forage or feed
  - *Which is an estimate of what the cow CAN eat when fed the forage not necessarily what she DOES eat*
  - *Potential intake is the maximum intake of a feed when the animal is achieving maximum productivity*

Feed Evaluation for Animal Performance – Intake

- Intake potential can be related to energy value, but most often it is a function of fiber, especially when rations containing maximum forage are desired
- In general, actual intake of the animal is related to one of two predominate mechanisms
  - *Physiological Energy Regulation occurs when high energy, low fiber rations are fed and the animal regulates intake to meet its energy requirement*
  - *If we feed a nonlactating cow a high quality alfalfa with low fiber and high energy, she will stop eating when she has met her energy requirement*
  - *For high-producing animals fed fibrous diets, it is typically fiber that limits intake*

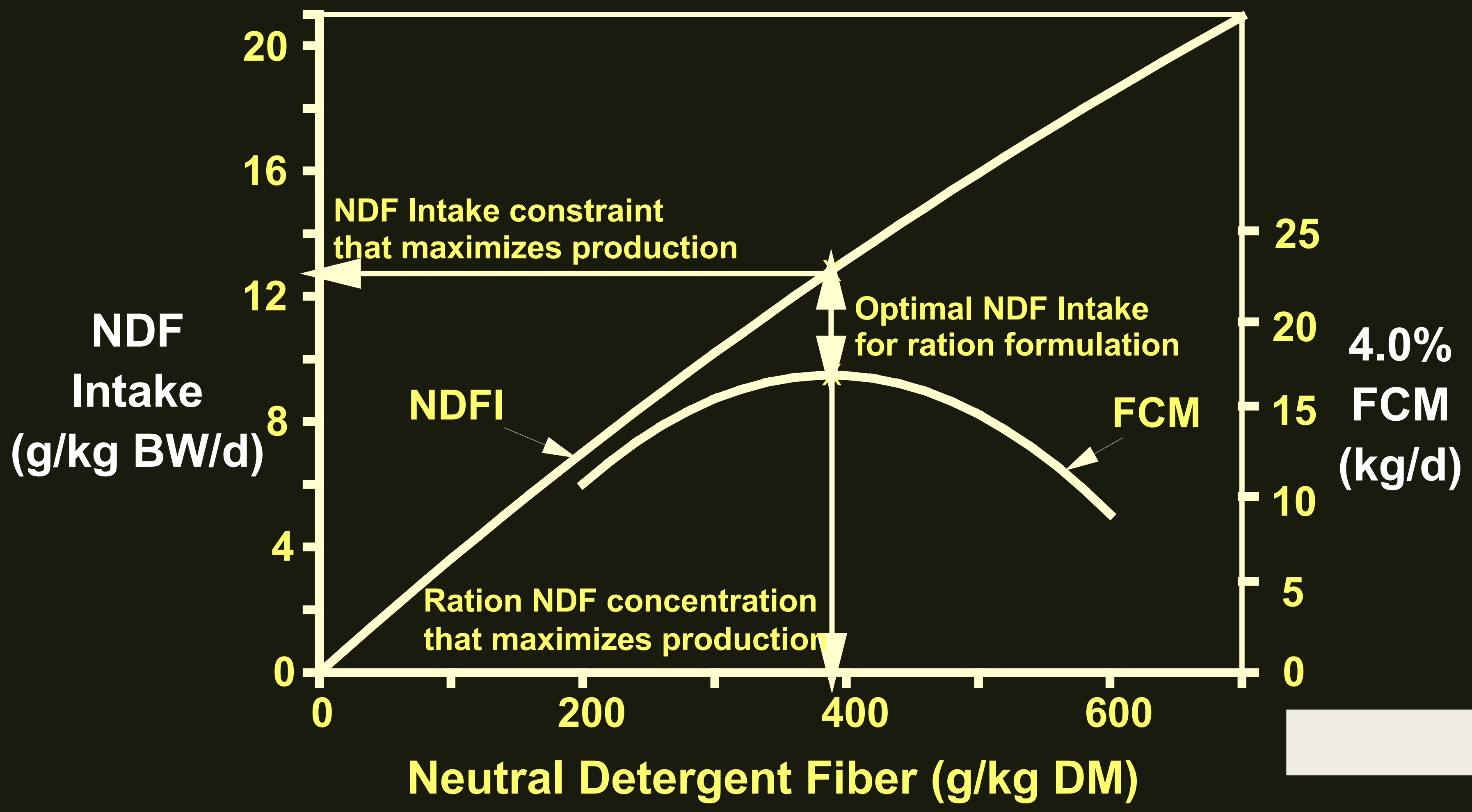
Feed Evaluation for Animal Performance – Intake

- In general, actual intake of the animal is related to one of two predominate mechanisms
  - *Physical Limitation occurs when high fiber, low energy diets are fed and the animal stops eating because it is "filled" before it can meet its energy requirement*
    - When we feed a lactating cow a high fiber, low energy straw diet she will eat until she is full and cannot chew, digest or pass any more fiber and will lower her milk production to match the energy she can consume
    - We can get high producing animals to eat large amounts of fiber, but they cannot or will not maximize production on these diets
    - So how do we determine the upper limit of fiber intake that most likely limits most forage intake?

Feed Evaluation for Animal Performance – Intake

- How much neutral detergent fiber (NDF) can a cow eat and still maximize her milk production (4% fat-corrected milk - 4%FCM)?
  - *Mertens (1970-80) fed total mixed rations to dairy cow that ranged in NDF concentration (%DM) from <25 to >55 %NDF*
  - *NDF was supplied by a wide range of forages, including alfalfa hay, orchardgrass hay, bermudagrass hay, corn silage, and sorghum silage*
  - *He observed that 4%FCM was maximized when NDF intake was 1.25% of bodyweight per day (±0.10% BW/d)*
  - *Will show that this concept is the basis for the intake portion of the RFV/RFQ indexes*

NDF-ENERGY INTAKE SYSTEM
DEFINING THE NDF INTAKE CONSTRAINT



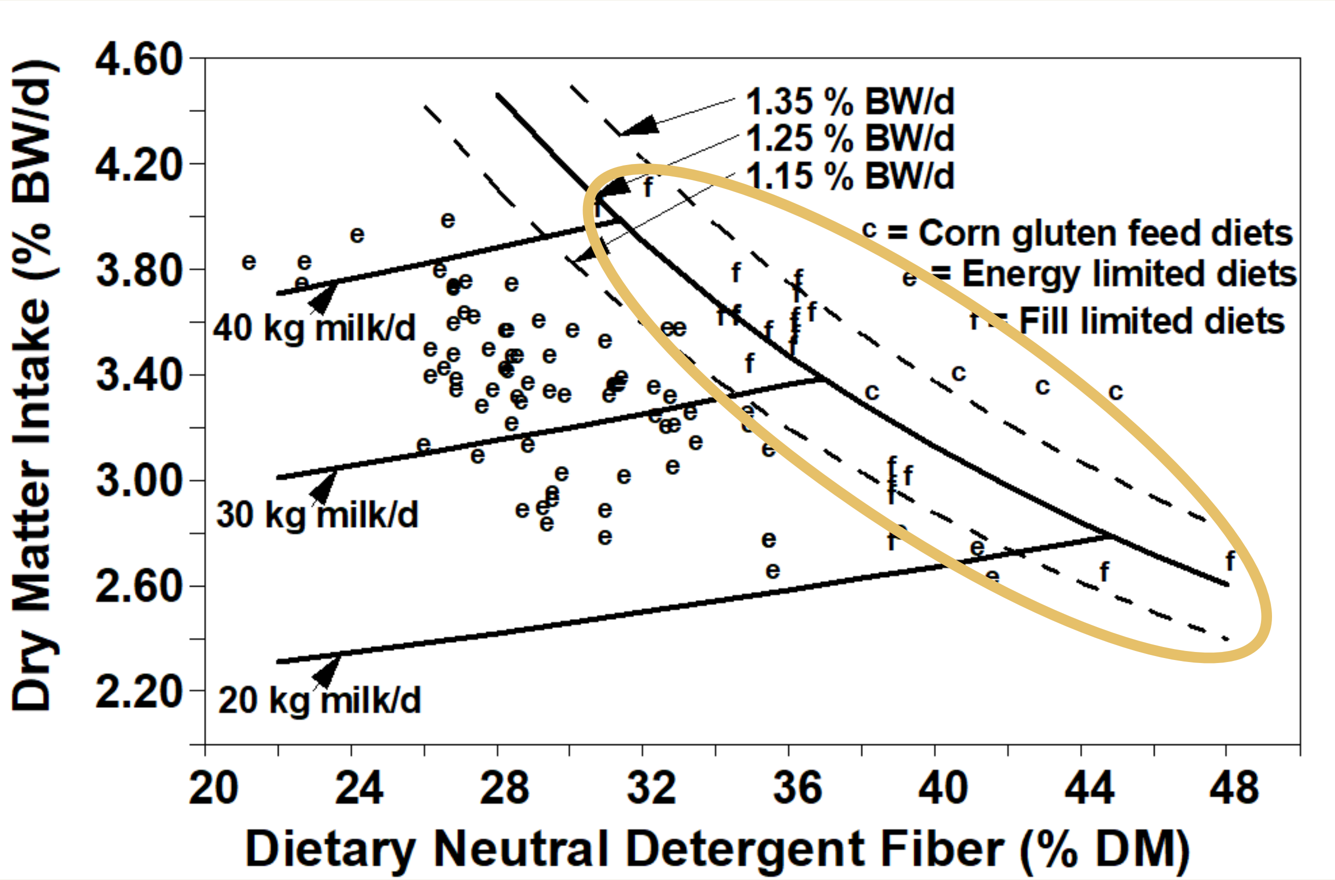
Feed Evaluation for Animal Performance – Intake

- In general, actual intake of the animal is related to one of two predominate mechanisms
  - *Mertens (1987) developed a mathematical description of both the energy demand and physical limitation mechanisms that used NDF and Net Energy of Lactation to maximize fiber intake while simultaneously maximizing milk production*
  - *NDF is a good analytical measure for the intake potential of a forage*
    - Intake potential of an alfalfa containing 34% NDF = 1.2/0.34 = 3.5%BW/d
    - Intake potential of a corn silage containing 40% NDF = 1.2/0.40 = 3.0%BW/d
    - Intake potential of a grass containing 55% NDF = 1.2/0.55 = 2.2% BW/d

Feed Evaluation for Animal Performance – Intake

- NDF provides a relative measure of intake potential among forages
  - *These are estimates of the potential intake of the forage when fed ad libitum to maximize milk production and forage in the ration*
  - *Intake potential is a curvilinear (reciprocal = 1/NDF) function of NDF (NOT linear)*
  - *It can be refined by information on digestion and passage of specific forages*
- NDF intake effect does not work well for high-fiber byproducts (nonforage fiber sources) because their particle size is small and their relationships to chewing activity and passage are very different from forages
  - *NDF intake/d is the amount of NDF that can be digested, chewed and passed in a day*
- When forage intake (Availability) is limited (5 lb/d), potential intake **has much less value**

Feed Evaluation for Animal Performance – Intake



Feed Evaluation for Animal Performance – Digestibility

- Intake X Digestibility are the key factors of feed evaluation for animal performance
  - *Digested Dry Matter (dDM) is the other important characteristic of feeds because it determines how much what is eaten is actually absorbed for use*
  - *Initially dDM was predicted using empirical (statistical) regression equations based on ADF, but estimating dDM using biological principles is more accurate*
  - *After developing the NDF method to measure the total insoluble fiber in feeds, Van Soest (1967) published a seminal (classic) paper showing that*
    - NDF has a unique relationship with dDM because it divides feeds into a
      - *faction that has variable and incomplete digestibility (NDF) and*
      - *a fraction that had consistent and nearly complete digestibility (NDS = neutral detergent solubles = 100 – NDF)*

Feed Evaluation for Animal Performance – Digestibility

- Van Soest's simple summative equation:
  - *dDM = digested NDF (dNDF) + digested NDS (dNDS)*
    - dNDF = NDFD*NDF
    - dNDS = .98*NDS – 12.9 (endogenous DM loss)
  - *dDM = NDFD*NDF = 0.98*NDS – 12.9*
    - Because NDS = (100-NDF)
  - *dDM = NDFD*NDF = 0.98*(100 – NDF) – 12.9*
    - dDM is a function of NDF and NDFD
    - NDFD is second only to NDF in determining dDM (next slide)
- The summative approach can be expanded by developing digestion coefficients for each ideal nutrient comprising NDS, e.g. CP, fat, and nonfiber carbohydrates (Weiss and the Ohio group)

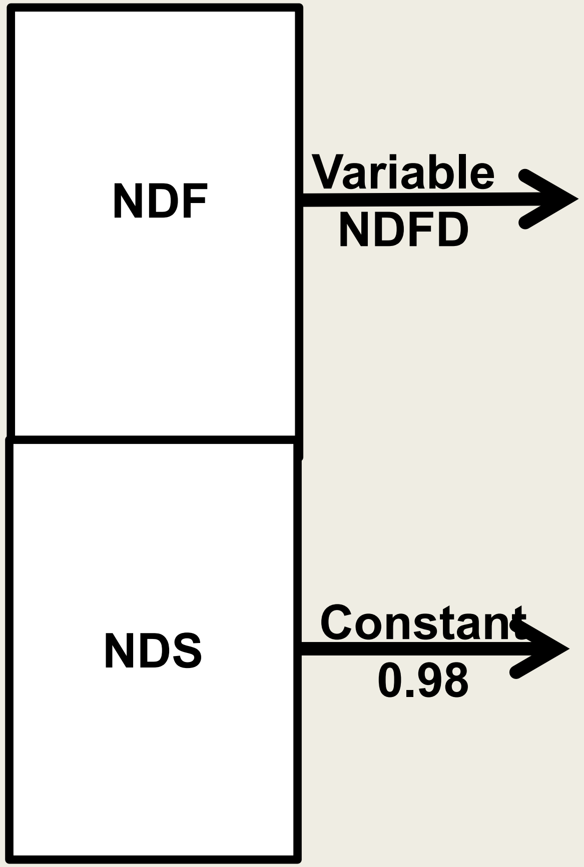
NDF and NDFD Determines digested Dry Matter

$$dDM = NDFD*NDF + .98*NDS - 12.9$$

Component	Corn Grain[a]	Grass Silage	Cereal Silage	Corn Silage[a]	Except. Alf.Hay	Very Hi. Alf.Hay	High Alf.Hay	Good Alf.Hay
aNDF, hay basis 90%DM					26.8	30.3	33.9	37.7
aNDF, % of DM	9.0	55.0	50.0	40.0	29.8	33.7	37.7	41.9
Fractional $NDFD_{30h}$	0.50	0.64	0.58	.600	.587	.541	.503	.469
digested NDF, % of DM	4.5	35.2	29.0	24.0	17.5	18.2	19.0	19.7
NDS, % of DM	91.0	45.0	50.0	60.0	70.2	66.3	62.3	58.1
digested NDS, % of DM	89.2	44.1	49.0	58.8	68.8	65.0	61.1	56.9
True DMD	93.7	79.3	78.0	82.8	86.3	83.2	80.0	76.6
Endogenous DM loss	-12.9	-12.9	-12.9	-12.9	-12.9	-12.9	-12.9	-12.9
Apparent DMD_{1Xmnt}	80.8	66.4	65.1	69.9	73.4	70.3	67.1	63.7
NRC 1978,2001 avg TDN					71.0	67.9	64.7	61.4

[a]Starch in corn must be finely ground, processed or fermented to be 98% digestible

Feed Evaluation for Animal Performance – Digestibility



1-pool model

Van Soest's initial concept essentially treated NDF as a single pool with a NDFD that varied among sources and had to be measured or predicted is some way

NDFD was related to lignin or lignin ratios

NDFD was measured in animals or in vitro

Feed Evaluation for Animal Performance – Digestibility

- in vitro and in situ $NDFD_{24\text{-}48h}$ can be directly related to DMI and Fat-Corrected Milk using meta-analysis of published reports

  DMI FCM

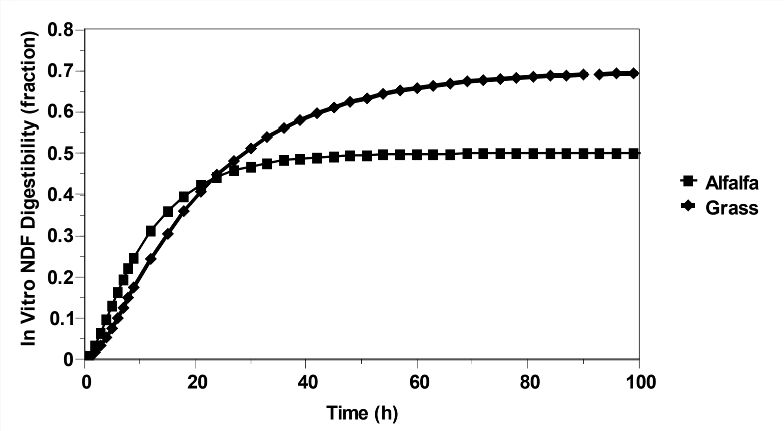
  - *0.37 lb/d and 0.55 lb/d (Oba and Allen, 1999)*
  - *0.31 lb/d and 0.26 lb/d (Jung et al., 2004)*
  - *0.21 lb/d and 0.31 lb/d (Mertens, 2006)*
  - *Comparisons were done within forage types*
  - *Consistent across experiments when experimental differences due to cows, diets, NDFD methods, etc. were removed*
  - *Mertens (2006) observed that the coefficients for NDF concentration was about 3X those of NDFD*
  - *Knowing NDFD, no matter how it is measured or calculated, without knowing NDF is risky – Get NDF in the ration correct first and fine-tune with NDFD*

Feed Evaluation for Animal Performance – Digestibility

- How is in vitro NDFD measured?
  - *Ground sample of forage is placed in a flask and mixed with*
    - Buffers to maintain pH and nutrients to stimulate fermentative digestion
    - Inoculum of ruminal microorganisms obtained from fistulated ruminants
  - *Fermentation in a water bath or other incubator to maintain temperature at 39°C*
  - *Fermentation is anaerobic (free of oxygen) using carbon dioxide (CO_2)*
    - Inoculum is collected and prepared anaerobically
    - Sample and media is anaerobic before inoculum is introduced
    - Typically flasks are maintained under CO_2 pressure
  - *Attempts to duplicate ruminal fermentation*
- Why do we use in vitro?
  - *We have found no chemical or enzymatic reagent that can duplicate the complex interaction between microorganisms and feed, especially fiber*
  - *It takes a "village" of microbes to digest fiber – there is no single fiber-digesting bug!*

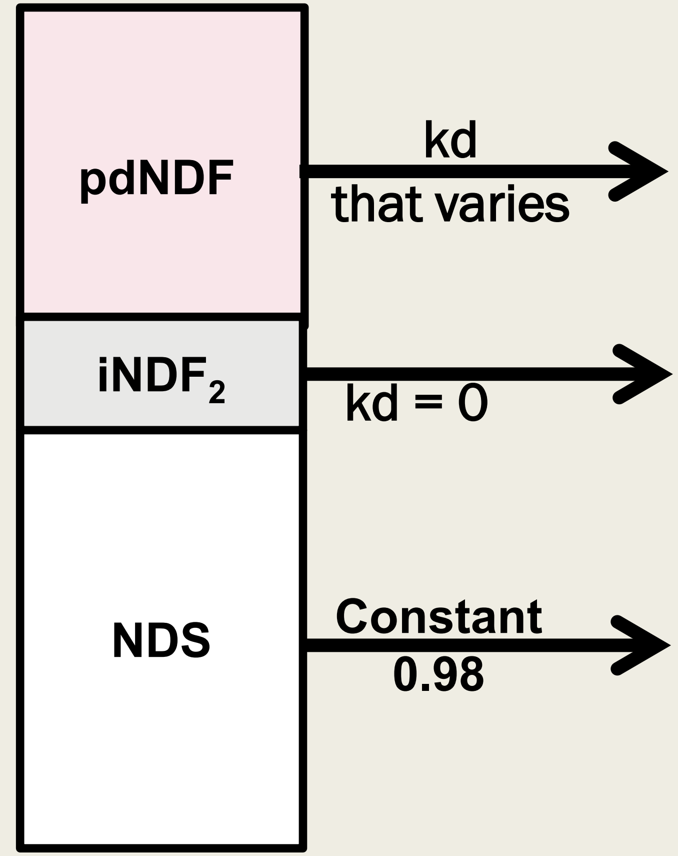
Feed Evaluation for Animal Performance – Digestibility

- Soon after in vitro methods were developed in the 1950s and 60s it was observed that the digestion of feeds, especially fiber components, did not go to 100% regardless of the fermentation time



  - *No one thought about the implications of this observation, until Waldo (1969) observed the work of Wilkins (1969) who used 6-day fermentations*
  - *Waldo proposed that some of the fiber may never ferment in the rumen environment*
  - *This changed our entire concept of fiber digestion – NDF was not a single entity with uniform digestibility that varied among sources*

Feed Evaluation for Animal Performance – Digestibility



The 2-pool model introduces the concept of digestion kinetics

- There is a faction that is indigestible
- The digestible fraction disappears at a fractional rate of digestion

Indigestible NDF ($iNDF_2$) in the model never digests even after infinite time

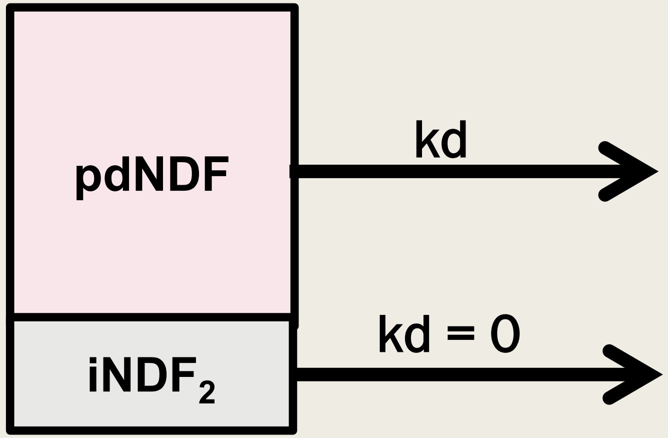
- We cannot measure $iNDF_2$ but we can estimate it with enough data (can extrapolate to infinite time)
- We measure undigested NDF (uNDF) and are currently using $uNDF_{240h}$ as our best estimate of $iNDF_2$

Potentially digestible NDF (pdNDF) is calculated as the difference between total NDF – $iNDF_2$ or NDF – $uNDF_{240}$

- Only the pdNDF, not total NDF, has a fractional rate of digestion
- Rate of digestion varies with forage species, maturity and growing environment

Feed Evaluation for Animal Performance – Digestibility

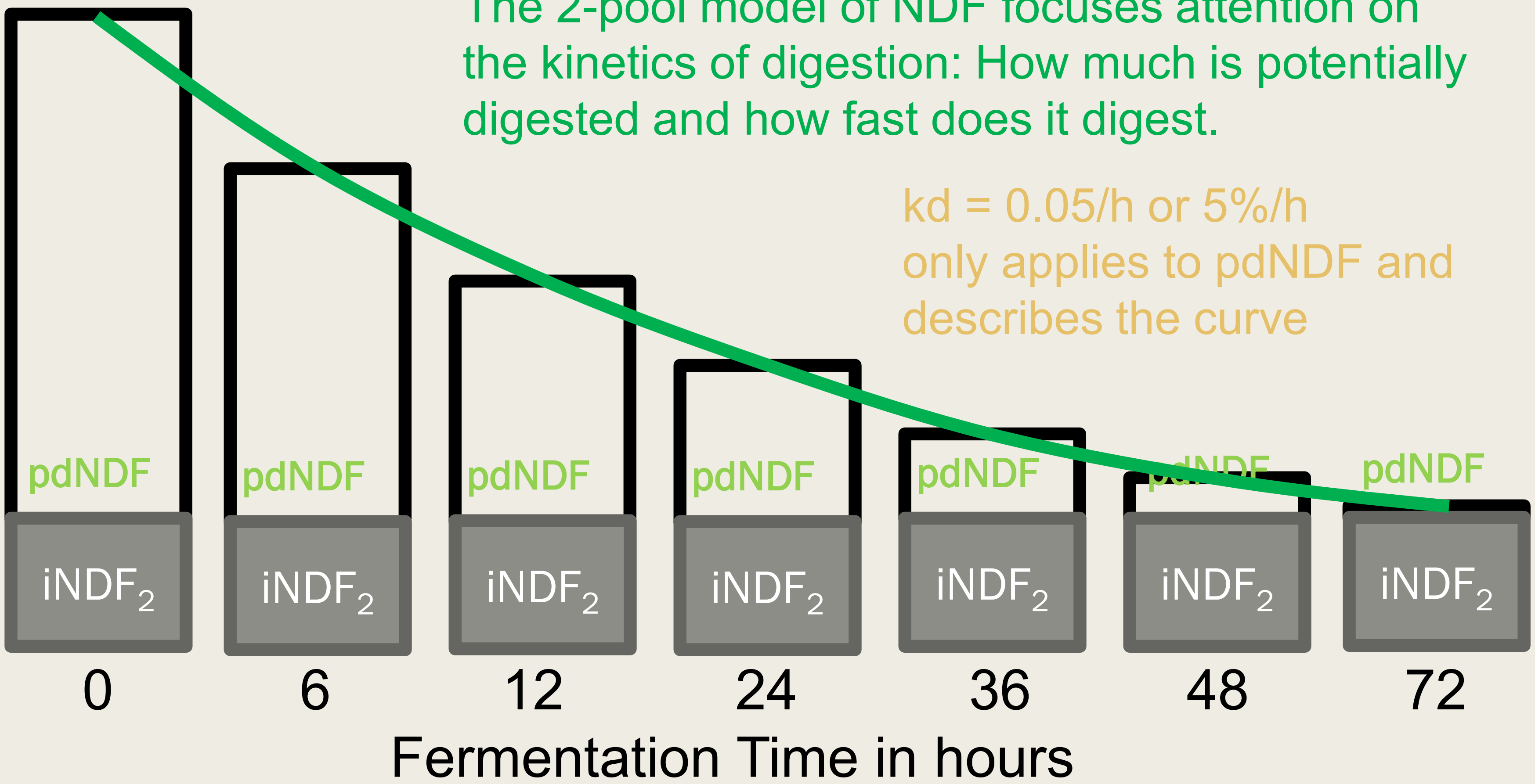
- What does the new 2-pool (or 3-pool) model provide?
  - *It allows us to measure and use the dynamic characteristics of NDF digestion*
- In vitro,
  - *There is no passage, so we can measure the lag time, $iNDF_2$, pdNDF and rate of digestion (kd) without the complication of passage (given we collect enough fermentation times)*
  - *We can also measure these kinetic parameters under optimal fermentation conditions because we can optimize and control the in vitro system*



2-Pool Model of NDF Digestion

The 2-pool model of NDF focuses attention on the kinetics of digestion: How much is potentially digested and how fast does it digest.

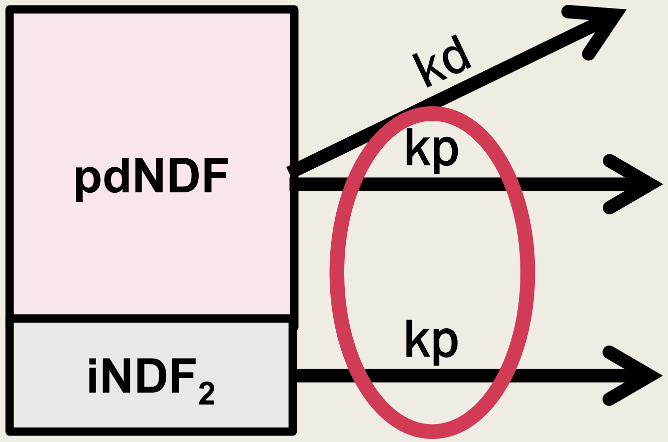
kd = 0.05/h or 5%/h only applies to pdNDF and describes the curve



- pdNDF cannot be calculated until $iNDF_2$ is estimated by models or fermentations >= 72 h
- Fractional digestion rate (kd) cannot be determined until residual pdNDF is calculated at each fermentation time by subtracting $iNDF_2$ sequentially or simultaneously

Feed Evaluation for Animal Performance – Digestibility

- What does the new 2-pool (or 3-pool) model provide?
  - *It allows us to measure and use the dynamic characteristics of NDF digestion*
- In vivo (in the animal)
  - *Digestion of fiber is more complicated because the feed can also (has to) pass out of the rumen*



Waldo solved this system at steady-state to determine NDF digestibility in the animal

IVV NDFD = (pdNDF/NDF)*[kd/(kd + kp)]

In vivo, there is a competition between digestion and passage (kp) and both rates have to be used to determine digestibility

Correction: The only significant animal characteristic affecting digestion is the rate of passage of digesta.

Feed Evaluation for Animal Performance – Kinetic Characterization

values on a DM not hay basis

Description	aNDF	$uNDF_{240}$	pdNDF	kd/h	kd/ (kd + 0.03)	Est TT NDFD
Exceptional	29.8	11.8	17.9	0.130	0.812	54.2
Very high	33.7	14.5	19.2	0.107	0.781	49.4
High quality	37.7	17.2	20.5	0.093	0.756	45.7
Good quality	41.9	20.1	21.9	0.082	0.732	42.5
Fair quality	46.3	23.0	23.3	0.073	0.709	39.6

- $uNDF_{240}$ (indigestible NDF) as a % of NDF increases from about 40% for immature, exceptional alfalfa to 50% for more mature, fair alfalfa
  - This means that a large proportion of NDF in alfalfa cannot be digested in the rumen
- However, the potentially digestible NDF (pdNDF) digests at a very high rate so that most pdNDF digests in the rumen
- Assuming 90% of NDF digestion occurs in the rumen then we can estimate the IVV total tract NDFD – these numbers are lower that $IVNDFD_{30}$ because some NDF escapes without digestion

Feed Evaluation for Animal Performance – Chemical Composition

values on a DM, not hay basis

Description	Ash	ADF	ADL	aNDF	aNDFom	$NDFD_{30}$
Exceptional	10.4	24.0	4.58	29.8	28.9	58.7
Very high	9.9	27.0	5.39	33.7	32.8	54.1
High quality	9.5	30.0	6.22	37.7	36.9	50.3
Good quality	9.1	33.0	7.06	41.9	41.1	46.9
Fair quality	8.7	36.0	7.93	46.3	45.4	43.9

- Moving from aNDF to aNDF organic matter (aNDFom) or ash-free NDF
  - Normally most of the ash in forages is soluble in neutral detergent (values given above)
  - However, ash from soil does not dissolve in neutral detergent so it increases NDF and decreases RFV – not a desirable thing for the hay grower or feeder!
  - Most of the soil contamination comes from consolidating windrows for large equipment
    - Typically 10 to 15% of the samples analyzed
  - Use aNDFom when total ash values are about 2%-units higher than indicated in the table

Feed Evaluation for Animal Performance – Chemical Composition

Description	Ash	ADF	ADL	aNDF	aNDFom	$NDFD_{30}$
Exceptional	10.4	24.0	4.58	29.8	28.9	58.7
Very high	9.9	27.0	5.39	33.7	32.8	54.1
High quality	9.5	30.0	6.22	37.7	36.9	50.3
Good quality	9.1	33.0	7.06	41.9	41.1	46.9
Fair quality	8.7	36.0	7.93	46.3	45.4	43.9

- In my opinion, the "sweet spot" for alfalfa is between the "very high" and "high" quality descriptions
  - A "dessert" alfalfa can be fed, but I question if the milk return on investment is acceptable
  - Especially concerned that we feed alfalfa of such a high quality that straw has to be fed to provide physically effective NDF (peNDF)
  - I personally cannot formulate dairy rations with significant amounts of dessert alfalfa, and if the amount is limited to 10% of the ration or less, any difference would be difficult to detect

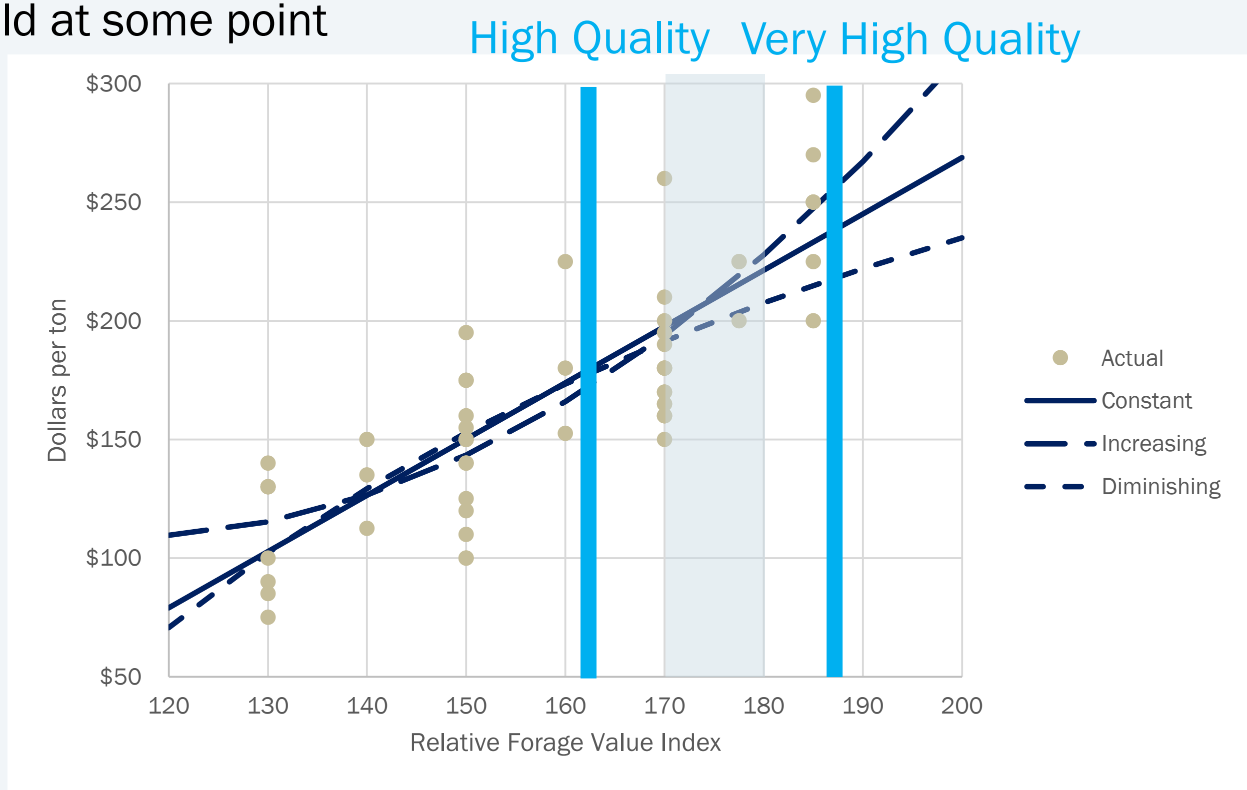
Feed Evaluation for Animal Performance – Nutritive Value Indexes

- Nutritive Value index was first proposed by Crampton et al. (1960)
  - *Their NVI was the product of Intake X Digestibility*
- 1950-70s was the greatest research generation for feed evaluation
- At a meeting in the 1980s to "standardize" equations for predicting dDM, I commented that worrying about dDM was missing the point that intake potential was a more important characteristic for forage evaluation and mentioned the NVI concept
- Relative Feed Value (RFV) was developed at Wisconsin
  - *DDM = 88.9 - (0.779 x ADF)*
  - *DMI = 120 / NDF - The 120 comes from 1.2%BW/d as optimum NDF intake*
  - *RFV = DDM xDMI / 1.29 – The 1.29 adjusts RFV = 100 for full bloom alfalfa (41%ADF and 53% NDF)*
- Relative Forage Quality (RFQ) uses a expanded summative equation to estimate TDN instead of DDM and a similar equation adjusted for NDFD to estimate DMI

Feed Evaluation for Animal Performance – Food for Thought

Should the price and response in milk production be a linear relationship with RFV?

- Linear price increase averaged $2.37 per unit of RFV (CA, ID, KS, MN, MO, MT, NB, NM, OK, SD, and WY)
- At RFV = 87 price is $0, below this grower should pay feeder to take the alfalfa!!!
- Law of diminishing returns would suggest that the value should plateau or reach a threshold at some point



SOMETIMES I THINK I SHOULD BE WORKING ON NDF MODELS AND THEN . . . .

Started running timed laps on road courses in 2015
My only hobby (vice??), except work and sim racing!
Have a bucket list of courses to drive in 2020

Original car was a 2012 Dodge Challenger SRT

New car: 2016 Dodge Challenger SRT 392ci 6.4L with 15.4” 6-piston front brakes, roll bar, and safety harness
2 metric tons of fun! 485 HP 475 ft-lb torque
More modifications planned

Be glad to answer questions at the panel discussion