Understand fiber: TMR NDF breakdown and reduced lignin feed potential. Make profitable decisions within these areas[1]

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Fiber in dairy diets

Carbohydrate impact upon animal and ruminant nutrition is not a new focal point for nutritionists. Hall and Mertens (2017) recently reviewed 100 years of carbohydrate research relative to ruminant nutrition. Fiber, defined as Neutral Detergent Fiber (NDF; Goering and Van Soest, 1970**)** in dairy nutrition, contributes two major facets of dairy diets. It is important for both physical and energetic aspects, but energetically fiber provides the least energy per pound of all nutrients in the total mixed ration (TMR). The balance of the diet is then more readily digestible carbohydrates (primarily sugar and starch), protein and fatty acid. It's important to simultaneously consider both fiber's physically effective and energetic attributes, and at times these are inter-related.

Physical attributes

With dairy diets, we typically feed adequate fiber to maintain sound rumen function and metabolism. There is often a perception of rampant clinical acidosis or sub-acute rumen acidosis (SARA). However, my belief, founded upon working with many consulting nutritionists across the US and reviewing diets, is that very few formulated diets today are responsible for clinical symptoms. Rather, management factors such as feed delivery timing or feed mixing are often the contributing factors toward rumen health and SARA.

To date, there is not a readily accepted "standard" in quantifying the aNDF percentage that is physically effective (peNDF, % of aNDF or DM). Prof Mertens' work suggested the 1.18 mm size was ideal, yet other work from Penn State and others suggested the 4 mm size may be more accurate in determining effectiveness. Both 1.18 and 4 mm sieves are now incorporated within the Penn State particle size separator and the aNDF percentage greater than these sizes can be readily determined (Heinrichs, 2013). Of note, the NRC (2001) held back from making recommendations for fiber effectiveness. Rather, the National Research Council committee provided recommendations for forage NDF, % of DM, at varying fiber to starch ratios.

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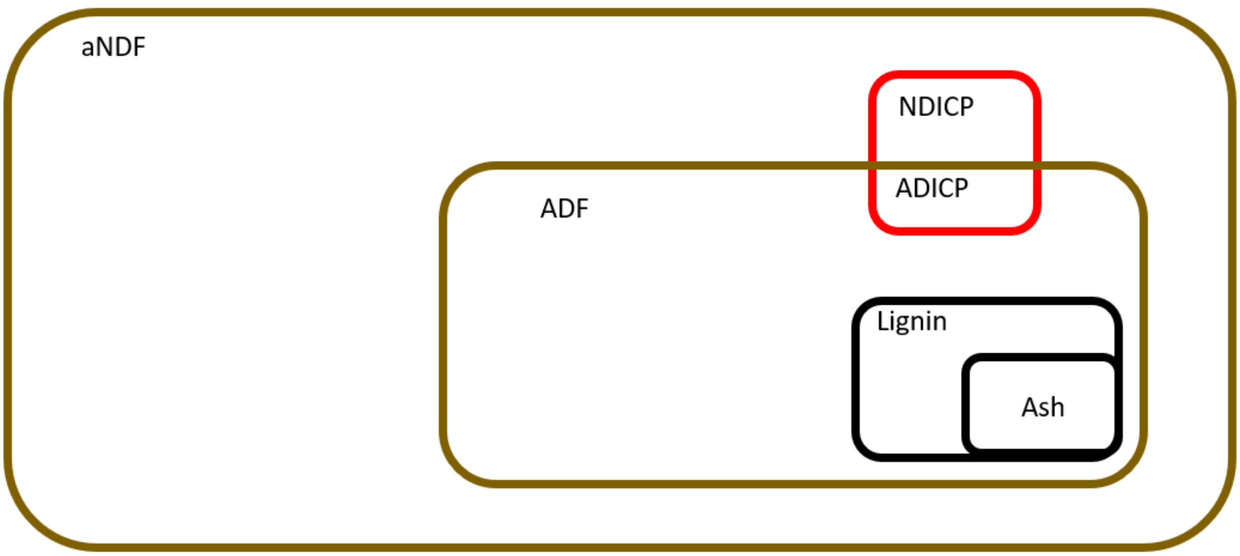
Fragility (i.e. alfalfa fiber being more fragile than grass fiber; Allen, 2000) is another concept contributing to fiber's effectiveness that warrants further exploration but is vaguely understood and characterized today.

Prior to discussing the energy side of fiber, the detergent fiber complex warrants discussion as considerable confusion exists yet today within the industry. **Figure 1** demonstrates the concept of various fiber fractions, each nested within aNDF. Forage analysis laboratories sequentially rinse (like a laundry machine) feed samples with neutral, mildly acidic and then strongly acidic solutions to wash away feed components and ultimately determine the fractions outlined in figure 1. Each is determined by relating the remaining sample weight to original mass after sequential rinses or burning in an often (ash).

Figure 1: The fiber nesting doll. The acid detergent fiber (ADF), neutral and acid detergent insoluble crude protein (NDICP, ADICP), lignin and some ash are nested within aNDF. Image Adapted from the March 10, 2018 Hoard's Dairyman article, "Dairy nutrition's tribal language: speaking fiber."



Energetic attributes

Starch and fiber contain the same calorie content per pound, around 4 calories per gram. Both starch and fiber (cellulose) are generally chains of glucose bonded together. Yet as nutritionists, we understand the energy available to the cow varies greatly between these two nutrients. The enormous difference in energy available is due both the type of glucose-glucose bond (alpha- vs beta- bond configurations) as well as lignin and cell wall cross linking that further zippers cellulose into a less digestible complex. In 2014, I surveyed several meta-analyses and summarized fiber and starch digestion data from more recent published lactating cow feeding studies. Total-tract fiber digestion in lactating cows averages about 40 to 50% (Table 1) whereas total-tract starch digestion averages over 90% (Goeser, 2014). Further, commercial dairy cow-level digestion (apparent digestion, % of nutrient) appear similar to published research (**Figure 3**). In the 2014 summary, my aim was to revisit laboratory fiber and starch digestion measures relative to real, *in vivo* data and recognized that 30h *in vitro* NDF digestion values often over-estimate cow level digestion thus questioned the utility.

Since the 2014 survey and time, the industry has better embraced the notion that single time point fiber digestion measures (i.e. NDFD30) are inadequate to describe complex rumen nutrient digestion. In conjunction with this better recognition, forage analyses laboratories have advanced multi-time point rumen fiber digestion predictions by near infrared reflectance (NIR) spectroscopy.

To merge the two points together and bring functional nutrition decision making tools to the field, two practical nutrition models have come online in the US:

1. Cornell Net Carbohydrate and Protein System v6.5 (Van Amburgh et al., 2015)
2. Total Tract NDF Digestibility (Combs, 2013)

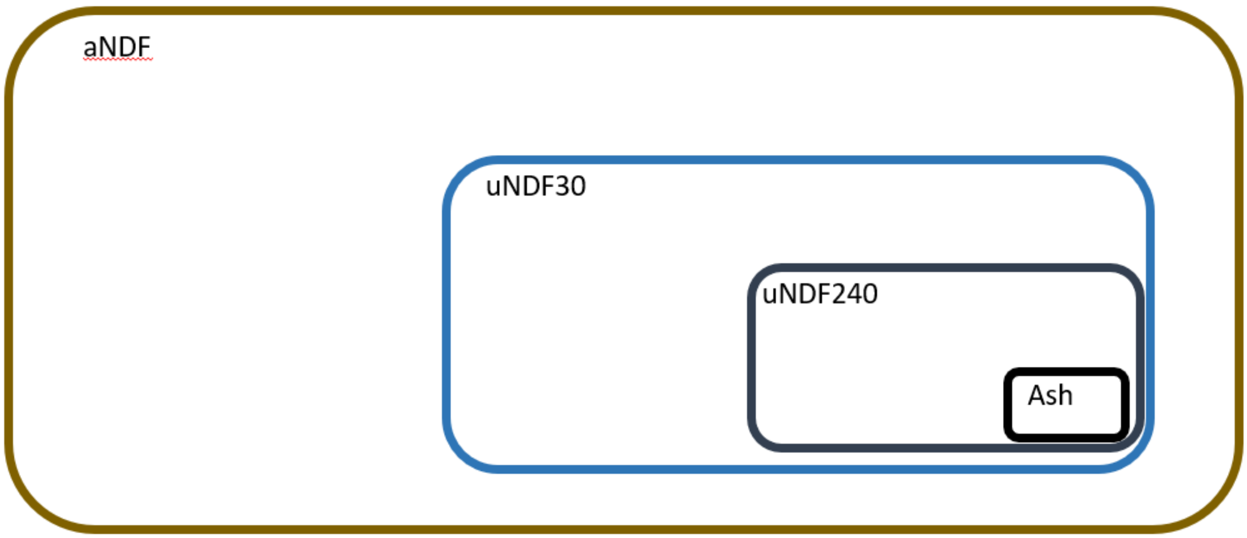
Another multi-time point analytic tool warrants recognition, Fermentrics™ (www.fermentrics.com, accessed online; Johnston, personal communication), which was developed using methodology and concepts described by Pell and Schofield (1993). Gas production is intriguing as these models allow one to consider thousands of data measures over time. However, the model fiber and starch digestion rates are determined via gas production curve peeling and not direct fiber quantification.

Each of these tools incorporate digestible nutrient pool sizes and nutrient digestion rates into compartmental models to predict fiber digestibility within the rumen or total-tract. To better understand both nutrient digestible pool size and digestion rate consider the following analogy and story.

uNDF and NDFD meaning and relationship

Similar to how the detergent fiber parameters can be depicted with a nesting doll analogy, uNDF30 and uNDF240 (% of DM or NDF) can be better understood relative to aNDF with a picture (**Figure 2**). Within the laboratory, the sample (and it's fiber) is digested for a time period and then it's washed with neutral detergent to determine the amount of fiber that's left. This ends up being a gram divided by gram type equation and NDF digested at time = x ($NDFD_x$, % of NDF) is then calculated by: (aNDF – $uNDF_x$) / aNDF x 100. Alternatively, the amount of fiber left after 30 or 240 hours may be a better lignified fiber indicator, thus comparing uNDF (% of DM) has become another measure we evaluation. In this case, the uNDF is looked at as a % of the original sample. Just like is the case with aNDF.

Figure 2: The undigested fiber nesting doll. Each uNDF30 and uNDF240 are nested within aNDF (% of DM).



Building a camp fire within the rumen: kindling and a bundle of fire wood

Continuing with the analogies, rumen fiber (or any other nutrient) digestion can be more simply understood by comparing to our experience with building a campfire. Both the wood pile size and moisture (i.e. dry vs wet wood) contribute the heat we feel through the night from the fire pit. Similarly, digestible fiber pool size (akin to the wood pile size) and fiber digestion rate (akin to wood moisture) must be accounted for to accurately predict rumen fiber digestion across different diets and intake levels. The same forage consumed in a high cow or dry cow TMR will actually be digested differently due to passage rate (i.e. rumen retention time). The only way this can be accurately predicted is by combining digestible fiber pool size and digestion rate in a model that also includes a passage rate. Reason being, fiber leaves the rumen in two ways; digestion or passage. Both the CNCPS and TTNDFD models combine passage rate (k_p, % hr^{-1}) with potentially digestible fiber pool and digestion rate (aNDFom k_d, % hr^{-1}) in the following equation:

Rumen NDF digestion (% of aNDFom) = potentially digestible fiber pool x fiber [kd / (kd + kp)], where:

- *pdNDF, % of aNDFom = NDFD240om = (aNDFom – uNDF240om)/aNDFom x 100*
- *fiber k_d, % pdNDF hr^{-1} = non-linear model determined using multi-time point NDFD (i.e. 24, 30, 48 or 30, 120, 240)*

Fiber digestion term dictionary

- aNDF = NDF determined with amylase in the neutral detergent solution
- aNDFom = aNDF corrected for ash
- uNDF = undigested aNDF following a discrete digestion time (i.e. 30 or 240 h)
- iNDF = indigestible aNDF, theoretical value determined only by nonlinear modelling
- uNDFom = undigested fiber corrected for ash
- NDFD = Digested aNDF, expressed as a percent of aNDF

- pdNDF = potentially digestible NDF
- NDF k_d = fiber digestion rate

Semantics

Often, "k_d rate" has been used to describe fiber or starch digestion rates. Like how Prof. Mertens helped the industry's understanding of uNDF (undigested NDF at time = x) vs iNDF (indigestible NDF at time = infinity), I'll attempt to help us understand rate coefficient terminology; "k_d rate" is grammatically incorrect as the "k" is defined as the *rate coefficient* and the "d" is defined as *digestion*. Hence, "k_d rate" is redundant and akin to stating, "Digestion rate rate".

Helping growers manager toward better feed and margins

While uNDF and digestion rate are related to one another, they both can theoretically be improved. Reduced lignin forages have lesser uNDF levels and correspondingly greater digestible NDF pools. This does not mean though that reduced lignin forage fiber digests faster, it just means there is more fiber to digestion similar to how a large bundle of wood offers more energy than does a small bundle.

Reducing uNDF in feeds can be achieved in two ways; 1) diluting the uNDF with more digestible nutrients such as starch, protein or sugar or 2) managing to lessen the uNDF in relation to total aNDF. The second strategy is the route that brown midrib corn mutants lessen uNDF and theoretically how reduced or low-lignin alfalfa varieties improve quality. Going forward, Prof Combs' (personal communication) has suggested that digestion rate may be heritable, which could then lead to advances in fiber digestion speed along with decreasing uNDF and increasing digestible NDF pool size.

In the field, harvesting alfalfa and grass crops earlier should result in both lesser uNDF and faster digestion rates. Cross linking within cell walls develops as plants mature and will be related to bacterial cellulose access, thus decreasing both digestion speed and extent as maturity advances. Cut first crop each year at 22 to 24" PEAQ (Hintz and Albrecht, 1993). Do not assume 28 day cutting intervals result in dairy quality forage, I suggest scouting fields starting about 17 days after the prior cutting and monitoring plant maturity every 3 to 5 days with scissor clipping.

Managing what the dairy has provided us with the campfire in mind

Balancing diets with 30 or 48 h NDFD could not be considered "old school" as the days of using a single NDFD measure to formulate are behind us. Given better information available from labs, I now recommend considering both pdNDF and aNDF k_d in formulation to accurately formulate with the same forage at different intake levels and passage rates. The aNDF k_d should not be used by itself under any circumstances as it depends upon the uNDF level. However, uNDF values have utility as "the new lignin" measures.

I suggest monitoring uNDF30 and 240 levels (% of DM) in diets on a herd by herd basis. To my knowledge, there is not an industry accepted or published benchmark for a certain uNDF level that will limit intakes, however within a herd these metrics can prove valuable to help formulate forage inclusion rates when switching forage sources. Further, uNDF level could be used within diet projections to evaluate potential income over feed costs within partial budgets. I've appreciated also learning from Dr. Sam Fessenden recently (AMTS technical services) to use uNDF (g CHO-C) as a tool to consider when forecasting an intake response due to lesser uNDF content in feeds. Sam has suggested that diet projections can be compared by using different forages at similar dry matter intakes but further by also comparing the diet scenarios and maintaining CHO-C relatively constant between diets.

On farm, consider using Prof Combs' TTNDFD as a forage analysis level tool to make decisions and allocate feeds. Many consultants have had success coaching their clients to focus on TTNDFD as a "new RFQ on steroids" in better projecting forage quality.

Speak a different language on farm

Lastly, try and change the language you speak on farm as the terms discussed in this paper are difficult to convey to those not skilled in the art. Rather than speak of uNDF or NDFD or NDF k_d, speak in terms of total fiber in the diet, pounds of fiber digested by the cow or the amount of fiber that washes out the back end in manure. For example, at 55 pounds dry matter intake and 28% aNDFom, this approximates to 15 pounds of fiber cows consume each day in the TMR. If diet digestibility is recognized to be only 40% whereas the goal is 50%, talk about the 15 pounds being digested at both 40 and 50% results in 6 versus 7.5 pounds of fiber digested. The 40 versus 50% may seem vague, but when we're talking about 1.5 pounds of digestible nutrient at hand it may spur change. This 1.5 pounds of digestible nutrient could correspond to 3 pounds of milk or more!

Economically balancing reduced lignin (and uNDF) feeds based upon published nutrition research, yield and digestible tons production potential, and disease resistance considerations

Research investigating reduced lignin corn silage, published by both plant breeders and animal scientists, dates back decades and *brown-midrib* mutations appear to largely impact the pdNDF and not the pdNDF digestion rate (Cherney et al., 1991). In many published studies, reduced lignin forages correspond to an increase in intake and performance. The production response is relatively well understood relative to other economically relevant factors related to growing and feeding *brown-midrib* or reduced lignin forages. These factors should also be evaluated when doing projections: feed conversion potential, yield and digestible nutrient yield, and disease resistance.

Feed conversion: the balance between intake and performance gain needs to be considered when evaluating reduced lignin feed potential. The aim should be to outpace increased intake with performance gains, thus increasing feed conversion efficiency. According to Prof Allen and colleague, a 1-unit gain in *in vitro* rumen NDF digestion corresponds to a 0.26 and 0.47 unit increase in DMI and 4% fat corrected milk production per cow, respectively (Oba and Allen, 2005). With a roughly 2:1 milk to intake increase per unit ivNDFD, theoretically feed conversion should improve via reduced lignin forages assuming ivNDFD increases. However Stone et al., (2012) reported no improvement in feed conversion with *brown-midrib* corn silage relative to convention. Feed conversion is not always reported within published studies yet is an increasingly important key performance indicator to track with dairies and feedlots during challenging economic periods. Interesting research coming from Dr. Rick Grant's group at the Miner Institute may also better help us understand intake and uNDF relationships (Grant, 2018).

Forage yield: lesser yield with *brown-midrib* or other reduced-lignin technologies are often expected. For example, data summarized from several years of Prof. Joe Lauer's hybrid trials detailed less yield with *brown-midrib* mutant corn relative to other conventional varieties (Lauer et al., 2016 and prior years; accessed online, http://corn.agronomy.wisc.edu/HT/Default.aspx). And a more recent publication with transgenic alfalfa reported lesser yield when managed in a similar manner to conventional lines. The reduced lignin alfalfa though may better maintain quality though with extended cutting intervals (Getachew et al., 2018).

However raw yield is not as economically relevant as the digestible nutrient yield. I suggest determining digestible yield with plot efforts by combining variety total yield (DM basis) with variety total digestible nutrient (TDN) measures, determined at a reputable forage laboratory, which incorporate the advanced fiber digestion concepts discussed here. Total digestible nutrient yield will more properly project energy harvested per acre.

Disease resistance: lastly, learning from Prof Damon Smith, among others, lignin is a plant defense mechanism. Seed genetics with a lesser ability to lignify may also be less able to withstand added disease pressure and could warrant additional crop protection. Crop protection inputs should also be considered in partial budgets evaluating reduced lignin seed economic impact.

References

Allen, M. S. 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. J. Dairy Sci. 83:1598–1624.

Cherney, J.H., D.J.R. Cherney, D.E. Akin, and J.D. Axtell. 1991. Potential of brown-midrib, low-lignin mutants for improving forage quality. Adv. Agron. 46:157-198.

Getachew, G., E. Laca, D. Putnam, D. Witte, M. McCaslin, K. Ortegac and E. DePeters. 2018. The impact of lignin downregulation on alfalfa yield, chemical composition, and in vitro gas production. J Sci Food Agric 2018; 98: 4205–4215.

Goering, H.K., and P.J. Van Soest. 1970. Forage fiber analyses (Apparatus, reagents, procedures, and some applications). ARS-USDA, Washington, D.C.

Goeser, J.P. 2014. What do cows have to say about fiber and starch digestibility?

Grant, R. 2018. Relationships Between Undigested and Physically Effective Fiber in Lactating Dairy Cows. Proc. 2018 Cornell Nurtition Conf., Syracuse, NY.

Hall, M.B. and D.R. Mertens. 2017. A 100-Year Review: Carbohydrates—Characterization, digestion, and utilization. J Dairy Sci. 100:10078–10093

Heinrichs, J. 2013. The Penn State Particle Separator. Reviewed by: V. Ishler and A. Kmicikewycz. Penn State Extension article. DSE 2013-186.

Hintz, R.W., and K.A. Albrecht. 1991. Prediction of alfalfa chemical composition from maturity and plant morphology. Crop Sci. 31:1561-1565.

Lopes, F., D.E. Cooks, and D.K. Combs. 2015. Validation of an in vitro model for predicting rumen and total-tract fiber digestibility in dairy cows fed corn silages with different in vitro neutral detergent fiber digestibilities at 2 levels of dry matter intake. J Dairy Sci. 98:574-585.

Oba M. and M. S. Allen. 2005 In vitro digestibility of forages. pp. 81-91 Proc. Tri State Dairy Nutrition Conference, Dept. Dairy Sci., The Ohio State University, Columbus, Ohio, 43210.

Pell, A.N., and P. Schofield. 1993. Computerized monitoring of gas production to measure forage digestion in vitro. J Dairy Sci. 76:1063-1073.

Schalla, A., L. Meyer, Z. Meyer, S. Onetti, A. Schultz, and J. Goeser 2012. Hot topic: Apparent total-tract nutrient digestibilities measured commercially using 120-hour in vitro indigestible neutral detergent fiber as a marker are related to commercial dairy cattle performance. J. Dairy Sci. 95 :5109–5114

Van Amburgh, M.E., E.A. Collao-Saenz, R.J. Higgs, D.A. Ross, E.B. Recktenwald, E. Raffrenato, L.E. Chase, T.R. Overton, J.K. Mills, and A. Foskolos. 2015. The Cornell Net Carbohydrate and Protein System: Updates to the model and evaluation of version 6.5. J Dairy Sci. 98:6361-6380.

Table 1: Rumen and total-tract fiber digestibility measures for lactating dairy cattle in published research. Table adapted from Goeser (2014).

Description	Digestion Site	Author(s)	Treatment means	Digestion Coefficient, %	SD

Mixed TMRs	Rumen	Firkins et al. (2001)	121	43.5	11.3
Mixed TMRs	Rumen	Hannigan et al. (2013)	152	42.8	12.8
Corn silage based TMRs	Rumen	Ferraretto and Shaver (2012)	39	41.9	NA
TMRs containing barley based grain	Rumen	Ferraretto et al. (2013)	30	39.4	NA
TMRs containing corn based grain	Rumen	Ferraretto et al. (2013)	82	39.3	NA
n or Weighted means	**Rumen**		**424**	**42.0**	**12.0**
Alfalfa and Grass Forage based TMRs	Total Tract	Goeser (2008)	75	47.4	8.0
Corn and Sorghum Forage based TMRs	Total Tract	Goeser and Combs (unpublished)	85	42.7	10.5
Mixed TMRs	Total Tract	Firkins et al. (2001)	75	48.0	10.9
Mixed TMRs	Total Tract	Hannigan et al. (2013)	137	49.2	10.7
TMRs	Total Tract	Krizsan et al. (2010)	172	59.7	12.8
Corn silage based TMRs	Total Tract	Ferraretto and Shaver (2012)	105	44.7	NA

TMRs containing barley based grain	Total Tract	Ferraretto et al. (2013)	62	47.2	NA
TMRs containing corn based grain	Total Tract	Ferraretto et al. (2013)	335	45.6	NA
n or Weighted means	**Total Tract**		**1046**	**48.5**	**10.7**

Figure 3: Apparent total-tract fiber digestibility measures for commercial dairies in the Midwestern US (Rock River Laboratory, Inc; unpublished data since 2015). Commercial measures performed using methods described by Schalla et al. (2012). Organic matter digestibility (% OM), total tract NDF digestibility (TTNDFD; % of NDF) and total tract starch digestibility (StarchD; % of starch) histograms.