

Wrap your Head around Today's Fiber Digestion Metrics: Working to Better Understand Feeds on Farm and Build Better Diets

Dr. John Goeser, PhD, PAS & Dipl. ACAN
Rock River Laboratory, Inc.
Adjunct - Asst. Prof, University of Wisconsin – Madison

What's the aim today with 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 recommen-

dations for fiber effectiveness. Rather, the National Research Council committee provided recommendations for forage NDF, % of DM, at varying fiber to starch ratios.

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 oven (ash).

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

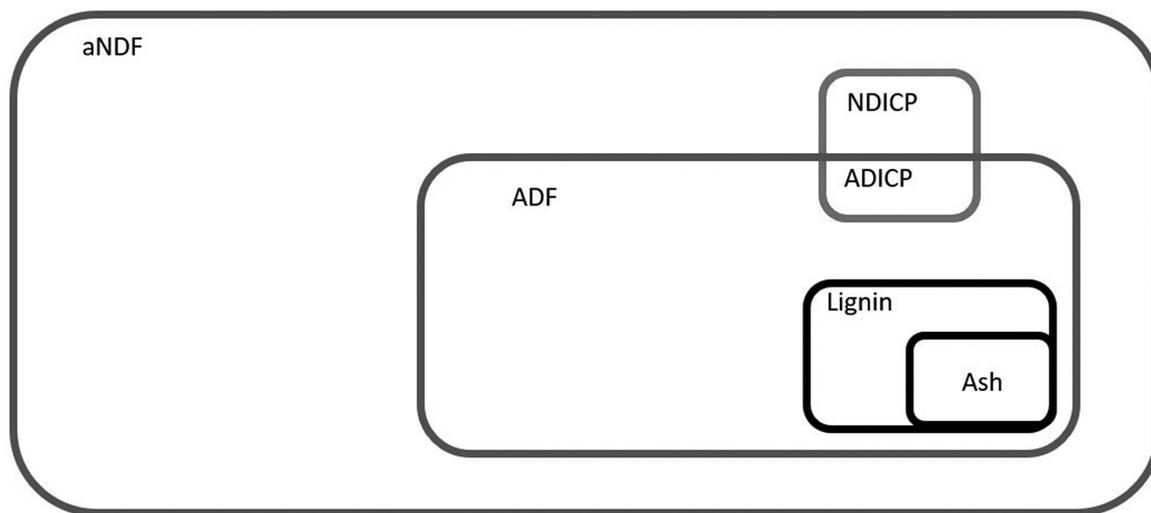


Figure 1: The fiber nesting doll. The acid detergent fiber (ADF), neutral and acid detergent insoluble crude protein (NDICP, ADICP), lignin and some ash are nested within aNDF. Image Adapted from the March 10, 2018 Hoard's Dairyman article, "Dairy nutrition's tribal language: speaking fiber."

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 its 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: $(\text{aNDF} - \text{uNDF}_x) / \text{aNDF} \times 100$. 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.

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 under-

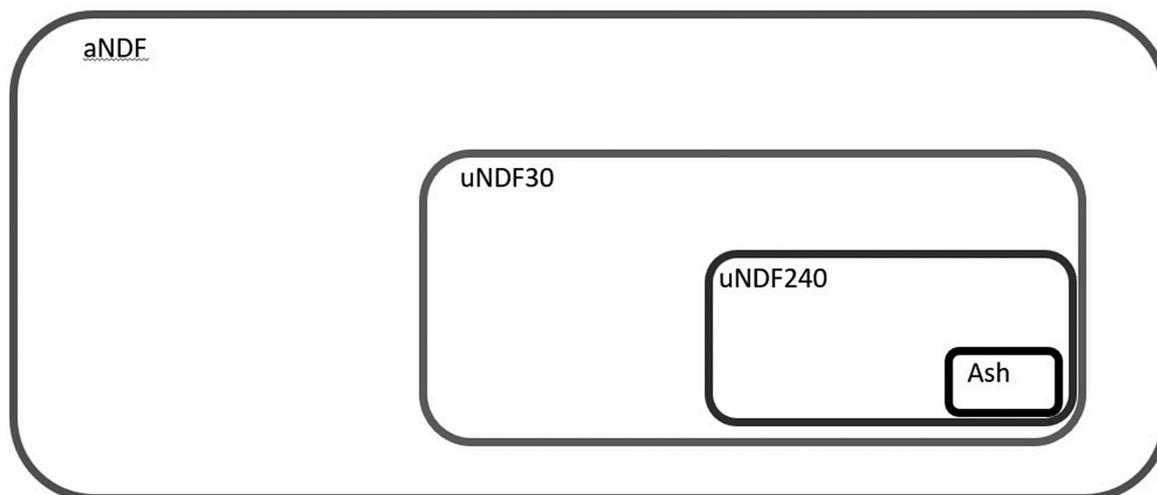


Figure 2: The undigested fiber nesting doll. Each uNDF30 and uNDF240 are nested within aNDF (% of DM).

stood 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 ($aNDF_{om} k_d$, % hr^{-1}) in the following equation:

Rumen NDF digestion (% of aNDF_{om}) = potentially digestible fiber pool x fiber [$k_d / (k_d + k_p)$], where:

- pdNDF, % of aNDF_{om} = $NDFD_{240om} = (aNDF_{om} - uNDF_{240om}) / aNDF_{om} \times 100$
- 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
- aNDF_{om} = 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
- uNDF_{om} = 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. Exceptional grain yields or leaf to stem ratio is the strategy 1 path to lessening uNDF, however with crops bred for grain yield the uNDF may be.

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 walking fields approximately 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 camp fire 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 "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!

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.
- 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.
- 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?
- 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.

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.

On Farm TMR Digestibility (TMRD)

Schalla et al., 2012 JDS

