NDF Intake = 1.25% * Body Weight … What are We Missing?

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SUMMARY

- Dry matter intake (DMI) for dairy cattle can be related to feed NDF level.
- Since the 1980's, ruminal NDF digestibility (dNDF) has been used in ration formulation. It has been reported that a unit increase in dNDF corresponds to a 0.25 kg increase in 4% fat corrected milk.
- When dNDF is increased, undigested NDF is correspondingly decreased. More recent observations suggest that the proportion of forage dry matter represented by undigested NDF (NDF_{u30}) is a major determinant of DMI.
- Understanding factors which cause a divergence between estimated NDF_{u30} and actual NDF_{u30} is critical. These include: improper ash correction in the NDF analysis, inherent variation in digestibility testing, increased rumen passage rate, and ruminal acidosis.

INTRODUCTION

In a recent conference proceedings, Mertens (2010) appropriately stated: "Although the basic biological principles by which fiber affects intake have not changed, our knowledge about the subtle ways in which the characteristics of fiber impact intake regulation and our ability to speculate about the dynamic mechanisms that affect the relationship have changed during the last 15 years.". A traditional view is that NDF intake can be expressed as a fraction of body weight. Waldo (1986) suggested that cell wall concentration (i.e., NDF) of forage diets is the best single chemical predictor of DMI by ruminants.

It is clear that increasing NDF digestibility increases intake (Oba and Allen, 1999). This understanding led to forages being characterized by NDF digestibility (NDF_d; % of NDF). Allen (2000) concluded that "Digestibility of NDF measured *in vitro* or *in situ* using a constant incubation time was a significant indicator of the filling effects of NDF …".

A common convention is to use a 30-hour *in vitro* incubation to estimate NDF digestibility (NDF_{d30} % of NDF). Feeds with higher NDF_{d30} (% of NDF) are generally found to promote more intake. However, the effect of the potentially digestible NDF fraction on gut fill was not clear when evaluated by Allen and Mertens (1988).

Jones and Siciliano-Jones (2013) proposed that the proper characterization of fiber related to intake is the pool size of undigested fiber (NDF_u; % of DM). Following the convention presented above, the pool size of undigested fiber after a 30-hour *in vitro* incubation was introduced ($NDF_{u30}^{©}$; % DM, Copyright FARME Institute, Inc).

Hall (2013) discussed a debate over which incubation time is most appropriate for estimating NDF digestibility (see Figure 1). The 2001 NRC uses a 48 hour incubation time to estimate energy derived from NDF. Our purpose is to estimate "gut fill" which must take into account passage rate. The 30-hour incubation time point seems appropriate given static *in vitro* fermentation and a standard particle passage rate. If the remaining particles have not been fermented or passed, they contribute to gut fill.

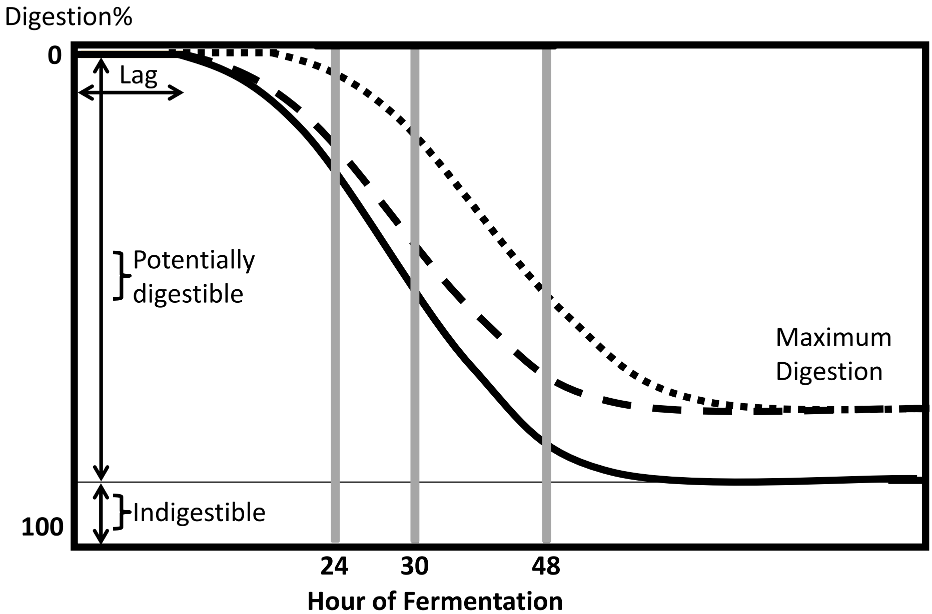


Figure 1. Rate of digestion as seen at different time points given different digestion rates and lag times (Hall 2013).

It is important to differentiate between the terms of "undigested" and "indigestible". The former refers to the ability to be digested given a finite time. In this case, 30 hours. The latter refers to the ability to be digested given infinite time. Usually this is estimated at 240 hours of incubation in rumen fluid.

Examining previous work on NDF digestibility, expressed as percent of NDF fraction, we can substitute the measure of NDF_{u30} expressed as pool size. Previous work that increased NDF digestibility in diets also decreased NDF_{u30}, usually without noting it. For example, Allen (2000) notes that "DMI by cows will be less limited be distention in the gastrointestinal tract as NDF digestibility increases." The concept of fiber digestibility impacting gut fill is not new. However, the proper representation and utilization of NDF_{u30} is new.

NDF_{u30} IN RATION DESIGN

NDF_{u30}© is proposed as an indicator of "gut fill" to be used in designing certain dairy cow rations (Jones and Siciliano-Jones, 2014). First, it is only appropriate to discuss NDF_{u30} in rations where DMI is limited by gut fill. This is typical of intakes during peak production (Mertens, 2010) Situations where DMI is limited by low energy requirement or acid load will likely not respond to manipulating NDF_{u30} content.

NDF_{u30} acts as a gut fill factor only when fed particle size is large enough to inhibit passage from the rumen. The threshold particle size allowing passage from the rumen appears to be 2-4 mm (cited by Allen and Mertens, 1988). Consequently, undigested NDF in particles below this threshold will not be expected to contribute to gut fill as they are not retained in the rumen. Therefore, we propose calculating the pool size of NDF_{u30} only on feeds that have a particle size above 4 mm. In general, only forages and certain large by-products (e.g., whole cotton seed) are included in the gut fill calculation.

Our basic procedure is to calculate the NDF_{u30} content in the forage portion of a ration for a high producing group of dairy cows. As a starting point, high producing large Holstein cows appear to eat about 6.2-6.5 pounds of NDF_{u30} per day. However, what is important is how this NDF_{u30} content changes over time relative to DMI (Jones, 2014). If a forage or ration change results in increased NDF_{u30} in the proposed ration, there is a high probability that DMI will decrease such that the group's actual threshold of NDF_{u30} capacity is not exceeded.

Using the above procedure requires two assumptions. First, it is assumed that gut fill (i.e., NDF_{u30} content) is the most constraining factor in the ration. Second, a forage base (including all significant sources of NDF_{u30}) must be the initial component of ration design. Designing a ration with NDF_{u30} starts with a forage base that does not violate gut fill. This is also intuitive since a ration should be first balanced for the rumen and then for the animal.

It is tempting to discuss NDF_{u30} as a percent of ration dry matter. This has benefits for ration formulation but does not reflect the underlying subject that gut fill is a pool size issue. Let's start with a farm specific assumption that the highest cows have not historically consumed more than 6.3 pounds of NDF_{u30}. Problems arise when a group is balanced for a DMI which is below that consumed by the highest producing cows. For example, a group ration might be balanced for 53 pounds of DMI. However, the highest producing cows might be eating 70 pounds of DM to support peak milk production. A typical calculation is to determine the percentage of NDF_{u30} to ensure that the highest producing cows are not challenged with more than 6.3 pounds of NDF_{u30} intake. In this case, the base ration needs to be 9% NDF_{u30} (6.3 # NDF_{u30}/70 # intake). Conversely if NDF_{u30} percentage is calculated from the group intake (6.3 # NDF_{u30}/53 # intake), the NDF_{u30} content will increase such that the highest producing cows will reach their fill capacity at a reduced DMI. Recommendations for NDF_{u30} as a percentage of DM should be avoided for this reason. This calculation is only useful in determining if the base ration for a group will support the highest producing cows.

Common ration design rules can violate the gut fill capacity of cows resulting in lower milk production. For example, a common ration feature is inclusion of 3 pounds of WCS (DM basis) in all diets. Assuming that WCS is 40% NDF_{u30}, WCS contributes 1.2 lbs of NDF_{u30} to these diets. In a year when NDF digestibility of CS corn silage is poor (e.g., NDF_{u30} increases from 15% to 18%), a ration containing 20 pounds of corn silage will see an increase of 0.6 pounds of NDF_{u30}. Without adjusting the WCS or the corn silage inclusion rates, the high producing cows will have DMI limited by gut fill due to excess NDF_{u30}.

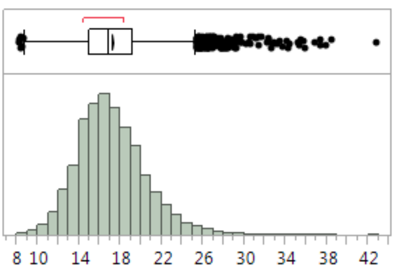
A common consequence of exceeding the gut fill capacity of high producing cows is lower than expected peak production. When DMI is limited by gut fill, the highest producing cows will be impacted the most due to the inability to consume sufficient DMI. When older animals are peaking poorly compared to their younger cohorts, especially when persistency is high, a gut fill problem should be suspected.

DISTRIBUTION OF NDF_{u30} IN FORAGES

Figure 2 contains the distribution of NDF_{u30} for both corn silage and hay crop silage in the Cumberland Valley Analytical Services database. Corn silage has a mean NDF_{u30} value of 17.2%. For hay crop silage, the mean is 23.9% NDF_{u30}.

Distributions

uNDF30 (cs)



Quantiles

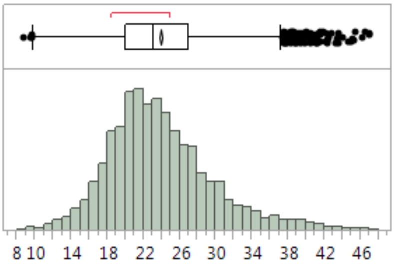
100.0%	maximum	42.7673
99.5%		28.3225
97.5%		24.5807
90.0%		21.4509
75.0%	quartile	19.1271
50.0%	median	16.89
25.0%	quartile	14.969
10.0%		13.391
2.5%		11.6215
0.5%		9.98573
0.0%	minimum	8.17646

Summary Statistics

Mean	17.225373
Std Dev	3.3169967
Std Err Mean	0.0310189
Upper 95% Mea	17.286176
Lower 95% Mean	17.164571
N	11435

Distributions

uNDF30 (hc)



Quantiles

100.0%	maximum	47.0018
99.5%		42.4452
97.5%		38.1842
90.0%		31.2629
75.0%	quartile	26.9821
50.0%	median	23.1107
25.0%	quartile	20.0685
10.0%		17.5634
2.5%		14.5019
0.5%		11.6742
0.0%	minimum	8.65938

Summary Statistics

Mean	23.901011
Std Dev	5.7100741
Std Err Mean	0.0971444
Upper 95% Mea	24.091477
Lower 95% Mean	23.710545
N	3455

Figure 2. Distribution of NDF_{u30} content for corn silage and haylage observed in the Cumberland Valley Analytical Service database. Provided by R. Ward, 2013, Cumberland Valley Analytic Services.

The variance seen in these distributions suggest fairly large gut fill differences. First, it becomes clear why high corn silage diets generally result in less gut fill. The average corn silage sample has nearly 7 percentage points less NDF_{u30}. A ration that contains equal amounts of average corn silage and average haylage with a constraint of 6 pounds of NDF_{u30} will contain 29 pounds of forage. Conversely, a diet with 80% average corn silage and 20% average haylage will allow 32 pounds of forage.

A common scenario occurs when a growing year results in lower fiber digestibility (i.e., higher NDF_{u30}). Consider again a 80:20 corn silage:haylage diet when the NDF_{u30} changes from an excellent corn silage (25% quartile; 14.97 % NDF_{u30}) to a poor corn silage (75% quartile, 19.12% NDF_{u30}). The NDF_{u30} content of the diet will increase from 6 to 7.3 pounds. If our group was eating 66 pounds of DM (9% NDF_{u30}), the intakes will probably decrease to 54 pounds due to increased gut fill.

A related topic is the accuracy of NDF digestibility as measured in the laboratory. One should remember that digestibility testing has been common since the 80's (Nocek and Russell, 1988) and was intended to be a qualitative test for ranking forages since the variability is much higher than typical chemical analyses performed on forages. Hall and Mertens (2012) reported that within a given laboratory, 95% of the digestibility results for a given forage sample fall between ± 4.9% NDFD from the mean. If we use a typical forage consisting of 40% NDF and a 50% NDFd, then the NDF_{u30} will be 20%. If the NDFd measure varies from 45 to 55% then the NDF_{u30} will vary from 18 to 22%. This does not take into account the variation inherent in NDF chemical analysis which would further increase the range of values. Using NDF_{u30} as a gut fill index is consistent with the notion of a qualitative index.

WHEN DOES PREDICTED NDFu30 ≠ ACTUAL NDFu30?

As forage analysis evolves, it is becoming more biological than chemical in nature. For example, measuring starch content is a simple chemical analysis. Conversely, estimating starch availability requires mimicking the biology of starch digestion. This is also true for NDF digestibility. To correctly apply NDF_{u30} in ration design, it is important to explore scenarios where the predicted NDF_{u30} does not properly estimate the biological NDF_{u30}.

As an example, consider the haylage sample shown below. The NDF_{u30} is 27% of the DM. If our new diet design calls for 2 pounds of NDF_{u30} from haylage, we will limit inclusion in the diet of this haylage to 7.5 pounds of DM. In this scenario, the cows will almost certainly increase DMI. Why? The NDF_{u30} is not really 27%. This analysis demonstrates a classic example of NDF which is not corrected for ash contamination. Looking closer at this sample, there is a 9 point difference between aNDF and aNDFom. Further, the NDF_{d30} and NDF_{u30} are calculated from aNDF (13.7% + 27% = 40.7%). From a typical haylage, the NDF_{u30} is overestimated by approximately 6-7 points. A better estimate is 21% NDF_{u30} which now allows an inclusion of 9.5 pounds of haylage in our example diet. When there is high ash content (> 3%) in the NDF fraction, the undigested portion will be overestimated when calculated using aNDF which is not corrected for ash content.

FIBER	% NDF	% DM
ADF	89.3	33.1
aNDF		**40.7**
aNDFom		31.8
NDR (NDF w/o sulfite)		
peNDF		
Crude Fiber		
Lignin	18.32	7.46
NDF Digestibility (12 hr)		
NDF Digestibility (24 hr)		
NDF Digestibility (30 hr)	**33.8**	**13.7**
NDF Digestibility (48 hr)		
NDF Digestibility (240 hr)	46.5	18.9
uNDF (30 hr)	66.2	27.0
uNDF (240 hr)	53.5	21.8

Figure 3. Example fiber analysis in a forage sample that contains ash contamination in the NDF fraction.

A second scenario which will overpredict the gut fill impact of forages is finely chopped diets. NDF_{u30} calculated *in vitro* is independent of passage rate. When passage rate increases, the amount of particles remaining in the rumen at a specific time decreases. Consequently, excessive NDF_{u30} intake can be an indicator of increased NDF passage. Another documented scenario is that passage rate changes with the animal's cold stress. Hence, gut fill capacity may change during periods of cold stress.

Ration characteristics that reduce fiber digestibility constitute a third scenario where gut fill is higher than predicted. Most common is increased acid load that inhibits fiber digesting bacteria. Low ruminal pH from highly fermentable feeds can decrease rate of fiber digestion and increase the filling effect of the diet (Allen and Mertens, 1988). Recently, ration starch has been a focus as a dietary component that lowers ruminal pH. This focus has ignored the reality that digestible NDF can also be highly fermentable and contribute to acidosis. In a recent popular press summary, Fredin (2014) showed that replacing starch with non-forage fiber sources did not change rumen pH. It should not be surprising that low starch diets combined with other sources of highly fermentable carbohydrate can result in low rumen pH which will depress fiber digestion. This, in turn, increases actual NDF_{u30} and the gut fill characteristics of the diet.

Differences in particle retention time for different types of forage NDF can cause predicted NDF_{u30} to not correspond to actual NDF_{u30}. In general, NDF in legumes is thought to have less filling effect than NDF in grasses (Oba and Allen, 1999). An example of this effect was seen in a study to examine perennial ryegrass silage compared to alfalfa silage where the alfalfa silage was found to support greater DMI (Hoffman et al., 1998). Recalculating their data into a gut fill context, the alfalfa silage was 20.9% NDF_u while the perennial ryegrass was 16.8% NDF_u as a percent of DM. However, in this case, the cows consuming the alfalfa silage ate nearly 5 pounds more DM than the perennial ryegrass. The differing gut fill effect of different forages types argues for monitoring the gut fill effects in diet specific scenarios (Jones, 2014).

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