# IMPORTANCE OF FIBER AND DIGESTIBILITY ANALYSIS TO PREDICT ANIMAL PERFORMANCE©

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## INTRODUCTION

Fiber concentration and its digestibility are major factors in determining the intake potential and energy availability of forages. This is particularly true for alfalfa, which has unique fiber characteristics that affect nutritive value. The two factors that have the greatest effect on animal performance are intake (70-75% of variation) and digestibility (15-25% of variation), and nutritive value is the product of these two factors (intake X digestibility). If we can estimate how much of a feed a dairy cow can eat and how much she can digest, we can be confident in estimating the feed's impact on animal performance.

Note that I am discussing a feed's intake "potential" and what a cow CAN eat, not necessarily how much she WILL eat in a given situation. Feed intake is a complicated process that is the interaction among animal requirements, diet characteristics, and feeding situations (management and environment). Thus, feed characteristics alone rarely determine feed intake, but they can certainly provide an upper limit for intake, i.e., intake potential. When discussing the intake potential of a feed we are referring to its maximum intake when the animal is achieving maximum productivity. Intake regulation is first in importance in evaluating a feeds nutritive value – no cow has ever produced milk from feed she did not eat.

After a feed has been eaten, the greatest loss of nutrients to the animal is in the feces – the fraction of the feed that is not digested and is excreted in the feces. Neutral detergent fiber digestibility (NDFD) is second to only the neutral detergent fiber (NDF) concentration for determining the total dry matter digestibility (DMD) of forages. The DMD of a feed is less affected by the animal than by the feed's characteristics. This is the justification for emphasizing the measurement of digestibility compared to measuring intake. The only significant animal characteristic affecting intake is the rate of passage of digesta. As intake increases (especially for dairy cows), passage increases, and the time allowed for digestion decreases. Fiber digestion is relatively slow compared to other nutrients; therefore, it is affected more by passage rate.

## INTAKE

The physical and physiological mechanisms of intake regulation have been described in detail Mertens (1994), but a few examples can describe the salient aspects. If we feed a straw only diet (high fiber/low energy) to a lactating dairy cow, there is a limit to how much of it she can eat because she fills with NDF. Her constraint is the amount of fiber she can process by chewing, digestion, and passage. She stops eating because of NDF fill, and limits her production to match


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her digestible dry matter intake. If we feed this cow a high energy/low fiber diet, she will eat until she has met the energy needed for her milk production potential. The same diet, when fed to three cows with different levels of milk production and stages of lactation, will generate three different intakes. To feed the maximum amount of forage in dairy rations, we need to maximize the fiber intake that still allows her to meet her energy requirements. Mertens (1987) observed that cows can maximize milk production when fed up to 1.2% of their body weight per day as NDF, and you typically see this number in forage evaluation indexes. Alfalfa is both palatable and low in NDF, and this results in high intakes of alfalfa.

## DIGESTIBILITY

Digestibility is important because it determines the proportion of the nutrients in the feed consumed that is absorbed and used by the animal. Initially, digestibility was predicted by empirical regression equations using acid detergent fiber (ADF). However, the development of the NDF method for forage analysis was a milestone because it divides feed into nutrients that are easily digested (NDS = neutral detergent solubles = 100 – NDF) and those that have variable digestibility (NDF). This resulted in a simple summative equation to describe DMD:

DMD (%) = NDFD*NDF + 0.98*NDS – 12.9 = NDFD*NDF + 0.98*(100 – NDF) – 12.9.

This equation indicates that DMD is simply a function of NDF and its digestibility (NDFD). We can easily measure NDF, but measuring its digestibility in the laboratory is difficult (we can’t feed the submitted sample to animals and collect their feces). We use an in vitro system in which the sample is fermented in a flask with buffers, nutrients and ruminal inoculum to mimic the fermentative digestion that occurs in the rumen of cows. Although in vitro methods are complicated, commercial feed analysis laboratories can reproduce measurements quite well when they follow a standard method. Thus, it is more appropriate to estimate DMD using summative equations that include NDF and NDFD instead of regression equations using ADF.

Initially, we treated NDF as a single fraction of dry matter that had variable digestibility (1-pool model, Figure 1), and used in vitro methods to measure NDFD after 24 to 48 h of fermentation. Longer times were used to estimate NDFD for animals with low intakes and shorter times were used for animals with higher intakes. In vitro NDFDs at 30 h ($NDFD_{30}$) are provided for various qualities of alfalfa in table 1. If you use the summative equation above with the NDF and $NDFD_{30}$ from table 1, you will obtain DMD ranging from 60.0 to 73.4. These DMD agree closely with values measured in digestion trials for the more mature alfalfas, but are slightly higher than observed for immature alfalfas.

Fiber digestibility is also related to intake because fiber that is more quickly digested allows room in the rumen for additional intake. Oba and Allen (1999) indicated that each percentage increase in NDFD of the forage resulted in increases in both intake and milk production. But NDFD does not indicate the amount of NDF in the feed. Mertens (2006) observed that NDF content was three times more important than NDFD in affecting production or intake. Thus, it is recommended that nutritionists formulate for NDF first and then fine-tune rations using NDFD.

Our conceptual model of NDFD has changed considerably since NDF was developed in the 1960s. It was observed that cellulose and NDF did not completely digest even when fermented for 4-6 days. This indicated that a certain fraction of fiber was indigestible in anaerobic fermentations like the rumen. This fundamentally changed our concept of fiber digestion (Figure 1) and introduced the concept of digestion kinetics (the rate and extent of fiber fermentation). The 2-pool model of NDF indicates that NDF is not a single entity with uniform digestibility, but that NDF consists of two fractions that have completely different digestive properties.

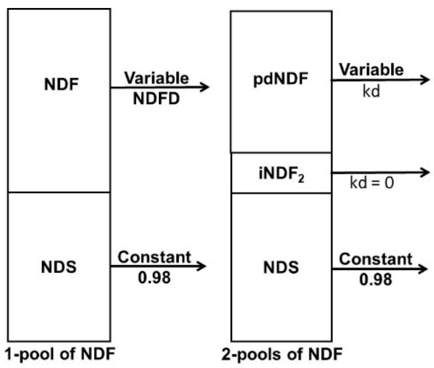

Figure 1. Illustrations of the original 1-pool model of NDF digestion compared to the current 2-pool model of NDFD.

Indigestible NDF ($iNDF_2$) does not digest in the rumen and the potentially digestible NDF (pdNDF) is the fraction of NDF that digests with fractional digestion rates that vary with the feed. Although we cannot measure $iNDF_2$ because it would take infinite time, we can estimate it as the undigested NDF (uNDF) after long fermentation times (>72h). Currently we are measuring uNDF after 240 h of in vitro fermentation ($uNDF_{240}$), but this is probably longer than necessary for alfalfa, which ferments very quickly (see kd in Table 1). The $uNDF_{240}$ of alfalfa increases with maturity and decreases with higher forage quality (Table 1). In immature alfalfa, it is about 40% of NDF, but $uNDF_{240}$ increases to over 50% of NDF in more mature alfalfa. The $iNDF_2$ provides structural support for the plant as it grows taller, but provides no digestible nutrients to the dairy cow. Because it does not digest, $uNDF_{240}$ may limit intake because it can only be passed out of the rumen after it is chewed. Thus, it may limit intake because it accumulates in the rumen.

Table 1. Typical chemical composition and kinetic properties (derived from multiple sources) for alfalfas of different qualities (all values as a percentage of DM except for NDFD and kd).

| Description | Ash | Pec[a] | ADF[b] | ADL[c] | aNDF[d] | aNDFom[e] | $NDFD_{30}$[f] | $uNDF_{240}$[g] | pdNDF[h] | kd/h[i] |
|---|---|---|---|---|---|---|---|---|---|---|
| Exceptional | 10.4 | 14.3 | 24.0 | 4.58 | 29.8 | 28.9 | 58.7 | 11.8 | 17.9 | 0.130 |
| Very high | 9.9 | 13.4 | 27.0 | 5.39 | 33.7 | 32.8 | 54.1 | 14.5 | 19.2 | 0.107 |
| High quality | 9.5 | 12.5 | 30.0 | 6.22 | 37.7 | 36.9 | 50.3 | 17.2 | 20.5 | 0.093 |
| Good quality | 9.1 | 11.5 | 33.0 | 7.06 | 41.9 | 41.1 | 46.9 | 20.1 | 21.9 | 0.082 |
| Fair quality | 8.7 | 10.5 | 36.0 | 7.93 | 46.3 | 45.4 | 43.9 | 23.0 | 23.3 | 0.073 |

[a] Pectin
[b] Acid detergent fiber
[c] Acid detergent lignin – 72% sulfuric acid method
[d] amylase-treated neutral detergent fiber
[e] amylase-treated neutral detergent fiber organic matter (ash-free aNDF)
[f] NDF digestibility (% of NDF) measured in vitro after 30 h of fermentation
[g] undigested NDF after 240 h of in vitro fermentation
[h] potentially digestible NDF (= NDF – $uNDF_{240}$)
[i] fractional rate of digestion per hour of pdNDF

## CHEMICAL ANALYSES

There is no chemical called fiber that could be a reference for fiber methods. Fiber (NDF) is a complex mixture of cellulose, hemicellulose and lignin that varies with plant species and maturity.  Fiber methods are empirical which means that the residue measured is a function of the method. Thus, accuracy in measuring fiber is determined by how closely the method is followed. The method for amylase-treated NDF (aNDF) was standardized by Mertens (2002), but recently differences among laboratories are occurring that may be related to the grinding technique and filters used to capture the fiber. Commercial laboratories typically use cyclone mills that generate a finer grind that the cutter-mill method used in the development of aNDF, and alternative filters are used that differ from the original crucibles. Efforts are in progress minimize the effects of these modifications. However, the major change to NDF analyses had been the adoption of ash-free NDF or NDF organic matter (aNDFom; Mertens, 2002). This has occurred because about 10-15% of forage samples have high levels of ash that appears to be due to field operations that mix soil with forages when windrows are combined for efficient use of large choppers and balers. Reagents used for NDF do not dissolve much of the ash in soil resulting in NDF values that are high due to ash contamination. Results for aNDFom shown in table 1 are not from samples contaminated with soil. If total ash values are 2%-units higher than those in table 1, soil contamination should be suspected and aNDFom should be measured. Not only does ash contribute nothing to digestible energy, but also when dairy farmers are feeding low fiber diets, the over-estimation of NDF can cause health and low milk fat issues.

Although the role of ADF in evaluating feeds and formulating dairy rations has diminished, it is still measured and used as a "check" on NDF analyses and forage characteristics. The difference between ADF and NDF is often used to estimate hemicellulose. Alfalfa has less hemicellulose than grasses and the difference between or ratio of ADF:NDF can be used to detect the predominant forage in mixed forages. It is often assumed that the difference between NDF and ADF should be about 8-10%-units for alfalfa, but laboratories report that they see as many values <4 and they do >8. Unfortunately, pectin in alfalfa, and feeds like citrus pulp, complicates this distinction. The NDF method was designed to dissolve most of the pectin because it is easily digested and, from a nutritionist's perspective, should be included in NDS. Acid detergent does not dissolve pectin as well as neutral detergent and the contamination of ADF with pectin increases as pectin concentration increases. In very immature alfalfa, pectin contamination of ADF can increase to the point that ADF can be close to or even exceed NDF.

## NUTRITIVE VALUE

The concept of a Nutritive Value Index was first proposed by Crampton et al, (1960) as the product of intake (relative to a reference animal) and digestibility. This concept was used to create the Relative Feed Value (RFV), which used NDF to estimate intake and ADF to predict digestibility. It is not surprising that RFV is highly correlated with NDF given that intake and DMD are related to NDF. Relative Forage Quality (RFQ) index is also based on the product of an intake and digestibility. It uses a summative equation to estimate Total Digestible Nutrients (TDN) base on crude protein, crude fat, nonfiber carbohydrates, NDF and NDFD. It estimates intake for legumes by adjusting the intake for used for RFV by the relationship of intake to NDFD proposed by Oba and Allen (1999). Intake for grass forage is estimated by a regression equation that predicts intake of nonlactating ruminants. Although we may quibble about the relative merits of different indexes, in principle they are correct in assuming that intake and digestibility are the key factors affecting forage value for ruminants.

## FOOD FOR THOUGHT

The greater concern with nutritive value indexes is the assumption that the economic/nutritional value of forages based on these indexes is linear. The October 2019 prices for alfalfa hays of different qualities in different states are plotted in Figure 2. The effects of each state's base price were removed to determine the average relationship between price and RFV. In general, there was a linear relationship with each unit increase in RFV increasing price by about $2.37/ton. Average values of premium, good and fair alfalfa hay were 215, 174, and 126 $/ton, respectively. Statistically, price actually increased above the average as RFV increased, which may reflect the rarity and cost of producing alfalfa hay with extremely high RFV (Figure 2). But the economic law of diminishing returns would suggest the nutritional value of each increasing unit of RFV should diminish in value (Figure 2) when all other dietary inputs are held constant. Although a small amount of alfalfa hay with extremely high RFV may stimulate additional intake (like our dessert at the end of a meal), it becomes difficult to formulate dairy rations with large quantities of these alfalfas because they are very low in fiber and very high in crude protein.

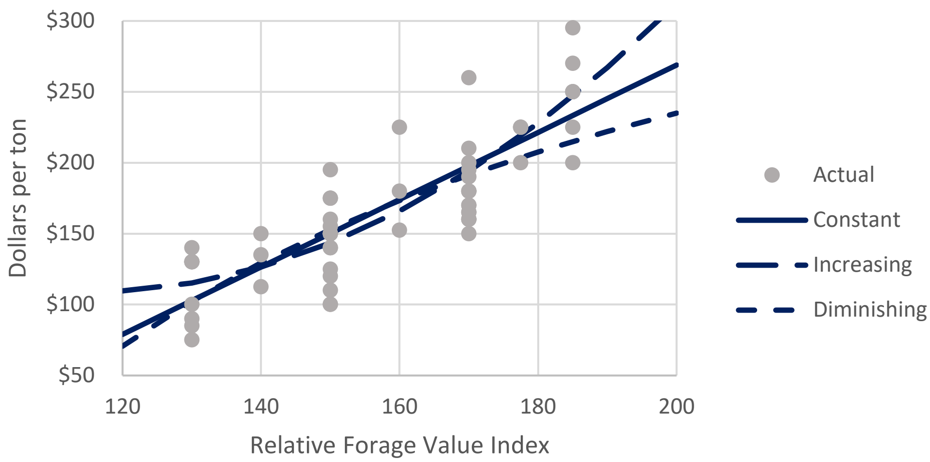


Figure 2. Prices per ton of alfalfa hays for different relative forage values as reported in *Hay & Forage Grower* for October 2019 (some prices included delivery).

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