FERMENTABLE FIBER FOR DIET FORMULATION

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INTRODUCTION

Feed formulation is the art of combining ingredients to meet nutritional requirements of animals. Ruminants have a 4-compartment stomach made up of the rumen, reticulum, omasum, and abomasum or true stomach. The largest compartment is the rumino-reticulum, which contains bacteria and protozoa and functions as a fermentation vat in which fiber is digested. Thus, appropriate feed components are needed for normal ruminal bacteria and protozoa to flourish in order to develop (Warner et al., 1956) and maintain proper rumen function. Diets for ruminants should, therefore, be formulated to provide: 1) feed components for fermentation by and multiplication of ruminal microbes; and 2) feed components that are directly digested into nutrients in the true stomach and intestines. The major end product categories of fermentation by ruminal microbes are 1) volatile fatty acids (VFA: acetate, propionate, butyrate), which are absorbed through papillae of the rumen wall; and 2) more bacteria and protozoa. The VFA are metabolized by ruminants into glucose and other carbohydrates or used directly as fuel and to synthesize tissues and milk. The bacteria and protozoa are passed to the abomasum and small intestine where they are digested to provide high quality protein and other nutrients.

TRADITIONAL DIET FORMULATION

In the past, ruminant diets have been balanced for energy, protein, vitamins, and minerals. In some systems, protein is balanced for 1) that degraded by ruminal bacteria and protozoa; 2) feed protein that escapes ruminal fermentation so that it is digested in the lower gut; and 3) microbial protein digested in the lower gut. Energy values of feed ingredients and energy requirements of animals were used to determine the amount of feed necessary for maintenance, growth, wool growth, pregnancy, and lactation. Traditional diet formulation begins by estimating dry matter intake. Ingredients to meet nutrient requirements are then chosen to fit into the estimated dry matter intake.

Dietary energy comes mostly from carbohydrates with some contribution from protein and lipids. Many energy systems have been developed. They all disregard the fact that the composition of the carbohydrate fractions (fiber, starch, sugars, pectins) can have dramatic influences upon feed intake, rumen function, and the nutrients that are available to the animal. Thus, as discussed below, any formulation system that estimates dry matter intake prior to diet formulation probably will result in formulation errors.

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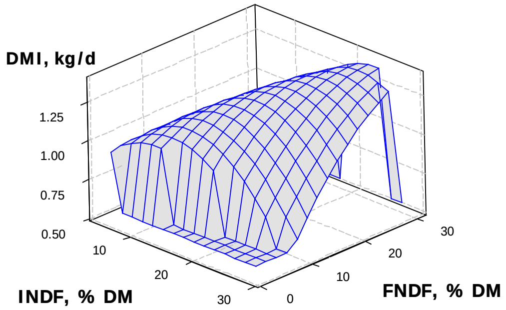
[1] Deceased.

EFFECT OF CARBOHYDRATE FRACTIONS ON FEED INTAKE

Dietary carbohydrates are categorized as nonstructural (mainly starch and sugars) and structural. Structural carbohydrates are those that shape plants and their products and they are usually referred to as fiber. Until the 1960's, fiber was not measured in any chemically-defined way. Then, Peter Van Soest, working at the USDA lab in Beltsville, MD and later at Cornell University, developed the detergent system (Van Soest, 1964; Van Soest, 1967), which quantified total fiber – or cell walls – of feed ingredients using neutral detergent. Neutral detergent fiber (NDF) includes cellulose and hemicelluloses, which both can be fermented by rumen microorganisms unless the fiber also contains too much indigestible lignin.

A meta-analysis of experiments to define the minimum NDF requirements of growing lambs (Hogue, 1993; Hogue, 1994; Hogue and Jabbar, 1991; Thonney and Hogue, 2007) showed that the source of NDF had a major effect upon feed intake. When included at high dietary concentrations, NDF from low digestibility oat hulls reduced intake while NDF from highly digestible soy hulls increased intake. The effect on intake of other high-fiber ingredients; such as beat pulp, alfalfa meal, corn gluten feed, and wheat middlings; varied with their digestibilities. The results are summarized in Figure 1. This led to the conclusion that high concentrations of indigestible NDF (INDF) reduce intake while high concentrations of fermentable NDF (FNDF) increase intake.

Figure 1. Surface plot showing the equation derived from multiple experiments that describes the relationship of feed intake of growing lambs to dietary INDF and FNDF.



Confirming Experiment[2]

A designed lamb growth experiment was conducted using 40 raised expanded metal floor pens with 2 lambs per pen to confirm the results of the meta-analysis. The objective was to quantify the responses for intake, digestibility, and growth rate to diets across the widest possible range of potentially-fermentable NDF (pfNDF, FNDF at maintenance intake) and INDF values.

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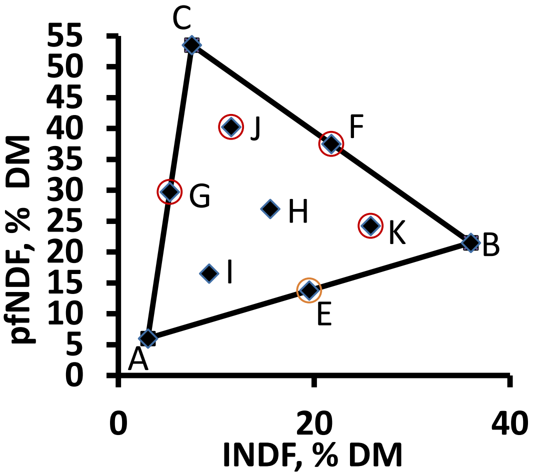
[2] Calvin Cho, Debbie Ross, Natasha Pettifor, and Tom Smith helped with the experiment.

The experiment used 80 January-born, ¼ East Friesian × ¾ Dorset ewe lambs (2 lambs per pen) in a 5-wk feeding trial begun on 5 April 2010 after a 1-wk transition from creep feed. Chromic oxide was added to the feed for 10 d at 0.5% during week 3 of the experiment to measure digestibility. Feces were collected on screens underneath each pen for the last 3 days of chromic oxide feeding.

Diets for Confirming Experiment

The proportion of feed ingredients that were indigestible NDF (INDF) was estimated by assuming that all of the non-metabolic portion of the fecal DM was undigested NDF (Thonney and Hogue, 2007). Fecal DM for each ingredient were computed from tabular values for DM digestibilities. Metabolic fecal losses were assumed to be 10 to 15% of the feed DM depending upon the type of ingredient (Van Soest, 1994). Thus, INDF was calculated as fecal DM – metabolic fecal DM. Potentially-fermentable NDF (pfNDF) was calculated as NDF minus INDF. Under this definition, because tabular feed ingredient digestibility values were obtained from animals at maintenance levels of intake, pfNDF values are assumed to be those that would result from maintenance levels of intake. Hein et al. (2009) showed that actual FNDF values decline dramatically as feed intake increases.

Figure 2. Design of response surface experiment for lambs (all diets) and ewes (circled diets).



Highly digestible soy hulls and poorly digestible oat hulls were used to formulate 10 diets (Table 1) that varied in estimated concentrations of INDF and pfNDF (the total is NDF) as shown in Figure 2. Each diet was assigned randomly to 4 elevated, expanded metal floor pens. The diets were corn-based with soybean meal substituted to balance for crude protein to be 16% of dietary dry matter. Diet A included no added NDF. Instead of corn, diet B contained mostly oat hulls. Instead of corn, diet C contained mostly soy hulls. It is not possible to use corn, soy hulls, and oat hulls to formulate diets with INDF and pfNDF concentrations outside of the triangle formed by points for diets A, B, and C. Diets E through K were selected to provide equal coverage of the INDF-pfNDF area. Diets E, F, and G represent the midpoints of the lines making the triangle. Diet H is at the center of the triangle. Diets I, J, and K are the midpoints of lines from H to the corners of the triangle.

Table 1. Diet compositions (% of feed).

	Diets									
Ingredient	A	B	C	E	F	G	H	I	J	K
INDF, % of DM:	3	36	7.5	19.5	21.8	5.3	15.5	9.25	11.5	25.75
pFNDF, % of DM:	6	21.5	53.5	13.8	37.5	29.8	27	16.5	40.25	24.25
Corn, cracked	78.98			39.91	0.63	39.69	26.79	52.06	13.70	13.85
Oat hulls		69.24	0.20	34.21	34.50		22.84	12.40	11.50	45.85
Soy hulls			84.48	0.35	42.30	42.49	28.49	13.95	56.39	14.20
Soybean meal	12.50	22.50	8.00	17.40	15.30	10.20	14.20	13.50	11.20	18.40
Molasses	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Cornell/Old Mill Premix[a]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ammonium chloride	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
CSF Vitamin E premix	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Deccox	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02
Calcium carbonate	1.30	0.80		0.90	0.05	0.40	0.45	0.85		0.48
Sodium phosphate, dibasic		0.24	0.10							
Total	100	100	100	100	100	100	100	100	100	100

[a] 50% salt, 45.9% dried distillers grain (carrier), 0.5% feed grade oil; contains 2500 ppm Mn, 9370 IU/kg vitamin E, 30 ppm Se, 2000 ppm Zn, 80 ppm I, 264552 IU/kg vitamin A, 33069 IU/kg vitamin D, 20 ppm Co, 70 ppm Mo.

Statistical Analysis of Confirming Experiment

Pens were the experimental units. Lambs were weighed weekly. Cubic regression equations for day of experiment were fitted to the 6 weights of each lamb to compute initial and final weights. These weights were then averaged within pen to compute average daily gain on a per lamb basis. Feed remaining was collected from each pen and weighed and sampled at the time of weighing the lambs each week. Samples of feed and feed remainders were dried in a 60°C forced-air oven to determine dry matter values.

The effect of diet was analyzed by one-way analysis of variance. A modified step-down regression procedure was used to show the response surface for ADG, DMI as a percentage of average experimental BW (DMI%BW), grams of gain per kg of DM (G/DM) and DM and NDF digestibility, First, a full regression model was fitted to INDF, FNDF, their crossproducts, their quadratics, and the crossproduct of their quadratics. Then, the highest order non-significant ($P > 0.10$) effect was removed from the model. This continued until only significant effects remained. The final regression equations were then used to generate response surfaces.

Results and Discussion of Confirming Experiment

One lamb in one of the four pens of lambs fed Diet E was removed because she did not adapt to the diet during the one-week transition from creep feed prior to the start of the experiment. One lamb in one of the four pens of lambs fed Diet B had lost significant weight by d 31 of the 35-d experiment and had to be removed; the data from that pen were included through d 31.

Table 2. Growth and feed intake of lambs.

	Diet design								
Diet	NDF, % DM	INDF, % DM	pFNDF, % DM	Initial weight, kg	Final weight, kg	DMI, g/d	DMI, % BW	ADG, g	Grams gain/kg DMI
A	9.0	3	6	22.6	31.0	901	3.4	240	267
I	25.8	9.25	16.5	25.5	34.2	1165	3.9	250	214
E	33.3	19.5	13.8	25.9	34.3	1202	4.0	240	194
G	35.0	5.3	29.8	24.7	33.4	1162	4.0	247	214
H	42.5	15.5	27	24.4	32.5	1198	4.3	231	190
K	50.0	25.75	24.25	23.6	30.8	1212	4.5	206	168
J	51.8	11.5	40.25	23.5	31.5	1276	4.6	227	178
B	57.5	36	21.5	23.3	24.9	717	3.0	44	46
F	59.3	21.8	37.5	23.7	30.9	1181	4.3	207	174
C	61.0	7.5	53.5	23.9	31.8	1260	4.5	226	179
			SE:	1.34	1.84	81.6	0.20	28.7	23.9
			P-value:	0.810	0.062	0.001	<0.001	0.001	<0.001

Growth and feed intake data are shown in Table 2 with diets ranked by level of NDF based upon tabular values for feed ingredients used to design the diets. NDF level had an inconsistent effect on DMI%BW, ADG, and G/DM that was partially explained by the portion of NDF that was fermentable (Figure 3 – Figure 5). As INDF increased, DMI%BW first increased to a maximum at 17% of dietary INDF and then it declined (Figure 3). As FNDF increased, DMI%BW increased continuously at any level of INDF (Figure 3). While a quadratic NDF equation explained only 17% of the variation in DMI%BW, dividing NDF into that which is fermentable and indigestible accounted for 57% of the variation. This raises two important points: 1) NDF is a poor predictor of DMI compared to its fermentable and indigestible components; and 2) the traditional approach of balancing diets by assuming a set amount of DMI is not consistent with the fact that dietary components influence DMI.

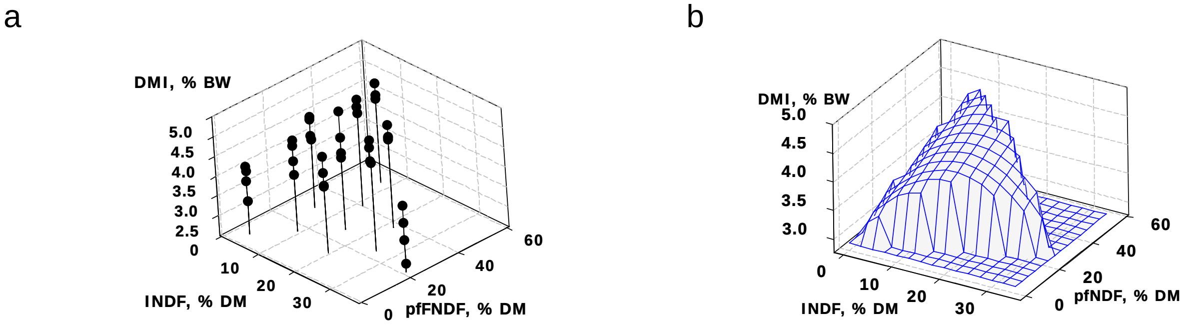
The results for ADG are shown in Figure 4. While ADG changed with feed intake levels as INDF increased and reached a peak at 17% INDF, there was no effect of pfNDF so that efficiency (G/DM) declined linearly with increasing pfNDF (Figure 5). The linear decline of efficiency with increasing pfNDF was partially a result of dilution of corn with lower digestibility soy hulls. But the decrease was also related to decreasing NDF digestibility (fermentability) as feed intake increased (Hein et al., 2009).

Grams of gain per kg DM declined quadratically as INDF increased. As shown in the surface plot in Figure 5b, increasing the INDF resulted in a much faster decline in efficiency than increasing pfNDF. While some lambs fed the highest levels of INDF consumed low levels of feed throughout the experiment, no lambs showed indications of rumen acidosis or going off feed. In fact, one of the conclusions that might be made from this experiment is that fiber, whether highly fermentable or not, added to high corn diets (like Diet A) simply reduces growth rate and efficiency. This would be a mistake because lambs in most lamb feeding operations are not as carefully placed on feed or monitored as they were in this experiment.

Analyzed dietary NDF values, and values for digestibility of organic matter and NDF, from which actual FNDF values were computed, are shown in Table 3. Analyzed NDF values were lower than expected based upon tabular values, primarily due to lower than expected NDF in oat hulls.

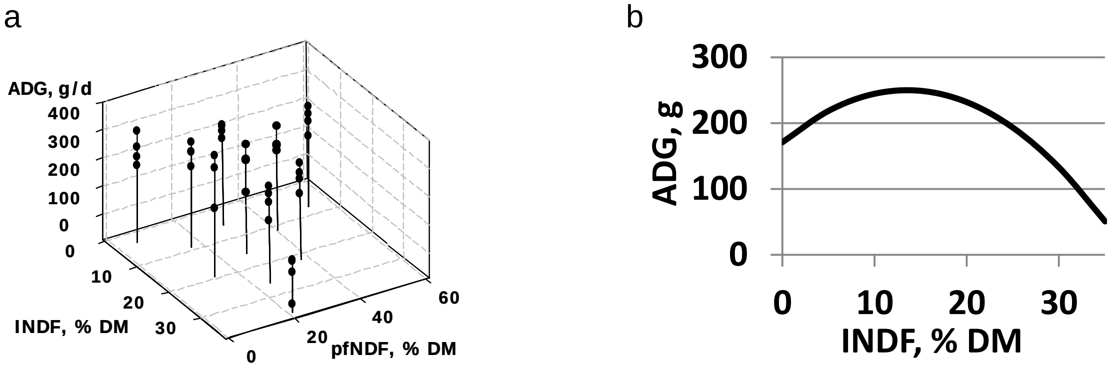
As expected, diet A – with no added NDF from soy hulls or oat hulls – resulted in the highest organic matter digestibility (OMD) of 86%. Although the OMD of diet I was moderately high (75%), diet G resulted in OMD of 78% even though the NDF concentration was much higher. The OMD of the other diets was not related to the NDF concentration and only somewhat related to the expected digestibility of the NDF. For example, diet J, which had the second highest pfNDF, had the lowest OMD, while diets B, F, and C – which had similar concentrations of NDF, but dramatically different pfNDF values – had similar OMD values. Digestibility of NDF and the actual FNDF values were somewhat more in agreement with expected values, but there were major inconsistencies. These are discussed further in relation to the INDF-FNDF response surfaces.

Figure 3. Effect of estimated dietary INDF and pfNDF concentrations on dry matter intake as a percentage of body weight. (a) Scatter plot of the data. (b) surface plot of the equation: DM%BW = 2.90 + 0.112*INDF + 0.0188*pfNDF – 0.00329*INDF^2 (r^2 = 0.57, SE = 0.40).



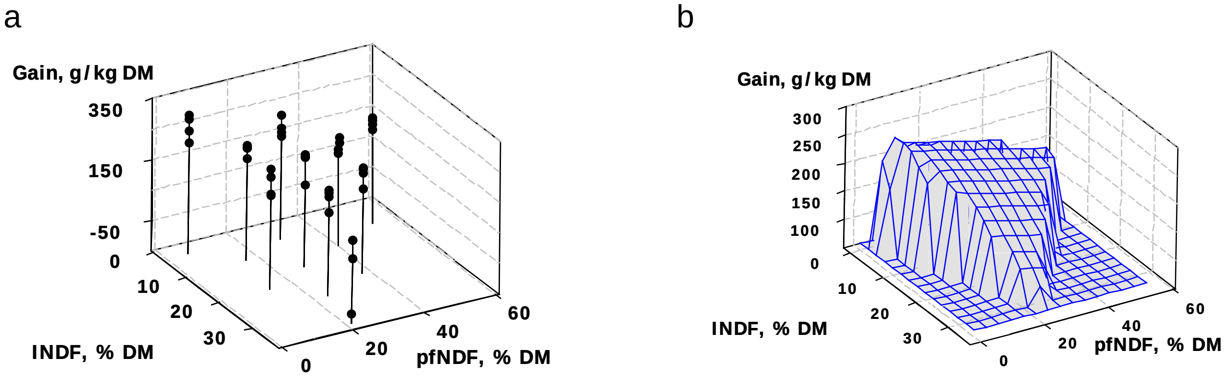
As expected, OMD declined as both INDF and pfNDF increased (Figure 6). The decline was rapid at first, especially as INDF increased. It reached a nadir at INDF = 19 and pfNDF = 30 and increased at higher INDF and pfNDF values. INDF and pfNDF together accounted for 71% of the variation in OMD, while NDF alone explained only 53% of the variation.

Figure 4. Effect of estimated dietary INDF and pfNDF concentrations on ADG. (a) Scatter plot of the data. (b) graph of the equation (pfDNF had no effect): ADG = 209 + 6.84*INDF– 0.0311*INDF^2 (r^2 = 0.54, SE = 54).



Digestibility of NDF (dNDF) declined rapidly with initially increased INDF, but it unexpectedly increased at the highest INDF levels (Figure 7). At any INDF concentration, dNDF increased as pfNDF increased. However, as pfNDF increased, dNDF increased at a decreasing rate. INDF and pfNDF together accounted for 66% of the variation in dNDF, while NDF alone explained only 6% of the variation. Similar results were obtained for actual FNDF (Figure 8) where INDF and pfNDF together accounted for 92% of the variation, while NDF alone explained only 40%.

Figure 5. Effect of estimated dietary INDF and pfNDF concentrations on G/DM. (a) Scatter plot of the data. (b) graph of the equation: G/DM = 265 – 1.42*pfNDF – 0.132*$INDF^2$ ($r^2 = 0.57$, SE = 46).



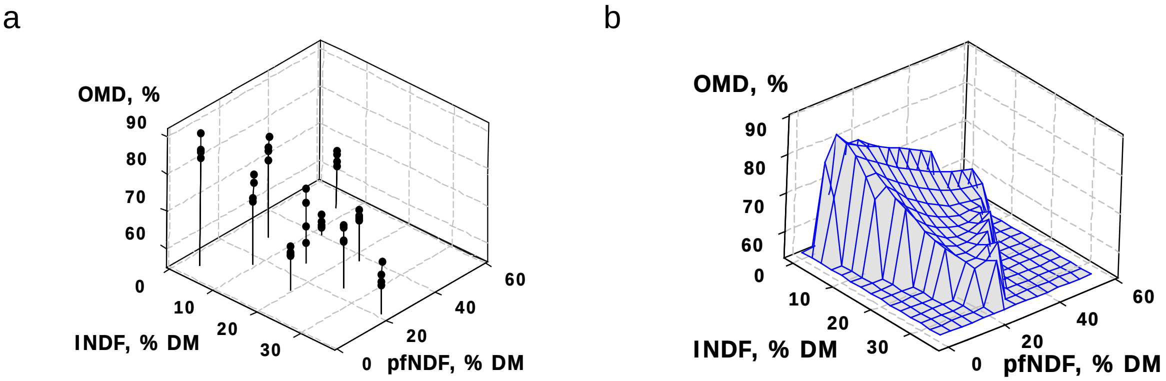
The unexpected increase in OMD values at high INDF levels and lower than expected dNDF values at high pfNDF values was likely the result of radically different levels of feed intake and the lower than expected NDF levels for diets high in oat hulls. A digestion experiment with ewes fed at near maintenance levels of intake will be reported later to obtain actual pfNDF values.

Table 3. Digestibility data for lambs.

	Diet design				Digestibility, %		
Diet	NDF, % DM	INDF, % DM	pFNDF, % DM	Analyzed NDF, % DM	Organic matter	NDF	Actual FNDF, % dietary DM
A	9.0	3	6	11	86.4	47.3	5.0
I	25.8	9.25	16.5	24	75.1	41.8	10.0
E	33.3	19.5	13.8	26	65.0	41.4	4.3
G	35.0	5.3	29.8	33	78.3	60.8	19.9
H	42.5	15.5	27	36	67.6	41.4	14.8
K	50.0	25.75	24.25	40	69.6	47.8	19.3
J	51.8	11.5	40.25	49	58.3	45.2	22.1
B	57.5	36	21.5	40	65.2	41.4	16.8
F	59.3	21.8	37.5	49	66.9	53.4	26.2
C	61.0	7.5	53.5	54	68.1	62.0	33.3
				SE:	1.51	3.66	1.08
				P-value:	<0.001	<0.001	<0.001

The results of this designed experiment confirm the effects of concentrations of INDF and pfNDF on feed intake of growing lambs and the digestibility results help to explain the effects. Other experiments with lactating ewes nursing twin or triplet lambs (Hogue, 1994; Schotthofer et al., 2007), lactating dairy cows, and feedlot cattle (Baker et al., 2009) have shown that minimum levels of pfNDF enhance intake and prevent rumen metabolic disturbances.

Figure 6. Effect of estimated dietary INDF and FNDF concentrations on organic matter digestibility. (a) Scatter plot of the data. (b) Graph of the equation: $OMD = 87.137 - 0.08364*INDFxFNDF + 0.00007382*INDF^2xFNDF^2$ ($r^2 = 0.71$ $S_{y.x} = 4.5$).



These results do not fit models that have used NDF (Mertens, 1987) and digestible dry matter (DDM) or functions of DDM, such as net energy for maintenance (Fox et al., 1992) to predict feed intake. The dry matter intakes of diets high in pfNDF in our experiments and in commercial applications have been much higher than traditional models of feed intake would have predicted. In fact, traditional models of feed intake would have predicted lower – not higher – feed intake at the high NDF levels in our experiments. In contrast and in support of the necessity to balance for FNDF, increased NDF fermentability resulted in higher feed intakes in dairy cows consuming diets with the same level of NDF (Oba and Allen, 1999). The dramatic intake-enhancing effect of diets high in FNDF also indicates that ruminant diets cannot be balanced properly by assuming a given intake level independent of the feed ingredients included in the diets.

Figure 7. Effect of estimated dietary INDF and FNDF concentrations on digestibility of NDF. (a) Scatter plot of the data. (b) Graph of the equation: $dNDF = 53.8 – 4.462*INDF + 1.0219*FNDF + 0.0561*INDFxFNDF + 0.07177*INDF^2 – 0.0150*FNDF^2$ ($r^2 = 0.65$, $S_{y.x} = 8.7$).

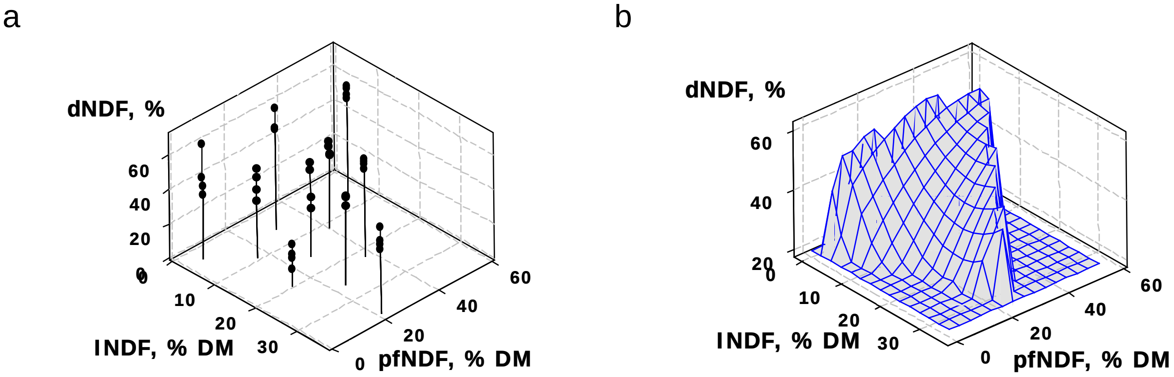
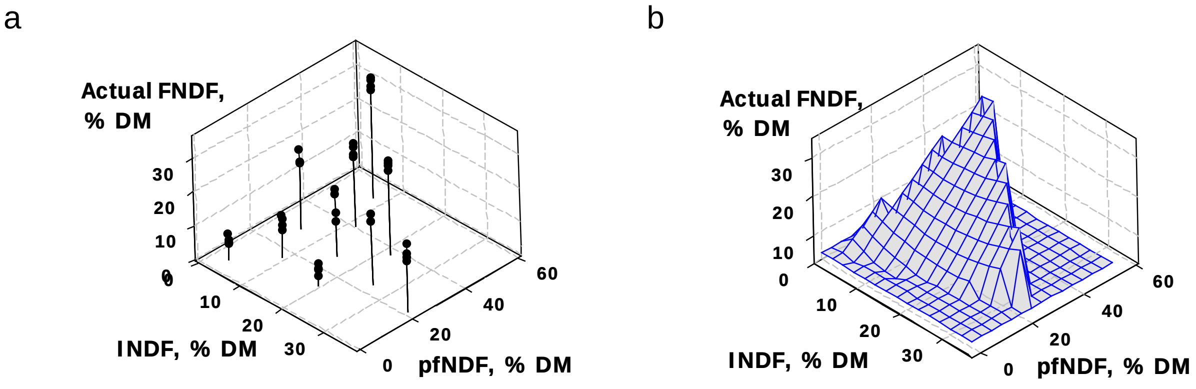


Figure 8. Effect of estimated dietary INDF and FNDF concentrations on fermentable NDF. (a) Scatter plot of the data. (b) Graph of the equation: FNDF = 4.65 - 0.822*INDF + 0.502*FNDF + 0.0163*INDFxFDNF + 0.0150*INDF^2 (r^2 = 0.92 $S_{y.x}$ = 0.027).



A NEW (?) CONCEPT FOR DIET FORMULATION FOR RUMINANTS

From the previous discussion, although ruminants can ferment nonstructural carbohydrates (NSCHO), it is obvious that ruminants need fermentable fiber. This should not be surprising to any ruminant nutritionist. Given the evolutionary development of ruminant animals, how else would the ruminal microbial population be able to function effectively?

A note on terminology:

We equate NDF fermentability with NDF digestibility. The reason for this is that NDF that disappears from the digestive tract must have been fermented by microorganisms or excreted in feces.

Quantitative terms for NDF:

- INDF (indigestible NDF): Proportion of a feed ingredient or diet that is indigestible NDF when intake is 1X maintenance.
- dNDF (digestible NDF): Proportion of NDF that is digested.
- pfNDF (potentially-fermentable NDF): Proportion of a feed ingredient or diet that is fermentable NDF when intake is 1X maintenance. This is the same as assuming that all the NDF that can be digested will be digested and is calculated by subtracting INDF form NDF.
- FNDF (fermentable NDF): Proportion of feed ingredient or diet NDF that is actually fermented.

The concentration of FNDF, INDF and nonstructural carbohydrates varies widely among feed ingredients. Because the dietary concentration of FNDF is so important to maintain rumen function and optimize intake, ruminant diets should be balanced for minimum levels of FNDF. This has led to a revised approach to feed formulation.

FNDF Values for Feed Ingredients

Most feed ingredient tables do not contain values for FNDF, where FNDF is defined as the proportion of the ingredient dry matter (DM) that is fermentable NDF. The main reason for this is that traditional methods of balancing diets do not consider the separate carbohydrate fractions; instead, they group them together into feed energy values. Most tables do, however, report some measure of digestibility, like total digestible nutrients (TDN) or digestible dry matter (DDM) or proportion of energy digested (DE), which can be used in a simple calculation to compute FNDF.

The calculation is based on the assumption that feces are composed primarily of NDF and endogenous losses. Endogenous fecal losses range from 10% of the DM for concentrates to 15% of the DM for low quality forages (Van Soest, 1994). Thus, for each feed ingredient, an appropriate endogenous fecal loss is subtracted from indigestibility of DM to give indigestible NDF (INDF). Then, indigestible NDF is subtracted from NDF to obtain pfNDF as a proportion of the ingredient dry matter. For example, if the DDM of alfalfa hay is 60%, then it is 40% indigestible. Subtracting 15% (endogenous loss) from 40% leaves a value of 25% for INDF. Assuming an NDF value of 46% for the alfalfa hay, then a value of 21% for pfNDF is calculated.

Tabular values for DDM were originally determined at maintenance levels of intake, but there is a major effect of level of intake on digestibility (Tyrrell and Moe, 1975; Wagner and Loosli, 1967). This was documented for DM and NDF by Hein et al. (2009) in weanling lambs and mature dry ewes and by Schotthofer et al. (2007) in lactating ewes. Because highly productive animals, like lactating ewes or dairy cows, consume feed at several times maintenance levels, feed passes through the digestive tract more quickly with less time for digestion. FNDF values can be estimated by using the digestibility discount factors of Van Soest (1992), but the discount factors are affected by the animal species and particular batch of feed ingredient. In our feed formulation system, therefore, we assign potentially-fermentable NDF (pfNDF) values to ingredients by subtracting INDF from NDF, where INDF is calculated (or measured) at maintenance levels of intake.

FORMULATING FEEDS WITH FERMENTABLE FIBER

The new feed formulation approach provides an effective method of feeding ruminants and overcomes some limitations of traditional systems. Specifically, the new approach recognizes that diet formulation can have a significant effect on feed intake and also that the proper balance of dietary components can effectively prevent most metabolic disturbances such as acidosis and animals going off-feed.

"Energy" terms

These 3 terms are approximately equal when expressed as percentages of the DM (TDN and DDM) or GE (DE):

TDN: total digestible nutrients
DE: digestible energy
DDM: digestible dry matter

Usually calculated from DE:

ME: metabolizable energy

NE terms are usually calculated from ME:

NE: net energy
NE_m: net energy for maintenance
NE_g: net energy for gain
NE_l: net energy for lactation
NEL: net energy for lactation and maintenance at 3X maintenance intake

Note that there are significant errors associated with multiple equations that predict one value from another. From the point of view of practical feed formulation, it may be more appropriate to use known values.

Pooled energy values such as TDN, DE, ME, NE, NE_m, NE_g, NE_l, and NEL are ignored in the new approach. Instead, diets are balanced on the carbohydrate components that generally make up those pooled values. The other dietary components are Ash, Ether Extract (EE), and Protein fractions (that is, crude protein or soluble, degradable, escape, and indigestible protein) that are included in traditional formulation systems. Because both EE and ash in ruminant diets are generally about 5%, both are suggested to be included at about this level and not discussed further. For simplicity, the protein fraction(s) are only considered as the total or crude protein. The carbohydrates are divided into INDF, pfNDF, and NSCHO and are the variable fractions that receive the most emphasis in the new approach. Decreasing the INDF in the diet and/or increasing the feed intake are the most effective ways of increasing the supply of nutrients available for animal production. However, at high feed intake levels, the proper balance between pfNDF and NSCHO becomes important, especially for preventing metabolic disturbances.

Feed components in the new approach

- Carbohydrates
  - NDF (neutral detergent fiber)
    - pfNDF
    - INDF
  - NSCHO (Nonstructural carbohydrates)
    - Sugars
    - Starches
- CP (crude protein)
- Ash (minerals)
- EE (ether extract = fat)

These components sum to 100% of the feed ingredient or diet.

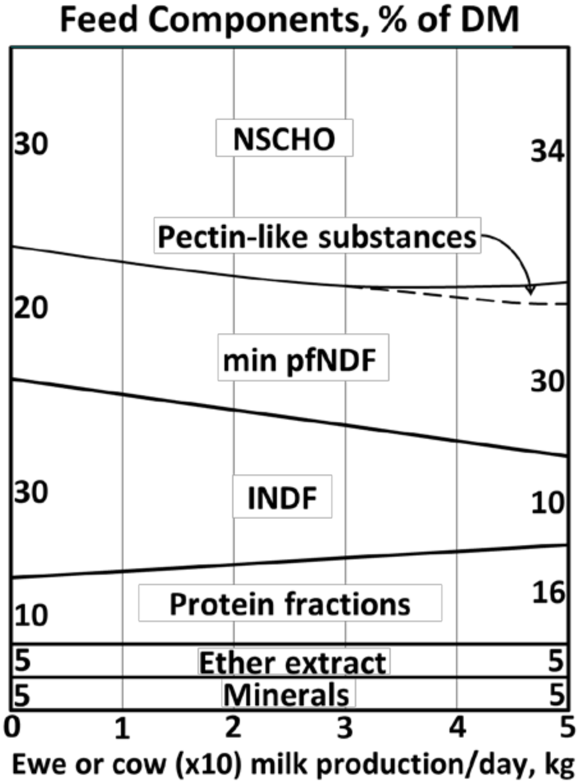
The Ash, EE, Protein fractions, INDF, pfNDF and NSCHO components can be summed together or properly pooled and adjusted to estimate a pooled energy value such as TDN or DE or ME or NE, but that pooling is unnecessary and redundant. Furthermore, the effects of the individual components are lost when pooled.

Minimum levels of pfNDF and maximum NSCHO are suggested. Animals fed diets high in good quality forage such as beef cows, sheep, or goats either at maintenance or pregnant or suckling a single offspring usually will consume more than the minimum suggested pfNDF. Higher producing lactating dairy cows, ewes or does suckling 2, 3, or 4 offspring, milking ewes or does, feedlot lambs, and feedlot cattle fed high grain diets often will not meet the suggested minimum pfNDF necessary to compensate for high NSCHO levels unless the diets are balanced carefully.

Lactating Ruminants

Because they have the highest nutrient needs, an example for lactating cows, ewes, or does is given in Figure 9. This includes the proportions of each suggested component for production of 0 to 5 or 50 of kg milk per day.

Figure 9. Suggested dietary levels of feed components for lactating ewes, does, and cows.



Pectin like substances (PLS) ferment like NDF and are therefore included in the pfNDF even though by analysis they will be included in the Neutral Detergent Soluble (NDS) fraction of the feed. The suggested level of both ash and EE (5%) is the same from maintenance (zero milk) to 5 or 50 kg of milk. The protein fractions are increased from 10 to 16%. Only the total of the protein fractions (CP) is indicated in this figure. The INDF is reduced linearly from 30 to 10% of the diet to account for comparable increases in DDM.

The remaining 2 components (pfNDF and NSCHO) are suggested at levels that should enhance feed intake and prevent metabolic disturbances, especially at higher levels of milk production. The pfNDF is expressed as a suggested minimum and, therefore, the NSCHO is a suggested maximum. At lower levels of production, suggested levels of minimum pfNDF and maximum NSCHO are usually not approached as these animals are usually fed high forage diets that contain higher levels of pfNDF and lower levels of NSCHO than are suggested. At the highest level of production indicated in Figure 9 (5 or 50 kg of milk), the minimum percentage of pfNDF is increased and the percentage of NSCHO is decreased to take into account the possibly that the lactating female will have difficulty processing very high amounts of NSCHO at the high feed intake needed to produce 5 or 50 kg of milk.

Note that "feed components" rather than "nutrients" are used. The only "nutrient" that is intentionally avoided is a pooled energy value, such as NE. Approximate "suggested dietary levels" are used instead of "requirements." Specific suggested values for feed components are provide in the feed library of the *FeedForm* diet formulation package[3] for a variety of farm animals.

Feed Component Values

Some approximate feed component values are given in Table 4. Included are several forages at different maturity levels, the major grains and a variety of by-products widely available for feeding. Values are listed for NSCHO (sugars and starches), neutral detergent fiber (NDF) divided into potentially-fermentable (pfNDF) and indigestible (INDF), crude protein (CP), ether extract (EE), and ash. These components sum to 100% of the dry matter.

The DDM, CP, EE and Ash values were taken from existing tables, primarily those of Van Soest (1992). Digestible dry matter generally was considered to be equivalent to TDN except for feeds rich in EE or Ash. Furthermore, INDF is highly negatively correlated with DDM so that one or the other could be omitted. However, digestible dry matter at 1X maintenance was included so that INDF could be calculated as the difference between indigestibility and endogenous fecal losses. Intake levels higher than maintenance result in a depression in digestibility (Tyrrell and Moe, 1975; Van Soest and Fox, 1992; Wagner and Loosli, 1967). Because it is primarily fiber digestibility that is depressed as intake increases, FNDF levels of ingredients will be lower for producing animals with consumptions above maintenance. To compensate for this digestibility depression, correspondingly higher pfNDF levels were suggested in Figure 9 and in the *FeedForm* diet formulation package. Most feed components will have considerable variation and therefore the numbers in Table 4 and in the *FeedForm* tool should be considered as being approximate.

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[3] Available at: http://www.sheep.cornell.edu/management/economics/cspsoftware/feedform/index.html.

Table 4. Some approximate feed component values for intake at maintenance.

Ingredient		NSCHO	pfNDF	INDF	CP	EE	Ash	DDM
Forages		- - - - - - - - - - - -	- - -	% of dry matter	- - -	- - -	- - -	- - - -
Alfalfa	Early bloom	27	19	23	19	3	9	62
	Mid bloom	25	21	25	17	3	9	60
	Late bloom	23	23	32	12	2	8	53
Orchard grass	Early bloom	20	37	20	10	3	10	65
	Late bloom	13	36	31	8	3	9	54
Timothy	Late veg.	20	40	15	14	3	8	70
	Early bloom	18	40	21	11	3	7	64
	Late bloom	14	39	29	8	3	7	56
	Seed stage	14	34	38	6	2	6	47
Corn silage, 45% grain		42	28	13	9	3	5	72
Wheat straw		2	40	45	3	2	8	40
Grains								
Barley	Heavy	63	14	5	13	2	3	84
	Light	52	17	11	14	2	4	77
Corn		75	6	3	10	4	2	87
Oats, 32 lb/bushel		37	27	15	13	3	5	73
Wheat		69	10	6	11	2	2	84
By-products								
Beet pulp		32	40	14	8	1	5	74
Citrus pulp (15 pls[a] in pfNDF)		44	32	6	7	4	7	82
Corn germ meal		26	29	12	27	3	3	76
Corn gluten feed		18	40	5	25	7	5	83
Cottonseed hulls		0	50	40	4	2	4	45
Dried brewers grains		17	28	18	26	7	4	67
Dried distillers grains		10	42	8	26	10	4	80
Hominy		25	50	5	12	7	1	85
Oat hulls		9	28	50	4	2	7	35
Soy hulls		11	62	8	12	2	5	80
Wheat midds		40	32	5	18	3	2	83
Protein supplement								
Soybean meal, 44% CP		28	9	5	49	2	7	80

[a] Pectin-like-substances.

REFERENCES

Baker, M. J., D. E. Hogue, M. L. Thonney, and D. J. Ketchen. 2009. Effect of type and length of dietary fiber on growth, efficiency and carcass characteristics of feedlot cattle. Pages 99-110 in Proc. Cornell Nutr. Conf., Ithaca, NY.

Fox, D. G., C. J. Sniffen, J. D. O'Connor, J. B. Russell, and P. J. Van Soest. 1992. A net carbohydrate and protein system for evaluating cattle diets: III. Cattle requirements and diet adequacy. J. Anim. Sci. 70:3578-3596.

Hein, D. C., M. L. Thonney, D. A. Ross, and D. E. Hogue. 2009. Effect of level of intake on digestibility of NDF in soy hulls. Pages 61-68 in Proc. Cornell Nutr. Conf., Ithaca, NY.

Hogue, D. E. 1993. Feeding strategies for highly productive sheep. Pages 121-125 in Proc. Cornell Nutr. Conf., Ithaca, NY.

Hogue, D. E. 1994. Further observations on feeding highly productive sheep. Pages 140-141 in Proc. Cornell Nutr. Conf., Ithaca, NY.

Hogue, D. E., and M. A. Jabbar. 1991. Intake and fermentation rates of diets in growing lambs. Pages 83-84 in Proc. Cornell Nutr. Conf., Ithaca, NY.

Mertens, D. R. 1987. Predicting intake and digestibility using mathematical models of rumen function. J. Anim. Sci. 64:1548-1558.

Oba, M., and M. S. Allen. 1999. Evaluation of the importance of the digestibility of neutral detergent fiber from forage: effects on dry matter intake and milk yield of dairy cows. J. Dairy Sci. 82:589-596.

Schotthofer, M. A., M. L. Thonney, and D. E. Hogue. 2007. Effect of level of fermentable NDF on feed intake and production of lactating ewes. J. Anim. Sci. 85 Suppl. 1:180 (Abstr.)

Thonney, M. L., and D. E. Hogue. 2007. Formulation of ruminant diets using potentially-fermentable NDF and nonstructural carbohydrates. Pages 113-123 in , Ithaca, NY.

Tyrrell, H. F., and P. W. Moe. 1975. Production efficiency in the high producing cow. Effect of intake on digestive efficiency. J. Dairy Sci. 58:1151-1163.

Van Soest, P. J. 1964. Symposium on nutrition and forage and pastures: New chemical procedures for evaluating forages. J. Anim. Sci. 23:838-845.

Van Soest, P. J. 1967. Development of a comprehensive system of feed analyses and its application to forages. J. Anim. Sci. 26:119-128.

Van Soest, P. J. 1994. Nutritional Ecology of the Ruminant. 2nd ed. Comstock Publishing Associates (Cornell University Press), Ithaca, NY.

Van Soest, P. J., and D. G. Fox. 1992. Discounts for net energy and protein - fifth revision. Pages 40-68 in , Ithaca, NY.

Wagner, D. G., and J. K. Loosli. 1967. Studies on the energy requirements of high-producing dairy cows. Cornell Univ. Agr. Exp. Sta. Memoir 400:1-40.

Warner, R. G., W. P. Flatt, and J. K. Loosli. 1956. Dietary factors influencing the development of the ruminant stomach. J. Agric. Food Chem. 4:788-792.