Making the Most of Grass-Based Forages in Diet Formulation

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Take Home Messages

- NDF (Neutral Detergent Fiber) intake even for high producing dairy cows can be as much as 1.4 or 1.5 % of body weight if the quality of the fiber is accounted for and the ration is fully balanced with regards to rumen degradation
- It is necessary to stimulate the entire rumen microbial ecology by supplying different carbohydrates to obtain maximum rumen degradation
- It is possible to adapt dynamic principles of outflow and degradation to simple figures for use in the field

Introduction

In the Scandinavian countries Norway, Sweden and Finland dairy cow diets are fairly uniform. Denmark has more varied feeding practices. Basically the rations are composed of grass silages, cereal grains, sugar beet byproducts and heat-treated rapeseed or soybean meal to provide rumen UDP (undegradable dietary protein). Even with this apparently small base of feedstuffs the official energy system, based on ME (metabolizable energy) was not permitting accurate ration optimizations of the different qualities for roughages in diets. Most of these feeds can be combined in infinite possible combinations and still result in some milk production. For high-producing cows the demand for high-energy intake requires an increasing concentration of energy per kg DM (dry matter). Using energy values to define dietary restrictions tends to disfavor the use of grass-based silages because of higher NDF content, which almost always have a lower energy value than other constituents of organic matter. Silage intake is generally reduced in favor of other, more quickly digested, components. Many of the more recent feeding systems have concentrated on the connection between degradation rate and intake capacity as the key to successful feeding of roughages. However a more simplified system would be preferred for use on the farm and also a system that allowed ration optimization. This is the aim of the LFU system.

■ Substrate Based Systems

The combination of associative effects of diet components on rumen digestibility and the effects of passage rate on, in particular, rumen fiber digestibility, has led to the development of several dynamic and mechanistic models. These include CNCP (Cornell Net Carbohydrate and Protein model, CPM Dairy (Cornell Pennsylvania Miner model), NRC (National Research Council), Molly, and Karoline. These often include computations to determine energy levels in the diet and energy requirements of the animals. These energy measures are not strictly needed in some of the models which can predict the flow of nutrients needed for body functions including ATP (adenosine triphosphate) synthesis and milk production. There are even models that operate on basic nutritional flows such as ATP. However, most of the models are not easy to use for ration optimization and require multiple runs to arrive at the best ration. Using only nutrient flows would even further complicate practical ration formulation.

Sufficient information is available to enable fairly accurate predictions of rumen metabolism. How intermediary metabolism is affected by nutrient flow has been more difficult to model but hopefully success will be achieved with these parameters, especially liver metabolism. In 1998 the Swedish Farmer's Cooperative, Lantmännen, introduced feed evaluation and feeding recommendations (LFU system) based on optimal ruminal metabolism of components in the feeds. These recommendations do not use the term energy. The major source of ATP for the animal, which is true energy, should come from catabolism of the VFA (volatile fatty acids) produced in the rumen. Therefore, an accurate prediction of the VFA production in the rumen is actually to be preferred to more diffuse energy terms such as NE (net energy), DE (digestible energy) or ME. As microbial digestion in the rumen results in the production of gases, new microbial matter and VFA, a measure of the microbial digestion, or rumen digestibility, should be sufficient to predict VFA production. The main points in the LFU system for successful diet formulation on the farm are: DMI (dry matter intake), rumen degradable NDF, rumen stable NDF, starch, RDP (rumen degradable protein) and UDP (rumen undegradable dietary protein).

Table 1. Recommended intake of dietary components for different milk yields according to the LFU system.

Milk Yield	20	30	40	50
DMI, kg	14.3	18.6	22.9	27.2
Crude Protein, %	16	17	18	19
RDP, %	10.7	11.0	11.3	11.4
UDP, %	5.3	6.0	6.7	7.6
Starch, %	14	17	19	20
NDF, %	42	37	34	32
Rumen digestible. NDF	21	19	18	17
Rumen resistant NDF	21	18	16	15
Crude fat	4	4	5	5
LLKH[a]	20	20	19	18

[a] readily soluble carbohydrates

■ The LFU System

The DMI recommendations in the LFU system, Table 1, are controversial. DMI in the LFU system is calculated as: DMI = 5.7 kg + 0.43*kg milk. These are meant to be approximate figures. The reason that it is necessary to stipulate DMI is that the system, as seen in Table 1, is based on percentages. This gives the farmer a simple and fast computation of the ration but requires a known amount of dry matter (DM) to be consumed. Knowing the DMI allows the feed mill to produce concentrates that are balanced, in terms of substrate supplies in the total diet, with the dairy farmer's silage quality and amount. The concentrate mix needed is different if the farmer is feeding large amounts of silage (>9 kg DMI) of good quality or lessor amounts (<8 kg DMI) of normal quality. Several feeding trials in Scandinavian countries have shown that the LFU prediction of DMI is extremely well correlated to the actual intakes. A similar equation has been used by Hutjens (2003) termed the 13 pound tax: the DMI needed for maintenance and milk is (DMI - 13 lb) * 2, e.g. (53-13) * 2 = 80 lb of milk. The conversion factor from lb to kg is 0.454. Rearranging the equation, converting to kg and considering that the Swedish cows are a bit smaller than Illinois Holsteins gives an equation similar to the LFU equation. The LFU system calculates with a higher efficiency, 0.43, compared to 0.5 in Hutjens equation. The equation is based on normal diets to dairy cows with normal (for Sweden) feeding stuffs. It is not intended as a general law for all ruminants in all situations.

The Fiber Fraction

The protein and fiber fractions actually utilized by the cow are key components of most systems. To effectively utilize the fiber fraction it is necessary to account for differences in quality of the fibre. Complicated models which combine non-linear functions of rumen outflow, particle reduction and microbial digestion of fiber are difficult to explain on the farm. It is also difficult to use non-linear computations of feed values in combination with the linear programs used in most feed mills. Assigning feed values based on farm variables such as live weight, stage of lactation, age, etc are not possible to use efficiently in the feed mill.

Subtle differences between feeds and on different diets detected in complicated systems might not be realized in practical situations where many other factors on the farm and in the herd are influencing cow performance. Therefore, we have adopted a simpler measure of rumen fiber degradability. In sacco (nylon bag) degradability is measured in a time series over 48 h. The fiber degraded as a percentage of the original fiber amount is cumulatively estimated taking into account the effects of feed passage out of the rumen (outflow) according to Christens (1982) assuming an outflow rate of 3 % per hour ($h^{-1)}$. This gives a single figure. For grasses, between 45 and 55 % of the fiber is usually digested in the rumen and this fraction of the fiber effectively degraded in the rumen is termed EFD (Effective Fiber Degradation).. The same technique is applied with all other feeds and used both in diet formulation and concentrate optimization at the feed mill.

EFD is determined in nylon bags using cows on a maintenance diet. As the LFU system is not a mechanistic dynamic model this value would not accurately predict the rumen degradation at all levels of feeding. Rather than use several different values, the feeding recommendations are adjusted for level of intake (Table 1). For a production level of 50 kg the EFD in the diet should be at least 53% while for a production of only 20 kg 50% EFD is sufficient. An inexpensive and quick determination of EFD is necessary because the fiber degradation is very variable in forages produced in Scandinavia and the farmers must analyze for this. While the in sacco method works fairly well for determining fiber degradation it is both expensive and time-consuming. There is a correlation, in grasses, between metabolizable energy (ME) determined in vitro and rate of fiber degradation. EFD can be computed from the energy value using a simple equation: EFD = 6.99 * ME – 22.4. The correlation to energy is not perfect and several growing conditions can result in high fiber crops with high digestibility that will not be accurately predicted. However, the coupling to energy is easy for the farmers to grasp and confirms the established connection between energy values in grass and DMI. EFD values for corn silages, grains and many of the feeds used in the feed mill are not correlated to energy but are fairly constant. EFD of heat-treated feeds can vary depending on the method of processing. Using several different recommendations, depending on production level, might appear to complicate diet formulation but since it is based on percentages and follows a logical development, implementation of this system is easy and practical

Fiber Quality in Diet Formulation

Specifying the quality of the fiber fraction allows for more accurate control of the use of roughage in the diet. The quality must be associated with the quantity. The amount of fiber, or NDF, is also differentiated according to production, ranging from 50 % NDF in the diet for a production of 10 kg of milk up to 31 % for a production of 50 kg. As the total DMI is greater for the 50 kg production level even the NDF intake will be greater. The amount of fiber digested in the rumen is determined as NDF * EFD/100, termed Effective NDF. The amounts recommended are in Table 2 for some production levels. If the dairy farmer wishes to feed 10 kg DM of silage with 48 % NDF and an EFD of 51% to a cow producing 40 kg of milk then the concentrates, including grain, should have a NDF content of 23 % with an EFD of 56. If a greater silage intake is desired then the quality, EFD, must be higher either in the silage or the concentrate.

Often an intake equal to 1.25 % of live weight is cited as a maximum for NDF intake without negative effects on total DMI. However, accounting for quality differences allows higher intakes. In Fig. 1 NDF intake in percent of body weight is presented for a 625 kg cow producing 30 to 50 kg milk. At 50 kg milk per day the cow should consume 1.4 % of her body weight as NDF. This will be even higher for a smaller cow. The recommendations are not altered for body weight. It is assumed that the driving force in DMI is the milk production and the requirements for milk production are the same regardless of body size. The variation in maintenance requirement, which would be affected by body size, is comparatively small in relation to the requirements for milk production.

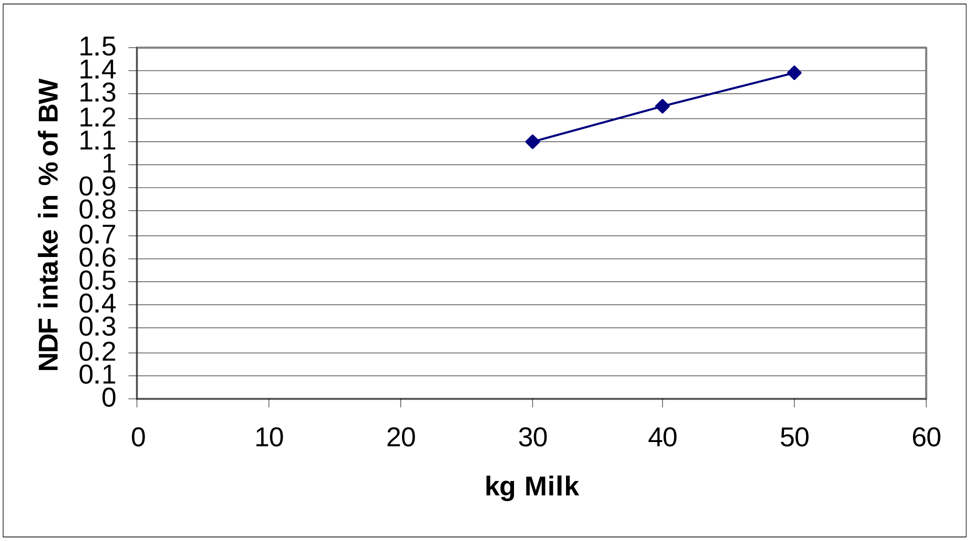

Fig. 1. The intake of NDF expressed as percent of body weight for production levels between 30 and 50 kg milk per day

It follows that the fiber not digested in the rumen, rumen stable NDF, is the difference between total NDF and effective NDF. This is not indigestible fiber as some of this fraction could have been digested in the rumen if retention time was longer. The rumen stable NDF, VSNDF, is the most important factor for maintaining favorable physical conditions in the rumen, such as a proper rumination, a stable pH, sufficient retention time, etc. VSNDF might be compared to physical effective fiber. There is no measure of particle size, as most farms in Sweden do not have finely chopped silages. TLC (Theoretical Length of Cut) is usually not less than 2.5 cm. Generally VSNDF is slightly less than half of the NDF fraction for high yielding cows and about half of the NDF fraction for cows producing less than 30 kg milk. There are no recommendations as yet regarding indigestible NDF (INDF) but research is being conducted. The maximum amount usually encountered in feeding trials has been about 4 kg INDF but this amount is probably directly limiting intake and such high levels of INDF are not needed for normal rumen function..

There is no differentiation between NDF from forages and NDF from concentrates. The NDF and related levels in the diets are total levels. This means that the farmer after computing the contribution from his own roughages and other feeds on the farm can choose different concentrates with different characteristics to arrive at the right combination of substrates in the diets. This is what permits an optimization of the farmer's roughages.

Microbial Protein

Another controversial parameter is the calculation of the flow of microbial protein from the rumen. In the official system for the Nordic countries, AAT/PBV (amino acids absorbed from the intestines/protein balance in the rumen), the flow of total protein to the intestines is determined from several constants for microbial protein production from total apparently digested carbohydrates and protein degradation determined in sacco. There is no adjustment for the effects of feeding level. In the LFU system microbial protein flow to the intestines is determined as 95 g per kg DMI. This figure is based on numerous feeding trials in the literature. Statistical analysis of reported values in the literature by Oldick et al. (1999) and Firkins et al. (1998) show that microbial N flows to the duodenum were accurately predicted by DMI alone. Increases in outflow rates are known to increase growth efficiency in microbes in in vitro trials and will also increase passage of microbial matter in vivo. Both reports sited several important dietary factors but at the present there is not sufficient information to accurately use these parameters in predictions. The proposed equation by Oldick, Microbial N = 16.1 + 22.9*DMI –0.365 * DMI^2 – 1.74*NDF % of diet was no better at predicting microbial protein flow to the intestines than using DM alone. Their equation would underestimate, in comparison to the LFU system, microbial protein flow by 300 and 200 g per day (or 17 % and 11%) for milk production of 40 and 30 kg respectively,. Using their equations would mean including more UDP in the diet, which is rather expensive for Swedish diets. The LFU recommendations for NDF in the diet are in line with the mean values in the data sets used by Oldick and Firkins (1998). There is some empirical evidence indicating positive effects of NDF on outflow on microbial protein from the rumen based on observations from organic milk producers who feed larger amounts of NDF (>50 % of the diet) to their cows.

The flow from the rumen of 95 g microbial protein per day per kg DMI means that the daily protein supply, or more specifically the N supply, to the rumen must at least equal 95 g protein. As the estimation of microbial flow is not completely accurate and the efficiency of microbial synthesis can vary the recommendation for RDP is 15 –17 % greater than the flow, or about 11 % of DMI per day. The recommendations for the UDP are based on empirical evidence and are in line with other systems. While RDP is fairly constant due to the indirect coupling to DMI, UDP will increase with increasing production levels. There are no recommendations regarding amino acid supply for use on the farm as the protein concentrates from the feed industry supply most of the UDP fraction. For the optimization of feeds in the feed mill there are amino acid requirements for the UDP but these are not declared.

Forage Protein

These recommendations for the protein fractions have important implications for the forages. Most of the protein in grass forage is highly degradable in the rumen. After ensiling there is a large proportion of non-protein nitrogen (NPN) as well. Grasses harvested for maximal fiber digestibility tend to have high (>18 % of DM) levels of crude protein. As between 70 and 80 % of this is RDP there are problems in balancing the diet. If the farmer was feeding 10 kg silage DM with 18 % CP (Crude Protein) the concentrate would have to contain 9 % UDP in a base of 18 % CP. This is not too expensive to achieve but increasing the CP of the silage above 18 % will greatly increase costs. Using legumes to minimize the need for chemical fertilizers also tends to increase CP and RDP in the diet. Bertilsson and Murphy (2004) did not see the positive effects of red clover on decreasing RDP as reported by Broderick (2001). There are several efforts underway to minimize CP in the grass and still maintain yields. The negative effects of high levels of RDP on health and fertility are a major factor in utilizing forages. In addition the high RDP levels in grass will have negative environmental effects.

Table 2. Recommended rumen degradable substrates in kg for different production levels.

Milk Yield, kg	DMI	Starch	Effective NDF	Soluble Carbohydrates
30	18.6	3.16	3.44	3.16
40	22.9	4.35	3.90	3.89
50	27.2	5.44	4.35	4.62

■ Non-Structural Carbohydrates

The contribution of starch to total fermentable carbohydrates in the rumen (Table 2) is less than that of fiber for the 30 kg milk production level and only 12 % greater than fiber at the 40 kg level. The contribution of starch at the 50 kg level is much greater than that of fiber but still much less than the combined contributions of soluble carbohydrates and fiber. The total cost of production of silage is usually greater than for cereal grains. Therefore, there is a tendency to feed a minimum of silage and as much grain as possible in those areas where grain production is favorable. The minimum requirements for effective NDF and VSNDF in the LFU system help to minimize the risk of formulating rations that are too high in readily soluble carbohydrates, thereby reducing the risks associated with feeding rations containing excessive soluble carbohydrate.

Starch

The starch in cereal grains is highly degradable in the rumen. The limit of 20 % starch in the diet was set with this in mind. However, if a starch source with a lower rumen degradability is used the maximum could be exceeded. Corn silage production is possible in southern Sweden and diets based on corn silage can contain up to 26 % starch. Research at our experimental farm (Murphy and Andersson, unpublished) indicates a positive effect of including rumen undegradable starch at up to 6 % of the diet, if the rumen degradable starch is 18 – 19 % of the diet. The supply of starch as a substrate for the rumen microbes has a positive effect on the entire rumen ecology and is a good source of the propionate needed for gluconeogenesis (glucose production in the liver). The challenge is to be near maximal levels of grain feeding but not high enough to stress the rumen. Starch will influence fiber degradation negatively. It is often assumed that the negative effects of starch on fibre digestion are related to low rumen pH caused by excessive degradation of starch. It appears that many fibre-digesting bacteria prefer to utilize products produced from starch digestion rather than attacking the fibre. Even if you add buffers to the diet to overcome the low rumen pH, you would still see a reduction in fibre digestion since some of the potentially digestible fibre would leave the rumen before it could be degraded. To overcome the negative effects of starch on fiber digestion we must use fiber with a higher degradation rate, that is, higher EFD (Effective Fiber Degradation).

Water Soluble Carbohydrate

The theoretical advantage of supplying a readily available energy source for the microbes to match the very soluble NPN fraction of silages has often been seen as a way to increase the feeding value of grass silages. The sugar content of grass grown in cool climates tends to be relatively high but variable. The sugar content of typical farm grasses in 2003 was between 11 and 20 % of DM. By the completion of ensiling process, this had decreased to an average of 6 %. The actual water soluble carbohydrate (WSC) content of the silage will depend to a great extent on ensiling techniques. An increased amount of WSC would, based on in vitro work (Eriksson et al., 2004b), increase microbial protein production but this has not been seen in production experiments (Eriksson et al., 2004a). However, for the general well being of the rumen microbial population there is assumed to be a positive effect of WSC. In the LFU system WSC is included in a term called readily soluble carbohydrates (LLKH) and includes, in addition to WSC, pectin and other ND solubles as well as fermentation acids. A more accurate description of this group would be desirable. Of particular interest is the influence that fermentation acids and ammonium have on DMI as has been noted in Finnish (Huhtanen et. al., 2002) and Swedish (Hetta et al. 2004) reports. Both of these factors can be reduced by proper ensiling techniques. High levels of sugar in the grass may be desirable in the diet but improper management at ensiling will lead to high concentrations of undesirable fermentation products with negative effects on DMI.

Fat

Feeding too much fat decreases DMI. Specifically the flow of unsaturated fatty acids to the duodenum has negative effects on intake. Fat recommendations in most feeding systems are based on crude fat. When formulating rations, we optimize using the predicted flow of individual fatty acids to the duodenum. A program for the calculation of fat flow to the duodenum is available with the CNCPS model. With increasing focus on the effect of dietary fat on milk composition, the fatty acid composition of grasses may be important. A large portion of the fatty acids in grass is unsaturated but these will be mostly biohydrogenated in the rumen. The relative distribution between 18 carbon and 16 carbon fatty acids are important for utilization by the cow.

Impact

Since the implementation of the LFU system in 1998 there have been several notable changes in the typical diets to dairy cows in Sweden. Protein levels have decreased while NDF and starch levels have increased. Changes to Sweden's milk pricing system encourage production of higher protein milk. The change in milk pricing along with the implementation of the LFU system has resulted in an increase in the use of starch in the diet. The downside to using starch to increase milk protein has often been a decrease in milk fat content. Altering the fatty acid profile of the concentrate mix to compliment the fatty acid profile of the grass has resulted in increased milk protein while maintaining milk fat content. The yield continues to increase. The removal of the energy limits in feed optimization has decreased production costs.

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