How much forage is okay in dairy diets?

GIVEN the economic and rumen health benefits of feeding high-forage diets, it comes as no surprise that dairy producers and nutritionists are fixated on forage quality.

It is not unusual today to find diets containing 55-70% forage on a dry matter basis. Much of what has allowed this to happen, concurrent with increasing cow productivity, is improvement in forage genetics, producers' management of those genetics and a better understanding of how to analyze and feed high-forage diets.

Driving factors

The quantity of forage that can be consumed by a dairy cow depends on the interactions among bodyweight, level of intake, rumen fill, passage rate, specific gravity (buoyancy), neutral detergent fiber (NDF) content, particle size, particle fragility/tensile strength and the pool size and digestion rates of potentially digestible NDF (pdNDF) versus indigestible NDF (iNDF) fractions.

Mertens (2010) reported that a total ration NDF intake of 1.25% of bodyweight optimized production of 4% fat-corrected milk across various forages when corn and soybean meal were the primary dietary energy and protein sources. If using the amylase-treated NDF organic matter value, the NDF intake value would be lowered to 1.2% of bodyweight. This value may not be the maximum NDF intake a cow could consume but is an estimate of the maximum intake while maximizing milk production (Chase and Cherney, 2012).

Reviews of pasture and total mixed ration-based research trials report that forage NDF intake can range from 1.3% to 1.8% of bodyweight, suggesting that dairy cows do have the ability to consume large quantities of forage NDF (Chase and Grant, 2013).

The Table provides details on six high-

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Bottom Line

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forage commercial herds in New York (Chase and Grant, 2013). High-forage intakes are possible by producing and feeding higher-quality, lower-NDF (and iNDF) forages. The classic multi-forage meta-analysis by Oba and Allen (1999) suggests that a one-percentage point increase in NDF digestibility can increase daily dry matter intake by 0.37 lb., resulting in a daily increase of 0.55 lb. of 4% fat-corrected milk.

Chase and Grant (2013) offered these guidelines for herds considering higher-forage rations:

1. Strive for consistent quality because variations in forage quality will have more effect on milk production as the level of forage in the diet increases;
2. Closely monitor forage inventory and considerations for required changes in the cropping (or sourcing) program;
3. Allocate the highest-quality forages to appropriate animal groups;
4. Frequently analyze forages (including particle size and digestibility) to keep the feeding program on target;
5. Monitor rations closely to determine if adjustments are needed based on frequent forage test results (including dry matter);
6. Target forage management, including silage face management, aerobic stability and palatability, feed delivery and the need for pushups, and
7. Track the need for more mixes per day or the need for a larger mixer given that high-forage rations will be bulkier and not as dense (pounds per cubic foot).

Lab, model challenges

Summary statistics from published studies suggest that *in vivo* NDF digestibility (NDFD) coefficients can vary by 30-35 percentage units among legumes, grasses and corn silages and that digestion rates of the pdNDF fraction can vary from less than 2% per hour to more than 6% per hour (Combs, 2013). As intake and rate of passage increase, the depression in fiber digestibility due to passage becomes pronounced in forages with lower fiber digestion rates.

Studies also support the notion that ruminants do not fully compensate for different rates of fiber digestion (Kd) by adjusting their voluntary intake to alter passage (Kp) of potentially digestible fiber (Combs, 2013).

Unfortunately, *in vitro* NDFD assays for a single time point (24, 30 or 48 hours) do not measure pdNDF or accurately reflect the rate of NDF digestion. A single-time point *in vitro* NDFD assay represents only the residual fiber remaining after a specific time period of exposure to rumen fluid and includes both iNDF and pdNDF.

Allen (2011) also suggested that fiber digestion determined from *in vitro* methods (traditional *in vitro* method) overestimates *in vivo* fiber digestibility (Combs, 2013).

The NDF Kd value reported on many

Examples of high-forage diets in northeastern U.S.

Item	Herd 1	Herd 2	Herd 3	Herd 4	Herd 5	Herd 6
Milk, lb./day	91	88	105	90	76	100
Milk fat, %	3.8	4.3	3.8	4.0	3.8	3.6
Milk true protein, %	3.10	3.10	3.10	3.25	3.15	2.90
Ration starch, % DM	27	24	26	24	24	24
Ration crude protein, % DM	15.5	15.7	18.3	17.3	16.3	17.2
Ration NDF, % DM	32.7	33.3	32.7	30.8	34.4	32.0
Forage NDF, % bodyweight	1.0	1.1	1.0	0.9	1.0	1.0
Forage, % of ration DM	65	64	62	70	75	62
Corn silage, % of forage DM	66	36	56*	60	61	56
Alfalfa silage, % of forage DM	34	0	29	0	0	40
Legume/grass forage, % forage DM	0	64	15	40	0	0
Grass silage, % forage DM	0	0	0	0	39	4

*BMR corn silage.
DM = dry matter.
Adapted from Chase and Grant (2013).

forage analyses is the result of Van Amburgh et al. (2003) recognizing the limitation of individual NDFD time point values and developing a mathematical procedure to calculate the rate of fiber disappearance by assuming a constant lag time for their *in vitro* system and fixing the iNDF fraction as 2.4 x lignin.

Their approach used the log transformations of the residual pdNDF at zero hour, the measured single-time point NDFD value and the iNDF fraction to construct a model to describe fiber degradation as it would occur if there were slowly digesting and rapidly digesting pools of pdNDF. The proportion of NDF in the fast and slow pools and their rates were then mathematically combined to derive a weighted average rate of fiber degradation (Kd). The weighted Kd value was then used with an empirical estimate of forage dry matter passage to predict ruminal fiber digestibility (Combs, 2013).

Raffrenato and Van Amburgh (2010) more recently proposed that a more precise and accurate weighted average rate of NDF degradation could be achieved by using 36-hour and 120-hour *in vitro* NDFD values and a long-term (240-hour) *in vitro* NDFD to determine the indigestible NDF fraction. The fiber degradation rates derived from these approaches are then coupled with predicted rates of forage dry matter passage in the Cornell Net Carbohydrate & Protein System to predict fiber digestion (Combs, 2013).

An informal "fiber working group" has been meeting at the Cornell Nutrition Conference since 2010 with the objective of designing experiments and exploring laboratory methodologies to improve how nutrition models handle fiber digestibility. Their interest areas include:

1. Two-pool NDF and two-pool starch fermentations;
2. Multiple particle pools for passage and identification of factors affecting passage, including the interaction between long forage particles and smaller particles of non-forage sources of fiber;
3. Greater functionality of peNDF;
4. Improved modeling and understanding of roles of chewing/rumination, fragility and factors influencing the rate of particle breakdown, passage, sequestration and selective retention (possibly due to being floated by carbon dioxide bubbles produced by rumen bacteria);
5. Rumen pH impact on digestion;
6. Rumen carbohydrate pools, their fermentability and ability to predict rumen acid load, and
7. Steady-state versus dynamic models (Grant and Cotanch, 2012).

The working group's priorities are timely given the fact that current *in vitro* or *in situ* NDFD assays involve forage samples that are held "captive" within a flask or Dacron bag and cannot separate into portions that flow independently from the rumen.

It is a false assumption that fiber will enter the rumen, mix fully with rumen contents and exit the rumen at a constant rate. Yet, when passage rates are assigned by measuring the retention time for indigestible fiber in the rumen, that passage rate is assigned to all of the NDF captive in commercial assays rather than just the portion retained in the rumen for digestion (Owens, personal communication).

In 1979, Mertens and Ely proposed that NDF degradation in the rumen was a two-pool system (fast-digesting and slow-digesting fractions) rather than a single NDF pool.

Raffrenato and Van Amburgh (2010) suggested that higher-digestibility forages have a greater portion of total NDF in the fast-digesting fraction by contrasting conventional corn silage (60.7% NDF in fast pool, 18.7% NDF in slow pool and 20.6% NDF as iNDF) with brown mid-rib (BMR) corn silage (73.7% NDF in fast pool, 13.1% NDF in slow pool and 13.1% NDF as iNDF). They suggested that this same pattern likely exists in legume and grass forages, but commercial laboratory methods are not routinely available to provide these pool rates (Chase and Grant, 2013).

However, more recent developments in laboratory methods such as Fermentrics (*Feedstuffs*, Dec. 13, 2010) — to capture fast and slow pool sizes, rates and microbial biomass production — and total tract NDFD (TTNDFD) — an index of forage digestibility using a standardized *in vitro* method and an assigned rate of passage (Goeser and Combs, 2009; Goeser et al., 2009) — are attempting to overcome some of the current analytical limitations.

BMR example

BMR corn, as a reduced-lignin, modified grass plant, represents an interesting case study from both a digestive and physical perspective. It is known that legumes tend to break down into cuboidal fragments, whereas more flexible grasses break down into long and slender particles, likely contributing to more entanglement and the formation of a more effective rumen mat. The net effect of these differences could be a slower passage rate for grasses versus legumes, which may compensate for the typically slower rate of NDF digestion for grasses, especially with more mature grasses (Grant and Cotanch, 2012).

Corn hybrids with the BMR mutants have less lignin and a lower proportion of iNDF than isogenic conventional corn silages. The TTNDFD analysis indicates that improved fiber digestion in BMR hybrids is the result of a lower proportion of iNDF and that the rate of fiber digestion is also increased.

Oba and Allen (1999b) reported that the 30-hour *in vitro* NDFD for a BM3 corn silage was 9.5 percentage units higher than its isogenic control, but when the BMR corn and its isogenic control were fed to lactating cows, the diets differed in total tract digestibility by only two percentage units.

Data from Dave Combs' lab at the University of Wisconsin indicated that, on average, BMR corn silages are approximately five percentage units higher in TTNDFD than conventional corn silages when compared at equal feed intakes and are two to three percentage units higher in NDFD if dry matter intake (and Kp of pdNDF) is increased by 5-7%. According to Combs (2013), a 5-7% increase in intake is consistent with the change in dry matter intake observed in feeding studies summarized by Oba and Allen (1999).

Grant and Cotanch (2012) reported on a series of studies conducted at Miner Institute where BMR corn silage comprised the majority of the dietary forage. When BMR corn silage replaced conventional corn silage on a 1:1 dry basis at 43% of ration dry matter, cows chewed 23% less with the BMR diet, even though peNDF and digested starch were similar between the two diets. Rumen pH was typically lower throughout the day, and efficiency of solids-corrected milk production was reduced when cows consumed BMR diets. Part of this difference in response was likely due to differences in fragility and rate of particle breakdown.

Miner Institute studies also showed that dry matter intake is typically increased with BMR silage when fed at higher levels, but not when fed at lower inclusion rates. Even though the dietary NDF pool size can be similar between conventional and BMR silages, the NDF dynamics are quite different in high-BMR diets.

With BMR silage in a higher-forage diet, dry matter intake is higher, the ruminal turnover rate is greater and time spent in the rumen is reduced. Rumen digesta mass is usually less for cows fed a BMR diet, indicating that cows are able to obtain the required nutrient supply from this smaller — but more quickly turning over — rumen NDF pool. Microbial protein production is also typically increased with a BMR silage, presumably reflecting greater rumen fermentability (Grant and Cotanch, 2012).

These differences between BMR and conventional corn silage genetics likely have an impact on the amount of forage particles in the large, medium or small particle pools and the rate at which these particles break down and move from large to smaller pools. To accurately predict particle passage from the rumen, it is necessary to understand both the chemical properties of feed digestibility as well as the physical properties that influence size reduction (Grant and Cotanch, 2012).

When considering factors influencing pdNDF, it is important not to overlook the influence of the growing environment (*Feedstuffs*, June 14, 2010). Combs (2013) reported considerable overlap in fiber digestibility between conventional and BMR corn silages, which is consistent with data from controlled feeding experiments that support the notion that growing conditions, time of harvest and other factors beyond plant genetics also affect plant fiber digestibility.

Environmental implications

One potential concern with high-forage diets is an increase in methane emissions. Manure accounts for about 25% of dairy farm methane emissions, with the remaining 75% from enteric emissions, and this represents between 6% and 10% of the total gross energy intake of lactating cows (Chase 2010).

In December 2009, the U.S. Department of Agriculture and the Innovation Center for U.S. Dairy signed a memorandum of understanding to work jointly in support of the goal to reduce the dairy industry's greenhouse gas emissions 25% over the next decade (Bauman and Capper, 2011). The areas they have identified that directly affect methane emissions are: (1) rumen function (including microbial genomics/ecology) and modifiers, (2) enhancing feed quality and ingredient usage to improve feed efficiency, (3) genetic approaches to increase individual cow productivity, (4) management practices to increase individual cow productivity and (5) management of the herd structure to reduce the number of non-productive cow-days (Tricarico, 2012).

The U.S. dairy industry has had a remarkable record of advances in productive efficiency and environmental stewardship over the last half-century, with annual milk production per cow increasing more than 400% and a two-thirds reduction in the carbon footprint for producing a unit of milk (Bauman and Capper, 2011).

It is important to maintain a global perspective on the goal of reducing methane emissions. The U.S. provides about 16% of the world's total milk production but only about 8% of total greenhouse gas emissions (Chase, 2010). North America and Europe currently have the lowest greenhouse gas emissions per unit of fat-protein-corrected milk; the highest level is in sub-Saharan Africa. Also, the majority of the increase in global livestock production over the next 35 years will occur in the developing world (Mitloehner, 2010).

Recent research by Aguerre et al. (2011) on the (non-grazed) forage-to-concentrate ratio effects on milk production and methane emissions involved a 50:50 ratio of alfalfa silage and corn silage incorporated into diets containing 47%, 54%, 61% or 68% forage.

Milk production averaged 80-85 lb. in this trial, with no significant differences among treatments for dry matter intake or energy-corrected milk. However, cows fed the diet with 68% forage had significantly higher (17%) daily methane emissions than cows fed the 47% forage diet. Forage quality was the same for all four diets, highlighting the need for more work with respect to high-forage diets and methane emissions regarding the interactions among forage quality, dry matter intake, NDF digestibility and the associative effects of diet ingredients (Chase and Grant, 2013).

The Bottom Line

The amount of forage in the dairy diet today is primarily dictated by the need to maintain rumen health (and milk components) and the economics of forage production — which are influenced by yield potential and costs for harvest, storage and transportation (logistics) — versus the availability of other non-forage fiber sources such as co-products.

Improvements in forage genetics (e.g., BMR corn, reduced-lignin alfalfa), coupled with improved rumen models and forage analyses, are helping provide higher-quality forages and the understanding of how to capture their full value in the diet.

Potential carbon footprint regulatory hurdles and the balance between "starch for humans" versus "fiber for ruminants" may also change the optimum balance for forages in future dairy diets.

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