

Practical implications of fiber in dairy rations: making use of forage fiber

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Introduction: Challenges defined

Advances in our understanding of fiber digestion, analytical methods for useful fiber analysis and computer models for their practical application are transforming the practice of ration formulation for ruminants. Today, the profitability of ruminant production systems depends largely on maximizing productivity through the efficient use of available resources. Success lies in understanding and utilizing the knowledge base of multiple disciplines.

The importance of fiber in ruminant diets is undisputed and neutral detergent fiber (NDF) is widely used to characterize the fiber fraction of ruminant diets. While not a homogeneous entity, the role of NDF in ensuring proper rumen function and the influence of NDF digestibility on productivity are widely recognized. To put the latter in perspective, Oba and Allen (1999) estimated that a one percent (1%) increase in ruminal NDF digestibility, estimated *in vitro* or *in situ*, will lead to a 0.25 kg increase in 4.0% fat-corrected milk production. Today, the accurate knowledge of NDF digestibility has become extremely important particularly due to the rising costs of most feed ingredients. Under these circumstances, improved NDF digestibility becomes imperative to take full advantage of available resources in ruminant feeding programs.

Unfortunately the large variation in both the rate and extent of disappearance for both fiber (Table 1) and starch (Table 2) that we have observed present a major challenge when formulating dairy rations. The challenge is not only to understand the sources of variability but also to gain insight into which source of variability may give rise to the greatest cost or lead to the greatest return. Twenty years ago, St-Pierre and Harvey (1986) estimated that the economic benefit of routinely testing representative feed samples equated to \$0.27 per cow per day. While the decision to test representative feed samples seems obvious, the challenge then becomes that of deciding what to measure and how to interpret the results.

Table 1. *In vitro* NDF disappearance (% $\pm$ sd) and its associated variability for various forage sources as determined in our laboratories

Forage source	n	% NDF in residue		
		0 h	6 h	48 h
Haylage	525	46.0 $\pm$ 7.2	36.8 $\pm$ 8.1	17.9 $\pm$ 5.2
Grass Silage	26	55.5 $\pm$ 7.1	45.7 $\pm$ 7.9	21.6 $\pm$ 7.4
Rye Silage	25	51.7 $\pm$ 6.6	40.3 $\pm$ 10.4	17.0 $\pm$ 8.5
Corn Silage	838	42.2 $\pm$ 8.6	35.9 $\pm$ 8.0	18.8 $\pm$ 4.8
Hay	22	53.0 $\pm$ 9.8	41.7 $\pm$ 12.3	23.8 $\pm$ 8.4

Table 2. Range of *in situ* starch disappearance (%) for various feed ingredients as determined in our laboratories

Feed ingredient	n	% starch in residue	
		6 h	24 h
Flaked Corn	20	6.8 – 59.9	49.1 – 93.3
H.M Corn	100	7.1 – 89.9	28.4 – 97.8
Corn Meal	30	12.9 – 70.2	33.7 – 93.8
Corn Silage	350	20.4 – 50.2	33.7 – 98.4

Fiber digestibility and the use of exogenous enzymes

The use of wet chemistry or near infrared (NIR) spectroscopy is a good start to characterize the fiber content of feed ingredients; however, knowledge of fiber digestibility is much more valuable to practicing nutritionists. The possible options for evaluating ruminal digestibility of NDF in feedstuffs or complete diets include the use of *in vivo*, *in situ* or *in vitro* methods. While *in vivo* methods will probably provide the most accurate estimates of digestion they are both costly and difficult to conduct. *In situ* and *in vitro* methods, on the other hand, present some disadvantages but have the major benefit of practicality. Methodology is obviously of critical importance, as the measurement technique must demonstrate accuracy, without interfering in fermentation, in order to describe feed ingredients in a manner that can be used in rumen models. The *in vitro* measurement of digestibility has progressed from the early two-stage technique described by Tilley and Terry (1963) to the more automated systems of today. Several authors have reviewed the newer techniques (Garman et al., 1997; Cohen et al., 1997) and have shown that the results obtained from the new systems are reliable and repeatable. One technique reported employed the Ankom Daisy^{II} Incubator, with which NDF digestibility can be measured for forages, grains, or total mixed rations. The system utilizes miniature filter bags immersed in filtered rumen inoculum and buffer. The fermenting chamber holds up to four jars that can contain up to 25 filter bags each. This system offers a great deal of flexibility as far as experimental design is concerned.

One option of handling variation in NDF disappearance is the addition of exogenous enzymes. An experiment was undertaken to evaluate if the product Fibrozyme (Alltech Inc., Nicholasville, KY) affected *in vitro* NDF disappearance rates in corn silage, and if so in what manner. The study involved four corn hybrids planted at three densities (22K, 27K, and 32K per acre). The corn hybrids selected represented a reasonable cross section of those available to producers and included both leafy and grain-type corn plants. The hybrids in this study were grown in three blocks with three replicates per hybrid within each block. Samples were taken following 90 day fermentation, and fermented in the Ankom Daisy^{II} Incubator for 0, 3, 6, 30 and 48 hours at a constant temperature of 39.1°C using rumen fluid from lactating Holstein cows producing in excess of 30 kg/day. Fibrozyme was added at a rate that would be equivalent to 15 g/head per day.

Fibrozyme increased disappearance of NDF ($P<0.05$) across corn silage hybrids and planting rates within the first 6 hours of *in vitro* fermentation (Table 3). This effect is of particular interest as field reports on the success of enzyme supplements have been mixed. Use in the field has no doubt been based on “one enzyme fits all corn silage varieties” strategy; and the fact that there was a numerical ($P<0.06$) difference in how different hybrids responded to Fibrozyme offers one reason why field responses to enzymes may vary.

Table 3. The effects of Fibrozyme on the rate and extent of NDF disappearance from four corn silage hybrids grown at three planting densities

All hybrids	Initial rate of digestion (6 hours)			Extended rate of digestion (30 hours)		
	Control	Fibrozyme	Increase (%)	Control	Fibrozyme	Increase (%)
22K	1.39	2.13	72.8	13.08	12.86	19.9
27K	2.49	3.32	69.3	14.83	12.81	11.7
32K	2.57 ^a	4.66 ^b	196.7	14.35	15.17	13.3
Overall	2.15 ^a	3.38 ^b	112.9	14.09	13.61	7.1

^{a,b}Means with different superscripts differ ($P<0.05$).

Correlations between Fibrozyme response and plant characteristics or digestion rates were calculated (Table 4). Several relationships between ADF and NDF were also examined; as it had been hypothesized that the success of Fibrozyme could be predicted by the numerical difference between NDF and ADF. This hypothesis was not proven as the correlation coefficient between Fibrozyme response and NDF-ADF was very low. The correlation analyses revealed a window of opportunity for use of Fibrozyme based on initial NDF digestion (NDF disappearance within the first 6 hours of *in vitro* fermentation) which lies in the 37 to 42% NDF range. The practical importance of this information lies in the fact that Fibrozyme would not appear to alter the NDF disappearance of very high quality corn silage nor will it improve that of poor quality silage.

Table 4. The relationships between corn silage characteristics and the response to Fibrozyme

Factor	Correlation
Corn hybrid	0.077
Planting density	0.23*
NDF content	-0.25*
ADF content	-0.38*
NDF:ADF ratio	-0.02
NDF-ADF	-0.13
Initial NDF digestion	-0.40*

* $P<0.05$.

A milk production trial to test the application of the *in vitro* NDF digestibility data was conducted using a free stall dairy with 137 cows in a switchback design with two week periods. The majority of the cows on test were in either their first or second lactations, but this was felt to be a positive as these animals would face the greatest challenge as far as intake was concerned (Table 5). Corn silage samples were collected prior to and during the course of the trial to identify the NDF characteristics which fell within the 37-42% NDF window. Fibrozyme was added to the diet at 15 g/head/day by inclusion in a protein supplement that was pelleted at 165°F and 137 kPa. Once the trial began, the diet proportions remained constant except for DM concentrations. The performance results showed that addition of Fibrozyme increased milk yield while its removal from the diet was associated with a decline in milk production (Table 6). The production data demonstrated that *in vitro* analysis of NDF disappearance rate is a valid and valuable tool when designing rations. While the unequal parity and wide range in

days in milk of the cows in the trial made the statistical analysis a challenge (Tables 5-6), the average milk production change across parities amounted to 1.32 liter/day, with the second lactation cows increasing the most with a 1.88 liter/day change. The statistically significant milk response was lost, as expected, during the Fibrozyme withdrawal portion of the trial. Questions could be raised as to the measured effect when the Fibrozyme was reintroduced during the last part of the trial; and one possible answer is that there was a refractory response. If this is the case, it would be of minimal significance on a commercial basis as producers would not add and remove the enzyme on such short notice.

Table 5. Lactational status of the Holstein dairy cows used to examine the effects of Fibrozyme on milk production

Lactation	Average days in milk at start	Range in days
1	86.1	21-171
2	133.7	13-388
3	132.0	14-262

Table 6. Changes in milk production (%) associated with the supplementation of Fibrozyme in dairy rations

Parity	Number of animals	Period 1 (Fibrozyme)	Period 2 (no Fibrozyme)	Period 3 (Fibrozyme)
1	77	+5.33 ^a	-1.85 ^b	+0.31 ^b
2	31	+6.04 ^a	-4.53 ^b	+0.20 ^{ab}
3	19	+1.48 ^a	-1.18 ^{ab}	-8.81 ^b

^{a,b}Means within the same row with different superscripts differ ($P < 0.05$)

A more recent study (Colombatto et al., 2006) examined the effect of the addition of an exogenous fibrolytic enzyme mixture to alfalfa stems fermented in both the Ankom Daisy^{II} Incubator and a gas production system. The results indicated that the addition of the enzyme system increased gas production up to 12 hours and OMD for up to 19 hours of fermentation. These results parallel those of the corn silage trial discussed above in that exogenous fibrolytic enzymes can have a positive effect within the first hours of fermentation and this effect can be utilized during diet formulation.

Fiber digestibility and automated *in vitro* gas production

As mentioned earlier, *in situ* and *in vitro* methods have the benefit of practicality but also present some drawbacks. The major disadvantage for both methods is that estimates of ruminal digestion characteristics are based on gravimetric measurements of substrate disappearance at set time points. Thus, an incorrect choice of time points can lead to incorrect data interpretation, conclusions and decisions. In addition, even if the choice of time points is correct, what happens between the points, or the kinetic aspects of digestion, must also be considered. Additional time points can be included in the analysis to provide information on the kinetics of digestion and improve the estimates but the additional samples rapidly make the methods labor intensive and hence impractical.

In vitro techniques that estimate digestion kinetics indirectly by measuring gas production are a more viable option. Gas production, in this type of system arises directly from microbial substrate degradation or indirectly from the reaction of acid end products with the bicarbonate fraction of the buffering system. Therefore, gas production is highly correlated with substrate digestion and is a powerful and proven method to estimate the

rate and extent of ruminal OM degradation (Dijkstra et al., 2005). Its application to the simultaneous estimation of various OM fractions (NDF, starch, soluble carbohydrates) has limitations, but it is still a practical approach as pooled data from a wide variety of forage sources has proven to provide a usable correlation between gas production and NDF digested (gas yield = 0.35 ml/mg of NDF digested; $R^2=0.92$; Doane et al., 1997).

The qualitative and quantitative aspects of ruminal volatile fatty acid (VFA) production are of keen importance to ruminant nutritionists. Even though the VFA produced with *in vitro* techniques are not subject to ruminal passage rate or absorption, information on VFA concentrations and proportions is of considerable use. It must also be remembered that VFA concentrations measured *in vivo* do not reflect production, as they are the net result of multiple transactions in the rumen at a given point in time, hence VFA measurement in either case has limitations. Additional concerns revolve around ruminal VFA fluctuations following feeding, the concomitant changes in the non-gluconeogenic to gluconeogenic (NGR) ratio of VFA and their effects on nutrient partitioning in the animal (Robinson et al., 1986). The potential relationships between VFA measurements using *in vitro* gas production or *in vivo* methods has been reported in an experiment using mature weathers (Rymer and Givens, 2002). In this study, Rymer and Givens (2002) showed a correlation ($R^2=0.61$) between *in vivo* NGR and *in vitro* ATP production and time to maximum gas production. More importantly the total VFA, molar percentages of acetate, propionate, n-butyrate and the NGR ratio followed similar patterns when varying levels of corn were added to the diet and compared both *in vitro* and *in vivo*. The fact that the two systems followed similar patterns is encouraging as *in vitro* gas production methods then offer a valuable and inexpensive alternative to predict ruminal VFA profiles.

Microbial biomass is usually the major source of protein for ruminants hence its prediction is of paramount importance. Unfortunately this is not an easy task, as there are no rapid and simple laboratory techniques to estimate microbial protein synthesis (Menke et al., 1979). The combination of gas production methods and end point substrate degradation measurements do however provide a reasonable and practical approach to this problem. This approach estimates microbial protein synthesis from the stoichiometric partitioning of degraded substrate between gas production, VFA and microbial biomass (Blummel, 2000). A simplified approach for forage evaluation has recently been proposed by Grings et al. (2005) where microbial biomass production is predicted with the equation $MBP = TSD - (\text{gas volume} \times SF)$. In this equation, **MBP** represents microbial biomass production, **TSD** represents true substrate degradability as defined by Goering and Van Soest (1970) and **SF** represents a stoichiometric factor. Once the MBP figure is known the efficiency of microbial protein synthesis (**EMP**) can be calculated according to the equation $EMP = (TSD - (\text{gas volume} \times SF)) / TSD$.

An integrative approach

Gas production technology allows for the usable collection of digestion kinetics data and has given rise to for a growing body of knowledge that is directly applicable to the feeding programs that are in daily practical field use today (Pitt et al., 1999). This methodology has the limitations intrinsic to an *in vitro* batch culture system; however it can be used to generate both qualitative and quantitative data on the rate and extent of digestion in a relatively practical and inexpensive manner (France et al., 2000). *In vitro* gas production methodology becomes more powerful when combined with measurements of substrate disappearance and volatile fatty acid (VFA) production allowing for the

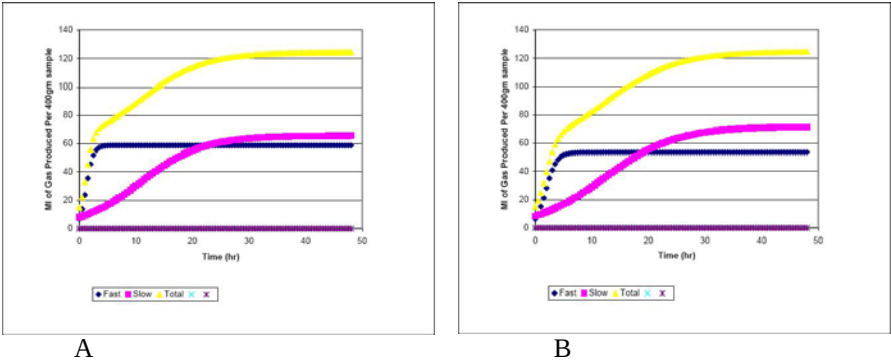
calculation of ruminal microbial efficiency estimates when evaluating forages (Grings et al., 2005). Since 2001, we have been using a wireless automated system, similar to that described by Adesogan et al. (2005), for monitoring gas production from *in vitro* ruminal fermentations. The system uses absolute pressure sensors with a range of 0 to 30 psi and temperature compensation (Point Six Inc., Lexington, KY) that use radio frequency to transmit pressure information to a computerized logging system.

In our experience, the greatest value is obtained when the system is used on a risk assessment basis on the total mixed ration (TMR) rather than the individual dietary ingredients. Data from TMR samples (n=100) from Ontario, Quebec, British Columbia, Pennsylvania, Massachusetts, and New York are presented in Table 7. The gas production profile data was analyzed using a two pool logistic equation and demonstrates that fermentations can be broken into a fast and slow fraction (Figure 1; Schofield et al., 1994).

Table 7. Chemical composition and ruminal fermentative kinetic characteristics of 100 TMR samples determined in our laboratories using *in vitro* gas production

Item	Mean	sd
Chemical composition		
Dry Matter, %	48.02	5.49
Starch, %	28.95	4.67
NDF, %	32.30	3.16
Ash, %	7.26	1.03
Fermentation kinetics		
Size of fast pool, ml	41.19	18.63
Rate of fast pool, %/h	24.1	7.08
Lag time, h.	0.013	0.002
Size of slow pool, ml.	48.32	12.36
Rate of slow pool, %/h	4.2	0.01

Figure 1. Representative fermentation cumulative gas production profiles for a grass silage (A) and a TMR (B) showing the fast and slow fractions of fermentation.



Neither of these two fractions is chemically homogeneous as fermentation of all OM constituents occurs simultaneously. In general our experience indicates that the fast fraction contains mainly starch and soluble fiber while the slow fraction contains fiber (cellulose and hemicellulose) and slow starch. While these observations may annoy those looking for an analysis that reflects the fermentation of chemically identifiable and

measurable feed fractions it does approximate the nature of ruminal fermentation. It therefore represents a practical means to evaluate rations, predict the productive response and make sound nutrition decisions that affect both animal productivity and ultimately economic costs and profitability.

A review of gas production data generated from haylage and corn silage samples harvested across the northeastern U.S., Ontario, and Quebec over the past 5 years is provided in Tables 8 and 9. Given the extensive changes in weather a significant year effect would not be unexpected, however as may be seen this did not happen in the case of haylage yet it did occur with corn silage. It is doubtful that there is a single explanation for this dichotomy, but the effect of genetic selection of hybrids cannot be discounted. Overall, designing dairy rations that include corn silages is obviously becoming more difficult due to fiber constraints and this trend will continue. However, the analytical technologies described here may be used not only to provide extremely valuable information relative to the ruminal fiber fermentation process but may also be employed to examine various dietary supplements and match their use to the appropriate diet.

Table 8. Effect of year on ruminal fermentative kinetic characteristics of corn silage samples ($\pm$ SE) determined using *in vitro* gas production

Item	Year			
	2003	2004	2005	2006
n	62	17	101	41
Fast pool size (ml)	40.9 $\pm$ 1.12 ^a	35.9 $\pm$ 2.14 ^{ab}	39.5 $\pm$ 0.88 ^a	32.0 $\pm$ 1.34 ^b
Fast pool rate (ml/h)	25.9 $\pm$ 1.26	25.6 $\pm$ 2.40	27.0 $\pm$ 0.99	24.0 $\pm$ 1.51
Slow pool size (ml)	50.1 $\pm$ 1.41	46.9 $\pm$ 2.70	49.3 $\pm$ 1.10	45.0 $\pm$ 1.67
Slow pool rate (ml/h)	4.37 $\pm$ 0.10 ^a	4.52 $\pm$ 0.19 ^a	4.13 $\pm$ 0.08 ^{ab}	3.65 $\pm$ 0.13 ^b

^{a,b}Means within a row with a different superscript differ ($P < 0.05$).

Table 9. Effect of year on ruminal fermentative kinetic characteristics of haylage samples determined using *in vitro* gas production

Item	Year			
	2003	2004	2005	2006
n	13	10	30	19
Fast pool size (ml)	35.5 $\pm$ 2.70	39.9 $\pm$ 3.08	37.3 $\pm$ 1.78	38.5 $\pm$ 2.39
Fast pool rate (ml/h)	48.0 $\pm$ 5.53	21.0 $\pm$ 6.76	33.8 $\pm$ 3.90	25.8 $\pm$ 4.91
Slow pool size (ml)	44.8 $\pm$ 2.91	51.1 $\pm$ 3.33	42.6 $\pm$ 1.92	53.2 $\pm$ 2.41
Slow pool rate (ml/h)	8.46 $\pm$ 0.90	4.01 $\pm$ 1.02	4.53 $\pm$ 0.59	4.23 $\pm$ 0.74

^{a,b}Means within a row with a different superscript differ ($P < 0.05$).

The use of gas production to evaluate feed additives

The value of knowing fiber digestibility rates to include exogenous enzymes during dietary formulation was proven in the previous example based on rates derived from the use of gravimetric procedures. The use of gas production and the integrative approach we described allows for the further refinement of this formulation exercise. Gas

production data from a corn silage-based TMR with and without supplemental Fibrozyme is shown in Figure 2. As may be seen, Fibrozyme increased cumulative gas production and shifted the relative pool sizes increasing the fast fraction at the expense of the slow fraction. These changes were also reflected in increased acetate and butyrate concentrations while propionate remained unchanged (Table 10).

Figure 2. Cumulative gas production profile and rate of fermentation for a corn silage-based TMR with and without supplemental Fibrozyme.

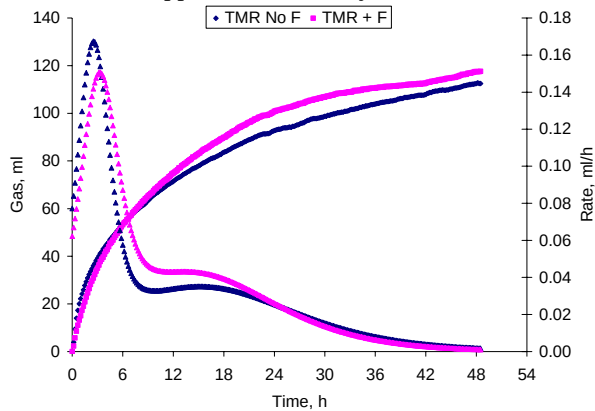


Table 10. Effects of Fibrozyme on VFA concentrations from a corn silage-based TMR fermented using the *in vitro* gas production system

	Control	Fibrozyme
Acetate (mM)	30.2	32.4
Propionate (mM)	10.3	10.31
Isobutyrate (mM)	0.63	0.62
Butyrate (mM)	7.18	7.42
Isovalerate (mM)	1.61	1.63
Valerate (mM)	0.96	1.03
Total VFA (mM)	50.92	53.41

One of the more common concerns that a nutritionist faces is that of choosing protein fractions and the resulting need to balance the form of ruminal nitrogen. Given the requirement of fiber digesting bacteria for ammonia-N, urea has long been a staple of ruminant diets both in the straight and protected form. Unfortunately practical application of protected urea sources has been variable in the past. The recent release of a new generation of sustained N release products has allowed for reexamination of this concept. Experiments were conducted with Optigen (Alltech, Nicholasville Kentucky) where equal portions of a mixture of haylage and corn silage were fermented in the gas system alone, with supplemental urea or Optigen. Cultures receiving urea or Optigen were isonitrogenous. The results (Table 11) demonstrate a significant reduction in the relative pool size of the slow fraction and significant increases in both rates of fermentation when Optigen was utilized. These changes resulted in a numerical increase in the size of the fast pool. This shift corresponded to a time range of 8-10 hours following the initiation of the fermentation and resulted in both a numerical increase in the total VFA concentration and a 5% improvement in MBP production ($P<0.05$) when calculated using stoichiometry (Table 12).

Table 11. Effects of supplemental urea or Optigen on the fermentation kinetic characteristics of a haylage/corn silage mix determined using *in vitro* gas production

	Control	Urea	Optigen
Fast pool size (ml)	23.9	22.8	26.1
Fast pool rate (ml/h)	14.7 ^b	15.0 ^b	36.7 ^a
Slow pool size (ml)	33.3 ^a	35.0 ^a	28.8 ^b
Slow pool rate (ml/h)	5.10 ^b	4.50 ^b	5.82 ^a

^{a,b}Means within a row with different superscripts differ ($P<0.05$).

Table 12. Effects of supplemental urea or Optigen on VFA concentrations of a haylage/corn silage mix determined using *in vitro* gas production

	Control	Urea	Optigen
Acetate (mM)	23.57	24.14	25.16
Propionate (mM)	10.73	9.32	9.86
Butyrate (mM)	4.81	4.34	4.6
Total VFA (mM)	42.28	39.34	41.24
A:P	2.36	2.59	2.55
MBP (mg)	93.5	108.3	114.2

The use of live yeast culture to improve ruminal function

The analytical technologies we described above and dietary supplements such as exogenous enzymes and sustained release NPN may be used as formulation tools to improve the use of fiber in the ration. However; dietary supplements that allow for ruminal conditions that are conducive to improved microbial growth and fiber digestion are also desirable. Several studies have demonstrated the ability of Yea-Sacc^{® 1026} (Alltech Inc., Nicholasville, KY) to increase ruminal pH and the rate of fiber digestion. Modeling these effects, while desirable, has long proven difficult. In an effort to address this difficulty a database was constructed by reviewing the available literature to identify Yea-Sacc^{®1026} effects on ruminal fermentation and derive equations based on those effects that could then be used in CPM-Dairy to predict its influence on milk production. The database was constructed from a total of 52 publications (34 peer-reviewed and 18 non peer-reviewed) including both *in vitro* and *in vivo* studies on multiple ruminant species (cattle, buffalo, sheep and goats). Studies that used other commercial yeast supplements were not included in the database. Ruminal fermentation variables examined included ruminal pH, rate of NDF digestion and microbial N yield. Lactation performance variables examined included dry matter intake (DMI), milk yield and milk composition. Data from the constructed database were analyzed using the MIXED procedure of SAS considering treatment effects fixed and experiment (study) effects random (St. Pierre, 2001).

The database analysis was then used to identify potential ingredient input modifications for the purpose of modeling effects on production. It was arbitrarily decided to apply ingredient input modifications only to forage ingredients. The database analysis revealed that Yea-Sacc^{®1026} supplementation increased ruminal pH ($P<0.01$) by 0.08 units and the rate of NDF digestion ($P=0.03$) by 10.9% (Table 13). In the CPM-Dairy program ruminal pH is estimated as a function of dietary physically effective NDF (peNDF) according to: ruminal pH = $5.425 + 0.04229 \times \text{peNDF}$ (if peNDF<24.5%) and ruminal pH = 6.46 (if peNDF >24.5%). Therefore, the effects of Yea-Sacc^{®1026} on estimated ruminal pH were modeled by adjusting the peNDF value for each dietary

forage according to the following equation ($\text{peNDF}_{\text{ys}} = \text{peNDF} + 4.93$; Equation 1). In the CPM-Dairy program the rate of available NDF digestion is an ingredient input represented by the rate of digestion of the carbohydrate B3 fraction (CHOB3 Kd). Therefore, the effects of Yea-Sacc^{®1026} on NDF digestion rate were modeled by adjusting the CHOB3Kd value for each dietary forage according to the following equation ($\text{CHOB3Kd}_{\text{ys}} = \text{CHOB3 Kd} \times 1.109$; Equation 2).

Table 13. Effects of supplemental Yea-Sacc^{®1026} on dry matter intake (DMI), lactation performance and selected ruminal fermentation characteristics from the meta-analytic review of 34 peer-reviewed and 18 non peer-reviewed publications

Item	n ¹	Treatment		SED ²	P-value
		Control	Yea-Sacc		
DMI (kg/d)	10	18.54	18.86	0.267	0.26
Milk (kg/d)	25	21.30	22.26	0.168	<0.01
Fat (%)	25	4.15	4.19	0.040	0.26
Protein (%)	25	3.28	3.33	0.025	0.06
Fat yield (kg/d)	25	0.83	0.87	0.012	<0.01
Protein yield (kg/d)	25	0.68	0.72	0.008	<0.01
FCM (kg/d) ³	25	22.65	23.81	0.235	<0.01
ECM (kg/d) ⁴	25	22.34	23.53	0.127	<0.01
Ruminal pH	44	6.45	6.53	0.023	<0.01
NDF digestion rate (h ⁻¹)	20	0.0412	0.0457	0.0019	0.03
Microbial N yield (g/d)	13	48.71	53.96	3.147	0.12

¹ n = number of experiments.

² SED = standard error of the difference.

³ FCM (3.5% fat corrected milk) = (0.4324 x kg milk) + (16.216 x kg fat).

⁴ ECM (energy corrected milk) = kg milk x (0.327 + (7.2 x kg milk protein) + (12.95 x kg milk fat)).

The database analysis revealed that Yea-Sacc^{®1026} supplementation increased milk production ($P<0.01$) by 0.96 kg/d, milk fat and protein yields ($P<0.01$) by 0.04 kg/d, FCM production ($P<0.01$) by 1.22 kg/d, and ECM production ($P<0.01$) by 1.19 kg/d (Table 1). CPM-Dairy simulations were ran with Yea-Sacc^{®1026}-adjusted forage inputs to generate predicted lactation performance values that could be compared to the average effects of Yea-Sacc^{®1026} supplementation on milk production identified by the database analysis. The application of Yea-Sacc^{®1026} adjustment factors (Equations 1 and 2) in CPM-Dairy evaluations of ten commercial and five experimental dairy rations accounted for an average increase of 0.4 kg/d in predicted milk production (Table 14).

Conclusions

Years of in depth research have provided modern animal agriculture with a large body of knowledge that should logically lead to formulating rations for ruminants that repeatedly provide maximum productivity. The use of *in vitro* or *in situ* fiber disappearance estimates at single time points is certainly more useful than simple fiber concentration determinations using wet chemistry or NIR spectroscopy. Automated gas production techniques coupled with measurements of VFA concentrations and undigested residue can certainly improve the predictability of ration formulation. The information on ruminal fermentation resulting from this integrative approach is invaluable to practicing nutritionists and may be used to match dietary additives to the appropriate diet. The recent rapid increase in the prices of feed ingredients has shown how precarious the profitability of dairy production can be. The utilization of futures options can buffer

profitability fluctuations in the short term, but in the long run the only sure method is to concentrate on reducing dietary input costs through the use of technology. Given that forage comprises roughly 50% of a dairy diet any improvements in the utilization of fiber will lead to cost reduction and improved profitability. Successful implementation is predicated on understanding the inherent variability in the dynamics of fiber disappearance, but once these are known tools such as exogenous enzymes, slow release non-protein nitrogen sources, and yeast can be used to advantage.

Table 14. Predicted metabolizable energy (ME) and metabolizable protein (MP) allowable milk production resulting from modeling Yea-Sacc^{®1026} effects on ruminal pH and rate of NDF digestion in CPM-Dairy evaluations of 10 commercial and 5 research dairy cattle rations

Ration	Target milk (kg/d)	Yea-Sacc ^{1026®} effect	
		ME allowable milk	MP allowable milk
Commercial			
1	31.7	+0.3	+0.3
2	34.0	+0.4	+0.5
3	35.0	+0.3	+0.3
4	38.5	+0.3	+0.5
5	22.7	+0.3	+0.5
6	38.5	+0.4	+0.5
7	22.7	+0.3	+0.4
8	38.5	+0.3	+0.5
9	38.5	+0.4	+0.6
10	24.9	+0.3	+0.5
Research			
1	18.9	+0.3	+0.3
2	31.0	+0.1	+0.8
3	31.0	+0.2	+0.7
4	40.0	+0.4	+0.6
5	40.0	+0.3	+0.5
Average		+0.3	+0.5

References

Adesogan A.T., N.K. Krueger, and S.C. Kim. 2005. A novel, wireless, automated system for measuring fermentation gas production kinetics of feeds and its application to feed characterization. *Animal Feed Science and Technology* 123-124:211-223.

Blummel, M., 2000. Predicting the partitioning of fermentation products by combined *in vitro* gas volume–substrate degradability measurements: Opportunities and limitations. In: *Gas Production: Fermentation Kinetics for Feed Evaluation and to Assess Microbial Activity*. British Society of Animal Science, Penicuik, Midlothian, pp. 48–58.

Colombatto D., F.L. Mould, M.K. Bhat, E. Owen. 2006. Influence of exogenous fibrolytic enzyme level and incubation pH on the *in vitro* ruminal fermentation of alfalfa stems. *Animal Feed Science and Technology*. In Press. (doi:10.1016/j.anifeedsci.2006.10.001)

- Dijkstra J., Kebreab E., Bannink A., France J., and S. Lopez. 2005. Application of the gas production technique to feed evaluation systems for ruminants. *Animal Feed Science and Technology* 123-124, 561-578.
- Doane P.H., Schofield P., and A.N. Pell. 1997. Neutral detergent fiber disappearance and gas and volatile fatty acid production in the in vitro fermentation of six forages. *Journal of Animal Science* 75:3342-3352
- France J., Dijkstra J., Dhanoa M.S., Lopez S., and A. Bannink. 2000. Estimating the extent of degradation of ruminant feeds from a description of their gas production profiles observed in vitro: Derivation of models and other mathematical considerations. *British Journal of Nutrition* 83, 143-150.
- Goering H.K., and P.J. Van Soest. 1970. Forage fiber analysis (apparatus, reagents, procedures, and some applications). In: *Agricultural Handbook No. 379*. USDA-ARS, Washington, DC, USA.
- Grings E.E., Blummel M., and K.-H. Sudekum. 2005. Methodological considerations in using gas production techniques for estimating ruminal microbial efficiencies for silage-based diets. *Animal Feed Science and Technology* 123-124:527-545.
- Menke K.H., L. Raab, A. Salewski, H. Sreingrass, D. Fritz, and W. Schneider. 1979. The estimation of the digestibility and metabolisable energy content of ruminant feedingstuffs from the gas production when they are incubated with rumen liquor. *Journal of Agricultural Science (Camb.)* 93:217-222.
- 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. *Journal of Dairy Science* 82:589-596.
- Pitt R.E., Cross T.L., Pell A.N., Scholfield P., and P.H. Doane. 1999. Use of in vitro gas production models in ruminal kinetics. *Mathematical Biosciences* 159: 145-163.
- Robinson P.H., S. Tamminga, and A.M. Van Vuuren. 1986. Influence of declining level of feed intake and varying proportion of starch in the concentrate on rumen fermentation in dairy cows. *Livestock Production Science* 15:173-189.
- Rymer C., and D.I. Givens. 2002. Relationship between patterns of rumen fermentation measured in sheep and in situ degradability and the in vitro gas production profile of the diet. *Animal Feed Science and Technology* 101:31-44.
- Schofield P, R. E. Pitt, and A. N. Pell. 1994. Kinetics of fiber digestion from in vitro gas production. *Journal of Animal Science* 72:2980-2991.
- St. Pierre N.R. and W.R. Harvey. 1986. Uncertainty in composition of ingredients and optional rates of success for a maximum profit total mixed ration. *Journal of Dairy Science* 76:3074-3086.