Impact of NDF Content and Digestibility on Dairy Cow Performance

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■ Take Home Messages

- In most situations NDF content and digestibility are the major factors determining the intake and digestibility of dairy rations
- Non-NDF components (neutral detergent solubles) of feeds typically have true digestibilities near 1.00
  - Measured digestibilities are apparent because feces contains endogenous matter from the animal
  - True digestibilities are determined by regressing digestible nutrient versus nutrient content across feeds
- A simple summative equation can be used to estimate digestibility
- It demonstrates that fiber content and its variable digestibility are the most important, if not only, factors affecting dry matter digestibility
- NDF content and digestibility also affect intake
  - Simple mechanisms of intake regulation can explain fiber's impact
  - When high-energy, low-fiber rations are fed, cows regulate intake to meet their energy demand for production
  - When low-energy, high-fiber rations are fed, cows limit intake based on fill capacity
  - NDF is negatively related to energy density and positively related to fill and therefore related to both mechanisms of intake regulation
- Summary of research trials suggests that ration NDF content is 2 to 3 times as important as fiber digestibility in affecting production and intake
- Rations should be formulated first to obtain proper NDF content and NDF digestibility used to fine-tune rations

■ Introduction

Dairy cow performance is determined by the amount of digestible nutrients that is consumed each day. The amounts of consumed digestible nutrients are related to both intake and digestibility. The intake and digestibility of dairy rations are related to the neutral detergent fiber (**NDF)** content and digestibility of forages. The simple summative equation of Van Soest easily demonstrates the impact of NDF content and digestibility on the total dry matter digestibility (**DMD**) of the forage or rations. Van Soest (1967) observed many years ago that NDF was negatively related to intake, which had been confirmed for high-producing dairy cows more recently (Dado and Allen, 1996). The objectives of this paper are to discuss fundamental relationships of NDF content and digestibility on the intake and digestibility of rations and use these relationships to demonstrate the impact of NDF content and digestibility on dairy cow performance.

▪ Effect of NDF Content and Digestibility on Forage or Ration Digestibility

Fiber content and its digestibility have the greatest impact on overall digestibility because fiber is the slowest digesting component in feeds. Most of the non-fiber components in diets have high true rates of digestion. There would be an evolutionary advantage to animals that developed digestive systems capable of maximizing the digestion of critical nutrients (protein, vitamins, energy) and those nutrient sources with high energy density (fats, sugars and starches in seeds). Thus, the true digestibility of proteins, fats, and sugars is between 90 and 100%. The apparent digestibility that we measure is lower than true digestibility because feces contain endogenous protein and fat from sloughed cells and digestive tract secretions (Figure 1). Because there is no easy and effective way of removing endogenous secretions of the animal from the feces, we have to estimate true digestibility using regression equations. If we plot the concentration of digestible nutrient in a feed versus its nutrient concentration, the slope of the line is the true digestibility coefficient and the intercept is the average endogenous secretion of the nutrient (Figure 2). Van Soest (1967) used this technique to determine that the true digestibility of neutral detergent solubles (**NDS** = 100 – NDF) was 0.98 with an endogenous loss of -12.9%. This ability to separate feed components into a fraction that is almost completely digestible (NDS) and one that varies in digestibility (NDF) is the greatest practical result of the detergent system of analysis.

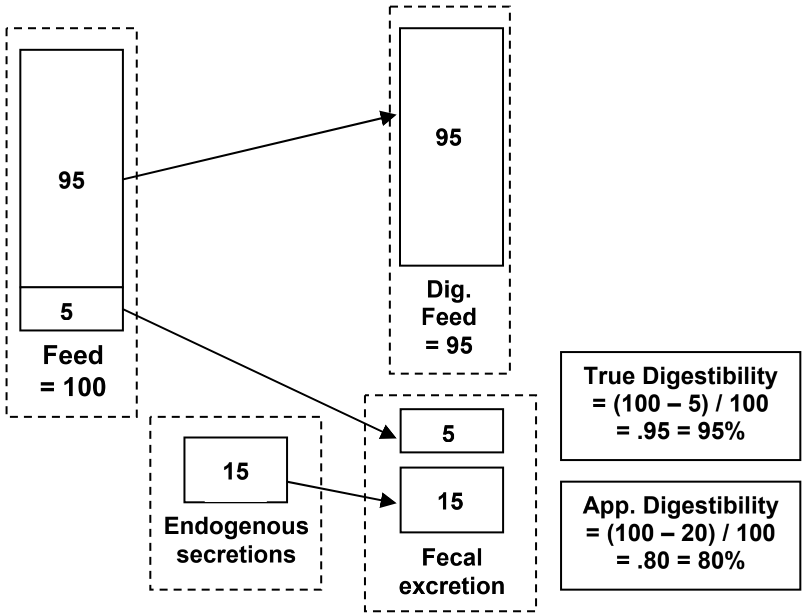

Figure 1. The relationship between true and apparent digestibility.

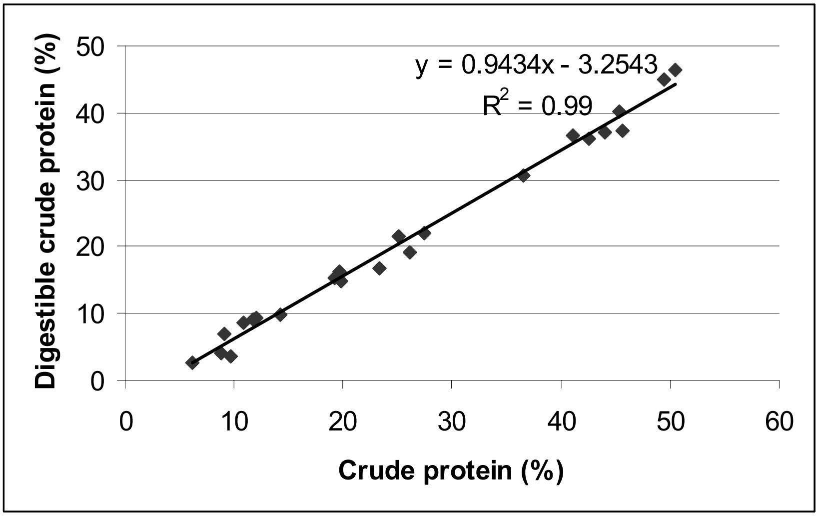

Figure 2. Determining the true digestibility of crude protein by regressing crude protein versus digestible crude protein. The slope of the line (0.9434) is the true digestibility of crude protein across all feeds (data from Morrison, 1956).

Given that NDS are almost completely digested regardless of the feed source (there are two exceptions to this that I will discuss later), it is easy to understand that NDF content (because it affects the content of NDS) and NDF digestibility (because it quantifies the variable digestibility of NDF) are the key determinants of dry matter digestibility (**DMD**). We can use the simple summative equation of Van Soest to show the impact of NDF content and digestibility on DMD (Table 1). Because the digestibility of NDF is always less than that of NDS, the NDF content of a feed has a huge impact on its DMD. The simple summative equation clearly demonstrates why low-fiber concentrates have more DMD than high-fiber forages. This can easily be extrapolated to demonstrate that lower fiber forages should have more DMD than higher fiber forages. Likewise the simple summative approach can be used to provide a simple and easy cross-check on the expected DMD for total mixed rations.

The variable nature of NDF digestibility (**NDFD**) among feed ingredients and forages also has an impact on DMD. Feeds with the same NDF, but higher NDFD, will have a higher DMD. Thus, we can obtain greater DMD by selecting for greater NDFD, so long as we do not allow NDF to increase. The large difference between digestibility of NDS (0.98) and that of NDF (0.40 to 0.70) indicates that changes in NDF content typically have greater impact on DMD than changes in NDFD. If the NDF content of a feed is fixed, the only way to improve DMD is to increase NDFD. However, there is an inverse relationship between NDF content and NDFD in forages as they mature. As plants mature NDF increases and the NDFD decreases that results in substantially lower DMD as plants mature. Genetic modification of forages may allow us to decouple this relationship and obtain higher NDFD for plants with higher NDF. Although it is possible to trade increased NDFD for increased NDF, in most situations, it is easier to modify DMD by controlling NDF content.

Table 1. Using the simple summative equation of Van Soest to demonstrate the impact of NDF content and digestibility on the dry matter digestibility of feeds.

Variable	High fiber feed	Low fiber feed	Low NDFD feed	High NDFD feed
NDF	60.0	10.0	50.0	50.0
NDF digestibility (NDFD)	0.6	0.6	0.4	0.6
Digestible NDF (dNDF = NDF X NDFD)	36.0	6.0	20.0	30.0
NDS (= 100 - NDF)	40.0	90.0	50.0	50.0
Digestible NDS (dNDS = .98 X NDS)	39.2	88.2	49.0	49.0
Endogenous loss	-12.9	-12.9	-12.9	-12.9
Dry Matter Digestibility (DMD = dNDF + dNDS – endogenous loss)	53.8	81.3	56.1	66.1

As indicated earlier there are two practical exceptions to the almost complete digestibility of NDS. Starch can be, but may not always be, completely digested. The lower digestibility of starch in sorghum, corn and to a lesser extent barley is related to the macro-protective coats of these seeds and the micro-protective coatings of starch granules within these seeds. If these grains are finely ground or chewed, are fermented >60 days as high moisture grains, or are steam/thinly flaked or treated with alkali, their starch is rapidly and almost completely digested by dairy cows. However, the incomplete chewing of high-producing dairy cows when combined with high intakes and rates of passage can result in diminished digestion of starch in dry, poorly processed grains. More complex summative equations try to account for this possibility by either adjusting the digestibility of non-fibrous carbohydrates, which is mainly starch in grains, (NRC, 2001) or by subtracting starch from non-fibrous carbohydrates and giving it an adjustable digestibility based on dry matter and processing as in Milk2006 calculations (Shaver et al., 2006).

The other exception is the lower digestibility of crude protein in feeds with tannins or with heat-damaged proteins. Tannins and phenolic compounds can form complexes with proteins that resist fermentation in the rumen, but can be digested in the intestines. However, if the tannin concentration is too high, the tannin-protein complex becomes indigestible in the rumen. Feeds with high tannin are often outliers on the digestible crude protein versus crude protein plots. When feeds are heated due to either spontaneous heating of silages that are too high in dry matter or by cooking during processing, proteins also form complexes with carbohydrates. These Maillard products also differ in digestibility in relation to the amount of heat applied. Much of the protein in acid detergent insoluble crude protein is either indigestible or unusable by animals. Like extensive tannin-protein complexes, heat damaged feeds often are outliers on the digestible crude protein versus crude protein plots.

▪ Effect of NDF Content and Digestibility on Intake

Intake regulation is an extremely complex process that involves many interactions among the animal, its diet, and the feeding situation (Mertens, 1994). However, relatively simple concepts of intake regulation can have practical utility in describing the impact of ration characteristics on intake of animals with a given requirement for energy. The first concept is that animals eat in an attempt to meet their energy demand. While protein is recycled and excess consumed protein is excreted, excess energy is stored (there may be a limited ability to modify metabolism to burn excess energy). If we change the energy density of the ration, animals will respond by adjusting intake. Thus, when fed a high-energy, low-fill diet, animals will adjust intake to meet their energy demand. In fact, animals may “over eat” and exceed their energy demand (they evolved in an environment where feed was typically limited and it was advantageous to eat when feed was available and store fat for the lean times). However, if we reduce the energy density of the diet, the volume of feed that needs to be consumed to meet energy demand exceeds the capacity of the animal to eat. This results in the second concept of intake regulation, when given a low-energy, high-fill diet, animal intakes will be limited by fill capacity.

These concepts are useful because they can be defined by simple equations that can be used to describe how animals and diets interact to obtain the intakes we typically observe. Simply stated, when fed high-energy diets, animals will regulate intake to equal their energy demand as described by the equation:

I_e X E = R; where $\mathbf{I_e}$ is intake regulated by energy demand (kg/d), **E** is the energy density of the ration (Mcal/kg) and **R** is the energy requirement of the animal (Mcal/d).

If we solve for intake we get the equation:

I_e = R/E.

When fed high-fill diets, animal will regulate intake to equal their capacity to process bulk through the digestive tract, which can be described by the equation:

I_f X F = C; where $\mathbf{I_f}$ is intake regulated by fill processing capacity (kg/d), **F** is the filling volume of the diet (L/kg), and **C** is the daily capacity to process fill (L/d).

If we solve for intake we obtain the equation:

I_f = C/F.

It is interesting that these equations suggest that intake is a linear function of animal characteristics (R or C), but a reciprocal function of diet characteristics (1/E or 1/F). These equations may explain why intake is often successfully related to animal characteristics such as body weight and milk production, which are related to maintenance and production energy demand, respectively. However, these equations become useful only if they can be expressed on a common scale. It is evident that energy density and fill are inversely related with high-energy, low-fill diets at one extreme and low-energy, high-fill diets at the other extreme. Although energy density and fill are useful concepts to develop theoretical equations of intake regulation, the equations will only be useful if related to a dietary characteristic that can be easily and routinely measured. Energy density could be related to DMD using the simple summative equation with the measurement of NDF and NDFD. However, animal requirements are not described in terms of DMD and the errors of measuring and converting NDF and NDFD to DMD can be substantial.

Although fill is a more nebulous concept than energy density, it may be more directly related to NDF. Van Soest (1994) proposed the “hotel theory” of fiber to explain how it might be related to fill. Imagine the space occupied by a multi-room hotel. This is analogous to the space occupied by plant cells that are enclosed in a fibrous cell wall. The volume of the cells probably represents the true filling effect of the diet just as the volume of the intact building represents the space it occupies. After the cells are ruptured by chewing and digestion, analogous to the demolition of the hotel, the volume is much less. Thus, the proportion of the diet in fiber that occupies space in the rumen and must be processed by chewing and digestion to pass out of the animal should be related directly to the fill processing capacity of dairy cows. Given that NDF is routinely measured, is directly related to fill effect, and is inversely related to digestibility, it seems the logical choice for expressing the equations for intake based on energy density and fill on a common basis.

If we simply let F be a direct function of NDF, then E will be a function of (100 – NDF) and both equations can be expressed on a common X-axis. Because R is typically measured as net energy of lactation (**NEL**), NDF must be converted to NEL using several equations that are available. Because fill is ill-defined, it is easiest to relate it directly to NDF and express C in terms of the amount of NDF that can be processed by dairy cows each day. In a series of experiments in which the NDF content of the ration was varied from 25 to 55% it was determined that dairy cows maximized 4% fat-corrected milk when they consumed about 1.2% of their body weight as NDF daily. This was selected as the NDF intake capacity.

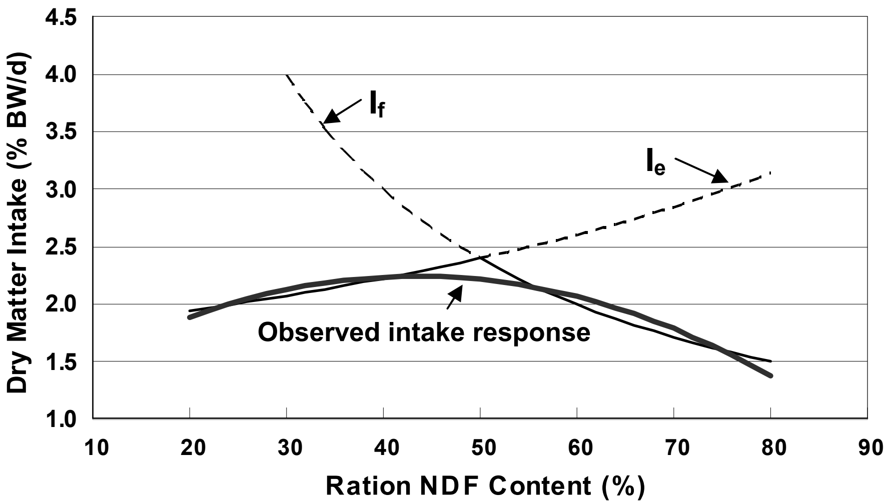

Figure 3. Illustration of intake predicted by simple concepts of energy demand (Ie) and fill limitation (If) when compared to intakes typically observed when ration NDF is varied.

A plot (Figure 3) of the simple concepts of intake regulation shows that they intersect and this intersection is the point at which the intake regulation mechanism would switch from intake regulated by energy demand to intake regulated by fill limitation. Thus, the correct equation for actual intake (I_a)would be:

I_a = minimum (I_f or I_e); where I_a is actual intake.

Intake predicted by I_a agrees quite closely with the intake response that we typically see as we change the NDF content of dairy rations. At low NDF concentrations intake is reduced because the diet is high in energy and animals reduce intake to match energy demand. As NDF increases, intake increases because the ration is less dense in energy and more is eaten to meet the energy demand. At some point, the ration becomes so bulky that intake is limited by fill and from that point intake is reduced as ration NDF increases. These simple concepts of intake regulation indicate that intake can increase, remain constant or decrease with changes in ration NDF thereby explaining the controversy in the research literature about the impact of NDF content on intake by dairy cows.

Oba and Allen (1999) compiled data from several experiments to evaluate the impact of NDFD on dairy cow performance. They concluded that increasing NDFD increased both intake and milk production. The impact of NDFD on milk production might be expected based on the increased DMD as predicted by the simple summative equation discussed earlier (Table 1). However, the NDFD obtained by cows is often less than that determined by laboratory in vitro assays. In vitro NDFD can vary considerably among and within laboratories because it is a biological assay that is relatively complex and because the ruminal fluid used in these assays can vary within and among donor animals. Even with this variability, in vitro NDFD are typically higher than observed in cows. This could be related to the time of fermentation in vitro not matching the retention time of fiber in cows and to reduction in fiber fermentation when forages are fed with concentrates in mixed rations.

The impact of NDFD on intake is much less clear than its impact on digestibility. If we assume that most dairy cows are fed rations high enough in fiber that fill limits intake, it would be reasonable to suggest that NDFD affects intake by reducing the effective filling effect of NDF. Van Soest's hotel theory would suggest that if digestion weakened plant cell walls they would disintegrate more rapidly thereby occupying less space in the digestive tract. Furthermore, rapid disintegration of cell walls would allow them to pass from the rumen more quickly. Reducing the volume and increasing the rate of passage are two mechanisms by which increased NDFD could increase intake when fill is the intake limitation.

▪ Relative Impact of NDF Content and Digestibility on Cow Performance

Oba and Allen (1999) compiled data from seven experiments with 13 comparisons and reported that an 8.4%-unit difference in NDFD between high and low digestibility forages resulted in 1.4 kg higher DM intake and 2.1 kg higher 4% fat-corrected milk (**FCM**). They concluded that a 1%-unit increase in NDFD measured in situ or in vitro resulted in an increase of 0.17 kg DM intake and 0.25 kg FCM. Mertens (2006) added ten additional experiments to the original database of Oba and Allen (1999) and adjusted all in situ and in vitro measures of NDFD to a fermentation time of 48 h (**IVNDFD48h**, %). Using meta-analysis, it is possible to remove differences among experiments in cows and techniques to evaluate the within-experiment effects of IVNDFD48h and NDF content on intake and milk production.

Mertens (2006) observed significant relationships between IVNDFD48h and intake and milk production and also extracted the effect of ration NDF (**RNDF**, %) content on dairy cow responses. Allowing an individual intercept for each trial, the regression coefficients within trial between forage IVNDFD48h or RNDF and cow responses for FCM (kg/d), DM intake (**DMI**, kg/d), or NDF intake (**NDFI**, % of BW/d) were:

FCM = Trial + 0.139*(IVNDFD48h) - 0.520*(RNDF); R^2 = 0.977.
DMI = Trial + 0.0970*(IVNDFD48h) - 0.312*(RNDF); R^2 = 0.949, and
NDFI = Trial + 0.00485*(IVNDFD48h) - 0.0237*(RNDF); R^2 = 0.930.

The regression coefficients from the larger database were smaller than the values determined by Oba and Allen (1999) for DM intake (0.097 versus 0.17) and FCM (0.139 versus 0.25).

The regression coefficients indicate the amount of change in FCM, DMI or NDFI that occurred for each percentage-unit change in either IVNDFD48h or RNDF. In these trials, the forage that differed in IVNDFD48h supplied 68% of the NDF in the ration. In research trials, the proportion of NDF from the experimental forage is often maximized; however, under most practical feeding situations, a single forage typically supplies only 30 to 50% of the ration NDF. Additional equations were calculated from the dataset in which the IVNDFD48h was weighted by the proportion of NDF in the ration supplied by the experimental forage. These equations determine the regression coefficient assuming all of the NDF was obtained from the experimental forage and can be used to calculate the effect of IVNDFD48h of the forage for any proportion of NDF obtained from forage:

FCM = Trial + 0.145*(wt)*(IVNDFD48h) - 0.537*(wt)*(RNDF); R^2 = 0.975.
DMI = Trial + 0.123*(wt)*(IVNDFD48h) - 0.268*(wt)*(RNDF); R^2 = 0.962, and

NDFI = Trial + 0.00585*(wt)*(IVNDFD48h) - 0.0253*(wt)*(RNDF); R^2 = 0.936; where (wt = 1.00) for the regression coefficient obtained.

When the average proportion of 0.68 of the ration NDF from the forages is substituted for (wt) in these equations the coefficient for IVNDFD48h is 0.099 and 0.084 for FCM and DMI, respectively. These values are slightly lower than the regression coefficients reported in the previous paragraph that were calculated directly. The results in the previous paragraph assume that the average proportion of ration NDF from forage was similar for all trials. The latter coefficients were derived using the actual proportion of NDF from forage in each trial and should be more accurate. They are also more useful because they can be used to estimate the effects of IVNDFD48h of a forage for any level of incorporation in the ration. For example, if the forage supplies only 30% of the NDF in the ration it would be estimated that each percentage-unit change in IVNDFD48h of that forage would increase FCM by 0.069 kg/d (= 0.145*.3) and DMI by 0.037 kg/d (= 0.123*.3).

The magnitudes of the regression coefficients for IVNDFD48h and RNDF in the FCM equation suggest that the effect of changing ration NDF has three times greater impact than does in vitro digestibility. Likewise the DMI equation indicates that ration NDF has more than twice the effect of in vitro digestibility. These observations suggest that it is most important to formulate the ration to have the proper NDF content than NDFD. Nevertheless, given an optimal ration NDF, increasing the NDFD of the forage or ration will always provide an additional benefit because of improved DMD and DMI. However, it is difficult for improved NDFD to compensate for increased NDF in the ration.

▪ Conclusion

In most situations, neutral detergent fiber (NDF) content and digestibility are the major factors determining the intake and digestibility of dairy rations because fiber is the least digestible component in feeds and also the one that varies the greatest in digestibility. Non-fiber components of feeds, such as neutral detergent solubles (NDS = 100 – NDF) typically have true digestibilities near 100%. It was an advantage to animals to evolve digestive systems that maximized the digestion of important nutrients like proteins, fats and sugars. The digestibilities we measure are apparent because feces contains endogenous matter from the animal. True digestibilities are determined by regressing digestible nutrient versus nutrient content across feeds. The detergent system of feed analysis is important because it separates feeds into NDS, which are 98% digestible and NDF, which has incomplete and variable digestibilities. A simple summative equation based on NDF can be used to estimate total dry matter digestibility. The equation demonstrates that fiber content and its variable digestibility are the most important, if not only, factors affecting dry matter digestibility. In addition to digestibility, NDF content and digestibility also affect intake and simple mechanisms of intake regulation can explain fiber's impact. When high-energy, low-fiber rations are fed, cows regulate intake to meet their energy demand for production. When low-energy, high-fiber rations are fed, cows limit intake based on fill capacity. Because NDF is negatively related to energy density and positively related to fill, it can be related to both mechanisms of intake regulation. Summary of research trials suggests that ration NDF content is 2 to 3 times as important as fiber digestibility in affecting production and intake. Thus, rations should be formulated first to obtain proper NDF content and then NDF digestibility can be used to fine-tune rations.

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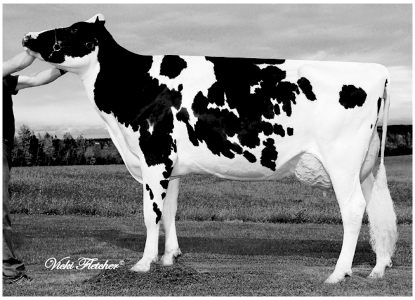
Holstein Canada Announces Canadian Champions 2008



A Canadian Champion is awarded to a Holstein cow that surpasses the previous all-time highest performance for milk, fat, protein, and total BCA in her age-at-calving category. If more than one animal in a given year exceeds the previous highest level, only the top individual is recognized.

Innislake Morty Lucky Charm

(VG-85-2yr-CAN)

- **2-Year-Old for Fat**
- 1 Superior Lactation
- Breeder: Innislake Dairy Farm Ltd., Olds, AB
- Owner: Leo Baumann and Robert Mallette, Lyn, ON
- Sire: Stouder Morty-ET (EX-CAN)

	Production (kg) 02-04 305	BCA (Deviation)
Milk	16,398	409 (+129)
Fat	976 6.0%	655 (+382)
Protein	511 3.1%	399 (+125)
Total		1,463 (+636)

Beaver Ray Blitz Mirka

(VG-87-5yr-CAN)

- **4-Year-Old for Milk**
- 2 Superior Lactations
- Breeder and Owner: Remi Leroux, Ste. Anne De Prescott, ON
- Sire: Fustead Emory Blitz-ET (EX-94-11yr-USA Extra'04 GM)

	Production (kg) 04-09 305	BCA (Deviation)
Milk	25,438	519 (+271)
Fat	979 3.8%	532 (+268)
Protein	777 3.1%	495 (+231)
Total		1,546 (+770)

Arla Outside Florissante

(GP-82-2yr-CAN)

- **7-Year-Old for Milk**
- 2 Super 3s
- 4 Superior Lactations
- Breeder and Owner: Conrad Riendeau, Saint-Césaire, Qc
- Sire: Comestar Outside (EX-95-CAN Extra'98)

	Production (kg) 07-09 305	BCA (Deviation)
Milk	23,772	476 (+165)
Fat	1,082 4.6%	588 (+279)
Protein	715 3.0%	453 (+139)
Total		1,517 (+583)