New Approaches to Feeding Dry Cows

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Abstract

Interest has surged recently in use of high-straw low-energy diets for dry cows. When implemented correctly, these diets have been successful in decreasing incidences of peripartal health disorders. These diets may work by controlling overall energy intake by cows and thereby prevent metabolic changes similar to those that develop in fat cows. By formulating high-bulk TMR that will limit total energy intake but provide adequate amounts of protein and other nutrients, cows can be allowed to consume feed ad libitum and meet their requirements, while preventing over-consumption of energy. Guidelines for formulating these rations are discussed, including the need to carefully interpret calculated energy values. Equally as important as diet formulation, however, is feeding management. Cows must not be able to sort the ration, and adequate bunk space must be available. Although other low-energy ingredients might also be usable to dilute the energy of corn silage and other higher-energy feeds, no comparative data are available. Research to evaluate additional ingredient options is needed.

Introduction

Dairy operations, large and small, continue to be plagued by a high incidence of metabolic disorders and infectious diseases around calving. Turbulent transitions increase health care expenses, decrease milk production, impair reproductive performance, and result in premature culling or death. Farm profitability and animal well-being both suffer. Despite many years of research and field emphasis, practical management strategies to minimize health problems while still promoting high milk production have remained elusive.

Over the last 20 years, it has become common practice to feed rations of higher energy and nutrient density during the close-up (pre-fresh) period, generally beginning around 3 weeks before expected calving. This approach was designed in an effort to adapt the rumen microbial population and rumen papillae to higher nutrient diets fed after calving, decrease body fat mobilization and fat deposition in liver, and control blood calcium concentrations. Although each of these ideas by themselves were sound and based on good research data, the ability of higher-energy close-up or "steam-up" diets to minimize production diseases in research trials and field experience has been disappointing and frustrating. Overall, research data fail to demonstrate that steam-up diets reliably and repeatedly improve production, body condition, reproduction, or health after calving.

We have been frustrated by this lack of success in both research and field settings and have searched for a better approach to dry cow nutritional management. The "new" concepts in this paper in many ways are nothing new, as they center on formulating dry cow rations to dietary energy densities that were established many years ago by

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the National Research Council **(NRC)**. The innovation is in interpreting these "old" concepts in new light relative to the existing dogma and in development of practical systems suitable for modern dairy management practices on both small and large dairy farms.

Controlling Energy Intake During the Dry Period

Over the last decade, our research group has investigated whether controlling energy intake during the dry period might lead to better transition success (Grum et al., 1996; Drackley, 1999; Drackley et al., 2001, 2005; Dann et al., 2005, 2006; Douglas et al., 2006; Loor et al., 2005, 2006). Our research drew both from our ideas and observations, as well as from field experiences by individuals such as Dr. Gordie Jones and Dr. Peter Drehmann. The data we have collected demonstrate that cows fed even moderate-energy diets (0.68 to 0.73 Mcal NE_L/lb DM) will easily consume 40 to 80% more NE_L than required during both the far-off and close-up periods. Cows in these studies were all less than 3.5 body condition score at dry-off, were housed in individual stalls, and were fed diets based on corn silage, alfalfa silage, and alfalfa hay with some concentrate supplementation. We have no evidence that the extra energy and nutrient intake was beneficial in any way. More importantly, our data indicate that allowing cows to over-consume energy to this degree may predispose them to health problems during the transition period if they face additional management challenges that create stress responses or limit feed intake.

We have collected a variety of data indicating that prolonged over-consumption of energy during the dry period can result in poorer transitions. These data include whole-animal responses important to dairy producers, such as lower post-calving dry matter intakes and slower starts in milk production (Douglas et al., 2006; Dann et al., 2006). We also have demonstrated that overfeeding results in negative responses of metabolic indicators, such as higher nonesterified fatty acids **(NEFA)** in blood and more triglyceride or fat in the liver after calving (Douglas et al., 2006; Janovick Guretzky et al., 2006). From a basic-science standpoint, there are alterations in cellular (Litherland et al., 2003) and gene-level responses (Loor et al., 2005, 2006) that potentially explain many of the changes at the cow level.

Our data demonstrate that allowing cows to consume more energy than required, even when cows do not become noticeably over-conditioned, results in responses that would be typical of overly fat cows. Because energy that cows consume in excess of their requirements must either be dissipated or stored, we speculate that the excess is accumulated preferentially in internal adipose tissue (fat) depots in some cows. The NEFA and signaling molecules released by some of these visceral adipose tissues go directly to the liver, which may cause fatty liver, subclinical ketosis, and other secondary problems with liver function. It is well-known that humans differ in their tendencies to accumulate fat in different locations, and central obesity is a greater risk factor for disease. Similarly, cows might also vary in the degree to which they accumulate fat internally. In many cases, the mechanisms we have been studying in dry cows are similar to those from human medical research on obesity, type II diabetes, and insulin resistance.

Other research groups around the U.S. (Holcomb et al., 2001), as well as in other countries (Agenas et al., 2003; Kunz et al., 1985; Rukkwamsuk et al., 1998), have reached similar conclusions about the desirability of controlling energy intake during the dry period. Our work has extended the ideas to show that over-consumption of energy is common, even when feeding typical dry period diets thought to be "safe", and this may be a predisposing factor to poor health. We also have extended the idea of the high-straw, low-energy ration as a simple and practical approach to achieve the control of energy intake.

Our solution to the potential for cows to over-consume energy is to formulate rations of relatively low energy density (0.59 to 0.63 Mcal NE_L/lb DM) that cows can consume free choice without greatly exceeding their daily energy requirements. It is important to note that we are not proposing to limit energy intake to less than cows' requirements but rather to feed them a bulky diet that will only meet their requirements when cows consume all they can eat. We have termed this the "Goldilocks diet" (Drackley and Janovick Guretzky, 2007) because, like the story of Goldilocks and the three bears, we don't want the cow to consume too much or too little energy, but rather just the right amount to match her requirements.

To accomplish the goal of controlled energy intake requires that some ingredient or ingredients of lower energy density be incorporated into diets containing higher-energy ingredients such as corn silage, good quality grass or legume silage, or high quality hay. Cereal straws, particularly wheat straw, are well-suited to dilute the energy density of these higher-energy feeds, especially when corn silage is the predominant forage source available. Lower quality grass hays also may work if processed appropriately but still may have considerably greater energy value than straw and thus are not as effective in decreasing energy density.

We are aware of no controlled data comparing different types of straw, but it is the general consensus among those who have years of experience using straw that wheat is preferred. Barley straw is a second choice, followed by oat straw. While reasons for these preferences are not entirely clear, wheat straw is more plentiful, is generally fairly uniform in quality, and has a coarse, brittle, and hollow stem that processes easily, is palatable, and seems to promote desirable rumen fermentation conditions. Barley straw lacks some of these characteristics. Oat straw is softer, and as a result, it does not process as uniformly. In addition, oat straw generally is somewhat more digestible and thus has a greater energy content. Research to document these potential differences would be very useful.

It is critical that the straw or other roughage actually be consumed in the amounts desired. If cows sort out the straw or other high bulk ingredients, then they will consume too much energy from the other ingredients and the results may be poor. A TMR is by far the best choice for implementing high-straw diets to control energy intake. Some TMR mixers can incorporate straw without pre-chopping and without overly processing other ingredients, but many mixers cannot. It may be necessary to pre-chop the straw to 2-inch or less lengths to avoid sorting by the cows.

As discussed in more detail in a later section, properly mixed high-straw, low-energy diets can be fed all the way through the dry period. The system can be tailored to a variety of management schemes and preferences.

Advantages and Beneficial Outcomes

Based on our research and field observations, adoption of the high-straw, low-energy TMR concept for dry cows might lead to the following benefits:

- Successful implementation of this program essentially eliminates occurrence of displaced abomasum. This may result from the greater rumen fill, which is maintained for some period of time even if cows go off feed for some reason, or from the stabilizing effect on feed intake (Janovick Guretzky et al., 2006).
- Field survey data collected by the Keenan company in Europe (courtesy of D. E. Beever, Richard Keenan and Co., Borris, Ireland) show

strong indications of positive effects on health. In 277 herds (over 27,000 cows) in the United Kingdom, Ireland, France, and Sweden, changing to the high-straw, low-energy TMR system decreased assisted calvings by 53%. In addition, the change decreased milk fever by 76%, retained placenta by 57%, displaced abomasum by 85%, and ketosis by 75%. Using standard values for cost of these problems, the average increase in margin per cow in these herds was $114 just from improved health alone. While these are certainly not controlled research data, they are consistent with the results in our research, as well as field observations in the USA.

- The same sources of observational data indicate that body condition, reproductive success, and foot health may be improved in herds struggling with these areas.

- Although data are limited, milk production appears to be similar to or slightly lower than results obtained with higher-energy close-up programs. There is some evidence that persistency may be improved, with cows reaching slightly lower and later peak milk. Therefore, producers should be careful to not evaluate the system based on early peaks and should look at total lactation milk yield, daily milk, and over time, indices of reproduction and other non-milk indicators of economic value.

- Straw and corn silage generally are lower in potassium content and thus help to control the dietary cation-anion difference (DCAD) without excessive addition of anionic salt mixtures.

- The program may simplify dry cow management and ration composition in many cases.

- Depending on straw cost in your area, the ration likely will be no more expensive than the average cost of far-off and close-up diets and could be cheaper in parts of the country where straw is plentiful.

Single-Diet Dry Cow Management?

Our most recent research (Janovick Guretzky et al., 2006), as well as considerable field experience, indicates that a single-diet dry cow program can be successful using these principles. Dry matter intakes remain more constant as cows approach calving when fed the high-straw, low energy diets (Dann et al., 2006; Janovick Guretzky et al., 2006) than in cows fed high-energy close-up diets (Grummer et al., 2004). Single-group systems would have the advantage of eliminating one group change, which may decrease social stressors as described by University of Wisconsin researchers (Cook, 2007). Single-group management may work particularly well for producers managing for shorter dry periods.

A variation is to maintain far-off and close-up diets, with essentially the same diet for both except that a different concentrate mix or premix is used for the close-ups, which may incorporate anionic salts, extra vitamins and minerals, additional protein, or selected feed additives. The optimal high-forage, low-energy dry cow ration will contain the primary forages and grains to be fed in the lactation diet but diluted with straw or low-quality forage to achieve the desired energy density. In this way, the rumen still can be adapted to the types of ingredients to be fed after calving without excessive energy intake during the dry period.

If producers desire to maintain the conventional two-group or "steam-up" philosophy for dry cow feeding, our research has shown that the most critical factor is to ensure that the energy density of the far-off dry period diet is decreased to near NRC (2001) recommendations (NE_L of 0.57 to 0.60 Mcal/lb DM) so that cows do not over-consume energy (Dann et al., 2006). In this research, wide extremes in close-up nutrient intake had very little effect compared with the effect of allowing cows to consume excess energy during the far-off period.

Specifications for Dry Period Diets

The controlled energy system works best for producers who are relying on corn silage as a primary forage. The combination of straw and corn silage is complementary for many reasons, including energy content, low potassium contents, starch content, and feeding characteristics.

The NE_L requirement for 1500-lb Holstein cows is between 14 and 15 Mcal per day (NRC, 2001). Some suggested guidelines for formulation of controlled energy diets to meet that requirement are as follows, on a total ration DM basis.

- Dry matter intake: 25 to 27 lb per day. For far-off cows, intakes by individual cows have often exceeded 30 lb/day of DM.

- Energy density: 0.59 to 0.63 Mcal NE_L/lb DM. This topic is discussed in more detail in a later section.

- Protein content: 12 to 14% of DM as CP; >1,000 g/day of metabolizable protein. Use a program such as the NRC (2001) model or Cornell Net Carbohydrate and Protein System/ Cornell-Penn-Minor (CNCPS/CPM; Cornell University, Ithaca, NY) Dairy to evaluate metabolizable protein.

- Starch content: 12 to16% of DM.

- Forage NDF: 40 to 50% of total DM, or 10 to 12 lb daily (0.7 to 0.8% of body weight). The target value should be on the high end of the range if more higher-energy fiber sources (like grass hay or low-quality alfalfa) are used and at the low end of the range if straw is used.

- Total ration DM content: <55% (add water if necessary). Additional water will help hold the ration together and improve palatability.

- Follow standard guidelines for mineral and vitamin supplementation. For close-ups, target values are 0.40% magnesium (minimum), 0.35 to 0.40% sulfur, potassium as low as possible, a DCAD of near zero or negative, 0.27% phosphorus, and at least 1,500 IU/day of vitamin E. Recent data suggest that calcium does not have to be increased beyond 0.6% of DM (Lean et al., 2006).

An example formulation is included in Table 1 from a recently completed experiment by our group (Janovick Guretzky et al., 2006). The example is for the far-off dry cow group, but the close-up diet was essentially identical except for the addition of anionic salts.

As long as the lactation diet is formulated appropriately, there seems to be little difficulty in transitioning to the lactation diet immediately after calving. Many producers have found that inclusion of ½ to 2 lb of chopped straw in the lactation diet improves rumen function and animal performance, particularly when physical fiber is borderline adequate. Addition of the straw postpartum also may help to ease the transition from the lower-energy dry cow diet.

Deciphering NE_L Values

The NE_L value specified for the same diet may vary considerably depending on method used to derive the value. While we have used NE_L widely to formulate and evaluate high-straw, low-energy diets, nutritionists, veterinarians, and producers have expressed confusion on how to arrive at the "correct" NE_L content of the rations. Because of the confusion, it may be better to focus on providing the recommended intakes of forage NDF (10 to 12 lb/day) as a primary guideline for achieving the correct energy density. Nevertheless, NE_L values are important and useful if applied and interpreted carefully.

In calculating NE_L values, some confusion stems from the changeover to use of the NRC (2001) equations and calculation methods, and some is related to differences in how feed analysis laboratories calculate and report NE_L values. It is important that those working to formulate and monitor the rations are using consistent units for evaluating NE_L density of the diets to avoid confusion. Moreover, users should realize that it is difficult to compare NE_L values across locations and analysis laboratories, so that a consistent system within a farm or nutrition consulting practice is more important.

An example of the potential confusion in using NE_L values for high-straw, low-energy rations is shown in Table 1. The diet was fed to one group of cows and heifers in our most recently completed experiment (Janovick Guretzky et al., 2006). Feed ingredients were sampled weekly, formed into monthly composites, and analyzed by Dairy One Laboratory (Ithaca, NY) using wet chemistry techniques. Using the actual measured cow variables and analyzed feed composition, we compared the NE_L density of the ration calculated 4 different ways. The value for the total diet calculated by the NRC (2001) model was 0.62 Mcal/lb DM. By using the analytical values for monthly composites of feed ingredients in the CNPS (Version 5.0), the comparable NE_L value was 0.59 Mcal/lb. If we used the NE_L values from Dairy One for individual ingredients to additively calculate the total dietary NE_L density, the value was 0.55 Mcal/lb DM. However, if we used the values for individual ingredients provided by Dairy One as “NRC values” for dry cows, the total diet NE_L was 0.67 Mcal/lb DM! Why the large discrepancy? Which is “correct”?

The NE_L value is technically correct only for the feed that a cow actually eats (NRC, 2001). This is because ingredients in a diet influence the rumen digestibility of other ingredients, some positively and some negatively. A classic example of this phenomenon is that high concentrate addition to a diet decreases the digestibility of the NDF components in forages by changing the rumen environment. Consequently, the NE_L density of a diet cannot be determined accurately by adding together the calculated NE_L values of individual ingredients. The NE_L value of an individual feed ingredient is only correct if it is fed as the only feed ingredient to a cow, which of course is uncommon.

In addition, the digestibility of the dietary DM decreases as total feed intake increases. This decrease is more pronounced for the NDF fraction than for starch and is greater for grass-type forages than legumes. The NRC incorporates a standard reduction of 4 percentage units digestibility for each multiple of maintenance intake. Because different components of the diet are affected differently by the intake effect, Van Soest (Cornell University) devised a variable discount system. These discounts are used by Dairy One, for example, to report an NE_L value at 3× maintenance, which would be equivalent to the intake needed to produce about 66 lb of milk (see www.dairyone.com/Forage/FactSheet/NRC_201_Energy_Values.htm. and www.dairyone.com/Forage/Newsletters/199903.pdf). Because the NE_L value of straw is severely penalized by the Van Soest variable discount system, the calculated value of the diet is considerably lower than the NRC-model value for the total ration (Table 1). On the other hand, using the laboratory values assigned to individual ingredients by the laboratory using NRC principles and then reconstructing an “average” value of the ration overestimates the NE_L density relative to the value determined for the total diet as consumed using the NRC (2001) model.

An alternate approach is to use net energy for maintenance (NE_M) values instead of NE_L. The NE_M of a ration should, by definition, be equal to NE_L at maintenance intakes (NRC, 2001). When we used NE_M provided by Dairy One for individual ingredients to calculate energy values for the diet shown in Table 1, the total ration NE_M (0.60 Mcal/lb DM) was close to the NE_L value calculated for the total diet (0.62 Mcal/lb DM) by the NRC (2001) model.

The bottom line is that those formulating and monitoring diets must be consistent in which energy and laboratory units are being applied and realize that comparison of dietary energy values across studies, laboratories, or farms must be done carefully and with understanding of how the values were derived. Using the assigned NE_L values from analytical laboratories may not be appropriate for dry cows fed mixed diets. Values for NE_L of the total diet calculated by using the NRC (2001) or CNCPS/CPM models will always be more accurate predictors. Use of NE_M values for individual ingredients to calculate an NE_M value for the total diet may be the most accurate unit for reconstructing a total diet value from individual analyses.

Practices Important for Success

Three factors are critical to successfully implement this approach: 1) prevention of sorting, 2) ensuring continuous and non-crowded access to the TMR, and 3) careful monitoring of DM content and attention to detail. In situations where "train-wrecks" have been reported, it has almost always been the case that one or more of these factors has been faulty, not the dietary approach itself.

The straw must be chopped into a particle size that cows will not sort out of the ration. In general, this means less than 2-inch particles. If the straw is pre-chopped, an appropriate chop is indicated by having about 1/3 of the particles in each of the three fractions of the Penn State shaker box. Because of the bulky nature of straw and the resulting TMR, producers may think that cows are sorting excessively when they are not. To verify that cows are not sorting, the feed refusals should be monitored carefully and compared to the original TMR. One simple way to evaluate sorting is to shake out the TMR with the Penn State box and then repeat the analysis on the feed refusals the next day. Results should not differ by more than 10% from TMR to refusal. Another way to monitor sorting is to collect samples of the feed refusal from several areas of the feedline and have it analyzed for the same chemical components as the TMR fed. Again, composition of NDF, CP, and minerals should not vary by more than 10% between the ration and refusals if cows are not sorting. If cows sort the straw, some cows will be consuming a higher energy diet than formulated, and some (the more timid cows) will be left with a much lower quality ration than desired. Herds in which sorting is a problem will be characterized by pens of dry cows that range widely in body condition: some will be over-conditioned and some under-conditioned, while of course some may be "just right".

Another common pitfall is poor feedbunk management that limits the ability of cows to consume feed ad libitum. Because of the bulky nature of the diet, cows may have to spend more time eating to consume enough feed to meet energy and nutrient requirements. Bunk space must be adequate and feed pushed up frequently. If feed is not pushed up, cows likely will not be able to consume what they need to meet requirements.

Other common problems arise when the DM content of straw, hay, and silages changes markedly from assumed values. This may happen, for example, if the straw is rained on or the DM content of silage changes without the feeders knowing it. Changes in DM of the ingredients mean changes in the DM proportions of the total diet unless the mix is corrected. Thus, energy intake may increase or decrease relative to the target, and producers may experience a rash of calving-related health problems until the situation is corrected.

While the nutritional concepts of these rations are simple, the approach and implementation are not problem-free. Attention to detail is a must. The system is not an “easy” or a lazy approach to dry cow care. When implemented correctly, results have been exceptional. However, high-straw, low-energy diets are not remedies for poor feeding management or bad facilities. Applied in these situations, results may be poor.

Additional Considerations

As mentioned earlier, the combination of straw and corn silage, along with other lactation ration ingredients, works well because of the complementary features of the components in the total diet. Straw has many desirable characteristics that seem to improve health and digestive dynamics in the rumen. The slow digestion and passage rate of straw certainly seems to be important in prevention of displaced abomasum. We think that the control of energy intake is a critically important factor in maintaining a more constant energy intake during the dry period and in preventing other disorders around calving, such as ketosis and fatty liver.

In this context, then whether other low-energy ingredients will produce the same desirable results remains uncertain. We are not aware of research that has compared other low-energy ingredients such as poor-quality hay, oat hulls, cottonseed hulls, corn stalks, soybean residue, or flax shives to straw or to conventional rations, although we have anecdotal reports from producers and nutritionists with varying reports of success. With roughage-type materials, the key consideration is uniform processing and palatability so that cows do not sort and the formulated profile of nutrients is actually consumed. In the case of the concentrate-type or finely ground ingredients, energy content is low but particle size is so small that rate of passage can be too fast, allowing particles to escape more quickly even though they are not digested. In this case, DMI by the cows may increase so that total energy intake still considerably exceeds requirements.

Although good-quality straw can be a consistent source of nutrients, its composition still can be variable (NRC, 2001). Table 2 shows means, standard deviations, and ranges for straw samples over 2 years during 2 recent experiments from our group (Dann et al., 2006; Janovick Guretzky et al., 2006). The mean values in general are close to those reported in NRC (2001), although CP was lower and NDF higher in our samples. Also of note is that analyzed concentrations of potassium and sodium were considerably lower than means reported by NRC (2001).

Just because straw or other low-energy ingredients are “low quality” by conventional standards of evaluation based on protein or energy content, this does not mean that other measures of “quality” can be ignored. Straw or other feeds that are moldy, severely weather-damaged, or have fermented poorly should not be fed to dry cows, especially the close-ups.

Extensive comparisons of high-straw, low-energy diets with conventional diets in cows of widely differing body condition scores are not available. In the field, the diets seem to work well in both thin and fat cows. In fact, many producers have concluded that these diets are the best way to manage obese cows through calving to minimize the usual problems expected with fat cows.

Conclusions

High-straw, low-energy rations are exciting for their potential to markedly improve health during the transition period. The key concept is to strive to meet the requirements of cows for energy and all other nutrients but to not allow cows to exceed their requirements for energy by consuming large amounts for the duration of the dry period. Provided that these high-straw, low-energy rations are formulated, mixed, and delivered properly, results have been positive. Research and field observations indicate that the rations result in better energy balance after calving, with subsequent improvements in health. Milk production is maintained, and field observations suggest that reproductive success also may be improved, although data are lacking. Research is needed to explore other low-energy bulky ingredients as options to straw.

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Table 1. Example high-straw, low-energy diet fed during the far-off dry period (Janovick Guretzky et al., 2006).

Item[1]	Amount in Ration (DM basis)
Ingredients	
Corn silage, %	35.3
Chopped wheat straw, %	31.8
Chopped alfalfa hay, %	17.1
Corn grain, ground, dry, %	3.6
Soybean meal, solvent, 48% CP, %	5.1
SoyPlus[2], %	4.0
Urea, %	0.9
Minerals and vitamins, %	2.2
Composition	
Forage NDF, %	50.4
NFC, %	25.4
CP, %	14.4
NRC (2001) Metabolizable protein, g/day at 26.5 lb DMI	1,085
NE_L, Mcal/lb DM[a]	0.62
NE_L, Mcal/lb DM[b]	0.59
NE_L, Mcal/lb DM[c]	0.55
NE_L, Mcal/lb DM[d]	0.67
NE_M, Mcal/lb DM[e]	0.60

[1]NDF = neutral detergent fiber, NFC = nonfiber carbohydrates, CP = crude protein, DM = dry matter, DMI = dry matter intake, and NE_L = net energy for lactation.
[2]West Central, Ralston, IA.
[a]Calculated for the total diet using the NRC (2001) model and analyzed chemical composition for corn silage, wheat straw, alfalfa hay, and concentrate mixture.
[b]Calculated for the total diet using the Cornell Net Carbohydrate and Protein System (Version 5.0; Cornell University, Ithaca, NY) model and analyzed chemical composition for corn silage, wheat straw, alfalfa hay, and concentrate mixture.
[c]Calculated additively using NE_L values assigned by Dairy One Laboratory for individual ingredients, using the Van Soest variable discount factors and corrected at an intake of 3× maintenance.
[d]Calculated additively using NE_L values provided by Dairy One Laboratory using NRC 2001 equations (Ohio State summative equation) for individual ingredients and at intakes appropriate for dry cows.
[e]Calculated using NE_M values for individual ingredients as specified by Dairy One Laboratory.

Table 2. Chemical composition of wheat straw in University of Illinois experiments.[1]

Component[2]	Mean	Standard Deviation	Maximum	Minimum
DM, % as fed	93.3	0.82	94.5	91.2
CP, % of DM	3.8	0.83	5.3	2.4
Soluble protein, % of CP	44.2	9.6	65.0	25.0
NDF, % of DM	79.6	3.7	85.2	69.9
ADF, % of DM	53.3	2.9	59.0	45.8
NFC, % of DM	11.6	3.0	19.2	6.8
TDN, %	49	1.4	53	47
NE_M, Mcal/lb DM	0.35	0.06	0.43	0.12
Ca, % of DM	0.27	0.11	0.57	0.08
P, % of DM	0.08	0.03	0.14	0.05
Mg, % of DM	0.12	0.04	0.26	0.09
K, % of DM	1.30	0.12	1.53	0.95
S, % of DM	0.07	0.03	0.18	0.04
Na, % of DM	0.02	0.01	0.06	0.01
Fe, ppm of DM	117	68	303	53
Zn, ppm of DM	16	11.6	59	7
Cu, ppm of DM	8	4.1	18	4
Mn, ppm of DM	75	15.3	119	51

[1]Values are from 21 monthly composite samples from two experiments (Dann et al., 2006; Janovick Guretzky et al., 2006) analyzed by wet chemistry techniques at the same laboratory (Dairy One, Ithaca, NY).
[2]DM = dry matter, CP = crude protein, NDF = neutral detergent fiber, ADF = acid detergent fiber, NFC = nonfiber carbohydrates, TDN = total digestible nutrients, and NE_M = net energy for maintenance.