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EFFECTS OF CONVENTIONAL OR BMR CORN SILAGE FED AT TWO LEVELS ON INTAKE, MILK YIELD AND COMPOSITION, AND RUMEN FERMENTATION OF HOLSTEIN DAIRY COWS

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ABSTRACT

The objectives of this study were to evaluate the effects of Brown Mid Rib (BMR) vs. conventional corn silage fed at two levels on production and rumen fermentation. Eight lactating (DIM=160; four rumen-cannulated) Holstein dairy cows were used in a replicated 4 × 4 Latin-Square design with 2 × 2 factorial dietary arrangement (silage type and level). The diets were formulated to contain either 35 or 50% of ration DM from corn silage, using conventional (CONV) and BMR genotype silage. The diets contained 16% CP, 34% NDF and 28% forage NDF; DM basis. Each experimental period was 14 d, 7 d adaptation and 7 d sampling period. Daily milk weights were collected, with sampling from four consecutive milkings the last two days of each period for components. Rumen samples were taken at set points over the last 24 hours of the sampling period. Intake was higher (level effect: $P \leq 0.01$) for cows consuming the 35% vs. 50% level of corn silage inclusion (28.2 vs. 26.4 kg/d). There was an interaction ($P \leq 0.01$) on DMI such that cows on the BMR silage maintained DMI (27.5 kg/d) on both levels of corn silage inclusion while those provided CONV reduced DMI (28.8 vs. 25.4 kg/d). Cows fed the BMR corn silage at 50% produced significantly more milk (corn silage type effect: $P \leq 0.05$) than cows fed the CONV hybrid at 50% (48.6 vs. 43.64 kg/d). Efficiency for converting feed to milk was greater (level effect: $P \leq 0.05$) for 50% vs. 35% inclusion rate (1.76 vs. 1.67, respectively)). Yields or percentages of milk fat, protein, and lactose were not significantly different across diets. Rumen pH and ammonia concentration were similar across treatments. No differences in VFA profiles were observed except that concentrations of isobutyrate and isovalerate were higher (corn silage type effect: $P \leq 0.05$) for cows fed CONV vs. BMR corn silage. Feeding BMR corn silage at 50% of ration DM did not affect DMI and maintained milk yield compared with CONV corn silage. Efficiency of converting feed to milk however was affected more by the level of corn silage inclusion in the ration than type of corn silage.

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Chapter 1

Introduction

The dairy industry is continually evolving to incorporate new feeding methods and practices to keep pace with feed availability and environmental restrictions. Milk production must be maintained for the dairy to remain profitable and efficient as new strategies are implemented. Increased input costs, increased milk production per cow, environmental regulations, and an overall drive to produce milk in the most efficient way possible have lead to the commercial adoption of many of these new feeding strategies. A constant in all dairy rations is the need for fiber, specifically Neutral Detergent Fiber (NDF). A certain portion of this NDF, 75%, (NRC, 2001) must come from forages to have optimum rumen function and cow health. The forage source may vary between grasses and legumes, to silages and hay, but all are an important source of NDF. Therefore, forages are an integral part of formulating rations for dairy cattle and producing and/or purchasing high quality forages is essential to the profitability of a dairy farm.

One of the most popular forages fed to dairy cattle is corn silage and it is one of the most popular crops in North America ranging from 77-84 million acres. Fifty seven percent of that crop goes toward livestock feed, with dairy being 15% of that segment. Corn silage is roughly 8-10% of the total corn acres (Mahanna, 2005). Due to the relative ease of production as an annual crop, and its nutrient density, corn silage is becoming more popular as the main source of feed in rations. That is, dairy producers are feeding diets with a greater portion of the ration dry matter (DM) coming from corn silage. As corn silage makes up more of the ration DM, its nutrient density and digestion characteristics become very important, especially as a source of NDF and this has led to many developments in corn hybrids. Many types have been developed recently for specific characteristics such as Roundup Ready corn, corn borer resistant, drought resistant, silage specific varieties, grain specific varieties, and Brown Midrib (BMR) silage.

First reported in 1924, the Brown Midrib trait was found in dent corn in St. Paul, MN. BMR corn is distinguished by a red or orange coloration of the underside of the leaf at mid-vein or mid-rib. The color is caused by lignified rind and vascular bundles. It will eventually fade from the leaves but will remain on the stalk until harvest (Hartnell et al., 2005). BMR is a natural mutation, not an engineered trait like Roundup Ready beans and corn. This plant has a "knock-out" of the lignin biosynthetic enzyme 0-methyltransferase. This mutation reduces the lignin content of the plant by approximately 40% (Hartnell et al., 2005). Lignin is an indigestible portion of plant cell wall that increases with plant maturity to stabilize the plant. Therefore, a plant with low levels of lignin contains NDF with increased digestibility which promotes greater dry matter intake (DMI) than varieties with higher lignin content (Ivan et al., 2004, Bernard et al., 2004, Oba et al., 1998). In dairy cattle, this translates into more energy and protein for milk production and weight gain. Due to these properties, BMR corn has been promoted as a silage specific hybrid, for incorporation into dairy rations. To fully understand the impact that BMR corn silage may or may not have on dairy rations, it is important to discuss how forages affect utilization of diets by dairy cows and impacts on production and composition of milk. Many aspects of forages and forage components interact with the physiology of the dairy cow and her rumen and intestinal tract to impact production and milk composition. Factors such as NDF, particle length, forage to concentrate ratio, and forage type will be covered in the following text.

There are some key differences between BMR and Conventional (CONV) corn that are both positive and negative aspects of choosing BMR over CONV silage. As stated above, BMR corn tends to be lower in lignin content compared to a CONV hybrid. This is an excellent trait in regard to rumen kinetics and digestibility, but can cause problems with actual production of the silage. Because the plant is lower in lignin, the strength of the stalk can be compromised. The plant is unable to grow to the height and diameter of a more conventional hybrid, so tonnage is often reduced at harvest. The plant is also less resistant to pest and drought damage. Extremes in temperature and moisture can have a more detrimental effect on BMR than on CONV hybrids (Shaver, 2008). Secondly, due to the special market niche for BMR, the seed is more expensive to purchase than CONV seed. All of these factors coupled with the development of CONV hybrids that perform similarly to BMR with higher yields, increase the opportunity cost of using BMR corn. Therefore, it is vitally important that the return on investment is realized in increased milk production, increased efficiency, and/or decreased feed costs.

A research study was conducted at the PSU Dairy Center to evaluate the effects of replacing conventional hybrid corn silage with BMR variety silage on dry matter intake (DMI) milk yield, milk components, and rumen parameters. The study compared both the type of silage fed, and the amount in the diet. By feeding the silage at increased rates, the hypothesis is the effect of BMR, if any, will be augmented by the higher inclusion rate of silage in the ration. The objectives of the current study were: 1) to determine the effects of conventional vs. BMR silage fed at two levels on dry matter intake, milk yield and composition and rumen fermentation characteristics and 2) to evaluate the cost effectiveness of feeding BMR corn silage compared to conventional corn silage.

Chapter 2

Literature Review

Neutral Detergent Fiber

Perhaps the most important contribution of forages to the diet of a dairy cow is neutral detergent fiber (NDF). Cows have a requirement for fiber and more specifically for fiber from forage sources. Generally, at a minimum of 28% of ration DM should be NDF, with 75% coming from forage fiber (Oba, et al., 1998). Carbohydrates are the largest component of dairy rations comprising 60-70% of the net energy used for milk production. (Mertens, 1992) They also provide the precursors for the milk components lactose, fat, and protein. Metabolism of carbohydrates by the rumen microbes results in the production of volatile fatty acids. These fatty acids then supply 70-80% of energy requirements of the cow (Fahey, 1993). The make up and digestive characteristics of carbohydrates affect many production factors of the cow such as intake, rate of passage, and utilization of the total diet. This in turn determines the nutrients available for milk production. Carbohydrates are made up of two portions, structural and non-structural. The non-structural portions are mostly starches and simple sugar derived from seeds, and to a lesser extent energy reserves in the stems and leaves (Mertens, 1992). The second type of carbohydrates are structural carbohydrates. Found in plant cell walls, these carbohydrates consist of cellulose, hemicellulose, pectin, and lignin. Lignin is a non-carbohydrate polymer. While the above definitions of carbohydrates apply to plant structure, nutritionally, the division for fiber and non-fiber are slightly different. Fiber is a general term given to the more slowly degraded or undegradable portion of feed such as cellulose, hemicellulose, and lignin. Non-fiber components are those that are more readily degraded such as pectins, starches, and sugars.

NDF is the analysis conducted in the laboratory which provides an estimate of the hemicellulose, cellulose, and lignin content of feedstuffs (Mertens, 1992). The importance of digestible NDF is that it is a digestible portion of NDF that is digested by the rumen microbes. Digestible NDF varies greatly across hybrids, growing season, timing of harvest, and environment. The rates of digestion can vary from 3-12% per hour for NDF, while the soluble nutrients of the diet may have a much faster rate of up to 20-200% per hour. The rate and extent of NDF digestion can be influenced by rate of passage and in high producing dairy cows that have high feed intake, can result in an increased rate of passage. Variations in rate of passage can cause variations in the digestion rate of NDF due to the fact that with increased rate of passage, there is decreased time for microbial degradation (Grovum, The Ruminant Animal, 1988).

Excess NDF in the diet may limit intake by way of rumen fill. Large amounts of NDF, especially if highly indigestible will have a slow passage rate and limit dry matter intake. Oba et al (1999) analyzed three different databases where the effects of NDF digestibility on DMI and milk yield were analyzed. The first database included 63 experiments where NDF digestibility was classified as high or low, and forage families (legume or grass) were fixed variables. The second database excluded experiments that compared legume with grass, resulting in 52 values in the data set. The third database again eliminated grass and legume comparisons, and included treatment means from experiments that reported differences in the digestibility of NDF among forages in situ or in vitro. Thirteen sets of comparisons were used. The goal was to quantify the importance of digestibility of NDF from forage and the influence that digestibility had on DMI and milk yield. In the first database there was a significant interaction of fiber digestibility and type of forage. DMI, milk yield of 4% fat corrected milk, and body weight gain were higher for cows fed forages with high NDF digestibility when the comparisons were made within forage families. Across forage families, however, cows fed forages with high NDF digestibility had lower intake, milk yield, and gain. It was thought that the increased rumen retention time and filling effect of grasses might skew the results and therefore such comparisons were eliminated from the other databases.

In the second data-base forages were compared within family only, in other words studies comparing legumes to grasses were eliminated from the data set. When compared within the legume or grass families, forages with high NDF digestibility produced higher DMI, milk yield, and 4% fat corrected milk yield. However, it was found that forages with high NDF digestibility produced lower ruminal pH on average. This was likely due to increased DMI due to less physical fill limiting feed intake; an increased rate of hydrolysis likely allowed for faster NDF movement out of the rumen. The increase in DMI would have provided more energy to quantify the difference in milk yield. Among the various treatments, however, diets were supplemented differently due to the different forage sources making it difficult to determine the effect of NDF digestibility of forage on DMI and milk yield.

The third data-base was limited to experiments that considered dietary NDF content, combined with forage to concentrate ratio. The effect of forage to concentrate ratio and the quadratic effect of NDF content as covariates were not significant for any variable, so data from all experiments were included. Cows consuming diets with more digestible forage NDF had increased DMI and also produced more milk, as well as more 4% FCM. The results indicated that the increased forage NDF digestibility increased milk yield by increasing DMI, thereby increasing energy intake available for milk production.

An attempt to quantify the effect of NDF digestibility from analysis of all experiments was limited by differing forage types, incubation times, and method (in situ or in vitro). In general, a one unit increase in NDF digestibility had a greater effect when it occurred at higher percentages of DMI rather than lower levels (i.e. 30 to 31% vs. 60 to 61%). In other words, a one unit increase in digestibility affected overall digestibility more than when the NDF had a low digestibility. However, regardless of the mode of action, increased NDF digestibility likely promotes increased milk production by increasing DMI. Overall, the results confirm the importance of forage NDF, and the need for quantification of the effects of forage NDF on ruminal digestion kinetics.

Ivan, et al. (2005), hypothesized that replacing a corn hybrid with a high cell wall content and high NDF digestibility with a hybrid bred to contain low levels of cell wall content and low NDF digestibility would increase feed intake and milk production in lactating Holstein cows. Using the minimum levels for NDF and forage NDF (DM basis) set by the NRC (2001) of 25 and 19% respectively, diets were formulated using the two types of corn silage. Typically, diets are formulated to the minimum requirements for fiber, and often to the upper limits on fermentable carbohydrates and protein to maximize DMI and milk production, so slight differences in digestibility and total content of NDF could make significant differences in the rumen environment. The investigators hypothesized that by using a hybrid that was high in NDF, and highly digestible, adequate amounts of fiber could be fed without limiting intake through gut fill. To test this theory, there were actually two different studies evaluated. In the first trial, the forage substitution was made on a DM basis. The second trial used NDF content as the basis for substitution. The diets fed during the trials had similar concentrations of DM, CP, RUP, and ADF.

In the first trial, milk yield and 4%FCM yield were significantly higher for cows fed the highly digestible cell wall (HCW) diet compared to the cows fed the low cell wall diet (4.1% higher 30 hr in vitro). DMI was also significantly higher for the HCW group, likely producing the observed 2.6 kg increase in milk yield (34.3 kg/d vs. 31.7 kg/d). As a result of the increased 4% FCM yield, milk component yield was also greater for the HCW group. A difference in gross efficiency, however, was not observed. The cows on the HCW diet had an increase in the percent turnover per hour (12.64 vs. 10.84 and 6.30 vs. 5.07) in OM and NDF turnover respectively, which may help to explain the negligible difference in efficiency when compared to the low digestible cell wall (LCW) diet. Normally, higher NDF concentration would tend to reduce passage rate, but it is possible the increased digestibility of the NDF in the diet was enough to overcome the difference. Digesta weight, ruminal volume, and digesta DM weight all tended to be lower for HCW diet compared to the LCW diet, and passage rates were similar. It would appear then that high NDF digestibility was in fact decreasing ruminal fill, and increasing ruminal digestion, allowing for higher DMI and energy for additional milk production.

In the second trial where substitution of silage was on an NDF basis, there was no difference in milk yield, but 4% FCM yield was higher for cows fed the HCW diet. Because the HCW silage was substituted on an NDF basis, it was included at a reduced rate compared to the LCW silage. This may have negated the effect of the increased digestibility. Milk fat concentration for the HCW diet was slightly higher than the LCW diet, contrast to findings of previous studies (Weiss, et al. 2002), where substituting a high NDF, high NDF digestibility corn silage resulted in a lower milk fat percentage. Weiss et al (2002) were unable to determine why they observed a decrease in milk fat percentage for the high NDF, high NDF digestibility silage diet compared to the diet containing a low cell wall silage, substituted on a NDF basis. It may have been the result of higher levels of starch as a result of feeding additional corn grain, the higher NDF digestibility, lower NDF concentration, or a result of the combination of these factors. Digesta weight, ruminal volume, passage rate, and digesta DM were similar between diets. OM digestibility was similar across diets, but NDF digestibility was slightly higher for the HCW diet. This may have allowed those cows to consume slightly higher levels of DM, increasing the 4% FCM yield.

Overall, when corn silage with HCW content, and high NDF digestibility was substituted on either an NDF or DM basis for LCW content and low digestibility silage, DMI and 4% FCM yield were increased. It was also shown that NDF can influence DMI in various ways. In the first trial, intake was influenced by digestibility and turnover of NDF in the rumen. In the second, total tract digestibility increased intake more so than NDF turnover.

Forage Particle Length

Particle length of the forages fed to dairy cows may similarly affect ruminal digestion characteristics as NDF form and content. Particle length effects rate of passage, rumen fill, intake, and digestion kinetics, and can also play a role in the storage fermentation of the feed. Finer chopped forages tend to provide a better fermentation in storage due to the shorter particle length making a more dense pack, eliminating oxygen. Shorter particle size allows for more complete exclusion of oxygen, and a more stable exposed area at feed out. Shorter particle size forage therefore may increase nutrient recovery from stored feed by increasing aerobic stability and increasing fermentation quality (McDonald, 1981; Ruppel et al., 1995.) Other factors such as proper moisture and packing equipment will influence the effectiveness of particle size at increasing fermentation quality, although a smaller particle size will augment these management factors. However, forages that have longer particle length are thought to provide a better rumen environment. Long particle length can be described using the PSU Forage Particle Size Separator

(Nasco Corporation, Fort Atkinson, WI). Long particles would be those retained on the upper sieve which would be 19.0mm in length or longer. Average length particles would be those retained on the following sieve which would range in size from 8.0-19.0mm. Short and fine particles would be contained on the last sieve and bottom pan, and would be any particles 8.0mm and smaller (Kononoff et al., 2003). There is a need for a certain amount of physically effective NDF, which can be achieved by proper forage particle length. Cows consuming adequate amounts of NDF without adequate amounts of long chopped forage have the potential to demonstrate the same metabolic disorders as cows consuming a diet containing inadequate fiber (Heinrichs et al., 1999). Insufficient particle size, diets containing more than 70% of the TMR particles on the last sieve and bottom pan, will decrease the ratio of acetate to propionate in the rumen and the rumen pH, potentially lowering milk fat percentage. At a pH of less than 6.0, the growth of cellulolytic bacteria is depressed (Heinrichs et al., 1999). When the growth of these organisms is depressed, there is an increase in the propionate-producing microbes and a decrease in the acetate to propionate ratio (Heinrichs et al., 1999). There is a point though at which the particle length of the TMR, specifically the forage in the TMR, can become too long as well. Diets containing more than 2-8% on the top sieve, or greater than 50% on the second will likely be too coarse and facilitate sorting behavior. So, a balance between the two extremes of particle length is the key to maximizing DMI and efficiency. However, reduction of forage particle size is associated with an increase in rate of passage, and higher dry matter intake. Smaller particles entering the rumen after initial chewing and swallowing will leave the rumen more quickly than those regurgitated numerous times (Zebeli, et al 2007). Smaller particles spend less time in the rumen to allow for microbial digestion. This is important in the case of fiber digestion due to the fact that the cow relies on the rumen microbes to break down the structural carbohydrate portion of the plant cell wall.

A somewhat common misconception is that increasing forage particle length will increase ruminal pH by increasing chewing time and saliva production to buffer the rumen. It has been shown in various studies (Kononoff et al., 2003a; Kononoff and Heinrichs, 2003ab; Beauchemin and Yang, 2005) that reducing the particle size of forage has no effect on mean ruminal pH. A reduction in forage particle size will increase DMI, increase NDFI, and decrease the NDF content of refusals of the TMR (Kononoff et al. 2003). Therefore, increased particle size (8-19mm) of the TMR may actually have the opposite effect than expected in regard to the rumen environment. Overall, shorter particle size (7.4-8 mm average in TMR) may actually create a more suitable ruminal fermentation. Shorter particles allow for less sorting, maintaining a consistent intake of nutrients including NDF. Also, consistent intakes of particles in the 8mm range tend to produce a very consistent rumen mat by reducing the filtering effect of the combination of long and fine particles, and increasing the entrapment of fine particles in the rumen mat. (Zebeli et al, 2007). This material is less susceptible to "sorting" by the rumen. The churning action of the rumen itself will tend to settle smaller, denser particles out of the mat. With overly long particles, this is more easily done. Shorter particles tend to decrease the retention time increasing passage rate of all particles (Owens and Goetsch, 1988). It may be more correct to say that avoiding extremes in particle length within the ration will provide a more consistent mat. In other words, adding long hay to a high concentrate diet as a way to buffer the rumen may not produce the desired effect if there is a large difference in particle size and sorting of the ration occurs.

Zebeli, et al (2007) found that there was a longer time spent ruminating per unit of DM when particles were greater than 1.18 mm in length for cows fed a high concentrate, long hay diet. This was associated with lower in situ hay DM disappearance and in vitro NDF disappearance. They also found a higher proportion of large particles of ruminal digesta indicating less digestion of fiber by the rumen microorganisms. When particles are a more uniform length, the mat is less porous, and smaller particles are effectively trapped in the rumen mat. When long particles (>19 mm) are introduced to the ration, they require more chewing activity than smaller particles. This reduces rate of passage and intake, and basically pulls the longer particles out of the rumen mat as they are retained and regurgitated during rumination (Kononoff et al. 2003).

Bhandari, et al. (2007) found, like many other studies that reducing the particle size of corn silage in the ration increased DMI and rumen pH but did not affect rumen VFA profile, rumen ammonia, and milk production. The greatest increase in DMI was seen when the reduced length corn silage was substituted in diets with longer chopped alfalfa silage than in diets containing shorter alfalfa silage. Diets containing particles longer than 7.7 mm on average may benefit more from shorter corn silage particle size than diets that are 7.3 mm on average. This is likely due to physical fill of the reticulorumen limiting voluntary feed intake when cows were fed the diets with the longer particle size. In other words, when mean particle size is smaller, reducing the chop length of corn silage has less of an effect than when mean particle size is larger than 7.7 mm and reduction of silage chop length brings mean particle size to 7.7mm or less. Corn silage tends to be chopped at a shorter length than other forages to increase compaction, process the cob, and decrease size of the kernel. Clark and Armentano, (1999) found that there was no difference in the effectiveness of NDF for mean particle size ranging from 2.57 mm to 8.74 mm when fed with alfalfa silage with a mean PS of 5.79-6 mm. This indicates a wide range of chop lengths for corn silage that would promote proper rumen function when combined with other ration ingredients. Similarly, when reducing the particle size of forages, it has been found that the increase in DMI will compensate for the smaller particles in reference to chewing time. Time spent chewing is associated with saliva production, which acts as a buffer in the rumen. Cows that consumed a diet of long particle size and those consuming a diet of shorter particle size actually spent similar time chewing. It is thought that increased DMI led to increased NDF intake, which along with particle size is a stimulant to chewing activity. Also, increasing the particle size of the diet increased sorting behavior. Longer particles are associated with facilitating sorting out of smaller grain particles by the cow. Cows consuming longer particle size diets actually do not consume significantly larger amounts of physically effective NDF (peNDF) when compared to cows consuming shorter mean particle length diets. Physically effective NDF is defined as the portion of the diet that stimulates chewing activity and as a result, salivary buffer production. (Kononoff, et al 2003) peNDF is calculated by multiplying the proportion of feed greater than 1.18 mm in length by total ration NDF. (Kononoff et al, 2003.)

There are many factors that impact ruminal digesta kinetics which are associated with particle size and can impact milk production and FCM yield. When nutrient flow to and from the rumen is optimized, nutrient digestibility is optimized, allowing the most efficient production of FCM. Specifically, when digesta contains adequate amounts of soluble protein and starch as nutrients for rumen microbes, and is retained in the rumen long enough to allow bacterial production of VFA's and amino acids, but is removed at a rate to promote adequate DMI, efficiency is increased. This is effected by not only adequate amounts of rumen degradable protein and starch, but also by the interaction of particle size, NDF content, and total DMI. Kononoff et al (2003) observed no differences in milk yield, protein percentage, or total protein yield when particle size of corn silage was reduced, providing mean dietary particle lengths of 7.4, 7.8, 8.3, and 8.8 mm. A quadratic effect on 3.5% FCM yield was observed for acetate to propionate ratio. The shortest particle length diet produced the lowest acetate to propionate ratio and lower milk fat while the intermediate treatments produced the highest fat yields and acetate to propionate ratio. A similar effect has been observed in other studies where the shorter particle length led to lower milk fat levels and was associated with decreased fiber intake and lower acetate to propionate ratios. Conversely, due to the ability of the cow to sort diets of longer particle size, NDF intake is often lower on these diets, decreasing rumen acetate concentration, and increasing rumen propionate concentration (Grant, et al, 1990; LeLiboux et al, 1998; Kononoff et al, 2003). Bhandari et al, (2007) found similar effects of particle size reduction on milk production and components. Alfalfa silage was reduced from a mean of 14.4 to 11 mm and corn silage from a mean of 14.2 to 10.4 mm. As a result, the percentage of the diet retained on the 19 and 8 mm screen of the PSU particle size separator dropped from 55 to 46%. They saw no difference in any of the variables measured factors when comparing diets of short or long particle length; milk fat percentage, over all diets however, tended to be low (ranging from 2.56-2.72%) compared to average (3.5%) fat content for Holstein cows. However, in this particular herd, milk fat was low both before and after the study (3.3 and 3.2% respectively). It was also thought that the additional dietary components were partially responsible for the lower milk fat. The diets were low in forage NDF (18.7-19.2%DM) according to recommendations of 22 to 23% of DM (Yang et al., 2007) for barley based diets, and in rations with longer particle length, the cows tended to select against longer particles, decreasing NDF content of the ingested diet further. Longer particle length led to a selection against the long feed in favor of fine feed particles. The resulting decrease in physically effective NDF combined with the increased starch digestibility from the barley based concentrate induced sub acute ruminal acidosis. The findings were similar to a study done by Yang et al., (2001), where it was concluded that the dietary levels for physically effective NDF (determined by diet DM retained by the PSU particle size separator sieves multiplied by dietary NDF content) were too low, and the levels of starch too high given that barley grain made up a large portion of the diet. For the long particle length diet, peNDF intake was 12.3% of DMI, with starch at 5.73 kg/d. For the short particle length diet, peNDF intake was 9.5, with starch intake of 5.83 kg/d. In this study ruminal availability of starch was improved with increased processing of grain, and milk production increased due to higher DMI and starch digestibility, however, ruminal pH and milk fat tended to be numerically lower (6.11 vs. 5.98 average pH, 3.94 vs. 3.77% fat).

Forage to Concentrate Ratio

Another factor contributing to proper rumen function is the forage to concentrate ratio. The forage to concentrate ratio tends to influence rumen function in much the same manner as the particle size of forage in the diet. When particle size of the TMR is decreased, it decreases rumen fill, increasing the capacity for DMI. Likewise, when the amount of forage in the diet is reduced while increasing grain, the bulk density of the ration is reduced allowing for more DMI. In fact, Zebeli et al (2006) found an interaction of particle size and forage to concentrate ratio when feeding diets with short and long hay with high and low concentrate levels. Their results supported the idea that simply adding long forage to a high concentrate diet in effort to increase rumen buffering and overall rumen health is not necessarily effective. Inclusion of long hay in high concentrate diets did increase ruminating time, but failed to produce more favorable rumen conditions. There was a shift in fiber digestion to the hindgut, increased fractional passage rate of solids from the reticulorumen, and a higher bailable liquid portion. The increase in DMI may be at the expense of rumen buffering capacity and increased rate of passage. Increased grain rates are associated with increased starch content of the diet, lowering the rumen pH as a result of grain digestion. Forage to concentrate ratio has similar influence on acetate to propionate ratio as particle size of the TMR. As the forage: concentrate ratio decreases, the acetate: propionate ratio also decreases. As the level of NDF (specifically cellulose and hemicellulose) increases in the diet relative to soluble carbohydrate and starch level, the acetate: propionate ratio will also increase. In the case of forage: concentrate ratio, however, the increase in intake may not translate into sufficient NDF intake as it does in the case of particle size reduction, given the reduced forage content of the diet. With regard to forage to concentrate ratio the increase in DMI is associated with decreasing the forage content of the diet, reducing the major source of NDF. Vlaeminck, et al, (2006) demonstrated that altering forage to concentrate ratio does in fact alter the fatty acid composition of the rumen. Increasing the forage to concentrate ratio caused a shift in the rumen bacterial population, and the fatty acid composition of rumen bacteria. In general, as the forage to concentrate ratio decreases, the acetate to propionate ratio also decreases. Conversely, as the level of cellulose and hemicellulose in the diet increase compared to the soluble carbohydrate level the acetate to propionate ratio also increases (Fahey, et al 1988). Murphy et al, (1982) found however, that the acetate to propionate ratio was influenced by diet composition. When hemicellulose was fermented in a high forage diet the acetate to propionate ratio was 3.2 compared to 2.2 when fermented in a high concentrate diet. With cellulose fermentation, the acetate to propionate ratio ranged from 13.1 in a roughage based diet to 7.3 in a grain based diet. This is likely due to the fact that the speed with which starch is hydrolyzed by rumen bacteria is affected by the source and processing level of the starch in the diet (Fahey, et al 1988).

Increasing the forage to concentrate ratio has also been associated with negative impacts on milk production. Yang et al (2001) found that the decrease in milk production observed was likely due to lower energy content of the diet, decreased DMI, and a lower total tract OM digestibility. However, in this study milk fat content tended to be higher for higher forage diets so despite lower yield, production of FCM was not affected.

Forage Type and Ratio

In the United States, the two main forages fed to dairy cattle, and therefore the largest sources of NDF, are corn silage and alfalfa hay or silage. However, the rate at which the two are fed differs from year to year, and region to region based on supply, quality, and cost. As major sources of energy and protein in the ration, the interaction of the two ingredients can be very critical to rumen function. Corn silage provides an opportunity for a consistent energy and fiber source due to the fact that it is harvested only one time per growing season, and offers many different options in seed variety to compliment its use in dairy rations. Alfalfa, while providing a significant amount of protein and fiber to the diet, is a more variable forage source. Alfalfa whether stored as dry hay or silage, is harvested up to 5 times during a growing season. This can cause greater variability in the nutritional characteristics of the feed. By utilizing both crops in dairy rations the risk from environmental effects on crop production are reduced. Also, due to differing harvest time and schedules these forages allow for more effective use of labor and equipment. Lastly, the use of both forages provides an optimal balance of protein and energy. The quality and feeding rate of alfalfa and corn silage offer the dairy producer the opportunity to significantly reduce, or increase the cost of the ration, as the higher the quality, the higher the rate of inclusion in the ration. Increasing forage and decreasing concentrate in the ration will decrease cost. However, the proportion of the ration that each makes up often is limited by inventory.

Dhiman et al, (1997), found that a mixture of either 1/3 or 2/3 corn silage to 2/3 or 1/3 alfalfa haylage were diets that promoted efficient rumen function and nutrient utilization. When either blend, 1/3 silage or haylage and 2/3 silage or haylage was fed, the supply of ruminally fermentable carbohydrate and protein likely was more balanced, increasing the microbial protein supply to the small intestine. While they found no significant of diet (all alfalfa silage, 1/3 CS 2/3 AS, and 2/3 CS 1/3 AS) on milk production, 3.5% FCM, or milk components, there was an effect on VFA concentration. The proportion of acetate tended to decrease while propionate levels tended to increase when the level of CS was increased in the ration. As discussed above, this can cause a shift in rumen pH. Overall, inclusion of CS in the ration allowed for more microbial protein production and increased efficiency of protein utilization based on the fact that diets with CS contained less protein and milk protein excretion was slightly higher. It also resulted in a 15% reduction in N excretion in urine and manure. Protein utilization efficiency increased from 29.5 % on an all alfalfa silage diet to 33.5 % on a 2/3 corn silage diet. This is an important factor in today's nutrient management environment.

Brito and Broderick (2005) fed dairy cows diets with increasing levels of corn silage combined with alfalfa silage. They also found that combining corn silage and alfalfa silage yielded favorable results in rumen health and nitrogen efficiency. There was also a decrease in N excreted in urine and feces. However, they demonstrated that CS could only make up a portion of the forage content such that as the level of CS in the ration increased, DMI, milk yield, 3.5% FCM, milk fat content, and apparent NDF digestibility decreased linearly. Therefore, the optimal range is an intermediate ratio between all alfalfa, and all corn silage diets. Some of this effect may have been due to what they considered to be overly mature corn silage. Therefore, as the level of CS increased in the diet, digestible NDF intake decreased by 27% from the diet lowest in silage content to the diet highest in CS. Furthermore, they theorized that the high DM content and maturity level of the CS fed in the diet would have abnormally high starch content, and produced lower ruminal pH. The lower ruminal pH may have caused incomplete ruminal biohydrogenation of unsaturated fatty acids resulting in decreasing milk fat content. As in their previous studies, they also observed a decrease in ruminal acetate concentration, and lower acetate: propionate ratio. As corn silage was increased in the ration DM a linear increase in N efficiency and decrease in N in urine and feces were observed. However, increasing the level of CS in the ration was also associated with a decrease in milk production. They found that the diet with an AS:CS ratio of 24:27 was the best ratio to optimize both milk production and N efficiency. Again, in areas where nutrient management restrictions are a concern, this aspect of nutrition is very important. The results of this study also suggest that optimal levels of AS and CS may vary from farm to farm based on feed quality and availability.

An important aspect of dairy cow nutrition is the correct balance of rumen degradable, and rumen undegradable protein in the ration. The level of each type of protein influences the amount of microbial protein produced. Specifically, rumen microbes utilize rumen degradable protein and starch as nutrients to synthesize microbial protein. Microbial protein provides the animal with an optimal balance of amino acids. This can be affected by the amount of corn silage and alfalfa haylage in the diet. Alfalfa haylage is high in both CP and RDP while CS is high in fermentable carbohydrate. As discussed above, a combination of the two would maximize rumen function, promote bacterial digestion, and as a result increase microbial protein production. However, because CS is relatively low in protein, as CS increases in the ration and AS decreases more high protein concentrates are required in the ration. Some protein concentrates are more resistant to rumen degradation than others, affecting microbial protein as well as RUP supply.

Increasing RUP may increase milk production and N utilization (Brito and Broderick, 2006). Brito, et al (2006) evaluated the affect of differing ratios of AS: CS on omasal flow and microbial protein synthesis. Diets were on a DM basis: A) 51% AS, 43% HMSC, and 3% solvent soybean meal SSBM, B) 37% AS, 13% CS, and 39% HMSC, and 7% SSBM, C) 24% AS, 27% CS, 35% HMSC, and 12% SSBM, and D) 10%AS, 40% CS, 31% HMSC, and 16% SSBM. As the percentage of AS in the diet decreased, the percentage of solvent soybean meal increased and the percentage of HMSC in the ration DM decreased. They found that total microbial NAN (nonammonia nitrogen) flow decreased as dietary AS and HMSC was replaced by CS and SSBM.

Microbial NAN was lowest when the most CS was fed. The supply of RDP was lower on diet D compared with the other three diets by 18%. This suggests that microbial NAN flow was depressed by reducing dietary RDP. Also, as CS increased, NFC content of the diet increased. As a result the ruminal pH was < 6 for longer periods on the highest corn silage diet compared to the other three. It is likely that this had detrimental effects on microbial protein synthesis. Total essential AA flow was lowest on the high corn silage diet.

Hybrid Development

Before and since the development of BMR corn as a silage specific hybrid, there have been other types of corn hybrids that have proposed benefits in either production (drought resistant, round-up ready, corn borer resistant, etc.) or nutritional (waxy, high lysine, BMR, high oil, and leafy) characteristics. Similar to BMR varieties, leafy varieties of silage have been developed in recent years. The selection process behind a leafy hybrid is similar to BMR silage. It is promoted as a silage that has increased NDF and starch digestibility. (Mycogen Seeds, Dow AgroSciences, Indianapolis, IN) In a study by Nennich et al (2003), it was demonstrated that there were no significant differences in milk yield, milk components, or DMI between two leafy hybrids, and a conventional hybrid. There were small numerical differences in nutrient content and digestibility however, but they did not significantly impact performance. However, in this study, corn silage made up only 40% of dietary DM, perhaps lessening the effect.

Bal et al (2000) also compared corn silage hybrids in three separate trials, the first of which compared a leafy variety to a conventional silage. Milk production was similar between treatments, but total tract digestibility of starch was higher for the leafy variety.

Benefield, et al (2006) conducted a feeding trial analyzing the NutriDense variety of corn. Specifically they compared NutriDense, (ND) and NutriDense leafy (LND) variety which are bred for larger proportion of grain endosperm, and increased leaves and NDF digestibility, respectively, to a conventional yellow dent (YD) hybrid. In this trial, the cows were fed a diet that contained 30.6% of the diet DM, and 27.7% corn grain from one of the specific varieties. Combinations were: YD grain and YD silage, YD grain and LND silage, ND grain and YD silage, and ND grain and LND silage. They found that the ND varieties did produce rations with increased digestibility of ether extract, and increased levels of CP, NDF, and ADF, but did not have a significant effect on lactational performance.

Grant et al, (2003) conducted two trials to determine whether corn hybrids bred to be Glyphosate-tolerant (GT) and corn rootworm protected had an effect on milk production and feed consumption in Holstein cattle. Glyphosate is the active ingredient in the herbicide Roundup that inhibits an enzyme needed for the production of essential aromatic AA (Grant et al, 2003). The second hybrid was developed to contain a protein derived originally from *Bacillus thuringiensis* (Bt) which is a naturally occurring soil bacterium. Hybrids that contain the Bt trait express insect control proteins. These traits allow for more efficient and aggressive agronomic practices to control stress to the corn plant and increase yield. GT corn allows the application of herbicide post-emergence to corn crops. The Bt corn is resistant to insect damage, especially damage from the corn borer which weakens the root system of the developing plant. In the first trial, the GT hybrid was compared to two non-transgenic hybrids, at 40% of the ration dry matter. Due to dry harvest conditions, and timing of harvest, the GT hybrid was the highest in DM, and consequently, reduced DMI and MY. However, milk composition and efficiency were unaffected. In the second trial the Bt corn grain was fed in a comparison with grain from a non-transgenic control hybrid and the same two non-genetically enhanced hybrids used for silage in experiment one. DMI, feed efficiency, and MY were not affected by diet when the corn grain was fed at 26.7% of ration DM.

A study by Taylor and Allen (2005) compared the interactions of corn grain bred to have different types of endosperm and BMR silage on the site and rate of nutrient digestion and overall rumen kinetics. It has been shown that BMR silage, through an increase in NDF digestibility, can increase DMI while providing forage fiber (Oba and Allen, 2000a). However, this also has a tendency to reduce ruminal starch digestibility by increased passage rate, which decreases the amount of time nutrients (i.e. starch) spend in the rumen. This often shifts the site of starch absorption from the rumen to post ruminal sections of the GI tract (Oba and Allen, 2000b). There is some discussion as to whether there is a benefit to either ruminal or post ruminal starch digestion. Ruminal digestion is needed for microbial growth and propionate production, but may decrease fiber digestion by lowering rumen pH. Post ruminal starch digestion would theoretically provide more glucose to the animal, which may be used for tissue retention or oxidized to CO_2 (Taylor and Allen, 2005). Taylor and Allen (2005) suggested that corn grain with floury endosperm is more rapidly degraded in the rumen and would be less compatible to feeding with BMR silage than corn grain with a vitreous endosperm. Vitreous endosperm would be degraded more slowly, and increase the potentially digestible NDF. The rate of ruminal starch digestion was faster and ruminal starch passage slower in the diets utilizing corn grain with floury vs. vitreous endosperm. This resulted in a net increase of 22 units for ruminal starch digestibility. There was compensatory post ruminal starch digestion which decreased the differences among treatments for total tract starch digestibility; starch entering the duodenum for floury endosperm was more digestible compared to vitreous grain. This resulted in greater total tract starch digestibility for floury endosperm. Digestible NDF was not influenced by feeding floury endosperm, but endosperm type did have a significant effect on the site of starch digestion.

Overall, there have been advancements in new silage varieties to fill special aspects of the high producing dairy cow diet. The goal of much of this work has been to increase the digestibility of two major nutrients provided by corn silage, starch and NDF. Along with developments in nutrient content, advancements have been made in the resistance of the plant to disease, weather, and insect stress. Maintaining a balance between yield, productivity, and nutrient content will continue to be the focus of the development of new hybrid varieties.

Conclusion

There are many factors that influence rumen health, milk production, and milk composition. Much of what is understood about rumen function and health is dependent on the quality and amount of NDF intake. NDF intake will influence various factors pertaining to rumen passage and degradation rates. NDF is an integral nutrient in dairy rations, supplied largely by forages. NDF can vary in quality not only between forage types, but among the same forage depending on maturity, weather conditions, and storage method. Composed of the structural components of a plant cell (cellulose, hemicellulose, and lignin) NDF content will tend to increase as a plant matures, often times limiting intake as a result of the indigestible portion; lignin content increases as a plant matures. Levels of cellulose and hemicellulose, which are more readily digested, decrease as the plant matures. NDF level in the diet has also been associated with an effect on rumen fill. In general, high levels of NDF in the ration tend to limit intake by gut fill, and decreased rate of passage. The extent to which this effect is realized is determined by digestibility of NDF and the influence digestibility has on rate of passage. Naturally, as rate of passage increases, the effects of gut fill on dry matter intake decreases. Due to the factors listed above, the level and composition of NDF can have a large effect on milk yield, components, and rumen health. Increased DMI either from increased fiber digestibility, rate of passage, or a combination of both will likely be translated into increased milk production. Adequate levels of NDF will also promote rumination which stimulates saliva excretion to act as a buffering agent in the rumen. Limiting drastic swings in the pH of the rumen over the course of feeding cycles promotes efficient bacterial degradation of feeds, supplying fatty acids and microbial protein for milk and component production.

A second important factor for rumen health and milk production is particle length of feeds, especially forages, in the lactating diet. In general, particle length can have many of the same effects as NDF on rumen function. The overall goal with diet particle length is to have a uniform supply of particles to the rumen. Formation of a consistent ruminal mat prevents the “settling” of finer particles out of the mat. When that occurs, smaller particles move quickly out of the rumen limiting their digestion by rumen bacteria. However, particle size must be of adequate length to promote rumination, achieving an optimal amount of saliva to buffer the rumen. When considered over the entire mix, shorter particle size will increase rate of passage, and longer particle size will decrease rate of passage. Shorter particles require less mastication, decreasing rumen retention time, decreasing gut fill, and increasing DMI. However, large disparities in particle size from the smallest to largest can lead to sorting during both intake and digestion in the rumen. Therefore, larger particles are retained while shorter particles pass through which can lead to fluctuations in rumen pH, and nutrient delivery to the lower gastrointestinal tract. Due to its effect on passage rate and rumen pH, particle size distribution can have a significant effect on milk production and components.

Forage to concentrate ratio is related closely to particle size given its effect on the characteristics of the diet. Obviously, as the level of concentrate in the diet increases, the particle size of the diet will decrease. Beyond this factor, forage to concentrate ratio affects the rumen environment by influencing the bacterial population. Levels of starch digesting bacteria will increase with increased grain feeding while forage digesting bacteria will decrease. This may have a profound effect on the acetate to propionate ratio. As discussed above, acetate to propionate ratio can have an effect on rumen pH, milk yield and component content. Also, concentrates in general have a higher digestibility than forages. This fact combined with the effect of particle size, will result in lower retention and rumination times for higher concentrate diets. In general, the goal of a well balanced lactating ration would include the highest level of forages possible; the limiting factor being the quality of those forages. Quality would be determined by laboratory testing and based on NDF content and digestibility. If forages contain high levels of indigestible NDF it will likely limit intake of a high forage diet. As quality of forages decreases, they will replaced by concentrate sources of energy and protein.

Having discussed the importance of the inclusion of high quality forages in dairy rations, there are many different forages and combinations of forages that produce varied results. The two main forages fed in dairy rations are alfalfa and whole plant corn silage. These two forages work very well when fed in combination. Alfalfa silage is a good source of rumen degradable protein. Corn silage is an excellent source of carbohydrates such as starch, pectin, and NDF. While protein is often a major concern in dairy rations, making alfalfa haylage very desirable in a ration, it is often more of a variable nutrient source. Alfalfa is harvested up to five times each growing season, increasing the variability in nutrient content between cuttings. Corn silage is harvested only once each growing season, offering a more stable source of energy. However, both feeds are influenced by weather, harvest, and storage conditions making them less consistent than concentrate sources of protein and energy. It has been shown that under most conditions, a combination of these two forages produces more desirable results than feeding either one alone.

However, inclusion rates from 1/3 haylage, 2/3 corn silage to the opposite of 1/3 corn silage, 2/3 haylage were found to be very effective combinations when considering milk yield, component content, and DMI.

Lastly, diet composition must be considered when feeding young stock that will later enter the milking string. Ration form and content have many effects on the growth characteristics of dairy heifers. It has been shown that increased energy intake and fat deposition have adverse effects on future milk production. In general, diets high in protein content and lower in carbohydrates produce effective and efficient growth in heifer rations. Traditionally, corn silage has made up a large portion of this diet due to its relatively low cost and availability. This likely provides a diet high in degradable carbohydrates, and low in available protein. However, a balance of protein and energy is needed in a growing heifer ration much as in a lactating ration. There may also be the opportunity to develop more cost effective rations that utilize more grain than traditionally fed to these animals to create a more energy dense ration that requires less DMI. By restricting intake of a nutrient dense diet, heifers are able to reach growth benchmarks on less feed producing less waste, and at a reduced cost per head per day. It is also possible that the inclusion of higher quality forage, traditionally reserved for lactating diets, could be used to formulate more energy dense diets for heifers, again creating a smaller DM package by utilizing restricted intake, further reducing cost by restricting intake and using less purchased feed.

Given the factors that have been discussed which combine to influence the effectiveness of dairy rations to maximize rumen efficiency, milk yield, and component production, the development of BMR corn silage could potentially provide significant benefits when included in rations fed on today's dairy farms. The research and development of the BMR variety has led to a hybrid that is promoted as a way to reduce feed costs, increase milk production, and reduce waste. This is accomplished by the nutritional characteristics of BMR silage influencing the dietary factors previously discussed. BMR silage is a corn silage hybrid that produces a plant with lower NDF content, specifically, lower lignin content. Lignin is an indigestible portion of structural NDF that increases in the plant cell wall as the plant matures. Because BMR corn does not typically reach the height that more conventional hybrids do, it requires less structural fiber. As a result, the fiber found in BMR silage is more digestible than those of conventional hybrids. Digestible fiber intake is associated with increased milk yield over similar diets with less digestible fiber content. Overall NDF content is also lower, so there is less limitation of DMI by rumen fill and passage rate. Also, because BMR silage provides a more energy dense, highly digestible silage, the ration should be able to include higher levels of forage in the ration. This provides optimal particle size distribution and reduces cost from purchased concentrate such as corn grain. Feeding more forage also allows more freedom to adjust the forage to concentrate ratio to better meet the nutrient requirements of the animal, again, hopefully utilizing more forage than grain.

When considering dairy cows in early lactation, BMR silage may have additional benefits. Higher DMI of an energy dense ration would benefit cows in early lactation. In early lactation, most dairy cows are producing more milk than they can consume nutrients to support. This leads to the mobilization of body reserves to maintain milk, and the animal enters what we call a negative energy balance. Early lactation animals must maintain intake to return to a positive energy balance. A positive energy balance must be attained before the cow can maintain a pregnancy. With most voluntary waiting periods (VWP) set at 60 days in milk, many cows may not yet have regained a positive energy balance at that point, affecting first service conception rate. Given the economic importance of establishing pregnancy as soon as possible after the VWP, BMR silage could play an important role in fresh cow nutrition. For those farms feeding separate groups, fresh cows could be fed a separate, high energy diet to support milk production and a rapid return to positive energy balance, and reproductive cycling.

With regard to forage ratios, it theoretically would require less BMR silage to provide the same level of nutrients as more conventional type silage. This is at least partially due to more efficient energy utilization seen with the incorporation of BMR silage compared to conventional silage. Oba and Allen (2000) demonstrated that cows fed BMR silage had lower rumen pH with no increase in variation of pH. Low rumen pH is associated with a decrease in methane production which indicates an increase in the availability of metabolizable energy. Oba and Allen (2000) theorized that because fatty acid absorption is affected by rumen pH that a more consistent rumen pH would allow for a steady supply of nutrients to the blood and mammary gland. While the cows on the BMR silage consumed more NEL, their results when analyzed independently of NEL intake showed that there was increased use of energy for milk production with the BMR silage. This effect may be partially due to increased NE intake and mathematical dilution of the maintenance energy requirement of the diet. Also, the starch content of the BMR silage was greater (38.3% vs. 35.4%) than the conventional silage. Less ground corn grain was required (26.2 vs. 29.2% of ration DM) in the BMR ration to obtain similar energy and starch levels between the BMR and conventional silage diets. With less corn silage and ground corn in the ration, there would be an opportunity to include more haylage and concentrate protein sources in the diet if needed. Given that an optimal diet would contain at least 1/3 haylage with increased response up to 2/3 of the forage in the diet from haylage, there would be an advantage to using BMR silage over conventional hybrids. Associated with increased haylage in the diet would be a reduction in purchased protein sources such as soybean meal. Provided that the haylage was of adequate quality, there may also be an increase in milk yield with this type of ration. That combined with a reduction in purchased protein feeds could result in a high return on investment.

There are a few considerations and possible disadvantages to utilizing BMR silage on farm. Perhaps the most significant of those would be the yield differences between conventional silage and BMR hybrid. Because of the low fiber characteristics of the plant, yields are reduced, and the crop is more susceptible to challenges from weather and other damages such as insects. Therefore, farms where land for forage production is limited, and purchasing outside forage is not an option, BMR may be a poor choice. A second consideration is that BMR hybrid corn is suitable only for silage production. Surplus inventories would be difficult, if not impractical to harvest as grain as many farms do with conventional hybrids. After silage inventories are met, many producers harvest the remaining corn crop for grain. Lastly, there is a significant increase in seed cost over conventional hybrids for BMR seed. So, there must be gain realized in either milk yield or purchased feed cost reduction to see an income over the initial investment.

The objectives of the current study were: 1) to determine the effects of conventional vs. BMR silage fed at two levels on milk yield, rumen fermentation characteristics, DMI, and milk components and 2) to evaluate the cost effectiveness of feeding BMR corn silage compared to conventional corn silage.

Chapter 3

Materials and Methods

Corn Silage

Conventional and BMR varieties of corn silage were used in this study. Both silages were planted and harvested in 2006 and grown under similar conditions by the PSU Farm Operations Department. The CONV variety was Mycogen TMF2Q728, and the BMR variety was Mycogen F2F797. Both varieties were planted over the course of two days on May 1st and 2nd 2006, at a population of 30,000 plants per acre. The conventional silage was harvested on September 15th, 2006, and the BMR on September 25th, 2006 using a John Deere Model 6750 self propelled forage harvester equipped with a model 676 rotary cutting head and kernel processor. The harvester was set to a 0.75" theoretical length of cut to obtain desired particle size distribution of 3-5%, 35-50%, 20-40%, and < 5% on the top, 2nd, 3rd, and bottom sieve of the PSU particle size separator respectively at feed out as presented in Table 1. DM at harvest for the CONV silage was 36%, and 43% for the BMR silage. The silage was stored in a 30'x100' concrete bunker, compacted using two tractors to obtain recommended pack density and covered with plastic and rubber tire sidewalls and stored until April of 2007. Analysis of nutrient content presented in Table 2.

Animals and Diets

The current experiment was conducted with approval of The Pennsylvania State University Animal Care and Use Committee. Eight mid-lactation, multiparous Holstein cows averaging 146.5 DIM ± 9.6 at the start of the trial were used. Four of the eight cows were ruminally cannulated. Cows were paired as one cannulated to one intact cow on each treatment. Each pair was rotated through each treatment in a replicated Latin Square Design. The animals were housed in a tunnel ventilated tie stall facility at the PSU Dairy Research and Education Center with ad libitum access to a Total Mixed Ration (TMR) and fresh water. The ration was mixed and fed daily at 0800h upon return from the milking parlor. Feed was mixed in a Kuhn Knight Model 3142 Reel Auggie Mixer Wagon, (Brodhead,WI 53520) consistent with the feeding of the rest of the herd at the PSU Dairy Center. Feed was pushed up to cows at 1330h, and again at 2300h. Cows were moved to a concrete exercise lot approximately 2h before each milking. The cows were taken to the parlor twice daily for milking at approximately 0630 and 1830h.

Four diets were fed as a TMR to test the effects and interactions of BMR silage when compared to conventional silage and the effect of the level of silage had on milk production, rumen function, and intake. The diets were formulated to contain 35 and 50% of the ration dry matter from corn silage, and corn silage was either a BMR or CONV variety. The ingredient composition of the diets is presented in Table 3, and nutrient composition is presented in Table 4. Each period consisted of 14 days with seven days of adaptation (d1-d7), and sampling for DMI and MY occurring the last seven days of each period (d8-d14), fecal sampling on d8-d12, milk component sampling and rumen pH sampling on d13 and d14 with the intensive rumen content sampling occurring on d14.

Sampling

Milk samples were taken during the last two days of each period from four consecutive milkings. They were preserved with 2-bromo-2-nitropropane-1, 3-diol. Samples were analyzed for fat, protein, MUN, SCC, and lactose content by Dairy One Milk Testing Laboratory. (University Park, PA). Samples were analyzed by using infrared spectrophotometry (Fossomatic 4000 Milko-Scan; Foss Electric, Hillerd, Denmark). Other solids were calculated as lactose % plus 0.91. Milk weights for each milking were recorded electronically daily using the Afifarm system (S.A.E.

Afikim, Kibbutz Afikim, Israel; US distributor: Germania Dairy Automation, Waunakee, WI). DMI was monitored daily for each period using weight of feed offered and weight of orts. TMR and ort samples will be taken each day of the sampling period and a composite sample saved for each week. Samples of each forage (corn silage, haylage, and grass hay/straw mixture) were taken the third day of each sampling period. Rumen fluid samples for VFA and pH were taken at 0, 1.5, 3.5, 5.5, 8.5, 11.5, 14.5, 18.5, 21.5, and 24.5 hours after feeding. Samples were collected from the dorsal, ventral, and caudal points in the rumen, mixed manually and immediately filtered through four layers of cheesecloth with a mesh size of 250 µm. The pH of the filtrate was measured (pH meter, model M90; Corning Inc., Corning, NY) and a 5 ml sample preserved by freezing in 1 ml of 1% H_2SO_4. Rumen fluid was later thawed and centrifuged at 3000xg for 30 minutes at 4° C. The supernatants were retained and re-centrifuged prior to analysis for NH_3 (Broderick and Kang, 1980), and VFA (Yang and Varga, 1988). On the last day of each sample period, total rumen contents were evacuated, weighed, and approximately 2 gallons of wet digesta was frozen for analysis. Fecal samples were collected at various times over the course of d1-d4 during sampling week to correspond with a sampling schedule of every two hours over a 24 hour period. Fecal samples were obtained directly by rectal grab sampling. Fecal samples were pooled, and a 100 gram sub sample was dried in a 55° oven for 48 hours. Fecal samples were then processed using a 1mm diameter screen with a Wiley Mill Grinder (Arthur A. Thomas Co., Philadelphia, PA).

Analytical procedures

Fecal and refusal samples were analyzed for CP (AOAC, 2006) and NDF (Van Soest et al, 1991). Particle size distribution of the composite TMR and forage samples was determined using the Penn State Particle Size Separator (Kononoff and Heinrichs, 2004). Particle size of the forages and TMR were determined the last day of each sampling period. The remaining samples were oven dried at 55° for 48h to determine dry matter. Samples were then processed thorough a 1mm diameter screen using a Wiley Mill Grinder (Arthur A. Thomas Co., Philadelphia, PA). Forage and TMR samples were analyzed for CP, soluble CP, ADF, NDF, fat, lignin, and minerals using wet chemistry (Cumberland Valley Analytical Services, Maugansville, MD). Crude protein was determined by combustion (Leco Instruments, Inc., St. Joseph, MI)(AOAC 990.06, 2006). Soluble CP was determined using a borate-phosphate procedure as detailed by Krishnamoorthy et al. (1982). ADF and lignin were analyzed according to AOAC 973.18 (2006) and NDF according to Van Soest et al. (1991). Fat was determined by using the Soxtec system (Tecator Soxtec System HT 1043 Extraction unit; Eden Prairie, MN; AOAC 2003.05, 2006). Minerals were determined using a Perkin Elmer 3300 XL and 5300 DV ICP (Shelton, CT) with modifications (Ash 0.35 g sample for 1 hr at 535°C, digest in open crucibles for 20 min in 15% nitric acid on hotplate and then samples were diluted to 50 ml and analyzed on ICP;)(AOAC 985.01, 2006). In situ analysis was performed on fecal, forage, and TMR samples following completion of the trial for 72, 48, 24, 12, 8, 4, 2, and 0 hours to determine the indigestible NDF (INDF) content to be used as the internal marker to calculate fecal output and digestibility of DM, NDF, and CP based on the procedure described by Huhtanen et al. (1994). Two rumen cannulated cows consuming a standard 55% forage (ration DM) lactating cow diet in mid lactation were used for the in situ incubations.

Economic Analysis

Economic analysis was based on income over feed costs (IOFC). IOFC is calculated using the major income and expenses related to milk production. Income over feed costs is a measure of gross profitability and it accounts for the major source of income (i.e. milk components) and expenses (feed). However, IOFC does not reflect other sources of income such as premiums and cull sales, and other sources of expenses such as labor, veterinarian expense, and depreciation costs. Income represents milk production and components and the price received for them. Expenses are considered to be the cost of the ration including the cost of both forages and grains. Therefore, any reduction in cost associated with feeding additional low cost forage and less concentrate feed will be accounted for. Cost of production for each type of silage was reflected in the cost of silage per ton, and accounted for yield difference between hybrids and increased cost of seed for the BMR variety. Feed prices were based on an average value of each ingredient during a 5-yr period for forages and 4-yr for commodities. Milk component values were calculated using milk component prices obtained from the Agricultural Marketing Service (USDA, 2006) from January 2000 to May 2006. These milk component prices were averaged over a 5-yr period to reflect the manufactured value of milk. Other sources of revenue such as producer price differentials, over order premiums, quality premiums, volume premiums, and cull sales were not included in the calculations for milk value. This is because these other sources of revenue depend on time, marketing area, and management decisions regarding milk quality. These other sources of revenue have nothing to do with changes in feed rations; thus they would not change in this study under the alternative feeding trials. The value of IOFC calculated here only represented a response to changes in feed rations (i.e. milk volume and component levels). The 5-yr average price for milk fat was \$3.36/kg, protein was \$4.77/kg, and for other solids was \$0.18/kg in this study. Income over feed costs was estimated individually for each cow. The equation used to calculate IOFC is as follows:

$$IOFC = MV - FC$$

where MV is milk value (\$/kg) per cow per day and FC is the cost of feed (\$/kg) required to produce the amount of milk in MV. Feed cost is equal to

$$FC = \sum_i P^i * Q^i$$

where *FC* is feed costs, *P* is the price of feed ingredient *i*, and *Q* is the daily quantity of feed ingredient *i* consumed by the cow.

Milk value is defined as milk yield per day times the manufacturing value of milk,

$$MV = MY *(\%MF*\$3.36 + \%TP*\$4.77 + \%OS*\$0.18)$$

where *MV* is milk value per cow ($/day), *MY* is milk yield per cow (kg/day), *%MF* is percent milk fat, *%TP* is percent true protein, and *%OS* is percent other solids. Note that the manufacturing value of milk (MV) is equal to the milk component levels multiplied by the 5-yr average component values. This is similar to how dairy farmers are paid.

Feed efficiency, described as the ratio of milk produced to DMI, provides an additional indication of effects on lactation performance due to the ration. Feed efficiency has also been used in previous trials (Tine et al, 2001; Ivan et al, 2005; Weiss and Wyatt, 2006; Oba et al, 1999; Weiss and Wyatt, 2002; Qiu et al, 2003) to assess diet and lactation performance.

Statistical Analysis

Data were analyzed using the Mixed procedure of SAS (Version 9.1; SAS Inst., Cary, NC). The statistical model used included fixed effects of period, treatment, sampling time and interaction of treatment by sampling time. Denominator degrees of freedom were estimated using KENWARD-ROGER option in the MODEL statement (Kenward and Roger, 1997). Cow nested within treatment was used in the RANDOM statement. Sampling time (day or hour) was used in the

REPEATED statement. Methods of autoregressive order one, compound symmetry and unstructured were used to fit time-series covariance structure for equally spaced repeated measures. The method of spatial power law was used to fit time-series covariance structure for unequally spaced repeated measures (Littell et al., 1996). Option PDIFF of SAS was used for multiple comparison tests. All data are presented as least squares means ± standard error means (SEM). Statistical significance was declared at $P \leq 0.05$ and tendency or trend for significance were declared at $0.05 < P \leq 0.10$.

Chapter 4

Results and Discussion

Dry Matter Intake

Cows consuming either silage variety at 50% of the ration dry matter had higher dry matter intakes (DMI; $P < 0.01$) than cows consuming the 35% silage ration (Table 5). A significant interaction was observed for DMI such that cows on the BMR corn silage maintained DMI at both levels of silage inclusion while the cows fed the CONV silage at 50% of ration DM had lower DMI than those at the 35% level. (25.4 vs. 28.8 kg/d ± 1.18). There was no significant difference in DMI between the BMR and conventional silage at the 35% level of inclusion (average of 28.2 kg/d ± 1.17 DMI or 9.9 kg/d of corn silage) which is contrary to various other studies comparing BMR and conventional silages where cows consuming the BMR variety had significantly higher DMI (Fernandez et al, 2004; Ebling and Kung, 2004; Min, et al, 2007; Tine et al 2000; Oba and Allen, 1999). Cows in the current study consumed on average 4.7 kg/d or 19.8% more DMI when compared to the above studies. Cows in the current study consumed an average of 28.4 kg/d of DM, of which 9 kg/d and 11.4 kg/d were a conventional and BMR hybrid, respectively. In a study conducted by Weiss and Wyatt (2002) cows consumed an average DMI of 23.7 kg/d, 10.6 kg/d and 7.8 of which was from a dual purpose, and high NDF digestibility silage, respectively. In that study, the silage hybrids were fed at 45 and 33% of diet DM, and there was no significant level or treatment difference in DMI, milk yield, or yield and concentration of milk protein. When a rapidly degradable NDF silage made up 75% of the ration DM cows averaged 17.4 kg/d of DM compared to 16.4 kg/d of a slowly degradable silage (Fernandez et al 2004). Ebling and Kung (2004) fed cows a diet that contained 42% of the ration

DM as either a CONV or BMR hybrid. They demonstrated higher DMI for the processed BMR hybrid than a processed CONV hybrid (10.9 vs. 9.8 kg/d of silage or 25.9 vs. 23.4 kg/d TMR, respectively). Tine et al (2001) found that cows consuming a diet with a BMR hybrid had DMI that was 2.4 kg/d greater than cows consuming a diet with CONV silage when silage was 60% of the ration DM. Cows consumed 22.8 and 25.2 kg/d DM which equaled 13.68 and 15.12 kg/d of corn silage on the CONV and BMR diets, respectively (Tine et al, 2001). In that study, no type effect was observed between BMR and normal silage on DMI, but there were significant type effects on digestibility of DM, organic matter, NDF, and CP. In the current study, at the 50% level of silage, cows consumed significantly more DM on the BMR silage than those on the CONV silage diet agreeing with the above studies (27.4 vs. 25.4 kg/d of DM, or 13.7 vs. 12.7 kg/d of corn silage, respectively) where at a high inclusion level of corn silage intake was higher for the BMR when compared to a CONV corn silage. When silage was provided in the ration at 35% of ration DM, cows consumed 9.7 and 10.1 kg/d on the BMR and CONV diet, respectively. Based on these findings, it would appear that the level and intake of silage in the ration influences the effect of BMR varieties. Based on the results of the current study corn silage should make up at least 50% of the ration DM to produce significant differences in performance measures. Perhaps it is a linear association in that as the level of silage increases, these effects are increased as well as small differences in digestibility and passage rate are magnified by increased feeding rate.

However, there are studies that show no differences between the two varieties as was seen in the current experiment on the 35% level of inclusion of ration DM. Weiss and Wyatt (2002) found no difference in DMI across all four diets, when two types of silage were fed at two levels of DM, high and low NDF at 33 and 45% of ration DM. Average DMI was 23.7 kg/d while cows consumed 10.7 kg/d of corn silage on the 45% diet and 7.8 kg/d on the 33% diet. Weiss and

Wyatt (2006) compared a BMR hybrid to a CONV hybrid at 55% of the ration DM and observed no difference between hybrids (DMI was 24.3 kg/d with 13.36 kg of DM from corn silage). The decrease in DMI observed with the CONV silage in the present study when level was increased to 50% from 35% DM (28.8 vs. 25.4 kg/d DMI, 10.1 vs. 12.7 kg/d of corn silage) suggests that NDF digestibility or rate of passage may have affected intake. In general as the NDF digestibility of the diet decreases, DMI decreases (Oba and Allen, 1999). NDF content was similar across diets, however, the 50% diet actually equated to an increased intake of corn silage, resulting in higher NDF intakes. If there were slight differences in NDF digestibility, it would have had an impact on rate of passage as well. In the current study, there was a significant effect of level on apparent total tract NDF digestibility, in that the 50% was more digestible than the 35% level (43.0 vs. 33.6 % ± 1.74). The effect of type for NDF digestibility was not significant, but was numerically greater (39.4 vs. 37.2) for the BMR diet compared to the CONV silage. At the 50% inclusion of BMR corn silage NDF digestibility was (45.8%) higher than the BMR and CONV at the 35% level (33.0 and 34.2%, respectively). This is an indication that the slight difference in type when combined with an increased feeding rate effects NDF digestibility, DMI, and as a result, milk yield. As the digestibility of NDF increases, so does the rate of passage, allowing for greater amounts of DMI (Oba and Allen, 1999). When the cows were consuming the 50% diets, this difference would have been magnified, translating into increased rate of passage and DMI on the 50% BMR diet compared to the 50% CONV diet. In the current study, average NDF content was 33.5% ± 0.23, ranging from 32.9 to 34% of DM across the four diets. This likely indicates some effect on rumen kinetics whether it be digestibility, grain to stover ratio, or rate of passage.

Milk Yield and Milk Components

No effect of corn silage inclusion level in the ration was observed on milk yield, however cows fed the BMR silage produced more ($P < 0.05$) milk than cows fed the CONV silage (47.6 vs. 45± 1.98 kg/d). A trend for a type x level interaction ($P <0.06$) shown in Table 4, was observed for milk yield such that cows on the BMR corn silage maintained milk yield across both levels of inclusion in the ration while cows provided the CONV silage reduced milk yield when corn silage was increased from 35 to 50% of ration DM. Milk yield is also shown graphically in Figure 1. These findings agree with those of other studies (Fernandez et al, 2004; Oba and Allen, 1999). Oba and Allen (1999) described in the third database they compiled that the effect of NDF content and digestibility for forages with higher NDF digestibility were associated with greater milk yield (41.0 vs. 38.4 kg/d on a 4% FCM basis). Fernandez et al (2004) demonstrated a 2.75 kg/d increase in milk yield when cows were fed a rapidly digestible NDF hybrid at 75% of the ration DM when compared to a hybrid with more slowly degraded NDF. Min et al (2007) found that cows consumed less feed, but produced similar amounts of milk on a high NDF BMR silage diet when compared to cows eating a lower NDF diet based on alfalfa silage or BMR silage. Also, there was little difference in milk yield between the low forage diets based on either alfalfa or BMR silage. This indicated that the benefits of highly digestible forage are not as evident in a low-roughage, high concentrate diet. They found that when the forage levels were increased to 33% NDF that the benefit of BMR silage was more pronounced.

Kung et al (2008) demonstrated an effect on milk production of increased cutting height of a conventional hybrid compared to BMR silage harvested at a normal height where cows on the BMR diet produced more milk than those on a CONV hybrid, and a high cut CONV hybrid (48.8, 46.8, and 47.7 kg/d). Theoretically, by increasing the cutting height of the CONV silage, a reduction in the lignin and NDF (plant) content of the silage is likely achieved. By cutting the plant higher, the most lignified portion of the plant (bottom stalk portion) is left in the field, increasing overall content of more digestible NDF. The theory being that this silage would perform similar to a low lignin BMR variety. However, they found that even with increased cutting height of CONV silage, BMR silage still increased milk production (48.8 vs. 46.8 kg/d), as well as feed efficiency (1.83 vs. 1.75). Bernard et al (2004) found similar results when comparing highly digestible and average digestibility silage at two different cutting heights. They found that there were no differences in cows fed the highly digestible silage at either cutting height. When comparing the two cutting heights of the average digestibility silage, there was an increase in *in vitro* DM digestibility and a decrease in ADF content. Given that there may have been differences in the rate of passage among the diets in both studies there may also have been an effect of post ruminal digestion and absorption of key nutrients needed for milk production.

Starch and ruminally undegradable protein are two specific nutrients absorbed post ruminally which would be made available for milk production. Starch is effectively utilized in the rumen by bacteria to produce volatile fatty acids, which are then absorbed by rumen papillae. When the production of VFA's exceeds the absorption capability of the rumen papillae, they can be absorbed post ruminally as well (Beauchemin, 2007). Greenfield et al (2001) found that while BMR silage had increased rumen DM and organic matter digestibility, dietary intake and duodenal flow of starch were greater and rumen and total tract starch digestibilities were lower for BMR silage diets than a conventional hybrid. They calculated that starch was digested and absorbed post ruminally for the BMR cows, because duodenal flow of NDF was 0.9 kg/d lower, and ruminal and total tract digestibilities were higher for BMR compared to the conventional corn silage. These findings support the idea that the decreased fiber content, coupled with increased fiber digestibility may lead to increased rate of passage and post ruminal absorption of nutrients for milk production. The diets in the study of Greenfield (2001) also contained 60% of the rumen DM as corn silage and would be considered a high level of silage in the ration and would support the findings of the current study of more pronounced effects when silage makes up a larger portion of the diet. Bal et al (2000) also found that as the level of forage in the diet increased (67% forage vs. 53%) differences in milk and milk fat yield were greater. BMR hybrid silage yielded more milk and fat than a conventional hybrid. As forage (specifically corn silage in this case) level increases in the diet, differences in NDF digestibility will have increasing effects on milk yield, DMI, and digestibility. Min et al (2007) concluded from a recent study that feeding BMR silage with increased NDF digestibility allowed for similar production and rumen kinetics when feeding a high forage diet compared to a high concentrate diet. They found that diets containing BMR silage with low forage to concentrate ratio did not result in increased milk yield. However, similar diets containing BMR in higher forage to concentrate ratio allowed for replacing some concentrated energy sources with the BMR silage while increasing milk yield. In the present study, there was no difference between silage varieties in milk yield when fed at 35% of ration DM. This suggested that some of the differences in milk yield response to BMR in previous studies may be related to inclusion level of silage in the diet. Diets based more heavily on forage, specifically corn silage, would benefit more from the increased NDF digestibility and decreased lignin content in BMR silage. If differences in digestibility were similar to the current study, increased milk yield from BMR silage may not be detected when comprising a smaller portion of the ration DM. However, assuming all of the factors related to NDF digestibility are additive, (rate of passage, DMI, lignin content, grain to stover ratio, and silage feeding rate) while individually these factors are not significant, they may combine to increase milk yield significantly.

Energy balance was calculated from the difference in energy consumed vs. the energy produced in milk plus energy required for maintenance was different among diets. Average energy difference across diets was 2.0 ± 0.68 Mcal/kg. There was no effect of type, but there was a level effect ($P<0.01$). The energy balance for the 50% level of corn silage inclusion averaged 1.4 Mcal/kg while the 35% level resulted in an energy difference of 2.6 Mcal/kg ($P<0.01$). There were type by level interactions as well ($P<0.01$). At the 35% level, the energy balance was higher for the CONV hybrid compared to the BMR hybrid (3.2 vs. 1.9 ± 0.7 Mcal/kg, respectively). At the 50% level, the CONV hybrid energy balance was lower than the BMR hybrid (0.9 vs.1.9 Mcal/kg, respectively). This would indicate that at the 50% inclusion level, cows consuming the BMR hybrid would have more energy to regain body condition than cows consuming the CONV hybrid. The opposite would be true when feeding silage at the 35% inclusion level.

Milk composition data is presented in Table 5. Milk fat percent and yield were not significantly affected by any of the treatments, averaging 3.61± 0.18%, and 1.65± 0.12 kg/d across all diets. Previous studies have reported slight decreases in milk fat production on BMR based diets (Weiss and Wyatt 2006; Ivan et al, 2005). In those studies, this could be a result of increased rate of passage, or decreased rumination time due to more digestible NDF or increased grain to stover ratio resulting in inadequate effective NDF. Milk protein percent was numerically higher ($P<0.05$) for cows fed the BMR vs. CONV silage. Protein yield was also higher ($P<0.05$) for the BMR variety compared to the CONV variety. (1.37 vs. 1.30 kg). There was also a type x level effect where at the 50% rate, the BMR variety yielded more protein (1.42 vs. 1.27 ±0.07kg) compared to the CONV. This may be at least partially due to the increased level of milk production between the diets as well.

Production of lactose was numerically higher ($P<0.13$) for the BMR ration compared to the CONV ration (2.18 vs. 2.07 kg/d). There was a type level interaction ($P<0.01$) where the 50% BMR ration yielded more lactose than the 50% CONV ration. (2.26 vs. 2.02 kg/d). However, lactose content was not significantly different, averaging 4.58%, indicating the increased lactose yield was likely due to the significantly higher milk production between the two groups.

Milk urea nitrogen (MUN) concentration was higher (11.6 vs. 10.7± 0.76 mg/dl) for the 35 and 50% level of corn silage in the ration, respectively. Cows that consumed the BMR corn silage diets had lower (10.2± 0.76 mg/dl) MUN levels than cows on the CONV silage (12.0± 0.76 mg/dl). There was a significant type by level interaction for MUN concentration such that when level was increased from 35% to 50% the BMR diet had higher MUN and the CONV diet had lower MUN. These effects may be the result of protein supplementation in the diets. At the increased level of corn silage inclusion, alfalfa haylage was eliminated from the ration, and concentrates were used to supplement protein levels. When alfalfa makes up a significant portion of the dry matter, protein degradation in the rumen may lead to inefficient utilization of protein resulting in depressed milk and protein yield (Broderick et al, 1993). Increased levels of RUP are needed when feeding alfalfa silage, indicating that alfalfa silage may be a variable source of protein, specifically rumen degradable, and undegradable protein. When alfalfa silage was dropped from the ration at the 50% corn silage level, more concentrated sources of protein were used to supplement requirements for RUP and RDP. It is likely that this change in protein source increased efficiency of N utilization, as well as efficiency of production of microbial protein. However the exception may be when the BMR ration produced an opposite effect on the 50% diet and higher MUN values were observed compared to the 35% level inclusion. This may be an indication of more ruminal starch degradation with the BMR silage that would complement RDP content of haylage. However, there was no difference in N efficiency observed in the current study. The mean for the BMR silage was 30.5 ± 1.03 % and the CONV averaged 29.4± 1.04 %. There was also no difference due to level of corn silage inclusion, in contrast to MUN, with the 50 and 35% rations averaging 30.6± 1.04 % and 29.3 ± 1.03 % respectively. There was a significant difference ($P<0.05$) such that N efficiency for the 50% BMR diet was highest (30.8± 1.14 %), and the 35% CONV had the lowest N efficiency (28.3 ± 1.16%). The increase in roasted soybeans and bypass protein source would have provided post ruminal amino acids to the diet. Also, supplementation with canola meal would have provided a more stable supply of rumen degradable protein for microbial protein synthesis and may explain the increased N efficiency for the 50% inclusion level where the combination of the increased protein concentrate supplementation and the BMR variety increased rumen availability of nutrients.

Energy Corrected Feed Efficiency

Cows fed the 50% corn silage ration were more efficient ($P<.05$) than those provided the 35% ration (1.77 vs. 1.60). (Table 5) The efficiency of converting feedstuff into milk was highest (1.82) for the 50% BMR ration compared to cows fed the 35% CONV ration (1.57). There was no effect of silage type on efficiency. As stated above, this may in some part be due to slight differences in rumen kinetics leading to increased milk production. DMI was highest for the 35% CONV diet, and while the 35 and 50% BMR diets were not significantly different from the 35% CONV diet in intake, milk production increased 4.6% on the 50% BMR.

Apparent Total Tract Digestibility

Apparent digestibilities of DM, crude protein and NDF are represented in Table 6 were all increased ($P<0.01$) as inclusion level of corn silage was increased in the ration. There was no effect of corn silage variety on apparent digestibility of any of the nutrients measured. Apparent DM digestibility for the BMR and CONV silage at the 35% inclusion rate averaged 56.9%, and increased to 65% when BMR and CONV silage were increased to 50% of the ration DM.

Apparent crude protein digestibility increased from 51.9 to 61.5% as BMR and CONV were increased from 35 to 50% of ration DM, respectively. Results of in situ digestibility indicated similar disappearance rates of DM for both silages, becoming nearly equal at 16 hours. In general, from hours 0-16, the CONV silage had slightly higher DM digestibility value than the BMR silage, but from 16-72 h the BMR silage was more completely digested. Therefore, at the 50% DM level, the BMR silage may have allowed cows to eat more due to higher digestibility and rate of passage. As discussed above, there was a significant effect of corn silage level on apparent NDF digestibility (33.6 vs. 43% for the 35 and 50%, level respectively). NDF digestibility increased significantly for the 50% BMR ration when compared to the 35% inclusion rate diets. When compared to the 50% CONV ration, there was a trend for higher digestibility for the BMR silage. Previous studies have reported an increase in NDF digestibility for BMR variety silage compared to conventional hybrids (Fernandez et al. 2004). Given the increase in DMI and milk yield observed on the 50% BMR diet, it is likely that the digestibility of the NDF impacted DMI and performance. However, apparent NDF digestibility does not take into account effects on post ruminal digestion. The difference could have also been due to the proportion of plant material and grain in the silage. Typically, corn silage contains 30% grain at 1/3 milk line, and can contain roughly 50% grain at physiological maturity (Dupchak, Manitoba Ag, Food, and Rural Initiatives). Consequently, silage could easily range from 50-70% plant material. The tissues that comprise the leaves and stem of the corn plant can be less digestible than grain. Since silage particles take less than 24 hours to pass through the rumen on average, a large proportion of the plant particles may escape digestion (DiMarco, et al. 2005). To compensate somewhat for this, cows are able to digest various nutrients such as starch and protein post ruminally especially when high starch concentrates such as corn are fed in larger amounts. Because BMR is bred to contain lower levels of lignin, it would likely have a different grain to stover ratio due to decreased stalk growth when compared to CONV silage (Mahanna, 2005). However, Qiu et al

(2003) found that BMR corn contained 57.4 % of DM as stover, and 42.6% as grain before ensiling. In another comparison, a CONV hybrid contained 46.9% stover and 53.4% grain (Thomas et al, 2001). However, this difference may be due to the CONV hybrid that was meant for dual purpose production of either silage or grain; therefore, it would have been bred at least partially for high grain content. In general, advances in silage genetics to this point have been driven by grain production, and so whole plant yields have increased faster than yields of stover. Stover content has not really changed, but as advancements are made in hybrid selection for silage, there has been some dilution effect (Mahanna, 2005). Therefore, the increased DM digestibility may be a result of not only lower lignin content, but an increase in grain to stover ratio as well. Combined with a potential for increased rate of passage due to the more digestible NDF in the BMR variety, this may help to explain some of the differences seen in cow performance, but a limited effect on NDF digestibility. In a sense, the increased digestibility effect may have been tempered by other factors influencing rumen kinetics such as rate of passage.

Rumen Measurements

Rumen measurements are summarized in Table 7. Rumen pH was not significantly different among treatments, averaging 5.85 (± 0.10) across all treatments. Ammonia N, shown in Figure 2, was not different across treatments, and averaged 7.25 mg/dl ± 1. There was no effect of silage type or level on ammonia concentration. Total VFA concentration, shown in Figure 3, averaged 145.3 ± 7.21 mol/L and did not differ across diets. There were no significant differences observed due to treatment on any of the individual VFA. There were, however, numerical trends for propionate for a type and level interaction where the BMR and 50% inclusion rate produced slightly higher and lower propionate levels, respectively illustrated in Figures 4 and 5. As a result of the numerical differences in propionate, acetate to propionate ratio was highest (2.30) for the 50% CONV diet and lowest (2.07) for the 35% BMR diet. There was also a corn silage type effect on isobutyrate, shown in Figure 6, where the CONV diet produced higher levels than the BMR diet. NDF content of rumen digesta was not significantly different between diets, and averaged 10.25 ± 0.96 kg across all diets. This could indicate an effect on NDF digestibility given that DMI and milk production varied across diets, yet NDF content of the rumen was relatively consistent. The current findings are similar to that of Bal et al (2000) who found that total VFA's were not significantly different between a low or high NDF corn silage fed at either 40.4 or 35.6% of ration DM to cows averaging 10.7 and 9.9 kg/d DMI from corn silage (135.2 mol/100mol). They also found a similar trend for acetate to propionate levels and ratio; for the low forage, low NDF diet at 2.1. Fernandez et al (2004) also found similar results when comparing a slowly and rapidly degrading hybrid. DMI from corn silage averaged 8.75 and 9.27 kg/d for the slowly and rapidly degrading hybrid, respectively, and no significant differences in total VFA or individual VFA were observed. Qui et al (2003) also demonstrated no difference in total VFA, but did see a significant effect on acetate to propionate ratio for level of forage NDF where rations with 21% forage NDF had higher ratios than those with 17% forage NDF; BMR silage produced more propionate than the CONV silage (23.6 vs. 21.3 mol/100mol). In that study, cows were consumed 8.25, 10.5, 7.87, and 9.18 kg/d of corn silage on the 17% NDF and BMR, 21% NDF and BMR, 17% NDF and CONV, and 21% NDF and CONV silage diets, respectively. Ivan et al (2005) demonstrated a significantly higher level of propionate (30.5 mol/100mol) in silage with low cell wall content and digestibility than silage with high cell wall content and digestibility while total VFA did not differ across diets. Cows were consumed 10.9 kg/d of corn silage with low cell wall content and low digestibility, and 11.4 kg/d of corn silage with high cell wall content and high digestibility. Acetate to propionate ratio decreased with decreasing levels of NDF and increasing levels of soluble carbohydrate and starch (Ivan et al, 2005). The ratio often decreases in rations where forage to concentrate ratio is low. So, the ratio is lowest where the diet contains a lower level of silage, supplementing with more concentrated energy sources, and the silage is likely higher in soluble carbohydrates. The highest ratio is seen when feeding the most silage, decreasing high starch, high energy concentrates, and feeding silage that may contain less soluble carbohydrate. Given the similar ratios for the 35% CONV and 50% BMR, it is possible that the BMR silage did in fact provide a diet with more digestible NDF content. It allowed for the feeding of 7.8% or 1.2 kg more forage DM in the ration (15.42 vs. 16.63 kg) while maintaining acetate to propionate ratio.

Economics

Costs of production including seed, yield difference, planting, and harvest were calculated with the assistance of the PSU Agronomy Department. The conventional hybrid (Mycogen, TMF2Q728) yielded an average of 25.9 tons per acre. Cost for seed was $45 per acre, with a planting and harvesting cost of $359 per acre factoring in no till seeding management and harvest costs. Cost of production was $13.86 per ton at 35% DM. The BMR hybrid (Mycogen, F2F797) yielded an average of 19.5 tons per acre. Cost for seed was $82.50, with a planting and harvesting cost of $396.50 per acre factoring in the same seeding and harvest management. Cost of production was $20.33 per ton at 35% DM. Therefore, there was a 47% increase in cost over the CONV variety to produce the BMR silage.

Given the above calculations for cost of production, and average prices paid for feed and received for milk, on an as fed basis, there was a type by level effect ($P<.01$) on income over feed cost (IOFC). The CONV silage fed at 35% of ration DM returned the highest IOFC at $8.59 (± 0.41), while the BMR silage at 35% produced the lowest IOFC at $7.42 (± 0.41). While the IOFC decreased from $8.59 to $7.68 when the CONV silage was increased to 50% of the DM, the BMR diet produced increased IOFC ($8.35 vs. $7.42) when the level was increased to 50% of ration DM from 35%. Therefore, when feeding corn silage at higher dietary inclusion levels, the BMR silage returns a higher IOFC than CONV silage. The additional cost for BMR silage was associated with yield loss and price paid for seed. Therefore, if yield loss were not a factor and seed pricing differences were less pronounced the data for IOFC may show greater returns in IOFC for the BMR silage at lower feeding levels. This trial was also very intensive, utilizing measurements from a small group of cows. Larger group feeding situations may yield different results.

Chapter 5

Conclusion

A study was conducted to determine the effects of a CONV hybrid and a BMR hybrid, at two dietary levels on DMI, milk yield and composition, economic return, and rumen characteristics of Holstein dairy cows. Corn silage was fed at two levels of DMI, 35 and 50% of total ration DM. Cows consuming the BMR silage maintained DMI when silage DM was increased from 35 to the 50% level, however cows provided the 35% CONV vs. the 50% CONV decreased DMI by 3.4 kg/d. NDF content was similar across diets, however, the 50% diets resulted in higher intakes of corn silage and therefore, NDF. NDF digestibility was 9.4 units higher for the 50% inclusion level of silage compared to inclusion at the 35% level. When cows were fed diets containing silage at the 50% level, NDF digestibility was higher than either variety fed at the 35% level. There was a numerical trend for a 2.2% increase in NDF digestibility for the BMR variety compared to the CONV variety. Milk yield was not affected by level; however the BMR variety produced 2.6 kg/d additional milk yield compared to the CONV variety. There was a trend for a type by level interaction where the cows consuming the BMR ration maintained production at both levels while the CONV ration resulted in a drop in production between the 35 and 50% levels. Milk fat content and yield were not affected by treatment. Milk protein was higher for the BMR diets. Protein yield, as a result of increased content and milk production was higher for the 50% BMR ration than the 50% CONV ration. Lactose content was higher for the BMR variety. The 35% rations produced higher MUN values (.9 units) when compared to the 50% rations while the BMR variety was associated with lower MUN values than the CONV variety. At the 50% level however, the BMR variety resulted in higher MUN levels than the CONV variety however this likely has little impact physiologically to the animal. Apparent total tract digestibility of DM, CP, and NDF were increased with the increased feeding rate of silage however there was no variety effect on total tract digestibility. Feed efficiency was also increased as the feeding rate of silage increased, and was highest for the 50% BMR ration. The effects on IOFC followed a similar pattern to the other measured effects, where at the 50% feeding level BMR silage returned a higher IOFC than the CONV silage ($8.35 vs. $7.68). Using a four year average for concentrate pricing, and a five year average for the alfalfa silage pricing, and current prices for the BMR and CONV silage, the BMR silage returned a higher IOFC despite having an increased cost of production. In the current study, there was an advantage in overall IOFC, and production at the 50% feeding level for the BMR silage when compared to the CONV variety. When cows were fed at the 35% feeding rate, there was little to no difference in IOFC, production, or rumen characteristics between BMR and CONV silage.

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Appendix

Table 1. Nutrient Composition/Fermentation Profile of CONV and BMR Silage.

Nutrient	CONV Silage	BMR Silage
Dry Matter	31.4	32.1
CP %DM	7.2	6.6
Sol. Pro %CP	46.1	64.2
Deg. P %CP	73.0	82.1
TDN %DM	69.3	70.8
NEL Mcal/kg	1.54	1.64
ADF %DM	26.6	24.3
NDF %DM	43.9	39.4
NFC %DM	42.9	48.8
Ca %DM	0.23	0.19
P %DM	0.22	0.16
pH	4.1	3.5
Lactic Acid %DM	3.7	8.2
Acetic Acid %DM	2.94	1.42
Iso-Butyric Acid %DM	<0.01	<0.01
Butyric Acid %DM	<0.01	<0.01
Total VFA	6.6	9.6
Lactic acid/VFA %	55.7	85.2
30 Hr. NDF Digestibility %NDF	66.9	54.0

Table 2. Average Particle Size of Finished TMR Fed to Cows in the Study

Sieve	**% Retained/Treatment**			
	50% BMR	**50% CONV**	**35% BMR**	**35% CONV**
Top (19 mm)	4.3	4.7	6.1	5.5
2^{nd} (8 mm)	35.9	32.3	30.7	29.0
3^{rd} (1.19 mm)	48.0	44.6	45.5	41.9
Pan (0 mm)	10.2	11.2	10.5	11.9

Table 3. Ingredient Composition, as % of Dry Matter for 35% CONV, 50% CONV, 35 %BMR, and 50% BMR Diets.

Ingredient	**% of DM**			
	35% CONV	**50% CONV**	**35% BMR**	**50% BMR**
Alfalfa Haylage	14.84	----	14.84	----
Corn Silage	35.28	50.42	35.28	50.42
Straw/Grass Hay	8.12	8.12	8.12	7.90
Fine Ground Corn	8.21	8.21	10.14	6.84
Roasted Soybeans	7.56	7.56	7.61	7.71
Canola Meal	7.04	7.04	5.50	8.44
Cookie Byproduct	6.84	6.84	6.84	6.84
Sugar Blend	4.31	4.31	4.31	4.31
Heat Treated Soy Meal	4.60	4.60	4.19	3.93
Corn Distillers	1.65	1.65	1.65	1.65
Vitamin Premix[1]	1.65	1.65	1.65	1.65
Limestone	0.15	0.15	0.11	0.39
Urea	----	0.43	----	0.25

[1] Minerals and vitamins contained 10.64% Ca, 0.40% P, 3.54% Mg, 0.47% K, 0.41% S, 1671.83 ppm Mn, 558.36 ppm Cu, 1687.95 ppm Zn, 245.31 ppm Fe, 10.77 ppm Se, 6.44 ppm Co, 16.10 ppm I, 96196.12 IU vitamin A, 23995.22 IU vitamin D, 738.32 IU vitamin E, and10.59 % salt.

Table 4. Nutrient Content of 35% BMR, 35% CONV, 50%BMR, and 50% CONV Treatment diets.

Nutrient	**Treatment**				**SEM**
	35% BMR	**35% CONV**	**50% BMR**	**50% CONV**	
CP, %DM	15.8	16.6	16.4	15.9	0.2
Soluble Protein, %CP	39.4	38.1	36.7	39.1	1.1
RDP %CP	69.7	69.1	68.4	69.5	0.5
TDN	71.8	72.2	73.4	72.4	0.3
Mcal/kg	1.65	1.69	1.69	1.69	0.003
ADF %DM	22.1	21.3	20.1	21.3	0.6
NDF %DM	34.9	33.4	35.0	34.4	0.5
Fat %DM	4.0	4.2	4.1	4.1	0.1
Ash	6.9	6.5	6.3	6.2	0.3
NFC %DM[1]	39.6	40.6	39.3	40.8	0.5
Ca %DM	0.96	0.86	0.84	0.93	0.1
P %DM	0.37	0.39	0.41	0.39	0.01
Mg %DM	0.32	0.31	0.34	0.35	0.02
K %DM	1.74	1.65	1.41	1.32	0.03

Table 5. DMI, Milk Yield, Milk Component, and Feed Efficiency for 35% BMR, 35% CONV, 50% BMR, and 50% CONV Diets.

Variable	Treatment					P-Value	
	35% BMR	35% CONV	50% BMR	50% CONV	SEM	Trt	Trt*Level
DMI, kg/d	27.60[ab]	28.76[a]	27.37[b]	25.42[c]	1.18	<0.01	<0.01
MY, kg/d	46.57[ab]	46.46[ab]	48.60[a]	43.64[b]	1.98	0.08	<0.06
Fat, %	3.61	3.66	3.62	3.53	0.18	0.87	--
Fat yield, kg/d	1.63	1.67	1.77	1.53	0.12	0.26	--
Protein, %	2.91	2.88	2.94	2.87	0.07	0.25	<0.05
Protein yield, kg/d	1.33[ab]	1.33[ab]	1.43[a]	1.27[b]	0.07	0.12	<0.03
Lactose, %	4.58	4.58	4.61	4.55	0.08	0.43	--
Lactose yield, kg/d	2.11[ab]	2.12[ab]	2.26[a]	2.02[b]	0.13	0.23	<0.01
MUN, mg/dl	9.09[b]	12.24[a]	11.32[a]	11.82[a]	0.81	<0.01	<0.01
SCC, x 1000 ml	452	207	185	171	133.55	0.25	--
Efficiency	1.70[ab]	1.63[b]	1.79[a]	1.72[ab]	0.08	0.05	--

Table 6. Dry Matter, Crude Protein, and Neutral Detergent Fiber Digestibility in 35% BMR, 35% CONV, 50% BMR, and 50% CONV Diets.

Nutrient	**Treatment**							
	35% BMR	**35% CONV**	**50% BMR**	**50% CONV**	**SEM**	**Type**	**P-Value Level**	**Type* Level**
				% Digestibility				
DM	55.64[a]	58.22[a]	65.20[b]	64.73[b]	1.81	0.58	<0.01	0.43
CP	51.28[a]	52.43[a]	60.04[b]	62.96[b]	2.32	0.42	<0.01	0.72
NDF	32.97[a]	34.17[a]	45.77[b]	40.13[ab]	2.67	0.45	<0.01	0.25

Table 7. pH, Total Wet Weight of Contents, Total VFA, Individual VFA, and Acetate to Propionate Ratio for 35% BMR, 35% CONV, 50% BMR, and 50% CONV diets.

	Treatment					
Variable	**35% BMR**	**35% CONV**	**50% BMR**	**50% CONV**	**SEM**	**P-Value Trt**
pH	5.87	5.92	5.77	5.90	0.10	0.70
Total content, kg wet	103.9	103.5	102.2	99.0	4.80	0.79
NDF Content, kg	10.6	10.6	9.9	9.9	0.96	0.62
NH_3, mg/dl	7.46	6.58	6.55	7.51	2.38	0.74
Total VFA, mmol/L	144.5	142.4	150.5	143.7	7.21	0.66
Acetate (A), % total VFA	56.6	56.9	57.3	58.0	1.36	0.79
Propionate (P), % total VFA	27.3	26.8	26.7	25.2	0.78	0.37
Isobutyrate, % total VFA	1.12	1.22	0.94	1.18	0.07	0.46
Butyrate, % total VFA	11.1	10.8	11.1	11.3	0.32	0.33
Isovalerate, % total VFA	1.56	1.67	1.39	1.80	0.14	0.19
Valerate, % total VFA	2.44	2.62	2.48	2.44	0.38	0.30
A:P	2.07	2.12	2.14	2.30	NA	NA

Figure 1. Graph of Milk Yield for 35% BMR, 35% CONV, 50% BMR, and 50% CONV Treatments.

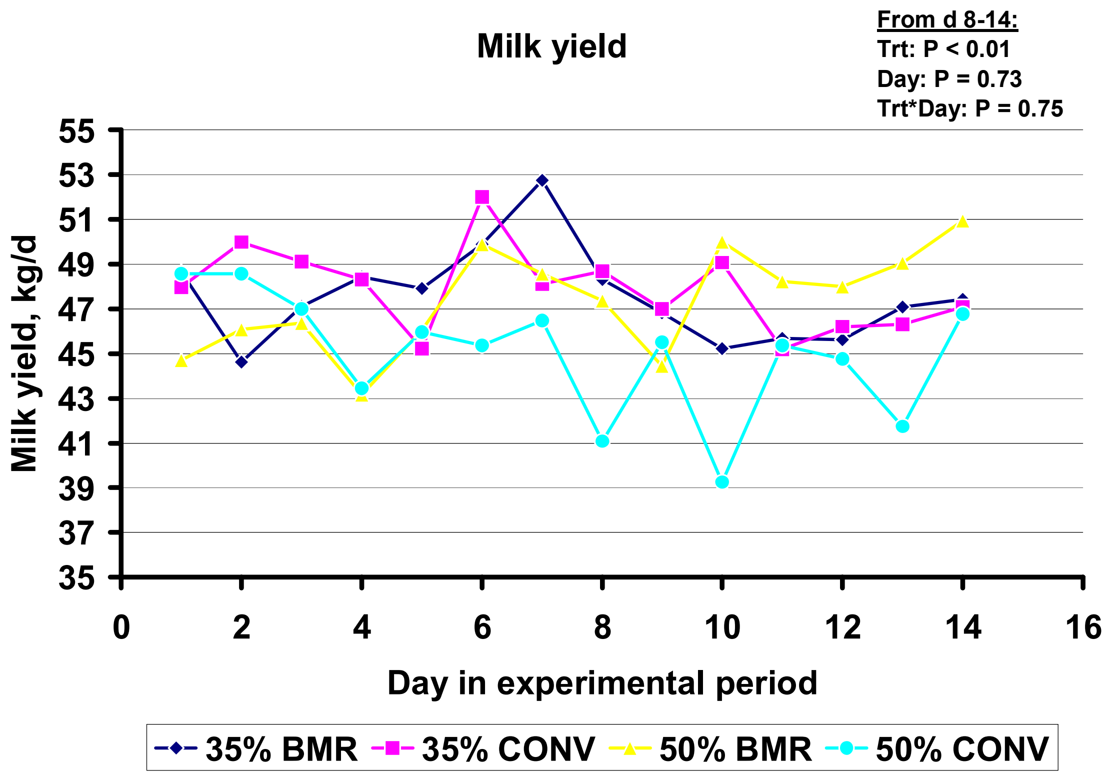

Figure 2. Rumen Ammonia Concentration mg/dl at 0, 4, 8, 12, 16, 20, and 24 Hours After Feeding.

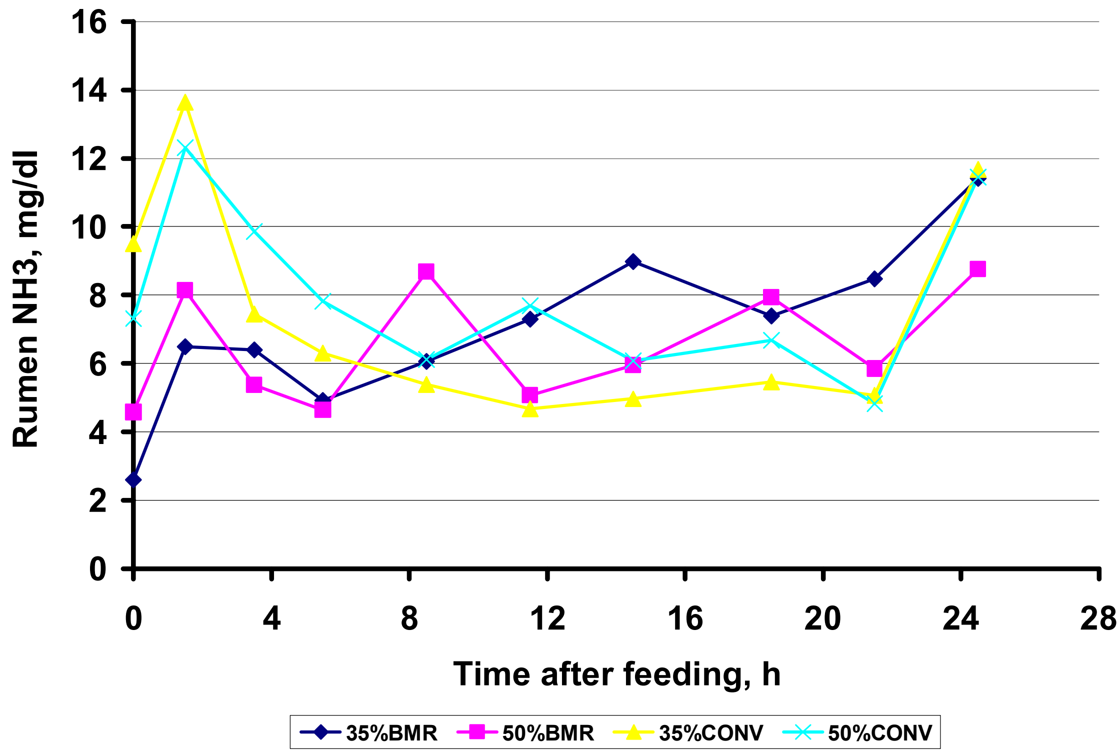

Figure 3. Total Volatile Fatty Acid Content, mmol/L, of the Rumen at 0, 4, 8, 12, 16, 20, and 24 Hours After Feeding for 35% BMR, 35% CONV, 50% BMR, and 50% CONV Treatments.

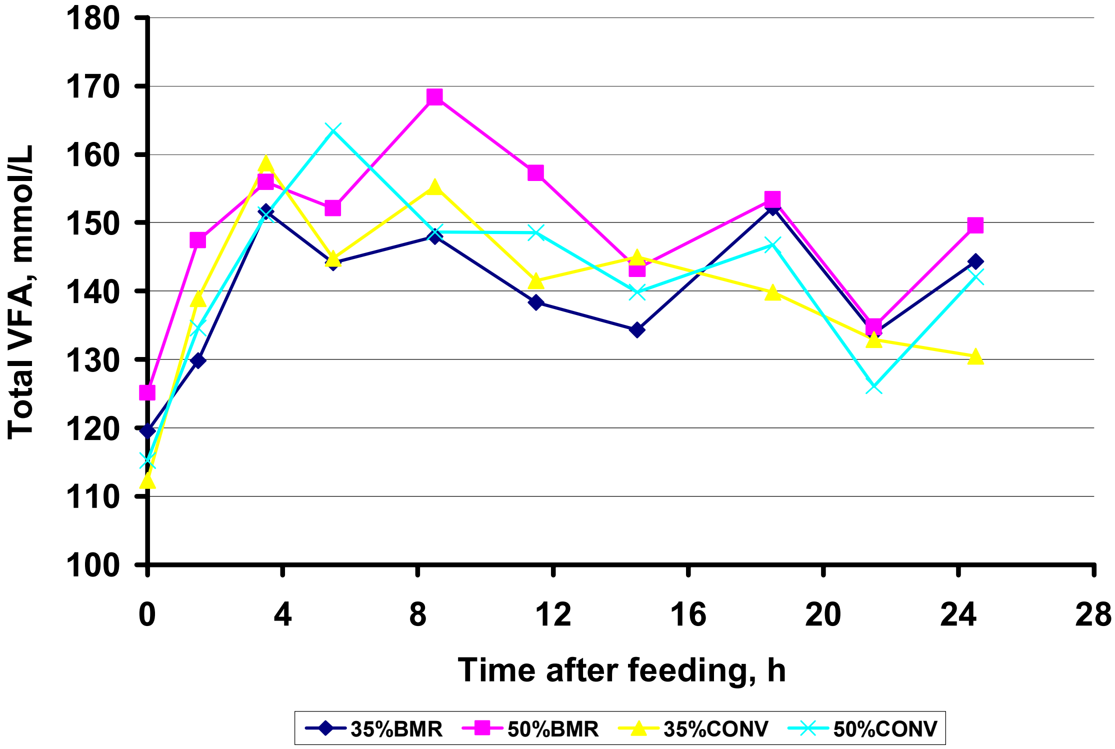

Figure 4. Concentration of Propionate as % of Total Volatile Fatty Acids in the Rumen for 35% BMR, 50% BMR, 35% CONV, and 50% CONV Treatments.

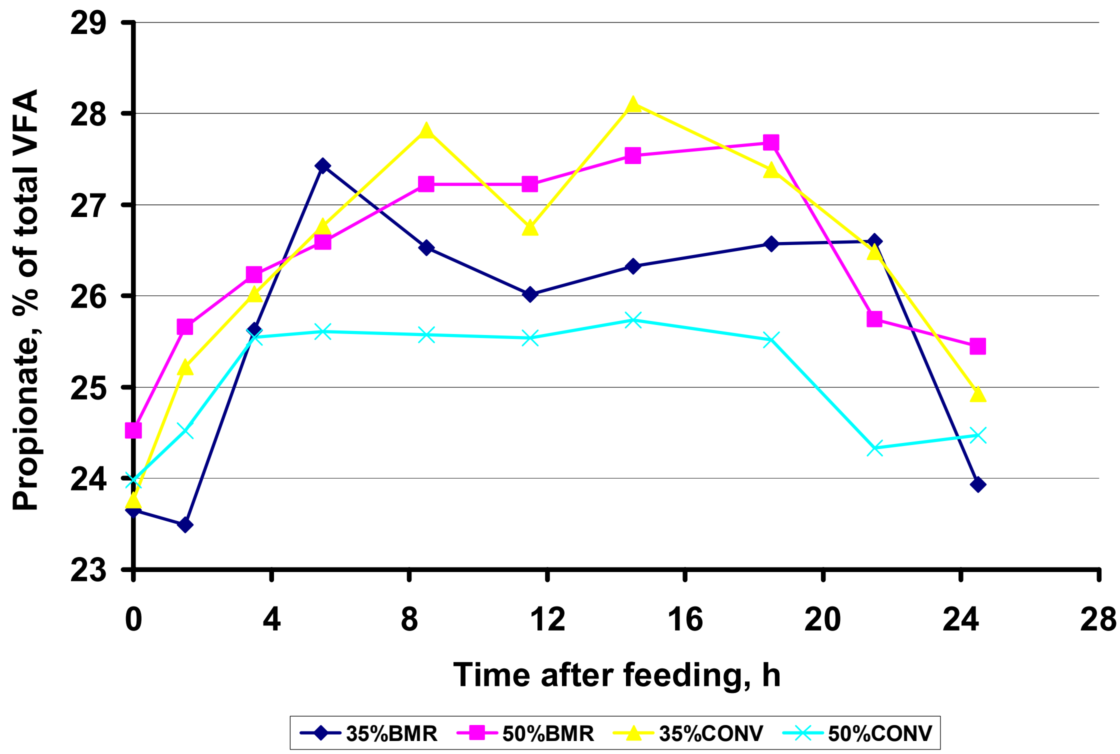

Figure 5. Propionate Content of Rumen as % of Total VFA for Corn Silage at 35% and 50% of Ration Dry Matter.

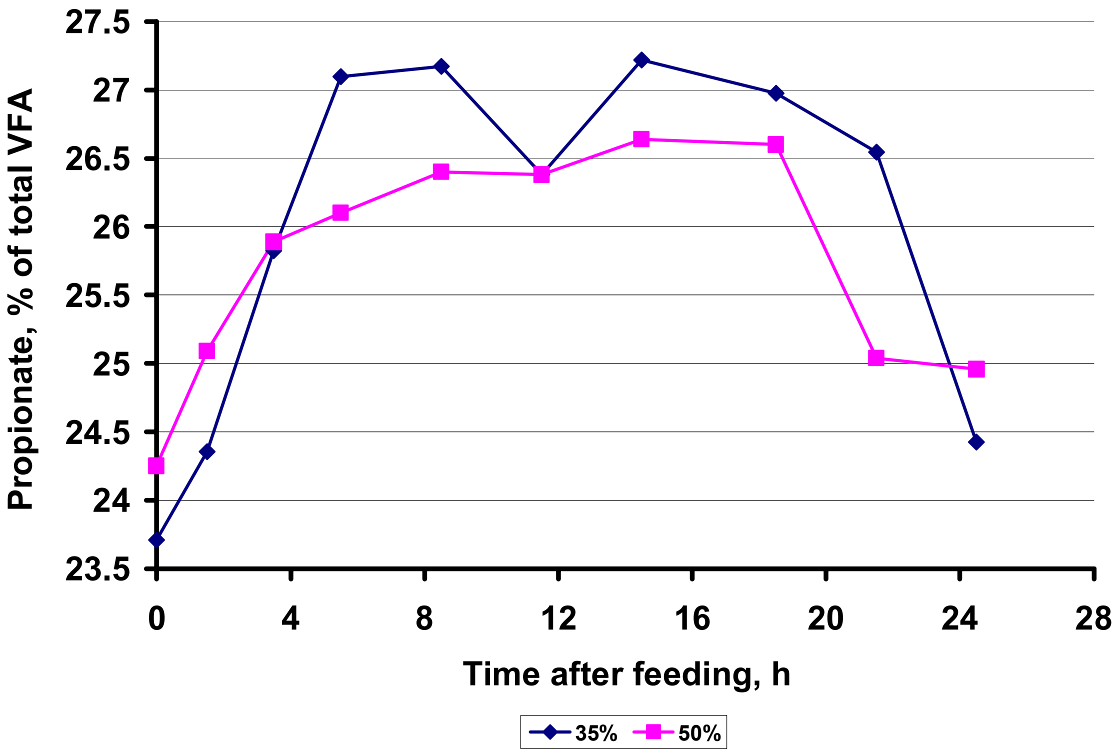

Figure 6. Rumen Isobutyrate Content as % of Total VFA for 35% BMR, 50% BMR, 35% CONV, and 50% CONV Treatments.