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EFFECTS OF BM3 CORN SILAGE ON THE LACTATIONAL PERFORMANCE OF DAIRY COWS

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ABSTRACT

THE EFFECTS OF BM3 CORN SILAGE ON THE LACTATIONAL PERFORMANCE OF DAIRY COWS

By

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Effects of brown midrib-3 (*bm3*) mutation in corn silage on lactational performance were evaluated using 80 Holstein cows (30 primiparous and 50 multiparous) in a full lactation experiment. Treatments were diets containing *bm3* or isogenic normal (control) corn hybrids. *In vitro* NDF digestibility at 30-h was greater for bm3 corn silage compared with control (63.1 vs. 48.8%). Cows were offered diets containing a forage-mix of 67% treatment silage and 33% alfalfa silage on a DM basis. Animals were fed once and milked three times daily. Cumulative yield of SCM was greater (P = 0.01) for cows fed *bm3* treatment from 50 to 150 DIM compared with cows fed normal (3150 vs. 2948 kg) but was similar from 0 to 50 and from 150 to 300 DIM. Cumulative yields of 3.5% fat-corrected milk and milk fat also were greater for cows fed *bm3* treatment compared to normal from 50 to 150 DIM but were similar from 0 to 50 and from 150 to 300 DIM. Milk fat concentration was similar between treatments (3.6%). Multiparous and primiparous cows fed *bm3* treatment had higher milk protein concentrations from 0 to 50 DIM. Primiparous cows fed *bm3* treatment also had higher milk protein concentrations from 50 to 150 and 150 to 300 DIM. Results suggest that milk yield responses for dairy cows fed *bm3* corn silage compared with normal corn silage are greatest at peak lactation.

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INTRODUCTION

Concentration of forage NDF affects DMI by dairy cows and, thus, milk production. Because forage NDF is filling, DMI decreases as forage NDF increases in the diet. However, insufficient forage NDF can result in ruminal acidosis. Forages with enhanced NDF digestibility are thought to increase DMI by decreasing the filling effect of NDF in the rumen. The naturally occurring genetic mutation in corn plants, designated as brown midrib-3 (***bm3***), has consistently greater NDF digestibility compared with corn hybrids not containing *bm* mutations.

Several short-term studies have evaluated the effects of *bm3* corn silage-based diets on milk production in dairy cows with mixed results. Differences in dietary NDF concentrations, stage of lactation and energy balance of the cows and source of dietary NDF among the studies make it difficult to draw conclusions regarding the expected response to *bm3* corn silage by stage of lactation. The objective of the study reported herein is to evaluate milk production responses of lactating cows fed *bm3* corn silage-based diets versus isogenic normal control corn silage-based diets throughout a complete lactation.

LITERATURE REVIEW

This literature review begins with a history of the brown midrib mutation starting with its discovery in the early 1920's. The filling effect of NDF and how NDF digestibility affects fill are then discussed followed by factors that influence NDF digestibility of forages. Finally, the effects of *bm3* corn silage as it relates to animal performance are reviewed.

History of the Brown Midrib Mutations in Corn

Discovery of the Four Brown Midrib Mutations. Among the earliest known published accounts describing the brown midrib mutation in corn plants was by Kiesselbach in 1922 at the University of Nebraska (Kiesselbach, 1922). While researching the breeding of genetically pure lines of corn, he found that one strain yielded a corn plant that exhibited what was referred to as an orange-colored midrib (eventually to become known as brown midrib). Kiesselbach noted that the orange midrib phenotype was recessive in F_1 hybrids and as generations progressed the trait exhibited simple Mendelian ratios. In the second generation, for example, 78 plants showed the orange midrib characteristic while 273 plants maintained green midribs. This amounted to 22% of the plants with the orange midrib, which Kiesselbach observed is similar to the 1:4 ratio typical of the Mendelian inheritance ratio for recessive genes in the F_2 generation.

Eyster (1926) showed that the brown midrib trait resulted from a homozygous recessive factor pair that he named *bm bm* (hereafter referred to as *bm*). It also was noted that the *bm* gene was associated with the *Pr pr* factor pair, which is responsible for the changing of the aleurone color in corn plants from purple to red. Jorgenson (1931) confirmed the linkage of the *bm* gene to the *Pr pr* factor pair. Through the use of several chemical analyses, Jorgenson also showed that the brown pigment characteristic of corn plants with the *bm* mutation was not carotin, xanthophyll, tannin, anthocyanin or flavone. It was theorized that the pigment was either "... a compound of the lignified tissue or was deposited in the interstices..." of the corn plant.

The importance of light for the development of the phenotypic character of *bm* mutated corn also was determined. Jorgenson planted six *bm* corn seeds in each of 10 pots. Five of the pots were located in a dark room and five were placed outside the dark room exposed to light but at the same temperature as those pots in the dark room. At the three and four leaf stage no brown pigment formation was noted for those plants in the dark room, however, twelve of the plants at the four-leaf stage outside of the dark room exhibited the brown midrib characteristic.

The discovery of a second *bm* gene (*bm2*) by Burnham and Brink in 1932 mandated that the bm factor pair described by Eyster (1926) and Jorgenson (1931) be designated as *bm1*. The *bm2* gene, like the *bm1* gene, appeared to be associated with the lignified tissue and was inherited as simple recessive. The authors noted that the brown midrib plants were not visibly weaker than their genotypically normal counterparts, however, the basis for this observation was not given. More recent evidence suggests that brown midrib plants are slightly more predisposed to lodging but proper genetic selection might alleviate this potential problem (Weller and Phipps, 1985; Miller et al., 1983; Nesticky and Huska, 1985).

Burnham and Brink (1932) also showed that the expression of the *bm2* gene was linked to the *P-br* factor pair where *br* is associated with plant height. Specifically, corn plants exhibiting the *br* gene yield plants one-fourth to one-half the height of normal corn plants (Emerson et al., 1935). Others have noted decreased plant height in brown midrib plants when compared with isogenic normal plants and this possibly could be the reason for decreased yields commonly associated with the brown midrib mutation (Miller et al., 1983).

A summary of genetic linkages in corn by Emerson et al. (1935) attributed the discovery of the third bm mutation, *bm3*, to unpublished data by Burnham. This memoir from the Cornell University Agricultural Experiment Station describes the *bm3* mutation to be similar to the *bm1* mutation but the chromosome as unknown. Burnham also was credited with the discovery of a fourth *bm* mutation in corn known as *bm4* (Coors and Lauer, 2001).

Kuc and Nelson (1964) confirmed Jorgensen's theory that the brown midrib phenotype was in some way associated with the lignin fraction of the corn plant. Corn plants that differed only in the allelic presence of the *bm* mutant or normal gene were grown and the stalks and leaves were analyzed for differences in lignin type and/or amount. The *bm* mutant corn plants at maturity had 14% less lignin when compared with normal corn plants. Using labeled precursors of lignin formation (phenylalanine and tyrosine) Kuc and Nelson found that normal plants incorporated more of these compounds into alkali lignin than did the *bm1* plants. Alkali lignin concentration was described by Kuc and Nelson (1964) as the fraction that represents the "core" of the lignin polymer. They hypothesized that corn plants with the *bm1* allele control the type of lignin that is synthesized thus altering the lignin. Further work has shown differences in the composition of lignin between *bm1* and normal corn plants. Gee et al. (1968) found that the lignins of the *bm1* corn plants yielded approximately 50% less *p*-coumaric acid than those of normal corn plants but similar ferulic acid concentrations.

Differences in the Brown Midrib Mutations. The effects of the different *bm* mutations on lignin and CP concentrations were first evaluated by Muller et al. (1971) at Purdue University. Two single recessive *bm* mutant corn hybrids (*bm1* and *bm3*) and one double recessive *bm* mutant corn hybrid (*bm1*/*bm3*) and their isogenic normal corn hybrids were evaluated in a randomized complete block design with four blocks. Six plants from each replicate were harvested at 10, 35 and 55 d post-silking. The authors noted that most of the results presented are from the second harvest (35 d post-silking) because the timing of the second harvest most closely reflected the optimum time of silage harvest. The acid detergent lignin (**ADL**) concentration was lower for the *bm3* hybrid (4.37%) when compared with the *bm1* (5.13%) and normal (6.08%) hybrids. The *bm3* hybrid was statistically similar but numerically lower in ADL when compared with the *bm1*/*bm3* hybrid (4.37 vs. 4.60%). The *bm3* hybrid also had higher CP concentration compared with the *bm1* and normal hybrids at 10.2%. In a follow-up study using the same plant material, Barnes et al. (1971) compared the effects of the various *bm* mutations on *in vitro* DM disappearance (**IVDMD**). The *bm1/bm3* and the *bm3* hybrids had higher IVDMD when compared with the normal hybrid at all three harvest times (10, 35 and 55 d post-silking) by 11.8, 8.8 and 7.5%, respectively. The *bm1* hybrid had higher IVDMD when compared with the normal hybrid at 35 and 55 d post-silking but the hybrids were similar in IVDMD at 10 d post-silking. The authors concluded that the *bm3* mutation, either alone or as a double mutant, had the greatest influence on IVDMD when compared with the normal or *bm1* hybrids.

The final evidence that the *bm3* mutation had the greatest potential of all the *bm* mutations for increasing the forage quality of corn plants came from Lechtenberg et al. in 1972. They compared a corn hybrid with various *bm* mutations (*bm1*, *bm2*, *bm3*, *bm4* and *bm1/bm3*) along with the isogenic normal and a commercial corn hybrid for ADL and IVDMD. The *bm3* hybrid was lower in ADL concentration and higher in IVDMD% when compared with all the other hybrids. Although only one corn hybrid was used to compare the various *bm* mutations, the authors concluded that the *bm3* mutation in corn plants had the greatest potential for use as a forage source when compared with the other *bm* mutations because of its consistently lower ADL concentration and greater IVDMD%. The ease of back-crossing the mutation into high yielding corn hybrids was also an important attribute of the *bm3* mutation according to the authors.

Quality Characteristics of the bm3 Mutation. The *bm3* mutation was shown to have advantageous effects on corn silage quality in different corn hybrid types and growing conditions. Allen et al. (1997) planted and harvested

14 different corn hybrids with the *bm3* mutation and their isogenic normal counterparts in two maturity zones in 1994 and 1995. Three plots of each hybrid were grown in three different locations in the two maturity zones each year. Similar NDF concentrations were observed between treatments; however, *in vitro* NDF digestibility (**IVNDFD**) was greater by an average of 24% for the hybrids with the *bm3* mutation. Also, lignin concentration was lower and CP% greater for the *bm3* treatment compared with normal (1.7 vs. 2.8% and 8.4 vs. 8.2%, respectively). The authors also observed that the magnitude of the effect the *bm3* mutation has on corn plant quality is dependent on the hybrid in which the mutation is incorporated. The range of improvement in IVNDFD% for the individual *bm3* hybrids was from 15 to 38% when compared with the individual normal hybrids but the percent improvement decreased as the IVNDFD increased for the normal hybrids.

Ying and Allen (1997) showed that the *bm3* mutation enhances *in vitro* NDF digestibility by increasing both the rate and extent of NDF digestion in corn silage. One corn hybrid with the *bm3* mutation and its isogenic normal counterpart were grown, harvested and ensiled in mini-silos in three locations in two different years (1994 and 1995). As observed in several other studies comparing the *bm3* mutation and it's isogenic normal counterparts in corn silage, NDF concentrations were similar (42.9%) and lignin concentration lower for the *bm3* hybrid (1.74 vs. 2.73%). *In vitro* NDF indigestible residue (120 h incubation) was lower for *bm3* compared with normal (20.7 vs. 34.4%) with a greater rate of digestion of the potentially digestible NDF (3.84 vs. 2.89%/h).

The Filling Effect of NDF

Ruminal Receptors and Satiety. The ability of a ruminant to perceive satiety from physical fill has been attributed to sensory receptors within the reticulorumen (Leek, 1986). These receptors, which are within the muscle layers of the rumen, are excited upon distension of the rumen wall and have been shown to signal the brain satiety center. The existence of mechanoreceptors and chemoreceptors within the epithelial layer of the reticulorumen also are thought to be involved in the regulation of DMI; Forbes (1996) suggested that the stimulation of the tension receptors in the rumen due to distension are summed with other signals of satiety resulting in a gradual decrease in DMI when applied at "physiological " concentrations.

The evidence of mechanoreceptors in the rumen was presented by Baumont et al. (1990) where they suggested that the regulation of DMI in ruminants is, at least in part, due to mechanical stimulation of the dorsal sac of the rumen. In sheep fed a liquid diet, pseudorumination (rumination-like jaw movements with little or no fiber present) was observed when the dorsal rumen sac was stimulated with a bottle brush or floating polystyrene cubes. Contractions associated solely with the act of rumination imply that when these receptors are stimulated in the dorsal sac of the rumen the act of eating has ceased and rumination begins.

Forbes and Provenza (2000) proposed that hunger and satiety are balanced by signals from tension-, mechano- and chemoreceptors located within the viscera of the animal and integrated by the central nervous system (**CNS**) to signal "discomfort". The animal then alleviates discomfort by adapting the amount of feed intake, or feed type, until "discomfort" is again perceived by the CNS.

Ballast and Neutral Detergent Fiber. The concept that ruminants consume feed until a certain amount of "ballast" (non-digestible matter) is ingested was presented initially by Lehmann in 1941 (as cited by Blaxter et al., 1961). Several literature reviews have since been published acknowledging that DMI can be limited by physical fill in the gastrointestinal tract of ruminants when fed high fill diets (Baile and Forbes, 1974; Allen, 1996; Allen, 2000). Although some have suggested that the intestines may be the rate-limiting site of DMI for ruminants on high fill diets (Waldo and Jorgenson, 1981) physical limitation generally is thought to occur in the reticulorumen.

In an attempt to develop a prediction of DMI with forages of differing quality, Blaxter et al. (1961) fed three hay diets varying in fiber concentration to sheep. Hay quality for this experiment was poor, medium and good quality hays with crude fiber concentrations of 38.5, 30.8 and 22.1%, respectively. They showed that DMI increased as the "quality" of the hay increased.

Van Soest (1965) argued that before a correlation between "ballast" and DMI could be valid, a more satisfactory method for determining "ballast" should be developed. Crude fiber did not totally account for the hemicellulose and lignin fractions of a forage and the neutral detergent system for determining the fiber concentration of a feedstuff was proposed by Van Soest (1965). It is the NDF concentration (including the hemicellulose, cellulose and lignin fractions) of a diet that is the single most highly correlated chemical measure of DMI (Van Soest, 1965). Models attempting to predict the voluntary DMI of dairy cattle using NDF concentration of the diet have been proposed (Mertens, 1987; Williams et al., 1989).

Rumen Inert Bulk. The use of rumen inert bulk (**RIB**) to assess the effect of fill on DMI has been done extensively with varying results. Among the first of these experiments, Campling and Balch (1961) used three non-lactating, non-pregnant cows in a 3 x 3 Latin square design in 14-d periods. The three treatments were no bladder in the rumen (control), a bladder filled with 22.7 kg of water inserted in the rumen and a bladder filled with 34.0 kg of water inserted in the rumen. When these animals were offered all hay diets a decrease in voluntary DMI of 54 g/L of water in the bladders was seen.

Anil et al. (1993) showed similar results of RIB in lactating dairy cattle fed all hay diets. Two separate experiments with six cows each in a 3 x 3 Latin square design were used. Cows were offered hay ad libitum for only 3 h per collection period. Rubber bladders in the rumen of each animal were filled with either 7.5 or 15.0 L of water for animals in trial 1 and 12.5 or 20 L of water in trial 2. Control animals for both trials had no RIB in the rumen. Linear decreases in DMI were seen in both trials as RIB was increased ($r^2 = 0.82$ for trial 1; $r^2 = 0.80$ for trial 2) at a rate of 56 g/L of water in the bladders. In a follow up study utilizing ryegrass silage instead of ryegrass hay, Anil et al. (1993) showed a linear decrease in DMI as water filled bladders increased ruminal distension from 0, 15, 20 and 25 L ($P < 0.01$). The rate of decreased DMI was only half for ryegrass silage (28 g/L) compared with ryegrass hay (56 g/L) possibly indicating the importance of weight and weight-sensitive receptors in the rumen wall.

Other studies have shown no effect on DMI with the addition of RIB to the rumen. Waybright and Varga (1991) inserted water-filled bags into the rumen of sheep at the rate of 0.22, 0.44 or 0.66 L/L of pre-trial ruminal volume. The sheep were fed a high-concentrate diet with a NDF concentration of 22%, dry basis. No effect of DMI was observed as ruminal capacity decreased. Similarly, in a series of studies by Carr and Jacobson (1967), DMI did not decrease as RIB increased in the rumen of 500 kg non-lactating dairy cows. In these experiments it has been suggested that ruminal fill may have not been limiting DMI even after insertion of the RIB (Allen, 1996). Anil et al. (1993) suggested that no effect was observed in the Carr and Jacobson study because the amount of RIB used was not great enough.

Carr and Jacobson (1967) utilized the lower level of distension to more closely resemble "physiological levels" of fill. The animals used for the Carr and Jacobson (1967) study were non-lactating dairy cows fed a ground hay and concentrate diet (experiment 1) or a chopped hay diet (experiment 2). Allen (1996) speculated that these animals met their energy requirements and therefore, physical fill did not limit voluntary DMI. Non-lactating animals consume relatively less DM compared with lactating cows and differences may have, therefore, been more difficult to discern. The use of ground hay (experiment 1) and chopped hay (experiment 2) also may have allowed for greater passage out of the reticulorumen relative to coarse hay diets. Thus, a lack of physical fill may have negated any differences that might have been seen with the RIB because of decreased particle size of the forages.

Stage of lactation and energy balance status also may affect DMI of ruminants due to physical limitations of NDF in the reticulorumen. This is, at least in part, due to the increased energy requirements associated with milk production, especially in early lactation (NRC, 2001). A negative energy balance develops in early lactation when the demand for energy by the cow for milk production exceeds the energy consumed. In a review on the physical restraints of intake in ruminants, Allen (1996) concluded that the response to inert fill in the reticulorumen is a function of the energy requirement of the animal, the caloric density of the diet, the filling effect of the diet, the capacity of the reticulorumen, and the passage rate of digesta from the reticulorumen of the host animal. Johnson and Combs (1991) showed that ruminal fill might depress DMI for dairy cattle in early lactation. Rumen inert bulk was used to replace 25% of ruminal capacity in cows averaging 49 and 73 DIM in trials 1 and 2, respectively. A decrease in DMI of 99 g/L of added bulk was observed in trial 1 and 130 g/L of added bulk in trial 2. Dado and Allen (1995) further studied the effect of dietary ruminal fill on DMI of cows in early lactation. Twelve animals averaging 59 DIM were used in a 4 x 4 Latin square design. Cows were fed 25 or 35% NDF diets with or without the addition of 25% RIB (pre-trial rumen volume). There was a decrease in DMI of 5.1 kg/d for cows fed the high NDF diet when compared with cows fed the low NDF diet. Furthermore, the addition of the RIB had no effect on DMI of cows on the low NDF diet but decreased DMI of cows fed the high NDF diet by 2.1 kg/d. The addition of fill to the rumens in these experiments, whether by RIB or an increase in the filling effect of the diet (increased NDF), limited the potential maximum DMI in these early lactation cows.

Johnson and Combs (1992), however, observed no differences in DMI when RIB was added to rumens of cows past peak lactation and in a greater energy balance than early lactation cows (Johnson and Combs, 1991). Cows, with or without RIB at 25% of pre-trial rumen volume and averaging 229 DIM, had similar DMI when fed a 29% NDF diet. In a follow up study, diets of 27 and 34% NDF were fed to cows averaging 119 DIM with or without the addition of 25% RIB (pre-trial rumen volume). The increase in dietary NDF decreased DMI but no differences in DMI were observed for either concentration of dietary NDF when RIB was added.

Johnson and Combs (1992) noted that it is possible for the rumen to adapt to physical fill by altering ruminal capacity. The addition of a bladder with 19.5 L of water to cows averaging 229 DIM caused decreases in DMI of approximately 2, 1 and 0 kg/d for weeks 1, 2 and 3 of the study when compared with cows with no bladders. The cows with the bladders compensated for the RIB with a 6 L decrease in digesta volume and a 17.5 L increase in total reticuloruminal volume. This ability to adapt to increasing fill in the rumen also was observed by Dado and Allen (1995) for animals on the low fill diet (25% NDF); however, animals on the high fill diet (35% NDF) were not able to overcome the fill effect of NDF with early lactation cows.

It has been postulated that DMI will not be limiting until the reserve capacity for fill in the rumen is reached (Allen, 1996). Decreasing particle size or increasing the NDF digestiblity of the diet may potentially allow greater ruminal passage of NDF and thus increase DMI for cows limited by physical fill.

NDF Digestibility Affects the Filling Effect of NDF

Once the rumen's capacity for fill has been reached, movement of digesta out of the rumen must occur before feed intake can resume. Early work on this subject by Crampton (1957) showed that forages with the least amount of cellulose and hemicellulose digestion (essentially, NDF digestibility) were retained the longest in the rumen of sheep. He postulated that this increase in retention time of the feed in the rumen was a major factor in decreasing voluntary intake.

Other studies have shown how increased NDF digestibility can alleviate the filling effect of NDF in the rumen at similar dietary NDF concentrations. Ruiz et al. (1995) fed 48 Holstein cows averaging 110 DIM diets differing in NDF concentration (31.0, 35.0 and 39.0%) based on four different ensiled forage sources of differing digestibilities (twelve diets total). They found that at similar dietary NDF concentrations the diets with the greater *in situ* NDF digestibilities (whole plant corn and dwarf elephant grass) had greater NDF and DM intakes compared with the lower digestibility forage diets. Cows fed the more digestible forages had greater milk production compared with cows fed the lower digestible forages. However, because the treatments in this study consisted of four different varieties of grass, it is difficult to attribute the increased intakes and milk production solely to greater NDF digestibilities of the corn and elephant grass silages.

Robinson and McQueen (1992) fed diets of like-forage sources to test the effects of ruminal fill on intake and milk production. Twelve multiparous and 4 primiparous Holstein cows in mid-lactation (DIM not reported) were used in a replicated 4 x 4 Latin square design. A good timothy hay (GT) and a poor timothy hay (PT) were used to formulate diets with similar NDF concentrations (approximately 40.0%) but differing digestibilities. Diets were designated as having inclusion rates of GT at 0, 33, 66 and 100% of total dietary forage. The treatment hays accounted for 53, 50, 48 and 46 percent of diet DM for diets with GT inclusion rates of 0, 33, 66, and 100 percent, respectively. As inclusion rate of GT in the diets increased from 0 to 100%, the extent of NDF digestion (utilizing chromic oxide as an external digestibility marker) increased from 64.2 to 69.7%. No effect of diet digestibility on milk production or DMI were observed. The lack of effect of increased NDF digestibility on DMI could possibly be due, however, to the fact that fill was not limiting intake in this study (Jung and Allen, 1995).

Dado and Allen (1996) noted the possible limitations of the previous studies and harvested and ensiled alfalfa with similar NDF concentrations that differed in NDF digestibility by 2.8 percentage units. Diets based on these forages were fed to cows in early lactation (average DIM = 13 d). They found that although NDF intakes were similar between the treatments, DMI and milk production were greater for cows consuming the diet with the greater NDF digestibility. This coincided with greater total tract digestibilities of both NDF and

DM.

Oba and Allen (1999b) showed the impact that NDF digestibility can have on DMI and milk production in lactating cows. From the literature, 13 sets of forage comparisons from seven different studies were evaluated to determine the effects of NDF digestibility on DMI, milk yield, FCM yield, BW change and ruminal pH. Studies were included if the NDF digestibilities of the forages compared, determined *in situ* or *in vitro*, were different ($P < 0.10$) and if the comparisons were of forages within the same forage family (e.g., legume or grass). Not included in the database were studies not reporting dietary NDF concentration because dietary NDF concentration was used in the model as a covariate. The authors concluded that a one unit increase in NDF digestibility equated to a 0.17 kg/d increase in DMI and a 0.25 kg/d increase in 4% FCM yield.

Factors Affecting the Digestibility of Forage NDF

Forage Maturity. The maturity of a forage has long been thought a major determinant of forage quality (Woodward et al., 1939). Llano and DePeters (1985), however, were among the first to evaluate the effect of forage maturity on NDF digestibility *in vivo*. They harvested and preserved, as hays, alfalfa at 21 d (early cut) or 30 d (normal cut) intervals which were fed to both lactating and non-lactating dairy cows in a series of experiments. Both the early and normal cut hays were mixed with concentrates at 30 or 50% of diet DM and cubed. Dietary NDF concentrations were similar for all four diets (approximately 32%, DM basis). The apparent digestibilities of DM and NDF were greater for cows fed the early cut forage compared with cows fed the normal cut forage (67.4 and 45.1% vs. 61.5 and 30.5%, respectively). Dry matter intake, however, was similar at both maturities. Overall, the authors concluded that as plant maturity increased apparent digestibility of NDF decreased.

Maturity not only appears to affect the digestibility of a forage but also its rate of passage from the rumen. Llamas-Lamas and Combs (1990) harvested alfalfa at three maturities [early vegetative (EV), late bud (LB) and full bloom (FB)] and preserved the alfalfa as hay. Diets formulated from these forages were balanced for 29.4% NDF and 19.3% CP and fed to six lactating cows averaging 120 DIM in a replicated 3 x 3 Latin square design. Whole tract NDF digestibility (determined by samarium-marked grain) was greater for the diet containing EV when contrasted with diets containing LB and FB (55.0 vs. 46.0%). Dry matter intake and *in vivo* solid phase rate of passage also were greater for the EV diet compared with the average of the LB and FB diets (26.1 vs. 24.6 kg/d; 5.2 vs. 4.8%). Consequently, the authors concluded that cows fed the EV diet had greater DMI relative to the LB and FB diets because of the increased rate of passage and greater proportion of potentially digested NDF of the EV diet.

Dry Matter Intake. How well a forage or forage-based diet is digested by a ruminant also is dependent on the amount of intake for which a given forage is consumed. Colucci et al. (1982) fed whole plant corn and alfalfa silage-based low and high forage diets with dietary NDF concentrations of 29.7 and 37.8%, respectively, to non-lactating and lactating cows. The lactating cows had greater

DMI (as g/kg BW), but lower DM and NDF digestibilities than the non-lactating animals within a diet. They observed that the intake of NDF was correlated positively with particulate matter passage and theorized that decreased digestibility of diets at the higher intakes was caused by a faster rate of passage through the rumen.

Utilizing a 3 x 3 Latin square design, Shaver et al. (1986) evaluated the effects of various intake amounts and forage particle sizes on the digestion and passage of legume hay in dairy cattle. They fed pre-bloom alfalfa hay, either long, chopped or pelleted, in a 60:40 hay:concentrate diet to six Holstein cows in early- and mid-lactation (high and medium intake groups) and in the dry period (low intake group). Dietary NDF and CP concentrations were similar for all treatments (30.8 and 17.4%, respectively). They observed a longer whole tract retention time of ytterbium-marked hay (26.4 vs. 15.6 h) and greater total tract NDF digestibility (42.5 vs. 36.5%) for the low intake group compared with the high intake group. Like Colucci et al. (1982), the authors attributed the depression in NDF digestibility for the high intake group to the decreased ruminal retention time of the NDF. When the effect of particle size of the hay diets was evaluated, DMI was similar for all treatments but the pelleted diet had lower total tract NDF digestibility and ruminal pH compared with the long and chopped diets (36.8 vs. 41.1% and 5.77 vs. 6.34, respectively). The authors theorized that with high quality forages like pre-bloom alfalfa, particle size is not the factor that limits DMI because rapid reduction in particle size due to mastication and rumination occurs relative to lower quality forages. Therefore, the authors speculated that trying to decrease ruminal fill by reducing the particle size of a high quality forage may not increase digestibility because smaller particles in the rumen could decrease rumination and total chewing thereby causing a drop in ruminal pH and thus decrease fiber digestibility.

Particle Size. The effect of particle size on NDF digestibility also may be influenced by the type of forage offered. Osbourn et al. (1981) in two experiments, fed wether lambs five hay types representing both graminaceous and leguminous forages. Forages were fed as either long hay, pellets made from the long hay that was ground coarsely or finely or a combination of the coarsely and finely ground pellets (ratio of each not reported). These combinations also were fed at different amounts of feed offered in the second experiment. Overall, NDF digestibility decreased with a decrease in particle size and an increase in the amount of feed offered. This decrease in NDF digestibility was more prevalent for the grasses than the legumes.

Decreasing particle size of forages does not always decrease NDF digestibility. Woodford et al. (1986) observed no differences in DMI or NDF digestibility when cows were fed alfalfa hay-based diets chopped at mean particle sizes of 0.26, 0.46, 0.64, and 0.90 cm. Cows averaged 56 DIM and the dietary NDF concentration was 27%. It is possible, however, that fill was not limiting DMI in this study.

Environment. Forage NDF digestibility also is affected by environmental factors such as drought stress and temperature. Allen and Oba (1996) summarized data from 35 corn hybrids grown in two plots at two locations in two maturity zones in Michigan in both 1988 and 1989. Corn grown in 1998 was considered drought stressed relative to corn grown in 1999 because of a lower amount of precipitation (21.3 vs. 41.4 cm) and a higher growing degree-day value (2387 vs. 2072) from May 1 to September 1 of each year. Compared with the non-drought stressed corn plants, the drought stressed corn plants had slightly lower NDF and lignin concentrations (40.8 vs. 42.2% and 2.44 vs. 2.96%, respectively) and nearly a 20% greater 30-h IVNDFD (50.3 vs. 42.0%). Although both temperature and soil moisture are important factors affecting NDF digestibility in forages, it has been suggested that soil moisture may be more influential in determining forage quality than temperature (Crasta and Cox, 1996).

Increases in NDF digestibility of drought-stressed forages, however, may not be due necessarily to decreased soil moisture but to slow maturation of the forage itself. Deetz et al. (1996) harvested alfalfa at 21, 35 and 49 d of re-growth in plots irrigated at 65, 88 or 112% of field water holding capacity. Field water holding capacities of 65 and 88% were considered water-deficits. They found that as the amount of irrigation increased, the NDF concentration of the alfalfa increased, but lignification and NDF digestibility was not affected by water status. They concluded that water-stressed plants do not have greater quality characteristics due to being water-stressed, but because a delayed maturity and smaller concentrations of cell wall brought on by the lack of water during growth.

Lignin. A major determinant of NDF digestibility is the amount and/or the composition of lignin within the NDF fraction of the plant (Jung, 1989). Jung and Deetz (1993) theorized that lignin decreases the digestibility of plant NDF fractions by shielding the cell wall polysaccharides from enzymatic hydrolysis. Smith et al. (1972) harvested six legume and nine grass species at 1-wk intervals to determine the effects of species and maturity on the indigestibility of NDF. The rate and extent of NDF digestibility were determined by *in vitro* incubation. They found that lignin concentration was correlated positively with NDF indigestibility for both legumes ($r = 0.78$) and grasses ($r = 0.89$). The authors concluded that lignin concentration could account for up to 75% of the variation of *in vitro* NDF digestibilities across species and maturity, and that soluble DM concentration can account for approximately 50% of the variation in NDF rates of digestion.

Allen and Oba (1996) showed that lignin as a percent of NDF explained about 50% of the variation in IVNDFD for alfalfa and corn forage. However, for alfalfa the relationship between lignin as a percent of NDF and IVNDFD was greatest for first cutting, less for second cutting and not related for third or fourth cutting. For corn forage grown over two years there was no relationship between lignin as a percent of NDF and IVNDFD in a drought year but a significant relationship in a normal year and across both years (r^2 approximately 0.50).

Animal Performance with *bm3* Corn Silage

Sheep. The first study to evaluate *bm3* corn silage *in vivo* was published by Muller et al. (1972). They harvested *bm3*, isogenic normal and conventional corn plants and manually removed the ears prior to ensiling to avoid confounding results because of differences in grain concentration between the hybrids. The

NDF concentrations were 60, 61 and 62% (dry basis) for *bm3*, isogenic normal and conventional corn silages, respectively. Eighteen ram lambs were assigned randomly to either a *bm3*, normal or conventional corn silage-based diet fed as 90% corn silage and 10% protein-vitamin-mineral mix. Ad libitum DMI as a percent of BW for lambs on the *bm3* silage diet were greater when compared with lambs fed either the normal or conventional silage diets (2.43, 1.88 and 1.58%, respectively). Apparent digestibilities of DM, NDF and energy were all higher for *bm3* silage fed lambs when compared with normal and conventional silage fed lambs. The authors concluded that the *bm3* mutation produced corn silage with greater digestible DM, NDF and energy when compared with normal and conventional corn silage possibly because of decreased lignification of the cellulose and hemicellulose of the corn plant. They further hypothesized that the increase in DMI for *bm3* fed lambs could possibly be due to increases in the overall digestibility of the *bm3* corn silage.

Increased digestibility of *bm3* corn silage has also been observed in other studies utilizing sheep. Stallings et al. (1982) fed six yearling wethers *bm3* and isogenic normal corn silage diets in a single crossover design. Although feed intake was restricted to 90% ad libitum intake, DMI was greater for wethers fed the *bm3* corn silage diet (1.36 vs. 1.15 kg/d). Apparent DM digestibility was 6.6 percentage units greater for wethers fed the *bm3* diet when compared with wethers fed normal corn silage. Weller and Phipps (1986) noted smaller but still significant increases in apparent DM digestibility when feeding 18-mo old wethers *bm3* corn silage or isogenic normal corn silage. Three *bm3* hybrids and their isogenic normal counterpart hybrids were evaluated and the mean values from the lambs fed the three *bm3* hybrid silages were compared with the mean values from the lambs fed the three normal hybrid silages. Apparent digestibilities were higher for DM, OM, NDF, ADF, cellulose and hemicellulose for those lambs fed the *bm3* corn silage diets (2.9, 2.7, 4.5, 8.5, 6.6 and 2.0 percentage units, respectively). DMI was not reported for this study.

Dairy Cattle. Oba and Allen (1999a) showed that increased NDF digestibility observed for *bm3* corn silage *in vitro* does not necessarily correspond to similar NDF digestibilities *in vivo.* Thirty-two cows averaging 89 ± 27 DIM were fed *bm3* and isogenic normal corn silage-based diets in a single crossover design with 28 d periods. The IVNDFD of the *bm3* corn silage was 9.7 percentage units greater when compared with normal corn silage. However, when the corn silages were included in TMR diets at 45% of the diet DM the *bm3* fed cows had only 2.2 percentage units greater apparent total tract NDF digestibility when compared with cows fed the normal corn silage-based diet (P = 0.02). Dry matter intake was greater (P < 0.0001) for cows fed the *bm3* diet compared with normal fed cows (25.6 vs. 23.5 kg/d). The authors hypothesized that the decrease in the *in vitro* and *in vivo* NDF digestibilities between the two corn silage hybrids was a result of the increased DM intake observed for the *bm3* fed cows. The change in the total tract NDF digestibility response to the *bm3* treatment ranged from approximately plus 15% when DMI was greater for normal fed cows to approximately minus 15% when DMI was greater for *bm3* fed cows. This relationship between DMI response to the *bm3* treatment (response to *bm3* corn silage minus response to normal corn silage) and the response in total tract NDF digestibility showed a negative correlation (*P* < 0.001). As DMI increased, NDF digestibility decreased. The authors speculated that this was because of faster passage from the rumen for *bm3* as DMI increased. Because a constant retention time is used to determine *in vitro* digestibility values, the differences in NDF digestibility between *bm3* and normal corn silages may have been inflated compared with the *in vivo* results.

The increases in DMI and NDF digestibility observed by Oba and Allen (1999a) for cows fed the *bm3* treatment was accompanied by a milk yield response when compared with cows fed the isogenic normal treatment. Specifically, cows fed the *bm3* treatment yielded 2.8 kg/d more milk than cows on the normal treatment and 2.6 kg/d more 3.5% FCM. Because this study was a crossover design the authors were able to evaluate each animal's response to the *bm3* treatment. They plotted each animal's pre-trial milk yield against their milk yield response to the *bm3* treatment and observed a positive correlation. In other words, cows that had the highest milk yields pre-trial had the greatest response to the *bm3* treatment. Conversely, those cows that had lower milk yields pre-trial had little or no responses to the *bm3* treatment.

Increases in milk yield also have been observed with cows fed *bm3* corn silage diets without increases in DMI. Keith et al. (1979) randomly assigned 12 Holstein cows past peak lactation to one of four treatment combinations in a double switchback design. The diet combinations were *bm3* and isogenic normal corn silages fed at two forage to concentrate (**F:C**) ratios (75:25 and 60:40).

Cows received their assigned diet for 5 wk, were randomly switched to a second treatment diet for 5 wk and then were switched back to the original assigned diet for 5 wk. Although genotype or F:C ratio did not affect DMI, milk yields were higher for cows fed the *bm3* treatments. Cows on the *bm3* treatment had 1.3 and 1.6 kg/d greater milk yield and 0.9 and 1.0 kg/d greater FCM yield than cows fed the normal treatment at F:C ratios of 75:25 and 60:40, respectively.

Oba and Allen (2000a) also fed cows *bm3* and normal corn silage diets at two different dietary NDF concentrations (29 and 38% dietary NDF) but noted increases in DMI at both concentrations of fiber for cows on the *bm3* treatment. Along with the increases in DMI, cows fed *bm3* corn silage-based diets also had higher SCM yields regardless of the forage concentration. However, because no milk fat depression was observed for cows on the high forage *bm3* diet and solids not fat concentration also was greater for these cows when compared with the *bm3* low forage and normal diets. The authors contended that the feeding of *bm3* corn silage was more beneficial in high forage diets when fed to higher producing cows.

Frenchick et al. (1976) observed increases in milk yield for cows past peak lactation fed a *bm3* corn silage-based diet compared with cows fed an isogenic normal diet (22.5 vs. 21.7 kg/d). However, because cows fed the *bm3* treatment had a lower milk fat percentage the FCM yields between the two treatments were similar. Body weight gains, though, were greater for cows fed the *bm3* treatment (+3.1 vs. –0.6 kg for normal treatment).

Sommerfeldt et al. (1979) theorized that BW gains of cows fed *bm3* corn silage are due to partitioning of energy from milk production. In their study, cows (averaging 42 DIM) fed *bm3* corn silage-based diets had no advantages in DMI nor milk yield compared with cows fed isogenic normal corn silage diets but they did have greater ($P < 0.01$) daily BW gains (+58.4 vs. -47.3 g/d). Rook et al. (1977) also observed increased BW gains with cows fed *bm3* corn silage-based diets from 42 to 91 DIM (49.6 vs. 7.1 g/d), but there were also significant increases in DMI when compared with cows fed normal corn silage-based diets (20.2 vs. 18.6 kg/d). Cows beginning treatments at 7 DIM, however, had no advantage in DMI or BW gain from the *bm3* corn silage diet when fed to 56 DIM. Milk yields were not different between treatments at either stage of lactation.

The apparent partitioning of energy toward body condition rather than milk production for cows fed *bm3* corn silage was also observed by Block et al. (1981). From 18 to 74 DIM cows fed *bm3* corn silage had increased BW (+10.2 kg), whereas cows fed the isogenic normal corn silage actually lost BW (-24.6 kg). Cows fed the *bm3* treatment produced more milk throughout the study but this was not significant. The authors, however, noted that when the milk yield of the two groups were analyzed by week, cows receiving the *bm3* treatment produced more actual milk in wk 5, 6 and 8 compared to cows receiving the normal treatment. Statistics regarding these differences were not reported.

The effects of *bm3* corn silage on lactational performance also have been compared with other specialty hybrids. Ballard et al. (2001) fed late lactation cows (204 ± 104 DIM) corn silages from either leafy, brown midrib, or high grain yield corn hybrids. Because the leafy and brown midrib hybrids are considered for silage only they were compared with the grain hybrid and to each other. Direct contrasts between the grain hybrid and either of the silage hybrids were not performed. They found that cows fed the silage hybrids produced 1.1 kg/d more milk when compared with cows fed the grain hybrid and that the brown midrib treatment increased milk yield over the leafy hybrid by 2.3 kg/d. Yield of 3.5% FCM also was greater for cows fed the brown midrib treatment compared with the leafy treatment (35.8 vs. 33.5 kg/d) but cows receiving the silage hybrids had similar yields to the grain hybrid treatment fed cows (34.7 vs. 33.3 kg/d). An intake study conducted with the same hybrids in growing dairy heifers showed that the silage hybrids allowed greater consumption of DM compared with the grain hybrid as a percent of BW (2.13 vs. 2.02%) but that body condition and weight gains were similar between the treatments.

Transition cows have benefited by *bm3* corn silage-based diets. Santos et al. (2001) fed primiparous and multiparous dairy animals non-isogenic control corn silage-based diets at either 55:45 or 65:45 F:C ratios or a *bm3* corn silage-based diet at a 65:45 F:C ratio. Treatment diets began an average of 23 d prior to calving and continued for 33 d postpartum. Post calving health and DMI were similar between treatments for this study but a tendency ($P = 0.09$) for increased milk yield was observed for multiparous cows receiving the *bm3* treatment (+2.2 kg/d).

Beef Cattle. The effects of *bm3* corn silage-based diets also were evaluated in studies with beef cattle. Keith et al. (1981) studied the effects of *bm3* corn silage with various concentrations of additional grain in both beef steers and heifers in two different experiments. Steers fed *bm3* corn silage increased average daily gain (**ADG**) when compared with steers fed a conventional corn silage only diet (0.90 vs. 0.82 kg/d) but when each hybrid was supplemented with corn at 2% of BW feed efficiency was similar. In the second experiment heifers fed *bm3* corn silage only had greater ADG than heifers fed conventional corn silage only (1.03 vs. 0.90 kg) and similar ADG to conventional corn silage plus 1% added corn (1.03 kg for both treatments). Similarly, Woody et al. (1977) observed that beef steers fed *bm3* corn silage only diets had similar ADG when compared with steers fed conventional corn silage plus 40% corn grain.

Tjardes et al. (2000) fed eight beef steers *bm3* or normal corn silage diets at 86% of the diet DM both ad libitum and restricted intake. The *bm3* treatment increased DMI when fed ad libitum (5.06 vs. 4.44 kg/d). Apparent total tract fiber digestibility was 10.5 and 15.8 percentage units greater for steers on the *bm3* treatment when compared with normal treatment steers when fed ad libitum and restricted, respectively. These same diets were fed ad libitum to eight pens (eight steers per pen) for 112 d as a grower diet and then a common finishing diet was fed to all animals. Although DMI was greater for steers on the *bm3* diet (0.43 kg/d increase) during the growing phase no advantages in either DMI or ADG were observed for either treatment overall.

Lignin and Digestibility. The advantages observed for feeding *bm3* corn silage-based diets have been attributed to the increased digestibility of the fiber due to decreases in the lignin concentration of the whole plant. Only one study reported in the literature has shown similar lignin concentration between a *bm3* corn hybrid and its isogenic normal counterpart (Sommerfeldt et al., 1979) but NDF digestibility was still 9.6 percentage units greater for the *bm3* corn silage diet in that study. Kuc and Nelson (1964) determined that the lignin of brown midrib corn plants differs from normal corn plants by not only decreased lignin concentration, but also by altered lignin composition. Although overall NDF digestibility is typically increased for bmr corn hybrids, there is evidence that the NDF of bmr corn plants is less digestible per unit of lignin when compared with normal corn plant fiber (Thorstensson et al., 1992). Therefore, the observation of Sommerfeldt et al. (1979) is difficult to explain.

Microbial Efficiency. Microbial efficiency, defined as grams of bacterial N/kg of OM truly digested in the rumen, was greater for early mid-lactation cows fed *bm3* corn silage (Oba and Allen, 2000c) but was significantly decreased for late lactation cows (Greenfield et al., 2001) when compared with isogenic normal corn silage diets. The differences observed between these studies may be accounted for by the DMI for cows fed *bm3* treatments compared with normal treatments. The early mid-lactation cows of the Oba and Allen study (2000a) increased DMI by 4.8% whereas late lactation cows in the Greenfield et al. study (2001) showed similar DMI between the two treatment diets. Greenfield et al. (2001) attributed the differences in microbial efficiency between the early mid-lactation and late lactation cow studies to the differences observed in rumen retention times.

Physical Effectiveness. Although *bm3* corn hybrids typically are superior to isogenic normal corn hybrids in NDF digestibility the NDF of both hybrid types has been shown to be similar in physical effectiveness (Oba and Allen, 2000). Oba and Allen (2000b) observed that the turnover rate of ruminal digesta NDF was greater for *bm3* corn silage diets fed to lactating cows but that the pool size of the NDF remained similar to the normal corn silage fed cows due to an increase in DMI of cows fed the *bm3* treatment. No effects on eating or ruminating time were observed for cows on the *bm3* treatment in this study when compared with the normal treatment.

Milk Composition. The effects of *bm3* corn silage-based diets on milk composition and yield have given mixed results. Several studies have shown no effect on concentration or yield of milk components with *bm3* corn silage diets [Rook et al. (1977), Keith et al. (1979), Sommerfeldt et al. (1979), Stallings et al. (1982), Ballard et al. (2001), Greenfield et al. (2001) and Tine et al. (2001)].

Oba and Allen (1999a) observed increases in milk protein concentration and yield with cows fed *bm3* corn silage diets of 2.4 and 8.1%, respectively, compared with cows fed isogenic normal corn silage diets. In a subsequent study, Oba and Allen (2000a) again noted increases in milk protein yield for cows fed the *bm3* corn silage diets compared with cows fed normal corn silage diets but not for milk protein concentration. Oba and Allen (2001c) attributed the increased milk protein concentration and yield observed in these two studies to the greater microbial N production of cows on the *bm3* treatments.

Block et al. (1981) observed decreases in milk fat concentration of 8.9% for cows fed *bm3* corn silage diets compared with isogenic normal fed cows. The *bm3* corn silage in this study was lower in NDF concentration compared with the normal corn silage and the diets were balanced for the same forage to concentrate ratio rather than for NDF concentration. It is possible that the lower milk fat concentrations observed for by Block et al. (1981) was due to lower NDF dietary concentrations for the *bm3* treatments.

Oba and Allen (2000a) observed lower milk fat concentrations for cows fed *bm3* corn silage diets compared with isogenic normal corn silage diets at low (29%) but not high (38%) NDF concentrations. Two concentrations of dietary NDF with *bm3* and normal corn silage hybrids were fed to lactating cows in a 4 x 4 Latin square design with a 2 x 2 factorial arrangement of treatments. Milk fat concentration was depressed greatly for the *bm3* treatment compared with normal treatment for the low NDF concentration diets (3.28 vs. 3.67%) but not for the high NDF concentration diets (3.86 vs. 3.90%). However, milk fat yield was similar among treatments (1.24 kg/d). The milk fat depression observed for the *bm3* treatment in the low NDF concentration diet was hypothesized by the authors to be a dilution effect resulting from a greater rate of milk fluid synthesis relative to milk fat synthesis.

Ruminal pH. In the five studies that reported ruminal pH values when feeding *bm3* and isogenic corn silage-based diets to lactating dairy cows, four of the studies noted decreases in ruminal pH for *bm3* corn silage fed cows. Oba and Allen (2000b) observed depressed ruminal pH values for *bm3* corn silage fed cows compared with isogenic normal corn silage fed cows (5.68 vs. 5.84) although chewing activity and OM truly fermented in the rumen were similar between treatments. Similarly, Greenfield et al. (2001), Frenchick et al. (1976) and Block et al. (1981) observed lower ruminal pH values for *bm3* treatment cows compared with isogenic normal treatment cows by 0.11, 0.18 and 0.52 pH units, respectively.

In an attempt to explain ruminal pH value differences by salivary buffering capacity without measuring saliva flow to the rumen directly, Oba and Allen (2000b) measured chewing activity because of the expected relationship between saliva production and total chewing time. However, because chewing activity and OM truly fermented in the rumen were similar between the *bm3* and normal corn silage treatments in their study no explanation for the depressed ruminal pH was evident. The authors speculated that factors other than chewing time, which affect rate of absorption and passage along with the neutralization of fermentation acids, may explain the decreased ruminal pH with the *bm3* corn silage diets.

SUMMARY

Several short-term studies have evaluated the effects *bm3* corn silage-based diets on lactational performance of dairy cows, however, the results from these studies have been inconsistent. Increases in milk production of 1.6 kg/d (Keith et al., 1979), 2.8 kg/d (Oba and Allen, 1999a) and 3.5 kg/d (Oba and Allen, 2000a) were observed for cows fed *bm3* corn silage-based diets when compared with cows fed isogenic normal corn silage-based diets. Others comparing cows fed *bm3* and isogenic normal corn silage-based diets have observed no milk production differences (Rook et al., 1977; Sommerfeldt et al., 1979; Stallings et al., 1982). The varied responses observed could be because of the different stages of lactation of the cows in these studies.

Negative energy balance in early lactation occurs because energy intake lags behind the energy demands of milk production. The reasons for this are unknown but might be because feed intake is limited by physical fill in early lactation. The filling effects of a diet are affected primarily by NDF concentration and its digestibility. Brown midrib-3 corn silage is expected to increase feed intake when it is limited by fill because of its greater NDF digestibility relative to corn silage hybrids not containing *bm* mutations. The hypothesis for this experiment is that *bm3* corn silage based-diets will increase milk yield of cows compared with normal corn silage and that the response will be greater in early lactation compared with late lactation. Therefore, the objective of the experiment reported herein is to evaluate milk production responses of lactating cows fed *bm3* corn silage-based diets throughout a complete lactation.

MATERIALS AND METHODS

Experimental Treatments, Design, Diets and Cows

This experiment was conducted at the Michigan State University dairy facility at the Kellogg Biological Station in Hickory Corners, Michigan. The All-University Committee on Animal Use and Care of Michigan State University approved the animal care protocol (approval number 02/98-033-00). The experiment began on May 16, 1998 and ended on November 11, 1999.

Corn Hybrids Compared. The two corn hybrids used for the experiment were Cargill F657 (*bm3*) and Cargill 6208FQ (isogenic normal control). Each hybrid was planted, harvested and stored in 1997 (Year 1) and 1998 (Year 2). The normal hybrid was planted in Year 1 from 04/23/97 through 04/25/97 and again on 04/28/97. The *bm3* hybrid was planted in Year 1 on 04/24/97 and 04/28/97. The normal hybrid in Year 2 was planted on 04/24/98, 04/30/98 and 05/06/98. The *bm3* hybrid in Year 2 was planted on 05/06/97 and 05/07/97.

Harvest in 1997 and 1998 was initiated for each hybrid at approximately 30% whole plant DM. The *bm3* hybrid in Year 1 was harvested from 10/07/97 through 10/11/97 and the normal hybrid was harvested from 09/30/97 through 10/02/97 and from 10/06/97 through 10/07/97. Both the *bm3* and normal hybrids were harvested from 08/29/98 through 09/02/98 and from 09/07/98 through 09/09/98 in Year 2. The theoretical length of chop was one-half inch for each hybrid in both years. The chopped whole plant corn of each hybrid was stored separately in both concrete bunker silos and 2.5-m silage bags (150 tons, Ag Bag®, Ag-Bag International, LTD., Warrenton, OR) in both Year 1 and Year 2.

Storage of each corn hybrid in silage bags was necessary to allow the bunker silos to be available for filling the following fall of each respective harvest year. This also ensured that enough silage was available for the experiment, and that silage available for feeding was well fermented.

Design. A randomized complete block design was utilized with 80 Holstein cows. Cows were blocked on their actual calving day by parity (multiparous or primiparous), previous experimental treatment, and calving date. Of the 80 cows blocked, 50 were multiparous and 30 were primiparous. Prior to being utilized for this experiment each cow was a test subject in an experiment about dietary cation-anion difference (**DCAD**) pre-partum. There were a total of five DCAD diets before calving, and each cow was assigned randomly to only one of the diets. The DCAD diets were fed starting approximately 21 d before each cow's anticipated calving date and feeding of DCAD diets was terminated at calving.

Within 24 h of calving, cows within a block were assigned randomly to one of the two treatment diets (Appendix). Treatments were diets containing *bm3* or isogenic normal corn silages. Termination of treatment diets occurred when a cow had a milk yield of less than 13.6 kg/d for a 7 d average, was approximately 60 d from anticipated calving date or because a cow was in poor health. The experiment was considered complete when all cows had reached a minimum of 305 DIM.

Diets. Two diets with conceptually different nutrient densities were utilized for each treatment for this experiment (Table 1). The diet each cow received at calving and until at least 84±3 DIM was balanced for 30% NDF and 18% CP. This high nutrient dense (**HND**) diet consisted of the respective treatment corn silage (67% of forage DM), alfalfa silage (33% of forage DM), dry ground corn, high moisture corn, a protein, mineral and vitamin supplement, whole-linted cottonseed and a salt mix. Cows remained on their respective corn silage treatment but were switched to a low nutrient dense (**LND**) diet after 84±3 DIM if their BCS exceeded 3.0 (Wildman et al, 1982; on the five-point scale where 1 = thin to 5 = fat) and their milk production dropped below 31.8 kg/d for a multiparous cow or 24.5 kg/d for a primiparous cow. If poor health and/or environmental factors (e.g., hot weather, high humidity, etc.) were suspected to have decreased a cow's milk production below the LND criteria then the cow was not switched to the LND diet. The LND diets were balanced for the maximum concentration of NDF possible utilizing the treatment hybrid with the lowest fiber concentration, and were formulated to 17% CP. Ingredients used for the LND were the respective treatment corn silage (67% of forage DM), alfalfa silage (33% of forage DM), a protein, mineral and vitamin supplement, a salt mix and dry ground shelled corn if adjustment of dietary NDF% was needed.

The *bm3* and normal HND diets were simultaneously adjusted 20 times throughout the trial with each diet lasting an average of 20 d before the following diet adjustment. Brown midrib-3 corn silage and alfalfa silage accounted for 41.6 and 20.8%, respectively, of the *bm3* HND diet (DM basis). Normal corn silage and alfalfa silage accounted for 40.4 and 20.2%, respectively, of the normal HND diet (DM basis).

Cows. Cows were housed in a free-stall barn separated into pens by treatment (*bm3* or normal) and diet (HND or LND). Because of limited space availability, some non-experimental cows were co-mingled with experimental cows. The stalls of each free-stall pen had rubber-filled mattress bases and were bedded with wood shavings. The aisles within each pen were cleaned once daily of manure, urine and dirty bedding. Two small free-stall pens at the east end of the facility were used to house cows at the beginning of the experiment when few cows were on treatment. As more cows began the experiment the two groups of HND cows were housed in larger pens at the west end of the facility. The two smaller pens at the east end of the facility were then used for the LND cows when it became necessary.

Cows had continuous access to their respective treatment diets with the following exceptions: during milkings (3x/d), during BW measurements, during herd health checks and between orts removal (1x/d) and feeding (1x/d). Fresh water was continuously available to all cows with the following exceptions: during milkings, during BW measurements and during herd health checks.

Experimental Procedures

All treatment diets were mixed each morning using a model 3300 Knight mixer wagon. Cows were fed once per day following the mixing of each diet. Groups were fed at 110% of the expected intake. Samples of each TMR and individual diet ingredients were sampled each Monday and frozen immediately. A second sample of both treatment corn silages and the alfalfa silage was taken and frozen immediately. Orts for each treatment diet were sampled each Tuesday and frozen immediately. Frozen samples were thawed and composited by type every 2 wk on a Friday. Composited samples were dried in a 55° C forced-air oven for at least 48 h and DM concentrations were determined. Samples were ground (6 mm screen) with a Wiley® Mill, sub-sampled (approximately 30 g) and subsequently ground through a 1 mm screen. Forage samples were analyzed for NDF (Van Soest et al, 1991; method A) and CP (Hach et al, 1987) concentrations. Rations were adjusted if the NDF concentrations of forages increased dietary NDF greater than one percentage unit from the target NDF value of 30% for HND diets or if treatment diets were divergent greater than one percentage unit. Rations were always adjusted when a silage bag or bunker were newly opened. Post-trial end corn silage samples were analyzed for IVNDFD and IVTDMD with a 30 h incubation time (Goering and Van Soest, 1970).

The second sample of each corn silage treatment and the alfalfa silage were thawed every other Friday, composited by type and re-frozen. These samples were analyzed for fermentation acid and toluene DM (AOAC, 1990) concentrations as well as pH post-trial end.

For analysis of VFA and lactate concentrations in the forages, 15 g of each sample and 150 ml of de-ionized water was weighed into a 250 ml Sorvall® brand stainless steel container. The samples were mixed at setting three for one min using a Sorvall® Omni-mixer (model 17150). Samples were strained through two layers of two-ply cheesecloth and pH was determined immediately using an

Orion Research® Expandable ionAnalyzer (model EA 940). Five ml aliquouts of each sample were centrifuged at 26,000 x *g* for 15 min, and supernatant (600 μl) was mixed with 600 μl $Ca(OH)_2$ and 300 μl of $CuSO_4$ containing crotonic acid as an internal standard in 1.7 ml microcentrifuge tubes and frozen. Samples were thawed, centrifuged at 12,000 x *g* for 10 min, and supernatant (1000 μl) was taken and mixed with 28 μl of H_2SO_4 in 1.5 ml microcentrifuge tubes. Samples were frozen and thawed twice, and centrifuged at 12,000 x *g* for 10 min to precipitate and remove protein thoroughly. Supernatant was transferred to HPLC vials. Concentrations of VFA and lactate were determined by HPLC as described by Dado and Allen (1995).

Alfalfa silage and both the *bm3* and normal corn silages were sampled each Monday for particle size evaluation. Determination of particle size was performed on fresh samples using the Penn State Particle Size separator (Lammers et al., 1996).

The same person throughout the experiment scored cows within 21 d before their anticipated calving date for body condition each Friday of the experiment. Cows that calved since the previous Friday also were scored. The BCS that was closest to each cow's actual calving date was designated as the initial BCS on experiment. Body condition scores were determined on Friday of each week. The first scheduled BCS was determined at 14±3 DIM for each cow. The second scheduled BCS was determined at 28±3 DIM for each cow. Thereafter, the BCS of each cow was determined every 28±3 DIM throughout the experiment. The last BCS was assigned for each cow at the end of treatment.

Body weights were measured within 48 h post calving. All other scheduled BW measurements were measured on Friday of each week during the experiment. The first scheduled BW measurement was at 14±3 DIM for each cow. The second scheduled BW measurement was at 28±3 DIM for each cow. Thereafter, the BW measurement of each cow was every 28±3 DIM throughout the experiment. The last BW measurement was at the end of treatment for each cow. Cows were weighed using a stationary electronic floor scale that was calibrated prior to the experiment and approximately every three months, thereafter, during the experiment. A lightning storm on 06/25/98 disabled the electronic scale until it was repaired on 08/07/98. All initial and scheduled BW measurements during this time period were missed.

Cows were milked three times per day at approximately 0500 (Milking 1), 1230 (Milking 2) and 1900 h (Milking 3) in a six by six herringbone style parlor. Milk yield data was collected both manually and electronically. The primary source of milk yield data were the manually recorded values. Electronically captured milk yields were used only when manually recorded data were missed. Headgates in each freestall pen were closed prior to moving cows to the milking parlor, thus prohibiting the consumption of the incorrect treatment diets. From the beginning of the experiment (May 16, 1998) through March 8, 1999 the milking parlor was operated using Boumatic parlor equipment and electronics for data capture to computer. On March 9, 1999 the parlor was renovated using Surge brand equipment and electronics for data capture to computer.

Milk samples for composition were taken approximately once every 28 d by a Michigan Dairy Herd Improvement Association (DHIA) technician. Samples were composited in equal amounts across all three milkings for each cow. These samples were sent to Michigan DHIA for analysis of milk fat and milk protein concentrations by infrared spectroscopy along with somatic cell count. Calculations used to determine SCM yield, solids-not fat (**SNF**) concentration (Tyrell and Reid, 1965) and 3.5% FCM yield (NRC, 1989) are as follows:

SCM, kg/d = (12.3)(fat, kg) + (6.56)(SNF, kg) - (0.0752)(milk, kg)

where SNF, kg =

[(%milk protein + %milk lactose + %milk ash)/100] (milk, kg)

3.5% FCM, kg/d = (milk, kg)(0.43 + (0.162)(%milk fat))

For determination of SCM yield, milk lactose and milk ash concentrations were assumed to be 4.9 and 0.7%, respectively.

Statistical Analyses

Statistical analysis of milk production, BCS and BW data was based on a fourth order polynomial of DIM including cow-specific random regression curves for each given variable. If any of the polynomial by time terms was significant ($P \leq 0.05$), treatment by time interaction was indicated. Data were analyzed using the Proc Mixed procedure of SAS (SAS, 1999) according to the following model:

Y_{ijklmn} = $diet_i$ + $silyr_j$ + $tdate(silyr_j)$ + $pretrt_k$ + trt_l + cow_m + $morp_n$ + $block(morp_n)$ + dim1 + dim2 + dim3 + dim4 + $pretrt_k$*trt_l + $pretrt_k$*$morp_n$ + $pretrt_k$*$block(morp_n)$ + trt_l*$morp_n$ + trt_l*$block(morp_n)$ + trt_l*dim1 + trt_l*dim2 +

$trt_l*dim3 + trt_l*dim4 + cow_m*dim1 + cow_m*dim2 + morp_n*dim1 + morp_n*dim2 +$

$morp_n*dim3 + morp_n*dim4 + trt_l*morp_n*dim1 + trt_l*morp_n*dim2 + trt_l*morp_n*dim3$

$+ trt_l*morp_n*dim4 + e_{ijklmn}$

where:

Y_{ijklmn}	= response variable
$diet_i$	= fixed effect of diet
$silyr_j$	= fixed effect of silage year
$tdate(silyr_j)$	= fixed effect of milk test date nested within silage year
$pretrt_k$	= fixed effect of pre-experimental diet
trt_l	= fixed effect of treatment assignment
cow_m	= random effect of cow
$morp_n$	= fixed effect of parity
$block(morp_n)$	= fixed effect of block nested within parity
dim1	= effect of DIM
dim2	= quadratic effect of DIM
dim3	= cubic effect of DIM
dim4	= quartic effect of DIM
$pretrt_k*trt_l$	= effect of interaction of $pretrt_k$ and trt_l
$pretrt_k*morp_n$	= effect of interaction of $pretrt_k$ and $morp_n$
$pretrt_k*block(morp_n)$	= effect of interaction of $pretrt_k$ and $block(morp_n)$
trt_l*morp_n	= effect of interaction of trt_l and $morp_n$
$trt_l*block(morp_n)$	= effect of interaction of trt_l and $block(morp_n)$
trt_l*dim1	= effect of interaction of trt_l and dim1
trt_l*dim2	= effect of interaction of trt_l and dim2
trt_l*dim3	= effect of interaction of trt_l and dim3
trt_l*dim4	= effect of interaction of trt_l and dim4
cow_m*dim1	= effect of interaction of cow_m and dim1
cow_m*dim2	= effect of interaction of cow_m and dim2
$morp_n*dim1$	= effect of interaction of $morp_n$ and dim1
$morp_n*dim2$	= effect of interaction of $morp_n$ and dim2

$morp_n$*dim3	= effect of interaction of $morp_n$ and dim3
$morp_n$*dim4	= effect of interaction of $morp_n$ and dim4
trt_l*$morp_n$*dim1	= effect of interaction of trt_l and $morp_n$ and dim1
trt_l*$morp_n$*dim2	= effect of interaction of trt_l and $morp_n$ and dim2
trt_l*$morp_n$*dim3	= effect of interaction of trt_l and $morp_n$ and dim3
trt_l*$morp_n$*dim4	= effect of interaction of trt_l and $morp_n$ and dim4
e_{ijklmn}	= residual, assumed normally distributed.

If a significant treatment by time or treatment by time by parity interaction was observed for a given variable then cumulative differences of treatments were estimated by deriving contrast coefficients for the following time periods: 0 to 50 DIM, 50 to 150 DIM and 150 to 300 DIM. Significance for interactions was determined at $P < 0.10$. The estimated cumulative treatment differences were calculated by contrasts based on the area under the lactation curve using integral calculus for each time period. Also, differences of least squares mean estimates between treatments for variables with significant treatment by time or treatment by time by parity interactions at 25 d intervals through 300 DIM were analyzed. Both the cumulative treatment and the 25 d interval treatment differences were analyzed using the following model:

$Y_{ijklmn} = diet_i + silyr_j + pretrt_k + trt_l + cow_m + morp_n + block(morp_n) + pretrt_k*trt_l + pretrt_k*morp_n + pretrt_k*block(morp_n) + trt_l*morp_n + trt_l*block(morp_n) + e_{ijklmn}$

All data comparing the chemical analyses of the treatment corn silages were analyzed by t-test procedure of JMP (version 4, SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Nutrient Composition

The nutrient compositions of the treatment corn silages are shown in Table 2. Dry matter percentages, based on 55° C oven-dried samples, were similar between the treatment corn silages (33.4%); but DM percentage by toluene distillation was 2.4 percentage units lower ($P < 0.01$) for the *bm3* corn silage compared with the normal corn silage (31.4 and 33.8%, respectively). The reason for this discrepancy is not known.

Neutral detergent fiber and starch concentrations, as a percentage of DM, were similar for the two treatment corn silages (39.9 and 30.6%, respectively). Acid detergent fiber concentration was 1.3 percentage units lower ($P < 0.01$) for *bm3* corn silage compared with normal corn silage (22.7 and 24.0%, respectively). Crude protein concentration was higher ($P < 0.05$) by 0.4 percentage units for *bm3* corn silage compared with normal corn silage. Both lignin concentration and lignin as a percentage of NDF were lower for *bm3* corn silage compared with normal corn silage ($P < 0.001$). The lower concentration of ADF for the *bm3* corn silage is attributed partially to the lower concentration of lignin, which is a component of ADF. *In vitro* true DM digestibility and IVNDFD were greater ($P < 0.001$) for *bm3* corn silage compared with normal corn silage (85.4 vs. 79.4% and 63.1 vs. 48.8%, respectively).

Particle size distribution was similar for both treatment silages. The top, middle, and bottom screens of the Penn State Particle Size Separator retained 11.0, 74.9 and 14.2% of the treatment silage samples as a percentage of wet sample weight.

Acetic acid concentration, as a percent of silage DM, was greater (P = 0.001) for *bm3* corn silage compared with the normal corn silage (2.18 vs. 1.69%). However, lactic acid and propionic acid concentrations were similar between the treatment silages (Table 2). The silage pH also was similar averaging 3.8 for both silages.

Milk Yield, Milk Components, BW and BCS

Treatment effects on milk yield, BCS and BW are in Table 3 for the first 300 DIM. Cows fed *bm3* or normal corn silage based-diets had similar milk yields from 0 to 300 DIM (9111 kg), but there was a treatment by time interaction (P < 0.01). At 75 and 100 DIM the *bm3* corn silage treatment resulted in 6.2 and 4.9% greater milk yield, respectively, than the normal corn silage treatment (Table 4; Figure 1). There also was a tendency (P = 0.09) for the *bm3* treatment to increase milk yield at 50 DIM by 5.1% compared with the normal treatment. Milk yields were similar for all 25 d interval comparisons before 50 DIM and after 100 DIM. When analyzed by stage of lactation (Table 12), cows fed the *bm3* treatment tended (P = 0.06) to increase cumulative milk yield by 4.2% from 50 to 150 DIM compared with those fed the normal treatment (3421 vs. 3278 kg, respectively) but yields were similar from 0 to 50 DIM (1608 kg) and from 150 to 300 DIM (4153 kg).

Milk fat percentage was similar between treatments for the first 300 DIM and no interactions were detected. Milk fat yield was also similar between treatments for the first 300 DIM (313 kg), but there was a treatment by time interaction ($P < 0.05$). At 50, 75 and 100 DIM the *bm3* treatment had 8.5, 8.8 and 8.3% greater milk fat yield, respectively, than the normal treatment (Table 5; Figure 2). There was also a tendency ($P = 0.07$) for the *bm3* treatment to increase milk fat yield at 125 DIM by 6.1% compared with the normal treatment. Milk fat yields were similar for all 25 d interval comparisons before 50 DIM and after 125 DIM. When analyzed by stage of lactation (Table 13), milk fat yield increased from 50 to 150 DIM ($P = 0.02$) by 7.5% for the *bm3* treatment compared with the normal treatment (119.3 vs. 110.3 kg, respectively) but treatments were similar from 0 to 50 (65.5kg) and from 150 to 300 DIM (132.6 kg).

Cows fed *bm3* or normal corn silage diets had similar cumulative 3.5% FCM yields from 0 to 300 DIM (8932 kg), but there was a treatment by time interaction ($P < 0.01$). At 50, 75 and 100 DIM the *bm3* corn silage treatment resulted in 8.2, 8.1 and 7.0% greater 3.5% FCM yield, respectively, than the normal corn silage treatment (Table 6; Figure 3). There was also a tendency ($P = 0.10$) for the *bm3* treatment to increase 3.5% FCM yield at 125 DIM by 4.3% compared with the normal treatment. Yields of 3.5% FCM were similar for all 25 d interval comparisons before 50 DIM and after 125 DIM. When analyzed by stage of lactation (Table 14), the *bm3* treatment resulted in 6.2% greater ($P = 0.02$) cumulative 3.5% FCM yields from 50 to 150 DIM compared with the normal treatment (3410 vs. 3198 kg, respectively) but was similar from 0 to 50 DIM (1766 kg) and from 150 to 300 DIM (3862 kg).

The increased milk yields around peak lactation for cows fed *bm3* corn silage-based diets in the current study is supported by the findings of Oba and Allen (1999a). They observed that cows with the highest pre-trial milk production had the greatest response to a *bm3* corn silage-based diet compared with cows fed an isogenic normal corn silage-based diet; whereas, little benefit was observed in cows with lower pre-trial milk production fed the *bm3* corn silage-based diet. Peak milk production in dairy cows typically occurs between 28 to 74 d postpartum (Clark and Davis, 1980) so the observation that the *bm3* treatment began to increase milk yields at 50 DIM in the current study is not unexpected. Conversely, the lack of treatment differences in milk yield before 50 DIM and after 150 DIM is also reasonable.

Increased milk yields around peak lactation for cows fed *bm3* corn silage-based diets also have been observed in other studies comparing *bm3* and isogenic normal corn silages. Block et al. (1981) fed cows either *bm3* or normal corn silage-based diets from 18 to 74 DIM and found no differences in milk yield when analyzed cumulatively. However, when the data were analyzed as weekly averages, increased milk yields ($P < 0.05$) were observed for cows fed *bm3* at wk 5, 6 and 8 of the study, corresponding to 53, 60 and 74 DIM. Oba and Allen (2000a) fed *bm3* or normal corn silage-based diets to high producing (averaging 33.6 kg/d) dairy cows averaging 70 DIM at trial start and observed that cows on the *bm3* treatment had increased SCM yields compared with cows fed the normal treatment ($P < 0.05$).

If it is true that higher producing cows benefit more from *bm3* corn silage-based diets (Oba and Allen, 1999a), then the relative benefit a cow receives from consuming a *bm3* corn silage-based diet must be reduced as milk yield declines. Studies that compared cows fed *bm3* and isogenic normal corn silage-based diets without increases in milk yield used lower producing cows in later stages of lactation (Stallings et al., 1982; Tine et al., 2001; Greenfield et al., 2001).

The idea that physical fill limits intake of feedstuffs for dairy cattle in early lactation may, therefore, not be true because milk yield, or some other indicator of increased energy intake (i.e., BW gain or increased BCS), would logically be greater for cows fed *bm3* corn silage-based diets compared to cows fed normal corn silage-based diets. This is mainly because of increased NDF digestibility associated with *bm3* corn silage. Therefore, because higher producing cows benefit more from *bm3* corn silage-based diets (Oba and Allen, 1999a) it is possible that factors other than physical fill are limiting intake in early lactation and that physical fill is more limiting around peak lactation where increased milk yields (Oba and Allen, 1999a and Oba and Allen, 2000a) and BW gains (Rook et al., 1977 and Sommerfeldt et al., 1979) have been observed for *bm3* corn silage fed cows.

One study did observe increased milk yields for later lactation cows fed *bm3* corn silage but the diets may have favorably biased the *bm3* treatment. Keith et al. (1979) fed 12 Holstein cows past peak lactation (DIM not reported) *bm3* and isogenic normal corn silage-based diets at two F:C ratios (75:25 and 60:40) and observed increases ($P < 0.01$) in both milk and 3.5% FCM yields for the *bm3* corn silage-fed cows. However, the *bm3* corn silage was lower in NDF concentration (P < 0.05), but was included in the *bm3* diets at the same proportion as the isogenic corn silage in the normal diets. Also, the *bm3* corn silage analyzed higher in CP concentration and an increase in ground corn in the *bm3* diets was needed to offset increases in soybean meal additions to the normal corn silage-based diets to make the diets isonitrogenous. Both of these dietary differences could have biased the results in favor of the *bm3* diets by decreasing the NDF concentration of the rations. It has been observed that diets lower in fiber concentration can decrease the physical fill of the rumen possibly resulting in greater DMI and milk production (Dado and Allen, 1995).

A treatment by time by parity interaction was observed for milk protein concentration in the current study ($P = 0.05$). Primiparous cows fed the *bm3* corn silage treatment had greater milk protein concentration compared with primiparous cows fed the normal corn silage treatment at every 25 d interval from 25 to 300 DIM (Table 7; Figure 4). There was also a tendency ($P < 0.10$) for primiparous cows fed the *bm3* treatment to have greater milk protein concentration at 0 DIM compared with cows fed the normal corn silage treatment. Multiparous cows fed the *bm3* corn silage treatment had greater milk protein concentration compared with multiparous cows fed the normal corn silage treatment at 25 and 50 DIM (Table 7; Figure 5). There was also a tendency for cows fed the *bm3* corn silage treatment to have greater milk protein concentration at 75, 225 and 250 DIM compared with cows fed the normal corn silage treatment. Milk protein concentrations were similar between treatments for multiparous cows when compared at 0, 100, 125, 150, 175, 200, 275 and 300

DIM. When analyzed by stage of lactation, primiparous cows fed the *bm3* treatment had greater milk protein concentration from 0 to 50, 50 to 150 and 150 to 300 DIM compared with primiparous cows fed the normal treatment (Table 15). Multiparous cows fed the *bm3* treatment tended to have greater milk protein concentration from 0 to 50 DIM but similar milk protein concentration from 50 to 150 and 150 to 300 DIM when compared with cows fed the normal treatment (Table 16).

The increase in milk protein concentration observed in the current study supports the findings of others. Oba and Allen (1999a) observed increases in milk protein concentration for early- to mid-lactation cows fed *bm3* corn silage-based diets compared with cows fed isogenic normal corn silage-based diets. In a subsequent study, Oba and Allen (2000a) again observed greater milk protein concentration for early- to mid-lactation cows fed *bm3* corn silage-based diets compared with cows fed isogenic normal corn silage-based diets. Associated with the increased milk protein concentration, Oba and Allen (2000c) noted greater microbial nitrogen flow to the duodenum for cows fed *bm3* corn silage-based diets compared with cows fed normal corn silage-based diets. It is possible that cows fed *bm3* corn silage-based diets in the current study had increased milk protein concentrations because of an increase in microbial nitrogen flow (not measured).

A treatment by time by parity interaction was observed for milk protein yield in the current study ($P < 0.10$). Primiparous cows fed the *bm3* corn silage treatment had greater milk protein yield compared with primiparous cows fed the normal corn silage treatment at 75 DIM (Table 8; Figure 6). There was also a tendency for primiparous cows fed the *bm3* corn silage treatment to have greater milk protein yields at 50 and 100 DIM compared with primiparous cows fed the normal corn silage treatment. Yields of milk protein were similar for all 25 d interval comparisons before 50 DIM and after 100 DIM for primiparous cows. Multiparous cows fed the *bm3* corn silage treatment had greater milk protein yields compared with multiparous cows fed the normal corn silage treatment at 50, 75, 100 and 125 DIM (Table 8, Figure 7). Multiparous cows fed the normal corn silage treatment had a tendency for greater milk protein yield compared with multiparous cows fed the *bm3* corn silage treatment at 0 DIM ($P = 0.08$). Milk protein yields were similar between treatments for multiparous cows when compared at 25, 150, 175, 200, 225, 250, 275 and 300 DIM. When analyzed by stage of lactation, multiparous cows fed the *bm3* treatment had greater milk protein yield from 50 to 150 DIM compared with multiparous cows fed the normal treatment. Milk protein yields were similar between treatments from 50 to 150 and from 150 to 300 DIM for multiparous cows (Tables 17). There was a tendency ($P = 0.07$) for primiparous cows fed the *bm3* treatment to have a greater milk protein yield from 50 to 150 DIM but milk protein yields were similar between treatments for primiparous cows from 0 to 50 and 150 to 300 DIM.

Solids-corrected milk yields were similar between treatments from 0 to 300 DIM (8366 kg), but there was a treatment by time interaction ($P < 0.01$). At 50, 75 and 100 DIM the *bm3* corn silage treatment had 7.3, 8.6 and 7.2% greater SCM yield, respectively, than the normal corn silage treatment (Table 9; Figure

8). There was a tendency for cows on the *bm3* treatment to increase SCM yield at 125 DIM by 4.6% compared with cows on the normal treatment. Solids-corrected milk yields were similar for all 25 d interval comparisons before 50 DIM and after 125 DIM. When analyzed by stage of lactation (Table 19) SCM yield was greater from 50 to 150 DIM ($P < 0.01$) for cows fed the *bm3* treatment compared with those fed the normal treatment (3150 vs. 2948 kg, respectively) but were similar from 0 to 50 (1581 kg) and 150 to 300 DIM (3737 kg).

Cows fed *bm3* or normal corn silage diets had similar BW from 0 to 300 DIM (593 kg), but there was a treatment by time interaction ($P < 0.05$). However, no differences were observed when analyzed by 25 d intervals (Table 10; Figure 9) or stage of lactation (Table 20) between treatments for BW. Although treatment differences across time for BW were not detected with the parameters chosen to compare treatment by time interactions (25 d intervals at points in time along the BW polynomial curve and 0 to 50, 50 to 150 and 150 to 300 DIM cumulative differences along the BW polynomial curve), analysis of BW data defined by parameters with smaller increments (i.e., 10 d intervals) may detect treatment by time differences.

Shorter term studies by others have noted increases in BW changes for cows fed *bm3* corn silage-based diets with no concurrent increases in milk production (Rook et al., 1977; Sommerfeldt et al., 1979). Another study noted increases in both milk production and BW gains for *bm3* fed cows. Block et al. (1981) observed increases in BW change for cows fed a *bm3* corn silage-based diet from 18 to 74 DIM with increased milk production for the *bm3* fed cows only at 53, 60 and 74 DIM.

Cows fed *bm3* or normal corn silage diets had similar body condition scores from 0 to 300 DIM (2.43), but there was a tendency for a treatment by time interaction ($P < 0.10$). No differences in BCS due to treatments were observed when analyzed by 25 d intervals (Table 11; Figure 10) or stage of lactation (Table 21). As discussed with BW, treatment differences by time may be detectable for BCS data if analyzed by parameters smaller than 25 d intervals (e.g., 10 d interval comparisons).

The idea that milk yield in early lactation dairy cows is limited to less than optimal energy intake because of physical fill of the diet may not be true. Voluntary intake is regulated by many factors besides physical fill (Allen, 2000) and the degree to which each factor affects intake, and thus milk production, may change as energy status of the cow changes throughout a lactation. For instance, it has been suggested that intake in early lactation is controlled partially by an increase in *B*-oxidation of non-esterified fatty acids in the liver brought on by the mobilization of lipids from body fat reserves (Emery et al., 1992). In this case, body condition at calving may have more of an influence on voluntary DMI than physical characteristics of the diet consumed. Cows near peak lactation fed diets with higher NDF digestibility have greater increases in DMI and milk yield (Oba and Allen, 1999a; Oba and Allen, 2000a). Dry matter intake and milk yield in around peak lactation, thus, may be more influenced by physical fill than by other factors.

Influence of Diets on Production Data

Of the 80 cows that began this study, only ten cows met the criteria to switch to the LND diet prior to 300 DIM. Four cows on the *bm3* treatment and six cows on the normal treatment were switched to their respective LND diets, averaging 166 and 208 DIM at the time of switch for the *bm3* and normal treatments, respectively. The production data from this study were defined by 10,906, 10,501, 732, and 487 cow-days for the *bm3*-HND, normal-HND, *bm3*-LND and normal-LND diets, respectively. The HND diets of both treatments were assumed to have been more influential on the parameters measured in this experiment than the LND diets because of the relative difference of cow-days between diets HND and LND (averaging 10,704 vs. 610 cow-days, respectively).

Treatment vs. Pen Effects

Although cows were group-fed treatment diets during this experiment, inferences on the effects of *bm3* corn silage on the lactational performance of dairy cows were made using the cow as the experimental unit. However, treatment effects in this experiment are confounded with potential pen effects because cows on each treatment were housed in separate pens. A pen effect, however, is not expected because the two pens in which the cows were housed for the majority of the experiment were similar in location, size, number of cows per pen and design. Ideally this experiment would have been conducted with cows randomly assigned to individual stalls with a random allocation of treatments. The resources required for such an experiment were not available.

Therefore, the results of this experiment should be interpreted and applied in conjunction with results of other studies.

Summary

In this complete lactation experiment, cows fed *bm3* corn silage-based diets had greater cumulative milk, milk fat, 3.5% FCM and SCM yields from 50 to 150 DIM compared with cows fed isogenic normal corn silage-based diets. Yields of milk and milk fat were similar from 0 to 50 and from 150 to 300 DIM. Milk fat concentration was similar for both treatments throughout the study. Milk protein concentration and milk protein yield was dependent on treatment, DIM and parity. Specifically, primiparous cows on the *bm3* treatment had greater cumulative milk protein concentration from 0 to 50, 50 to 150 and 150 to 300 DIM compared with primiparous cows on the normal treatment. Multiparous cows on the *bm3* treatment had greater milk protein concentration compared with multiparous cows on the normal treatment, but only from 0 to 50 DIM. Primiparous and multiparous cows fed the *bm3* treatment had greater milk protein yields compared to primiparous and multiparous cows fed the normal treatment from 50 to 150 DIM but treatments were similar for both parities from 0 to 50 and from 150 to 300 DIM. Body weights and BCS were similar for both treatments throughout 300 d.

Conclusion and Implications

Cows benefited more from *bm3* corn silage-based diets during, and around, peak lactation by increasing milk yield and milk protein concentration without sacrificing body condition or milk fat concentration. The results from this experiment do not agree with the concept that cows in negative energy balance in early lactation would benefit most from *bm3* corn silage. This might be true if voluntary DMI was limited in early lactation by physical fill because the increased NDF digestibility of *bm3* corn silage would most likely increase ruminal NDF turnover. However, no study has yet to observe significant increases in voluntary DMI for cows fed *bm3* corn silage in early lactation but several studies have noted increases in voluntary DMI for cows near or past peak lactation (Rook et al., 1977; Tine et al., 2001; Block et al., 1981; Sommerfeldt et al., 1979; Oba and Allen, 1999a; Oba and Allen, 2000a). It is most likely that factors other than physical fill are limiting intake, and thus, milk yield, in very early lactation.

Hybrid seed corn with the brown midrib mutation is typically more than twice as expensive and lower yielding (an average of 9% lower in the current study) than conventional seed corn. Use of *bm3* corn silage might not be economically beneficial if it is fed to all cows in the herd. Targeting cows when they are most responsive by increasing milk yield will increase the economic benefit of *bm3* corn silage. Brown midrib-3 corn silage fed to cows around peak lactation may be most effective, whereas conventional corn silage might be fed to early and late lactation cows.

Table 1. Ingredient and nutrient composition of experimental diets.

	HND[1]		LND[2]	
	bm3[3]	Normal	*bm3*	Normal
	(% of DM)			
Ingredient				
bm3 corn silage	41.6	...	55.7	...
Normal corn silage	...	40.4	...	53.8
Alfalfa silage	20.8	20.2	31.5	31.2
Dry ground corn[4]	8.3	9.0	0.4	1.9
High moisture corn	8.3	8.9	...	...
Protein, mineral and vitamin supplement[5]	13.0	13.3	11.7	12.3
Whole linted cottonseed	7.4	7.4	...	...
Salt mix[6]	0.74	0.74	0.85	0.85
Nutrient				
DM[7]	41.7	42.1	35.4	36.5
NDF[7]	30.0	30.0	34.7	34.6
ADF[8]	20.0	20.0	23.4	23.3
CP[7]	17.9	18.0	17.0	17.0
NE_L[8], Mcal/kg	1.70	1.70	1.57	1.57
Ash[8]	6.7	6.7	7.6	7.5
Ca[8]	0.90	0.91	0.99	1.00
P[8]	0.44	0.44	0.41	0.42
Mg[8]	0.25	0.25	0.23	0.23
K[8]	1.55	1.53	1.85	1.81
Na[8]	0.18	0.18	0.18	0.19
Cl[8]	0.36	0.36	0.41	0.41
S[8]	0.19	0.19	0.18	0.18
Cu[8], mg/kg	16.74	16.99	16.95	17.43
Fe[8], mg/kg	212	211	247	247
Mn[8], mg/kg	76.1	76.9	80.2	81.8
Zn[8], mg/kg	66.9	67.9	67.5	69.5

[1]High nutrient density diet.
[2]Low nutrient density diet.
[3]Brown midrib mutant for corn.
[4]Dry ground corn was used to maintain similar dietary NDF concentrations between LND treatments.
[5]Protein, mineral and vitamin supplement was a contract mix with the following profile as a percentage of DM: 1.88 Mcal/kg NE_L, 51.6% CP, 42.0% undegradable protein, 3.48% Ca, 0.59% P, 0.54% Mg, 1.98% K, 0.52% Na, 0.82% Cl and 0.46% S,
[6]Salt mix formulated for the following profile as a percentage of DM: 12.53% Ca, 13.9% P, 12.2% Na, 18.9% Cl, 6.3 ppm Co and 9042 ppm Fe.
[7]From laboratory analysis.
[8]From diet formulation and nutrient compositions of individual ingredients from NRC (1989).

Table 2. Nutrient composition of corn silages used throughout the experiment.

Item	*bm3*[1]	Normal	SE	*P*
DM% (oven-dried at 55°C)	33.0	33.7	0.59	0.22
DM% (toluene distillation)	31.4	33.8	0.77	0.003
	(% of DM)			
NDF	39.5	40.3	0.59	0.16
ADF	22.7	24.0	0.40	0.002
Lignin	1.8	2.8	0.14	<0.001
Lignin, % of NDF	4.5	7.0	0.31	<0.001
CP	8.6	8.2	0.18	0.025
Ash	4.2	4.1	0.14	0.65
Starch	30.6	30.6	0.74	0.92
IV TDMD[2]	85.4	79.4	0.36	<0.001
IV NDFD, % of NDF[3]	63.1	48.8	0.72	<0.001
	bm3[1]	Normal	SE	*P*
Particle size[4], % of wet sample weight				
Top	11.02	10.90	0.73	0.87
Middle	74.32	75.40	0.69	0.12
Bottom	14.65	13.69	0.69	0.17
	bm3 [1]	Normal	SE	*P*
Fermentation Acids, % of DM				
Lactic Acid	5.27	5.86	0.39	0.14
Acetic Acid	2.18	1.69	0.15	0.001
Propionic Acid	0.30	0.23	0.05	0.17
pH	3.82	3.78	0.03	0.20

[1]Brown midrib 3 mutant for corn.
[2]IV TDMD = *In vitro* true DM digestibility estimated after 30 h incubation.
[3]IV NDFD = *In vitro* NDF digestibility estimated after 30 h incubation.
[4]Determined with Penn State Particle Size Separator.

Table 3. Estimates, standard errors and significance of effects of corn silage hybrids on milk yield for the first 300 d of lactation.

	Treatment			Effect[1]		
	bm3[2]	Normal	SE	H	H x T	H x T x P
Cumulative Yield, kg						
Milk	9165	9057	285	0.91	***	NS
Fat	322	304	12.5	0.28	**	NS
Protein	273	256	8.7	0.13	***	†
3.5% FCM	9116	8747	304	0.47	***	NS
SCM	8536	8196	271	0.45	***	NS
Milk composition, %						
Mean Fat	3.68	3.54	0.07	0.37	NS	NS
Mean Protein	3.07	2.92	0.05	0.02	NS	*
Mean BW, kg	588	597	12.5	0.92	**	NS
Mean BCS	2.38	2.47	0.10	0.80	†	NS

[1]H = Effect of hybrid type, H x T = interaction of hybrid type and time, and H x T x P = interaction of hybrid type, time and parity.
[2]Brown midrib 3 mutation for corn.
†$P < 0.10$
*$P = 0.05$
**$P < 0.05$
***$P < 0.01$

Table 4. Least square means, standard errors and significance of effects of corn silage hybrids on milk yield (kg/d) at 25 d intervals.

Days	Treatment			
In Milk	*bm3* [1]	Normal	SE	*P*
0	26.5	31.4	3.3	0.14
25	32.3	32.6	1.7	0.88
50	35.0	33.2	1.1	0.09
75	35.5	33.3	0.8	0.007
100	34.7	33.0	0.8	0.025
125	33.1	32.4	0.8	0.35
150	31.4	31.6	0.9	0.88
175	29.8	30.5	1.0	0.49
200	28.6	29.4	1.2	0.49
225	27.6	28.0	1.3	0.74
250	26.7	26.5	1.4	0.84
275	25.7	24.6	1.5	0.48
300	23.9	22.5	1.9	0.44

[1]Brown midrib 3 mutation for corn.

Table 5. Least square means, standard errors and significance of effects of corn silage hybrids on milk fat yield (kg/d) in 25 d intervals.

Days	Treatment			
In Milk	*bm3* [1]	Normal	SE	*P*
0	1.35	1.43	0.12	0.52
25	1.33	1.28	0.06	0.42
50	1.30	1.19	0.05	0.02
75	1.25	1.14	0.04	0.006
100	1.20	1.10	0.04	0.01
125	1.14	1.07	0.04	0.07
150	1.08	1.03	0.04	0.30
175	1.01	0.99	0.04	0.52
200	0.96	0.93	0.05	0.55
225	0.90	0.86	0.05	0.43
250	0.85	0.79	0.06	0.28
275	0.81	0.73	0.07	0.21
300	0.78	0.69	0.09	0.35

[1]Brown midrib 3 mutation for corn.

Table 6. Least square means, standard errors and significance of effects of corn silage hybrids on 3.5% fat-corrected milk yield (kg/d) at 25 d intervals.

Days	Treatment			
In Milk	*bm3* [1]	Normal	SE	*P*
0	33.7	36.8	3.1	0.33
25	35.9	35.0	1.6	0.57
50	36.4	33.7	1.1	0.02
75	35.7	32.8	1.0	0.003
100	34.4	32.0	0.9	0.009
125	32.6	31.2	0.9	0.10
150	30.8	30.1	1.0	0.49
175	29.0	28.8	1.1	0.85
200	27.4	27.3	1.2	0.90
225	26.0	25.5	1.3	0.69
250	24.8	23.6	1.5	0.43
275	23.5	21.7	1.7	0.28
300	22.0	19.9	2.3	0.37

[1]Brown midrib 3 mutation for corn.

TABLE 7. Least square means, standard errors and significance of effects of corn silage hybrids on milk protein concentration (%) at 25 d intervals by parity.

Days	Multiparous				Primiparous			
In Milk	*bm3*[1]	Normal	SE	*P*	*bm3*[1]	Normal	SE	*P*
0	3.07	3.04	0.11	0.77	2.97	2.73	0.14	0.08
25	2.91	2.80	0.05	0.05	2.83	2.65	0.07	0.01
50	2.85	2.72	0.05	0.01	2.79	2.63	0.07	0.02
75	2.87	2.76	0.06	0.06	2.83	2.67	0.08	0.04
100	2.92	2.84	0.06	0.17	2.90	2.73	0.08	0.04
125	2.99	2.93	0.06	0.33	2.99	2.79	0.09	0.03
150	3.06	3.01	0.07	0.42	3.07	2.86	0.09	0.02
175	3.12	3.06	0.07	0.36	3.14	2.92	0.09	0.01
200	3.17	3.09	0.06	0.21	3.19	2.97	0.09	0.01
225	3.21	3.11	0.06	<0.10	3.23	3.01	0.09	0.009
250	3.26	3.14	0.06	0.06	3.26	3.04	0.08	0.009
275	3.34	3.24	0.07	0.14	3.31	3.08	0.09	0.01
300	3.48	3.45	0.10	0.79	3.38	3.14	0.11	0.03

[1]Brown midrib 3 mutation for corn.

TABLE 8. Least square means, standard errors and significance of effects of corn silage hybrids on milk protein yield (kg/d) at 25 d intervals by parity.

Days	Multiparous				Primiparous			
In Milk	*bm3* [1]	Normal	SE	*P*	*bm3* [1]	Normal	SE	*P*
0	0.93	1.15	0.12	0.08	0.72	0.67	0.13	0.70
25	1.04	1.04	0.06	0.97	0.84	0.76	0.07	0.30
50	1.09	0.99	0.04	0.02	0.90	0.81	0.05	0.09
75	1.10	0.97	0.04	<0.001	0.93	0.84	0.05	0.05
100	1.07	0.97	0.03	<0.01	0.93	0.85	0.04	0.06
125	1.03	0.96	0.03	0.04	0.92	0.86	0.04	0.14
150	0.98	0.94	0.04	0.26	0.90	0.86	0.05	0.31
175	0.93	0.90	0.04	0.49	0.89	0.85	0.05	0.54
200	0.87	0.84	0.04	0.45	0.87	0.85	0.06	0.72
225	0.83	0.78	0.05	0.26	0.86	0.84	0.06	0.77
250	0.79	0.71	0.05	0.13	0.85	0.82	0.07	0.66
275	0.75	0.65	0.06	0.12	0.84	0.78	0.07	0.41
300	0.71	0.63	0.09	0.43	0.83	0.71	0.09	0.21

[1]Brown midrib 3 mutation for corn.

Table 9. Least square means, standard errors and significance of effects of corn silage hybrids on solids-corrected milk yield (kg/d) at 25 d intervals.

Days In Milk	Treatment *bm3*[1]	Treatment Normal	SE	*P*
0	29.3	33.1	3.1	0.22
25	31.9	31.4	1.6	0.76
50	32.9	30.5	1.0	0.016
75	32.7	29.9	0.7	0.0004
100	31.8	29.5	0.7	0.0017
125	30.4	29.0	0.8	0.07
150	29.0	28.3	0.9	0.47
175	27.6	27.4	1.0	0.86
200	26.3	26.1	1.1	0.88
225	25.2	24.6	1.2	0.65
250	24.2	23.0	1.4	0.37
275	23.3	21.4	1.5	0.20
300	22.1	20.0	1.8	0.26

[1]Brown midrib 3 mutation for corn.

Table 10. Least square means, standard errors and significance of effects of corn silage hybrids on body weight (kg) at 25 d intervals.

Days In Milk	Treatment *bm3*[1]	Treatment Normal	SE	*P*
0	609	628	34	0.22
25	576	591	29	0.25
50	563	573	29	0.40
75	562	569	28	0.60
100	568	572	28	0.79
125	577	579	28	0.89
150	586	587	28	0.89
175	592	596	28	0.78
200	597	603	28	0.59
225	600	611	29	0.41
250	604	619	30	0.28
275	614	631	32	0.24
300	635	651	38	0.34

[1]Brown midrib 3 mutation for corn.

Table 11. Least square means, standard errors and significance of effects of corn silage hybrids on body condition score at 25 d intervals.

Days	Treatment			
In Milk	*bm3* [1]	Normal	SE	*P*
0	3.10	3.22	0.14	0.43
25	2.66	2.78	0.12	0.32
50	2.42	2.52	0.11	0.38
75	2.31	2.38	0.11	0.53
100	2.28	2.32	0.10	0.70
125	2.29	2.32	0.10	0.81
150	2.31	2.33	0.10	0.80
175	2.32	2.37	0.10	0.65
200	2.32	2.40	0.10	0.44
225	2.30	2.42	0.11	0.27
250	2.29	2.45	0.12	0.17
275	2.32	2.50	0.13	0.16
300	2.42	2.59	0.16	0.32

[1]Brown midrib 3 mutation for corn.

Table 12. Estimates, standard errors and significance of effects of corn silage hybrids on cumulative milk yield (kg) by stage of lactation.

Stage of Lactation	Treatment			
(DIM)	*bm3* [1]	Normal	SE	*P*
0 - 50	1591	1625	90	0.70
50 - 150	3421	3278	75	0.06
150 - 300	4152	4153	182	1.00

[1]Brown midrib 3 mutation for corn.

Table 13. Estimates, standard errors and significance of effects of corn silage hybrids on cumulative milk fat yield (kg) by stage of lactation.

Stage of Lactation (DIM)	Treatment		SE	*P*
	bm3[1]	Normal		
0 - 50	66.4	64.5	3.32	0.56
50 - 150	119.3	110.3	3.67	0.02
150 - 300	136.4	128.7	7.75	0.32

[1]Brown midrib 3 mutation for corn.

Table 14. Estimates, standard errors and significance of effects of corn silage hybrids on cumulative 3.5% fat corrected milk yield (kg) by stage of lactation.

Stage of Lactation (DIM)	Treatment		SE	*P*
	bm3[1]	Normal		
0 - 50	1779	1753	83	0.75
50 - 150	3410	3198	86	0.02
150 - 300	3927	3796	196	0.50

[1]Brown midrib 3 mutation for corn.

Table 15. Estimates, standard errors and significance of effects of corn silage hybrids on weighted average milk protein concentration by stage of lactation for primiparous cows.

Stage of Lactation (DIM)	Treatment		SE	*P*
	bm3[1]	Normal		
0 - 50	2.85	2.66	0.07	0.01
50 - 150	2.91	2.73	0.08	0.03
150 - 300	3.23	3.00	0.08	0.009

[1]Brown midrib 3 mutation for corn.

Table 16. Estimates, standard errors and significance of effects of corn silage hybrids on weighted average milk protein concentration by stage of lactation for multiparous cows.

Stage of Lactation (DIM)	Treatment		SE	P
	bm3 [1]	Normal		
0 - 50	2.92	2.83	0.06	0.08
50 - 150	2.93	2.85	0.06	0.14
150 - 300	3.23	3.14	0.06	0.17

[1]Brown midrib 3 mutation for corn.

Table 17. Estimates, standard errors and significance of effects of corn silage hybrids on cumulative milk protein yield (kg) by stage of lactation for multiparous cows.

Stage of Lactation (DIM)	Treatment		SE	P
	bm3 [1]	Normal		
0 - 50	51.5	52.3	3.2	0.79
50 - 150	106.0	96.6	3.2	0.003
150 - 300	125.3	116.5	6.9	0.21

[1]Brown midrib 3 mutation for corn.

Table 18. Estimates, standard errors and significance of effects of corn silage hybrids on cumulative milk protein yield (kg) by stage of lactation for primiparous cows.

Stage of Lactation (DIM)	Treatment		SE	P
	bm3 [1]	Normal		
0 - 50	41.3	37.6	0.04	0.33
50 - 150	92.4	84.7	0.04	0.07
150 - 300	129.1	123.3	0.09	0.51

[1]Brown midrib 3 mutation for corn.

Table 19. Estimates, standard errors and significance of effects of corn silage hybrids on cumulative solids-corrected milk yield (kg) by stage of lactation.

Stage of Lactation (DIM)	Treatment			
	bm3 [1]	Normal	SE	*P*
0 - 50	1583	1578	84	0.95
50 - 150	3150	2948	71	0.0045
150 - 300	3803	3670	176	0.45

[1]Brown midrib 3 mutation for corn.

Table 20. Estimates, standard errors and significance of effects of corn silage hybrids on cumulative body weight (kg) by stage of lactation.

Stage of Lactation (DIM)	Treatment			
	bm3 [1]	Normal	SE	*P*
0 - 50	28,958	29,716	665	0.26
50 - 150	56,997	57,440	1,257	0.72
150 - 300	90,375	91,928	4,345	0.43

[1]Brown midrib 3 mutation for corn.

Table 21. Estimates, standard errors and significance of effects of corn silage hybrids on weighted average body condition score by stage of lactation.

Stage of Lactation (DIM)	Treatment			
	bm3 [1]	Normal	SE	*P*
0 - 50	2.70	2.81	.12	0.34
50 - 150	2.31	2.36	.10	0.64
150 - 300	2.32	2.43	.17	0.30

[1]Brown midrib 3 mutation for corn.

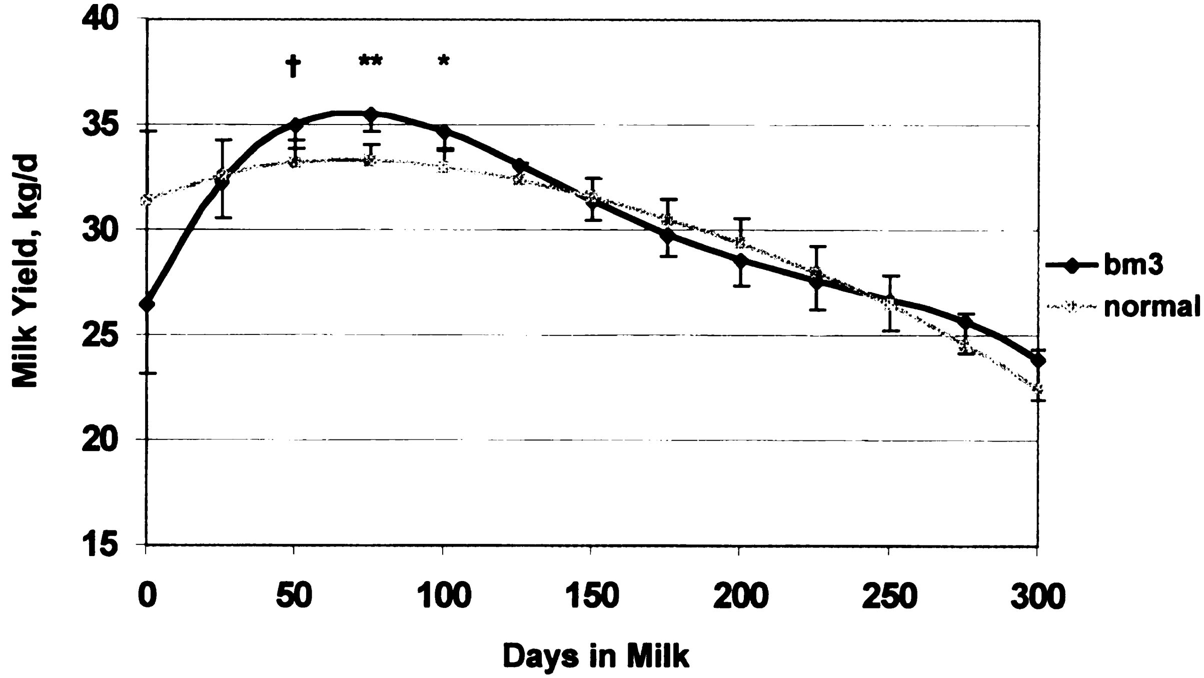

Figure 1. Least square mean estimates of effects of corn silage hybrid on milk yield (kg/d) at 25 d intervals. † $P < 0.10$; * $P < 0.05$; ** $P < 0.01$

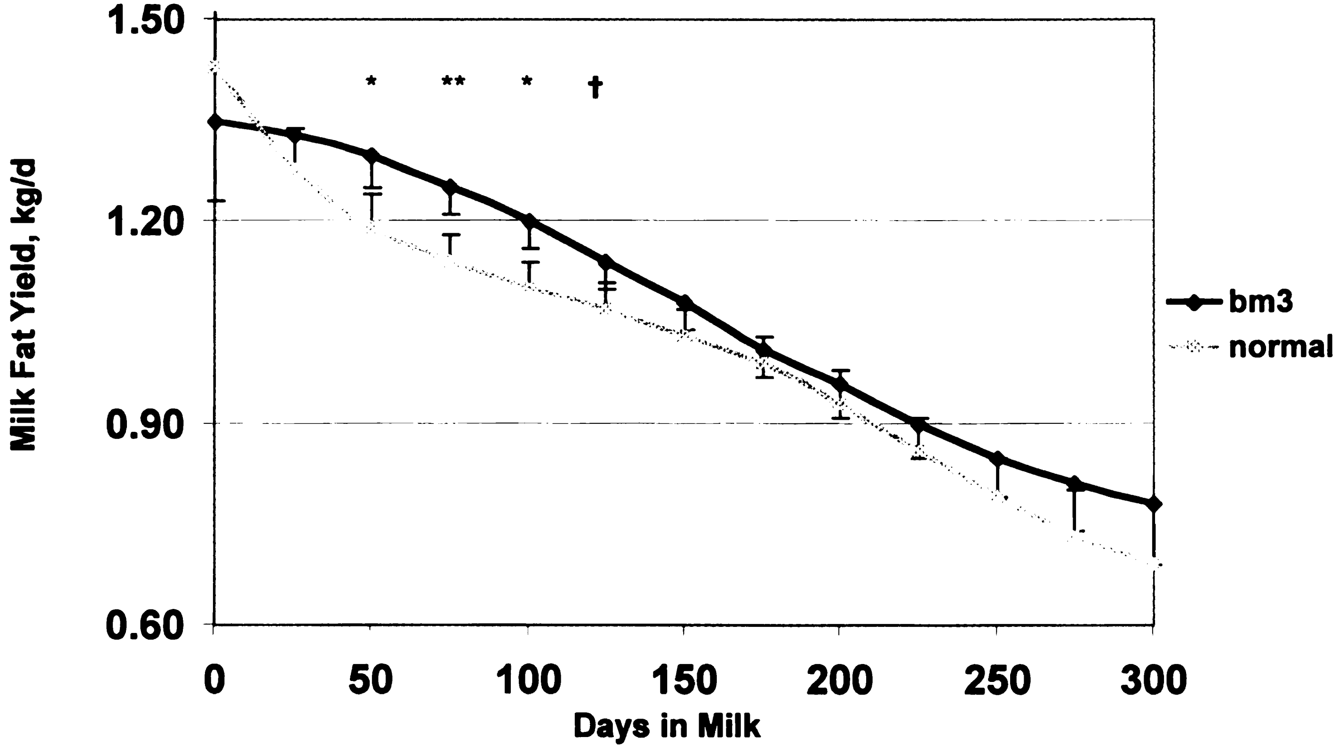

Figure 2. Least square mean estimates of effects of corn silage hybrid on milk fat yield (kg/d) at 25 d intervals. † $P < 0.10$; * $P < 0.05$; ** $P < 0.01$

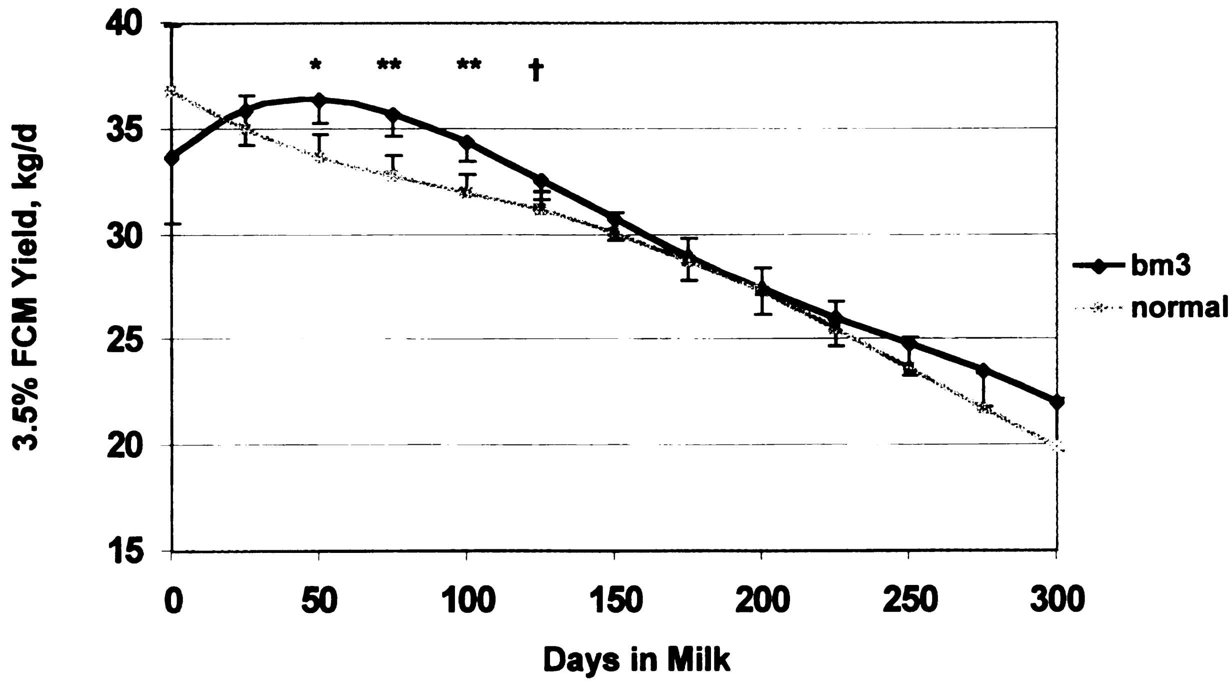

Figure 3. Least square mean estimates of effects of corn silage hybrid on 3.5% fat-corrected milk yield (kg/d) at 25 d intervals. † $P = 0.10$; * $P < 0.05$; ** $P < 0.01$

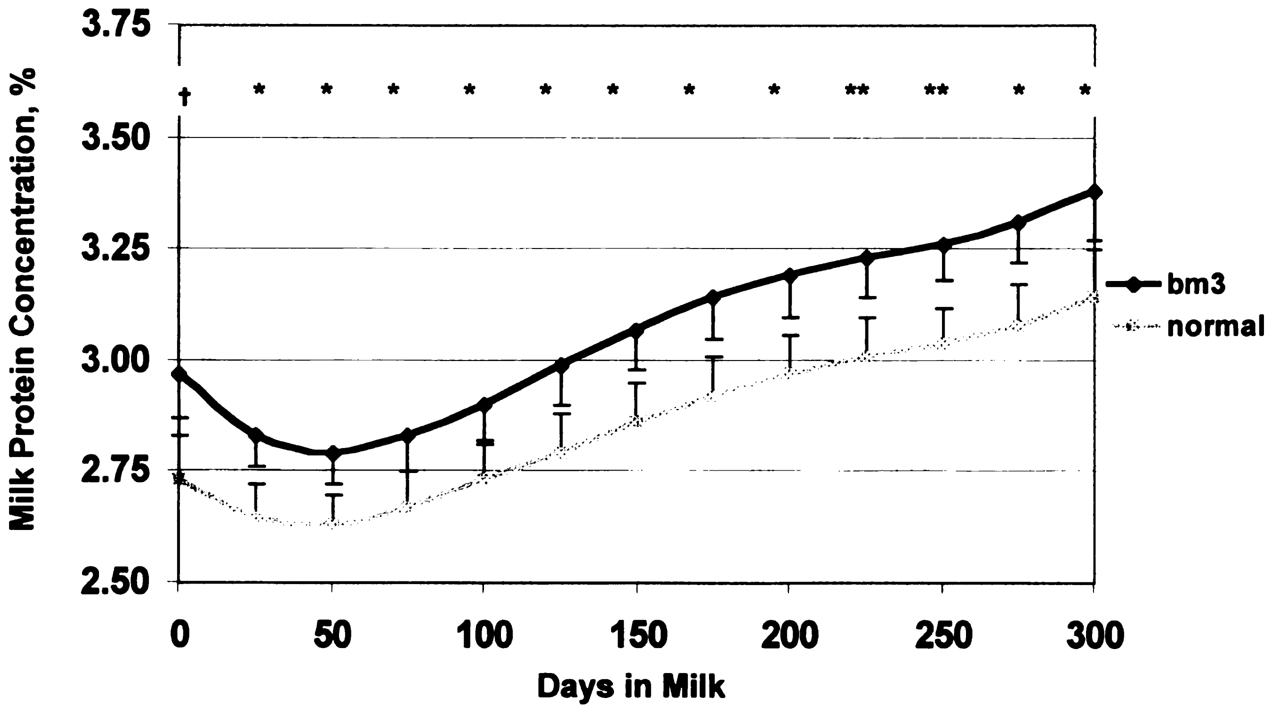

Figure 4. Least square mean estimates of effects of corn silage hybrid on milk protein concentration (%) at 25 d intervals for primiparous cows.
† $P < 0.10$; * $P < 0.05$; ** $P < 0.01$

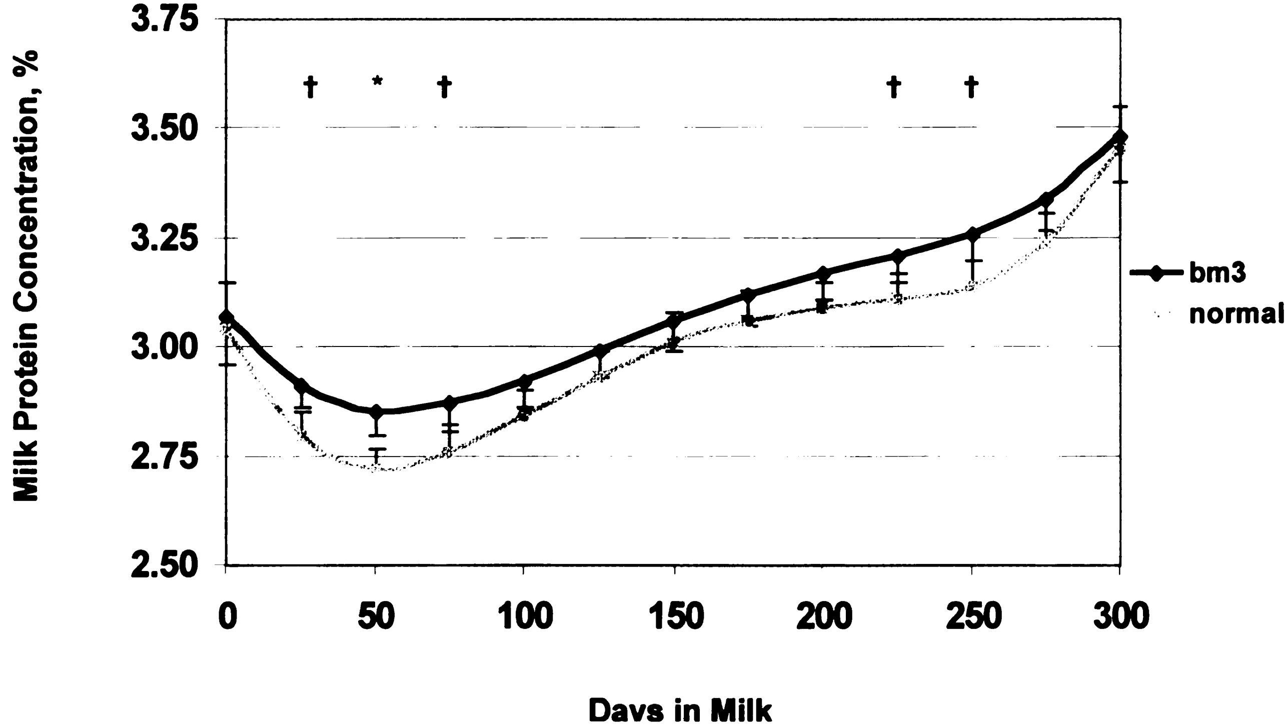

Figure 5. Least square mean estimates of effects of corn silage hybrid on milk protein concentration (%) at 25 d intervals for multiparous cows.
† $P < 0.10$; * $P < 0.05$

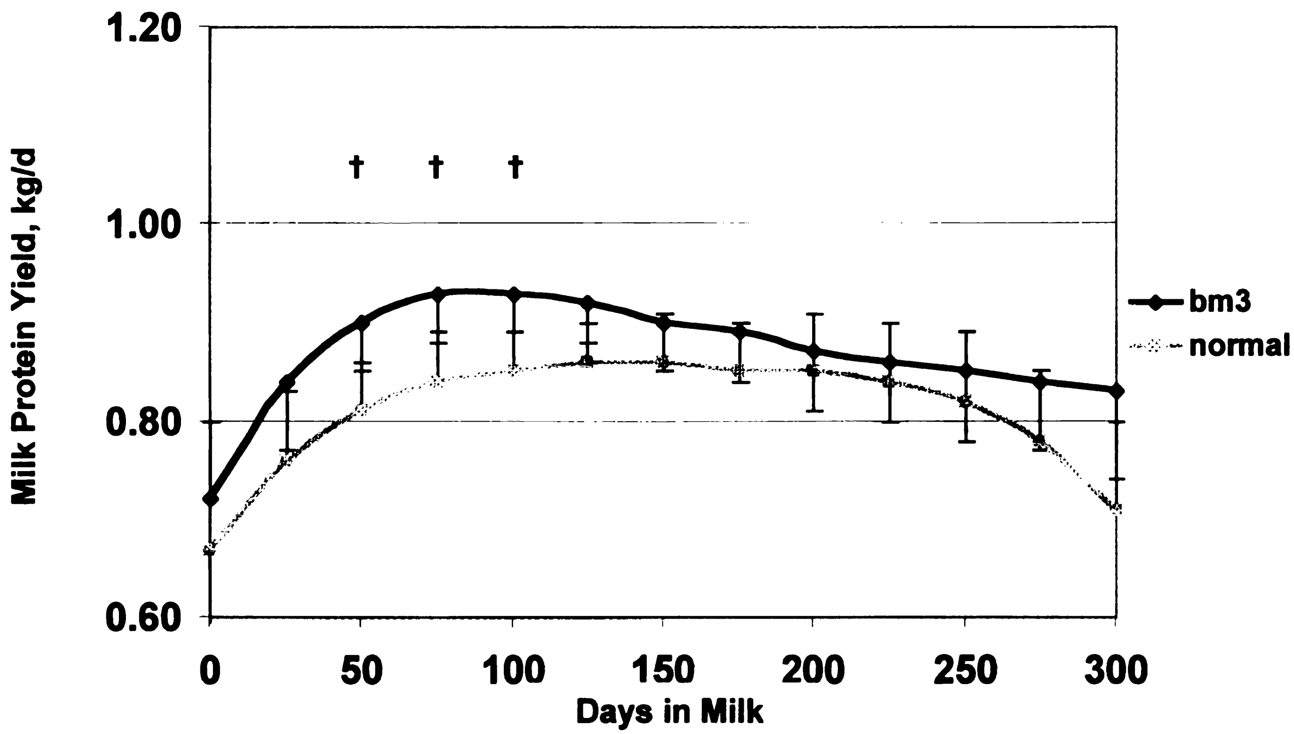

Figure 6. Least square mean estimates of effects of corn silage hybrid on milk protein yield (kg/d) at 25 d intervals for primiparous cows. † $P < 0.10$;

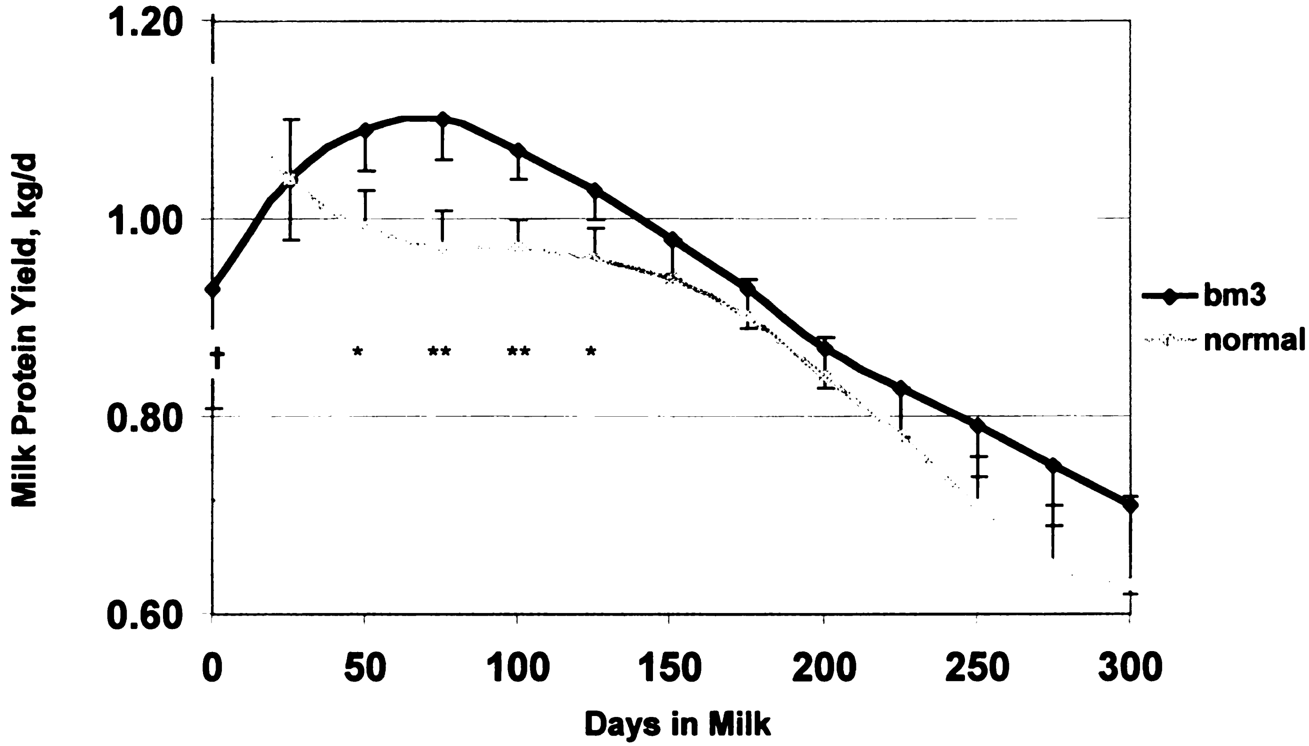

Figure 7. Least square mean estimates of effects of corn silage hybrid on milk protein yield (kg/d) at 25 d intervals for multiparous cows. † $P < 0.10$; * $P < 0.05$; ** $P < 0.01$

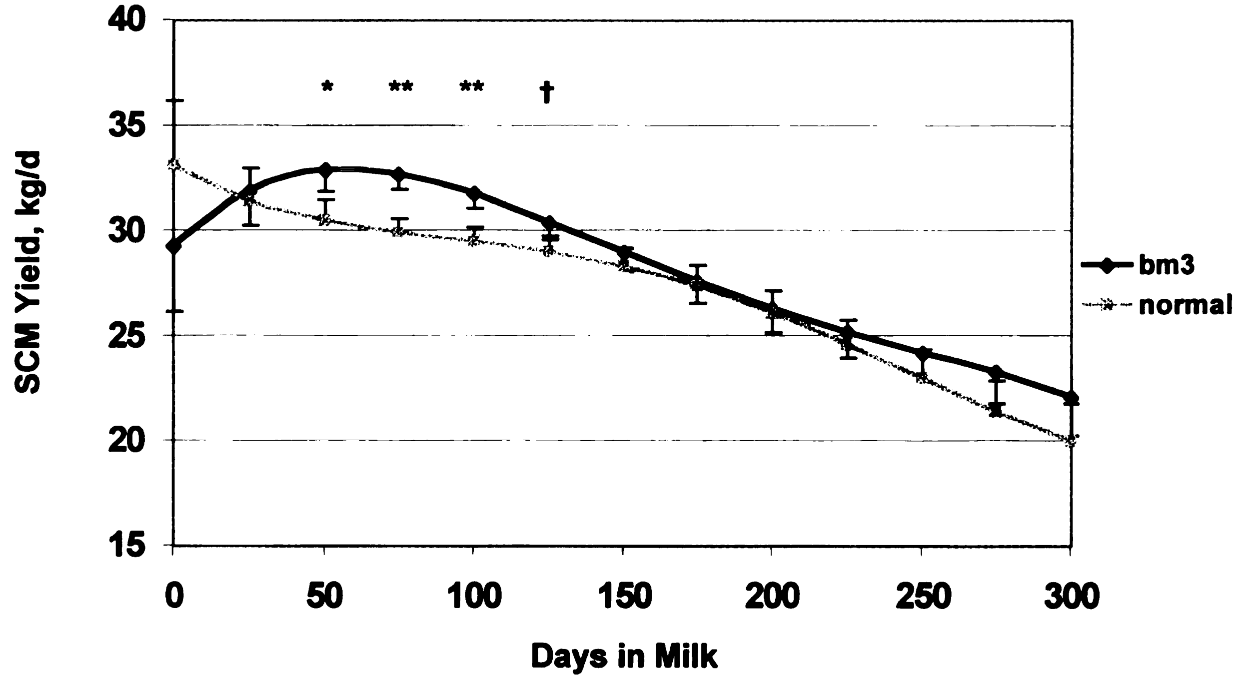

Figure 8. Least square mean estimates of effects of corn silage hybrid on solids-corrected milk yield (kg/d) at 25 d intervals. † $P < 0.10$; * $P < 0.05$; ** $P < 0.01$

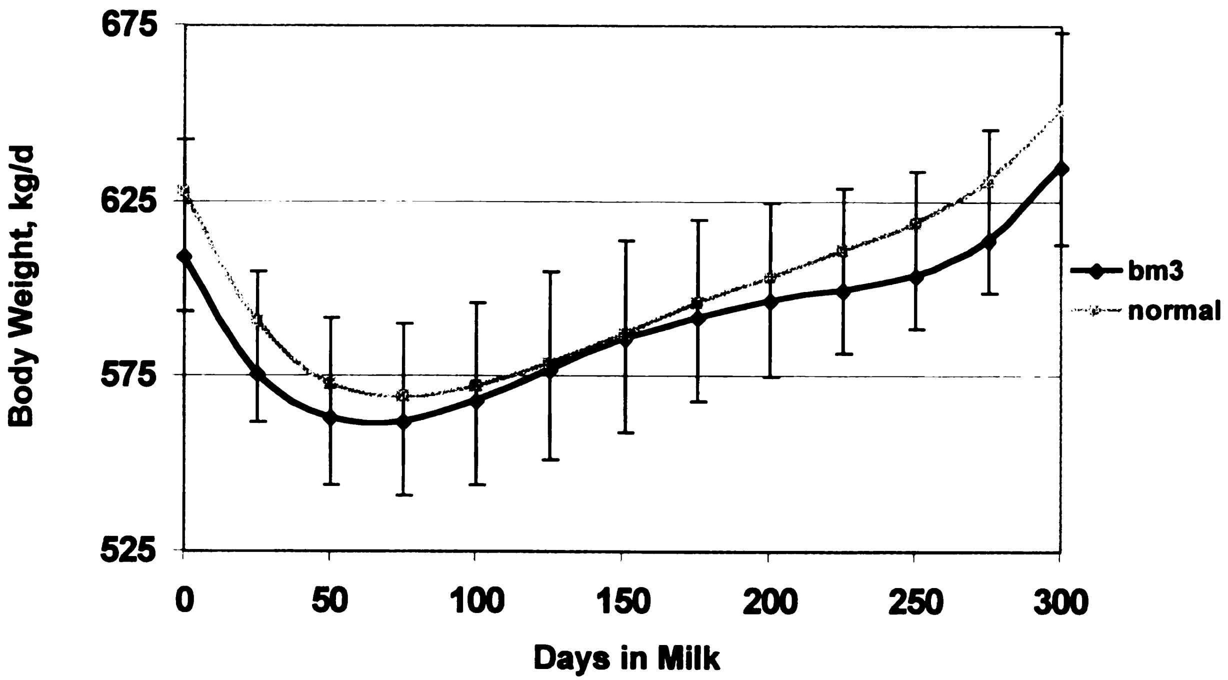

Figure 9. Least square mean estimates of effects of corn silage hybrid on body weight (kg/d) at 25 d intervals.

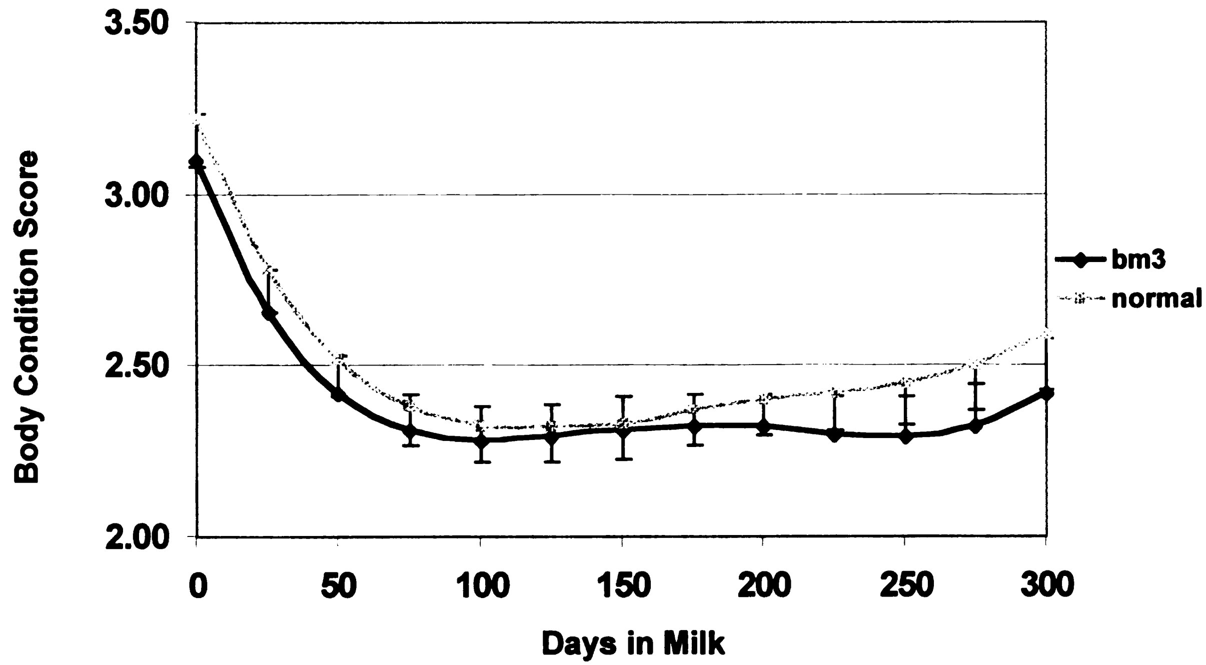

Figure 10. Least square mean estimates of effects of corn silage hybrid on body condition score at 25 d intervals.

Appendix. Block and treatment end summary.

Block	Parity[1]	Cow ID	Treatment[2]	Pre-treatment diet[3]	DIM at EOT[4]	Reason for treatment end[5]
A	M	1429	normal	DCAD 1	375	A
A	M	3227	*bm3*	DCAD 1	523	C
A	M	1331	normal	DCAD 2	62	D
A	M	1469	*bm3*	DCAD 2	285	A
A	M	1424	normal	DCAD 3	208	D
A	M	1492	*bm3*	DCAD 3	283	B
A	M	1236	normal	DCAD 4	302	A
A	M	1473	*bm3*	DCAD 4	401	B
A	M	1515	normal	DCAD 5	283	A
A	M	1266	*bm3*	DCAD 5	479	B
C	P	1608	*bm3*	DCAD 1	249	D
C	P	1627	normal	DCAD 1	337	A
C	P	1601	*bm3*	DCAD 2	283	A
C	P	1602	normal	DCAD 2	538	C
C	P	1657	*bm3*	DCAD 3	338	A
C	P	1642	normal	DCAD 3	420	C
C	P	1628	*bm3*	DCAD 4	352	A
C	P	1651	normal	DCAD 4	304	A
C	P	1619	*bm3*	DCAD 5	503	C
C	P	1623	normal	DCAD 5	470	C
D	M	1450	*bm3*	DCAD 1	400	C
D	M	1346	normal	DCAD 1	292	A
D	M	1411	*bm3*	DCAD 2	283	A
D	M	3273	normal	DCAD 2	257	B
D	M	1426	*bm3*	DCAD 3	197	D
D	M	1532	normal	DCAD 3	417	B
D	M	3269	*bm3*	DCAD 4	423	D
D	M	1534	normal	DCAD 4	341	C
D	M	1316	*bm3*	DCAD 5	363	A
D	M	1336	normal	DCAD 5	313	B

[1] Multiparous (M); Primiparous (P)
[2] brown midrib mutant for corn (*bm3*); isogenic corn hybrid to *bm3* (normal)
[3] Dietary cation-anion difference rations fed until calving (DCAD 1 - 5)
[4] Days in milk at end of treatment (DIM at EOT)
[5] Reason cow ended treatment

A = approximately 60 d from calving
B = milk yield is below 13.6 kg/d for 7d average
C = study completed
D = culled due to health problem

Appendix. Block and treatment end summary (continued).

Block	Parity[1]	Cow ID	Treatment[2]	Pre-treatment diet[3]	DIM at EOT[4]	Reason for treatment end[5]
E	M	1486	normal	DCAD 1	307	A
E	M	1438	*bm3*	DCAD 1	280	A
E	M	1495	normal	DCAD 2	249	B
E	M	1338	*bm3*	DCAD 2	359	A
E	M	1327	normal	DCAD 3	439	C
E	M	1529	*bm3*	DCAD 3	252	D
E	M	1481	normal	DCAD 4	299	D
E	M	1474	*bm3*	DCAD 4	492	C
E	M	3271	normal	DCAD 5	233	B
E	M	1419	*bm3*	DCAD 5	347	C
F	M	1430	*bm3*	DCAD 1	283	A
F	M	1432	normal	DCAD 1	313	A
F	M	1521	*bm3*	DCAD 2	282	A
F	M	1531	normal	DCAD 2	364	A
F	M	1445	*bm3*	DCAD 3	296	B
F	M	1323	normal	DCAD 3	286	B
F	M	1504	*bm3*	DCAD 4	404	B
F	M	1518	normal	DCAD 4	338	A
F	M	1435	*bm3*	DCAD 5	407	A
F	M	1501	normal	DCAD 5	340	A
G	P	1647	*bm3*	DCAD 1	375	A
G	P	1650	normal	DCAD 1	299	A
G	P	1612	*bm3*	DCAD 2	441	C
G	P	1653	normal	DCAD 2	414	C
G	P	1621	*bm3*	DCAD 3	390	A
G	P	1617	normal	DCAD 3	287	A
G	P	1641	*bm3*	DCAD 4	424	C
G	P	1632	normal	DCAD 4	386	C
G	P	1634	*bm3*	DCAD 5	361	A
G	P	1643	normal	DCAD 5	413	C

[1] Multiparous (M); Primiparous (P)
[2] brown midrib mutant for corn (*bm3*); isogenic corn hybrid to *bm3* (normal)
[3] Dietary cation-anion difference rations fed until calving (DCAD 1 - 5)
[4] Days in milk at end of treatment (DIM at EOT)
[5] Reason cow ended treatment

A = approximately 60 d from calving
B = milk yield is below 13.6 kg/d for 7d average
C = study completed
D = culled due to health problem

Appendix. Block and treatment end summary (continued).

Block	Parity[1]	Cow ID	Treatment[2]	Pre-treatment diet[3]	DIM at EOT[4]	Reason for treatment end[5]
H	M	1335	normal	DCAD 1	124	D
H	M	1535	*bm3*	DCAD 1	288	A
H	M	1477	normal	DCAD 2	359	A
H	M	1337	*bm3*	DCAD 2	330	C
H	M	1527	normal	DCAD 3	353	C
H	M	1333	*bm3*	DCAD 3	324	C
H	M	1483	normal	DCAD 4	291	B
H	M	1510	*bm3*	DCAD 4	400	C
H	M	1434	normal	DCAD 5	363	D
H	M	1459	*bm3*	DCAD 5	383	C
I	P	1629	*bm3*	DCAD 1	311	C
I	P	1646	normal	DCAD 1	288	A
I	P	1640	*bm3*	DCAD 2	400	A
I	P	1648	normal	DCAD 2	369	C
I	P	1661	*bm3*	DCAD 3	357	C
I	P	1667	normal	DCAD 3	316	A
I	P	1659	*bm3*	DCAD 4	284	A
I	P	3383	normal	DCAD 4	26	D
I	P	1666	*bm3*	DCAD 5	353	C
I	P	1644	normal	DCAD 5	340	C

[1] Multiparous (M); Primiparous (P)
[2] brown midrib mutant for corn (*bm3*); isogenic corn hybrid to *bm3* (normal)
[3] Dietary cation-anion difference rations fed until calving (DCAD 1 - 5)
[4] Days in milk at end of treatment (DIM at EOT)
[5] Reason cow ended treatment

A = approximately 60 d from calving
B = milk yield is below 13.6 kg/d for 7d average
C = study completed
D = culled due to health problem

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