Intake and Digestibility of Brown-Midrib Corn Silage by Lactating Dairy Cows

James Allen Rook

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INTAKE AND DIGESTIBILITY OF BROWN-MIDRIB CORN SILAGE BY LACTATING DAIRY COWS

BY

JAMES ALLEN ROOK

A thesis submitted in partial fulfillment of the requirements for the degree Master of Science, Major in Dairy Science, South Dakota State University

1976
INTAKE AND DIGESTIBILITY OF BROWN-MIDRIB CORN SILAGE BY LACTATING DAIRY COWS

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser

Date

Head, Dairy Science Department

Date
ACKNOWLEDGMENTS

The author wishes to thank Dr. Lawrence D. Muller for his guidance and confidence in me. Without his continuous support, this investigation would never have been completed.

I would also like to thank the Trojan Seed Company, Olivia, Minnesota for donating the seed and planter for trial 2 and for providing financial assistance.

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To my wife Ruth, thank you for accepting the moments of frustration and for sacrificing your own wants and needs while this investigation was proceeding. Thank you also for instilling self-confidence within my mind.

Finally, I want to thank God for giving me this opportunity in life, for allowing me to obtain the fellowship of my peers, and for showing me the path through frustration unto success.

JAR
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INTAKE AND DIGESTIBILITY OF BROWN-MIDRIB CORN SILAGE BY LACTATING DAIRY COWS

Abstract

JAMES ALLEN ROCK

Under the supervision of Associate Professor Lawrence D. Muller

Two short-term trials evaluated brown-midrib-3 (bm₃) mutant (low lignin) corn silage for early lactation Holstein cows. In trial 1, five cows per group were individually fed a ration of silage and grain (60:40 ratio, dry matter basis) from week 2 through 8 of lactation. Lignin percentages for bm₃ and normal silages were 4.9 and 6.4. Cattle fed the bm₃ ration consumed 19% more total dry matter as percent of body weight than cows fed normal. Digestibilities of dry matter, cell-wall contents, acid detergent fiber, and energy were 3 to 4 percentage units higher for the bm₃ ration. Milk yield was not affected by ration, but milk fat percentage was higher for cows fed the bm₃ ration. Total ruminal volatile fatty acids, pH, and ammoniacal nitrogen levels were similar.

In trial 2, five cows per group were individually fed a ration of either bm₃ or normal silage supplemented with a concentrate at an 85:15 silage to concentrate ratio (dry matter basis). Lignin percentages were similar. Lactic acid was higher and pH lower for bm₃ silage. All parameters of daily dry matter intake were higher by cows fed the bm₃ ration. Digestibilities of fiber components, energy, and nitrogen showed little difference between rations. Total digestible energy intake was 21.6% higher for cows fed the bm₃ ration.
Milk and milk component yields did not differ between treatments. Total and individual rumen volatile fatty acids were higher and pH lower for cows fed the \( \text{bm}_2 \) ration. No difference existed in rumen ammoniacal nitrogen.
INTRODUCTION

The use of corn silage as a forage for dairy cattle has increased rapidly because of its high yield of energy, ease of mechanization and storage, and uniformly high feeding value. Although high in energy, common nutritional deficiencies of corn silage include a relatively low protein content and the need for vitamin and mineral supplementation.

The first mention of storing and preserving green fodder was a German method of packing the direct-cut material into trenches, then covering it with boards and earth to facilitate sealing. Later, the practice of ensiling the entire corn plant also began in Germany. Work with corn silage continued throughout Europe, and it was not until the late 1870's that a Frenchman discovered concepts important for the preservation of corn silage. It was shortly after this that corn silage began to be used in the United States (14).

The use of corn silage has grown substantially with the hectares of corn harvested as corn silage more than doubling in the United States during the past 30 years. In 1945, only 5% of the total corn grown was harvested for silage, but by 1974, this figure had increased to 14% (2).

Unfortunately, the problem of providing domestic animals with adequate nutrient levels from our diminishing available feed supply has also become of critical importance in recent years. With continuing increases in the world population and the demand for food, it becomes imperative that methods be developed to extend and improve the utilization of feedstuffs. Because the area of tillable ground and
the plant yields achievable may limit increased production, the use of plant breeding to genetically alter plant material and increase productivity has gained importance. Plant breeding offers a method to improve the nutrient content and availability, and to increase the utilization of feedstuffs by humans and domestic animals. Some examples of genetic alteration and improvement are opaque-2 mutants of corn, high-protein oat varieties, and "Coastal" bermuda grass.

The brown-midrib mutant genotype of corn, a mutant strain which derives its name from the distinguishing brown midrib in its leaves, is still in the experimental stage. This mutant has been found to produce plants with a lowered and altered lignin content in the vegetative portion of the corn plant. These alterations in lignin make brown-midrib corn more digestible and thus provide a higher feed efficiency for ruminants (9,10,11,16,38,49). Thus, the use of brown-midrib rather than normal corn silage as the main forage in ruminant rations could greatly increase meat and milk production from a given amount of feedstuffs. The result of these increases would be to provide more food for man from the same amount of land.

The objectives of this study were to compare the intake and digestibility of brown-midrib and normal corn silages by lactating dairy cows, determine the utilization of each, and ultimately determine the efficiency of milk production by cows fed brown-midrib mutant corn silage as the main forage material.
LITERATURE REVIEW

Nutrient Makeup

Corn silage, the fermented product of whole corn plants plus ears, is well known for yielding more energy per hectare than any other crop (14). Total digestible nutrient (TDN) values of corn silage usually range from 60 to 70% compared to 73% TDN of ear corn (50). The average percent composition of corn silage on a DM basis for crude protein, ether extract, crude fiber, and nitrogen free extract are: 8.3, 3.0, 25.1 and 57.6, respectively (50). The average pH of corn silages summarized over a 17 year period was 4.0 (30).

Researchers generally agree that as the corn plant matures, there is an increase in the dry matter (DM) content of the total plant, but expressed on a DM basis there is a decrease in crude protein, crude fiber, and ash contents. In contrast, many workers have shown that the stage of maturity has little effect on the digestibility of corn silage DM (14). However, Gordon et al. (23) and Owens et al. (53) have reported a decrease in lactic acid production with advancing maturity of corn ensiled for silage. In another study, Lopez et al. (40) reported the peak in lactic acid concentration was reached about 21 days after ensiling for low DM samples; whereas, the peak was reached in medium and high DM samples 42 days after ensiling. They attribute this difference to the association of moisture level with microbial action and the buffering action of ammonia being formed. Other studies have reported a decrease in acetic acid and other volatile acids as corn increased in maturity (14).
On comparing the weights of the various constituents of green corn put into the silo with those of the silage removed, 1) there has been no change in the fiber, 2) all of the sugar and some of the less resistant celluloses disappear, 3) carbon dioxide is evolved and a number of acids appear which were previously not present, 4) the protein-nitrogen compounds are reduced to about one-half, and 5) the non-protein nitrogen compounds double in amount (56). The agents responsible for bringing about these changes in the silo are thought to consist of the living protoplasm carrying on respiration and other vital functions, various enzymes, and numerous microorganisms (56).

Feeding Value of Corn Silage for Dairy Cattle

High Corn Silage Ration. Because of its relatively high TDN and utilizable energy value along with several attributes previously noted, extensive research has been conducted in determining the nutritive value of corn silage for dairy cows. Various workers have either fed corn silage as the sole forage or in combination with hay or other forage materials.

In a 1933 winter feeding trial utilizing corn silage as the sole forage material for lactating cows, Canon et al. (7) showed similar body weight gains, milk and milk fat production, and persistency of production for cows that consumed only corn silage compared to cows that received corn silage and alfalfa hay.

In a Beltsville experiment, 12 cows were fed corn silage as the sole forage for varying lengths of time up to five lactations. The primary objectives were to determine the adequacy of corn silage fed
ad libitum with grain (25% crude protein) as the source of minerals and vitamins, and to determine the long term effect on reproduction and lactation. Although the results were generally favorable, corn silage intake was relatively low, ranging from 7.7 to 16.4 kg per day (wet basis) per lactation average (12).

A three lactation experiment by Maryland researchers is discussed in two different articles (24,66). The study compared cows fed corn silage as the only forage during the entire year to those receiving half of their forage DM from corn silage and half from second-cutting alfalfa hay. Each of the forage groups was split into three subgroups of five cows and offered supplementary concentrates to a limit of differing levels of energy intake. Eleven of the original 20 cows assigned to the forage groups fed hay completed all three lactations, while six of the original 20 cows assigned to groups fed all corn silage completed all three lactations. In each group, 18 of the 20 cows completed two or more lactations. In all cases, the cows fed corn silage as their only forage continued to produce well during successive lactations and responded similarly to those which received hay. Only small differences in milk production and composition were observed among the treatment groups. However, at the parturition following the first lactation, three of the cows in the all corn silage group had retained placentas and produced calves with goiters. It was concluded from this experiment that cows can maintain high levels of milk production for successive years when fed corn silage as the sole forage.
A later trial by Vandersall et al. (67) studied the effect of iodine supplementation in an all corn silage feeding program. Results indicated a significantly smaller thyroid in calves from cows fed iodine. Iodine supplemented cows consumed significantly more silage; however, no significant difference was noted in milk production.

Thomas et al. (60) fed cows either corn silage or alfalfa hay as the only roughage for three lactations. The production of milk, fat-corrected-milk (FCM), fat, and solids-not-fat (SNF) was similar for cows fed corn silage, hay, or their combinations for one lactation. When continued on only corn silage or only hay for two or three consecutive lactations, those fed corn silage consumed less forage DM, produced similar amounts of milk and FCM with similar persistencies, consumed slightly more grain, and had less weight loss. Health problems were encountered more frequently in the cows fed only corn silage as they had more treatments for ketosis. However, the incidences of metritis, mastitis, and retained placentas were approximately equal for all treatments.

In what is the most conclusive and accurate experiment to date evaluating an all corn silage feeding regimen, Trimberger et al. (62) utilized 50 Holstein cows over three lactation periods. The cows were selected as four groups of 10 cows each, with established production levels in groups one to four: Group 1 - control; Group 2 - liberal grain; Group 3 - restricted forage, liberal grain; and Group 4 - all corn silage, liberal grain. Five additional young cows were added to each of group's one and three, thus there were 15 comparable cows in
each of group's 1 and 3. In the control group, forage composition consisted of good quality alfalfa and grass hay ad libitum and 16.3 kg of corn silage per day. Group 4 had an advantage in average production of 395 kg milk over the control group, however, they were most erratic in feed consumption and milk production. Indications were that feed intake during late lactation and the dry period needs to be carefully adjusted to avoid overconditioning of cows on an all corn silage ration. Six of the cows on Group 4 completed the second lactation while only one completed the third. The cows in group 4 had the lowest total body weight of all groups in the month preceding the second calving, thus these cows were in good condition. Eight of the ten died and one additional cow was removed because of infertility. It was decided that these cows apparently had a decreased ability to withstand stress and six of the deaths were due to complications at parturition (displaced abomasum, metritis, retained placenta, and acute mastitis).

Two trials have also been conducted to compare corn and haycrop silages as fed to dairy heifers and to lactating cows. A 1974 trial by Johns and Holter (32) found no associative feeding effects between corn and haycrop silages fed to dairy heifers. In this trial, four nonlactating Holstein heifers were randomly assigned to a 4 X 4 Latin-square trial. The four diets were composed of urea-treated corn silage and early-cut wilted haycrop silage in various dry matter ratios. These rations were fed at 0.9 times energy requirements for maintenance and growth in an attempt to equalize energy intake among treatments.
Associative feeding effects were evaluated by comparing predicted and observed animal responses to mixed forage treatments. There were no significant differences among treatments for DM intake per unit metabolic weight. Digestibilities of gross energy, DM, crude protein, and ether extract were significantly higher for all corn silage and lower for all haycrop silage than for the two mixtures. In contrast, digestibility of acid detergent fiber was higher for the all haycrop silage diet than for the other diets. Although DM intake was not significantly different among diets, covariate-adjusted intake of gross energy increased with each incremental increase in haycrop silage; thus implying a higher concentration of gross energy in haycrop DM. Conversely, the percent of ingested energy lost as feces, methane, and heat was lowest for the all corn silage diet. Metabolizable and net energy in DM were also significantly higher for all corn silage than for all haycrop silage. Nitrogen intake did not vary among treatments but the percent of dietary nitrogen lost in feces was greater for all haycrop silage. Tissue nitrogen balance was significantly higher for the all corn silage diet.

From this study, it was concluded that urea-treated corn silage was more digestible than haycrop silage probably because of its grain content and lower fiber percentage. Energy from corn silage was more efficiently used, and it appeared that corn silage promoted greater body protein retention than haycrop silage.

A study by Holter, Johns, and Urban (26), concurrent with the above mentioned study, also found no associative effects between corn
and haycrop silages when fed to lactating cows. The experimental procedure was quite similar to the above trial, however, some of the results differed. Apparent digestibilities of gross energy, DM, protein, and crude fiber were not different among diets, however, fat was more digestible in corn silage. Ration DM intake and daily milk yields showed no significant differences among treatments. It was concluded that the two types of silage were equivalent in supporting milk production when fed in equal DM contents.

Of the multilactation studies reported in which lactating cows with high producing ability were fed corn silage as the sole forage, it appears that corn silage alone is at least equal to hay or combinations of hay and corn silage. Neither a consistent depression in appetite or production occurs when silage is fed over one or more lactations. However, several problems related to feeding and supplementing corn silage as the only forage have been observed or have been reported to occur.

Several health problems have also been attributed to the all corn silage diet during the past several years. In some cases (27,62) ketosis and listeriosis incidence was found to be much greater in the all or high corn silage diet. Some have attributed cases of metritis, mastitis, milk fever, retained placentas, and iodine deficiencies with forms of stress introduced by all corn silage feeding. Abomasal displacement occurred infrequently in the studies reviewed and has been attributed to high grain feeding concurrent with feeding corn silage as the sole forage (13).
Energy. The high energy content of corn silage has led to problems in housing systems where all cows in a herd are in one group and corn silage is offered free choice. A comparison of Tables 1 and 2 shows that a 600 kg pregnant, nonlactating cow could eat approximately 30 kg of wet (30% DM) corn silage per day to keep her in energy balance. However, by doing this the cow would then not be receiving adequate levels of digestible protein in her diet. Likewise, in comparing the requirements and levels of nutrients consumed by a high producing individual, a 600 kg cow producing 35 kg or more of 3.5 percent milk per day would need to consume over 65 kg of wet (30% DM) silage per day to nearly meet her energy needs, but would still be substantially below her protein needs. Further observation indicates that a critical mineral imbalance could occur if supplementation is not provided.

The over-consumption of energy mentioned above can provide the dairyman with problems. Several studies have indicated that over-consumption of energy by growing heifers results in growth rates which may be detrimental to later lactation ability, and results in greater loss of cows from the herd because of sterility (12). Likewise, if dry cows are allowed to consume corn silage free choice, over-consumption will occur and the probability of encountering the above mentioned problems is again present.

It has been a highly publicized fact that many high-producing cows cannot consume enough energy in early lactation to meet their energy requirements. Because of this, some replenishment of energy reserves is appropriate after production has decreased to a level
where this is possible. However, field observations (12) indicate that over-consumption of energy from mid- to late-lactation may: 1) depress production in the current lactation— that a fundamental metabolic antagonism may exist between milk production and body fat and that excess dietary energy in late lactation may tend to divert the cow's use of that energy to body fat deposition instead of milk production, 2) depress appetite in the following lactation, and 3) result in an animal which is prone to develop clinical ketosis because of the over-conditioning (12, 62).

**Nitrogen Supplementation.** Another observation from Tables 1 and 2 reveals that dietary protein requirements could not be met by corn silage alone. One study by Owen (52) evaluated the method of attempting to raise the crude protein content of the corn silage by nitrogen fertilization. In this study, nitrogen fertilizer applied at rates of 27 to 195 kg per hectare increased the crude protein of the whole plant DM from 7.7 to 11.2 percent. Other studies concerned with the possibility that the increased application of nitrogen to the soil could increase the nitrate content of the corn plant have found this problem to be of regional concern (12).

The problem of urea use lies not in the question of whether to use urea, but rather under what conditions and by what techniques and routes of administration of appropriate levels can the most effective use of urea be achieved. Huber et al. (28) compared the utilization of nitrogen by lactating cows fed corn silage *ad libitum* as the only forage. The silage was ensiled with either 0.0, 0.5, or 0.75 percent
TABLE 1. Daily nutrient requirements of lactating, non-lactating, and pregnant dairy cattle.\(^a\)

<table>
<thead>
<tr>
<th>Animal</th>
<th>Live Wt. (kg)</th>
<th>Prod. (kg)</th>
<th>Protein (kg)</th>
<th>Energy (Mcal)</th>
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<td>TPE DPI</td>
<td>DES MEN NEI</td>
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<td>600</td>
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<td>0.9 0.5</td>
<td>24.6 20.2 13.5</td>
<td>5.6 .03 .03</td>
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\(^a\)National Research Council Requirements of Dairy Cattle, 4th Ed. 1971 (50).

\(^b\)Body weight

\(^c\)Milk produced

\(^d\)Milk fat

\(^e\)Total Protein

\(^f\)Digestible protein

\(^g\)Digestible energy

\(^h\)Metabolizable energy

\(^i\)Net energy

\(^j\)Total digestible nutrients, kg

\(^k\)Calcium, kg

\(^l\)Phosphorous, kg
TABLE 2. Daily nutrients provided to animal consuming various amounts of 30 percent dry matter corn silage.\textsuperscript{a}

<table>
<thead>
<tr>
<th>Silage consumed Wet Basis (kg)</th>
<th>Nutrients Provided</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DM\textsuperscript{b}</td>
<td>CFC</td>
<td>TP\textsuperscript{c}</td>
<td>DFE</td>
<td>DE\textsuperscript{d}</td>
<td>ME\textsuperscript{e}</td>
<td>NE\textsuperscript{f}</td>
<td>TD\textsuperscript{g}</td>
</tr>
<tr>
<td>30</td>
<td>8.4</td>
<td>2.2</td>
<td>0.7</td>
<td>.41</td>
<td>25.9</td>
<td>21.5</td>
<td>14.2</td>
<td>5.9</td>
</tr>
<tr>
<td>50</td>
<td>14.0</td>
<td>3.7</td>
<td>1.2</td>
<td>.68</td>
<td>43.1</td>
<td>35.9</td>
<td>23.7</td>
<td>9.8</td>
</tr>
<tr>
<td>65</td>
<td>18.1</td>
<td>4.8</td>
<td>1.5</td>
<td>.89</td>
<td>56.0</td>
<td>46.6</td>
<td>30.8</td>
<td>12.7</td>
</tr>
</tbody>
</table>

\textsuperscript{a}National Research Council Requirements of Dairy Cattle, 4th ed. 1971 (50).

\textsuperscript{b}Dry matter, kg

\textsuperscript{c}Crude fiber, kg

\textsuperscript{d}Total protein, kg

\textsuperscript{e}Digestible protein, kg

\textsuperscript{f}Digestible energy, Mcal

\textsuperscript{g}Metabolizable energy, Mcal

\textsuperscript{h}Net energy, Mcal

\textsuperscript{i}Total digestible nutrients, kg

\textsuperscript{j}Calcium, kg

\textsuperscript{k}Phosphorous, kg
urea. A 70-day continuous trial was employed in which concentrates were fed at the rate of one kg per three kg of milk produced and the rations were calculated to be isonitrogenous and isocaloric. The level of urea in the silage was found to not significantly influence the level of silage intake, total feed intake, or milk produced. In the second half of Huber's trial, corn silage which had been ensiled with 0.0, 0.6, or 0.85 percent urea was fed ad libitum as the only forage to lactating cows in a 63-day trial. Again no significant differences were observed in feed intake or milk production. However, a digestion-nitrogen balance determination made during the eighth week of the study discovered that the cows fed the 0.85 percent urea-corn silage were in severe negative nitrogen balance. This imbalance was attributed to the lowered protein digestibility and larger urinary nitrogen losses of the cows fed the higher urea diet. These results tend to agree with another study (12) in which cows fed only urea-corn silage (0.7 percent) used 8.0 percent of the dietary nitrogen for milk production and retention in body tissue, whereas a similar group fed alfalfa hay and grain utilized 22 percent of the dietary nitrogen. Hillman (25) explains the above mentioned experiments in stating that the maximum utilization of urea for complete replacement of natural protein supplements appears to be dependent on controlling its rate of hydrolysis to ammonia and identification of specific rumen microbial protein. According to some sources, the control of these factors amounts to limiting the urea content to 1.5 percent of concentrate
rations, or 0.5 percent urea ensiled with corn silage fed as the only forage (25).

The theory that the addition of urea would satisfy the high protein levels required by the high producing cow has been dampered by the above mentioned studies. However, other workers have continued to experiment with other high protein additives for all corn silage diets. Schingoethe and Beardsley (57) fed corn silages containing either 0.5 percent urea plus 1.0 percent dried whey or 0.5 percent urea ad libitum as the sole source of roughage to lactating cows over a ten week period. Cows fed the urea-dried whey silage produced more milk and were more persistent than the cows fed urea-silage. Thus, these results indicated that adding dried whey to urea-treated corn silage did improve the silage's feeding value.

Limited work has been done on other non-protein-nitrogen additions to silage. In two lactation trials by Huber et al. (29) in which 0.43 percent ammonia was added to corn silage at ensiling or just prior to feeding, the silage and total DM intakes were higher for the prior-to-feeding group than the ensiling group.

**Vitamin and Mineral Balance.** Various vitamins and minerals are also deficient in the high corn silage rations. Corn silage is low in calcium, sodium, phosphorous, magnesium, and cobalt, and may be deficient in iodine for ruminants in some geographical areas (12,25). Other studies indicate that it may be necessary to supplement with sulfur when urea is added and silage is fed as the major or only forage (31). Thomas et al. (61) found that the addition of sulfur to
urea corn silage rations enhanced daily gains of growing heifers in only one of four trials. However, they concluded that cows fed silage that is high in non-protein-nitrogen may be more susceptible to sulfur deficiency than those fed normal corn silage.

Most researchers agree that corn silage generally contains enough carotene to meet vitamin A requirements and that vitamin D levels are usually sufficient. However, most still agree that supplementation of these two vitamins is desirable (12).

The results of several experiments suggest that ad libitum feeding of high quality forage with liberal grain is a sound practice. Most sources agree that heavy feeding of corn silage will support high milk production adequately without endangering herd health conditions where care is taken in supplementation and in avoiding overconditioning in late lactation and during the dry period. However, because the all corn silage diet has been contributed to some health problems when fed for greater than one lactation, small amounts (less than two kg) of hay fed with ad libitum amounts of corn silage may be desirable and practically feasible over longer periods of heavy corn silage feeding, but no research demonstrating the need of small amounts of hay with an all-corn silage feeding program is available.

Factors Affecting Intake and Digestibility

Fermentation. There is more to making corn silage than merely harvesting the crop and putting it into the silo. When fresh crops are chopped and packed in the silo, they must then undergo the process of fermentation. According to Webster (73), fermentation is the
chemical decomposition which takes place in an organic substance exposed to the air, due to the action of microscopic organisms.

Langston and Bouma (36) stated that in a natural silage fermentation, the mass is acidified by lactic and acetic acid forming bacteria that ferment sugars in the plant material. When forage is ensiled the plant cells continue to respire for a time, using up the oxygen and giving off carbon dioxide and heat. As conditions become favorable, acid producing bacteria increase rapidly and, at the end of three or four days, each gram of silage will contain several hundred million bacteria. These organisms produce acid until the sugar is exhausted or until the pH becomes unfavorable for further growth. It is thought that a sufficient concentration of lactic acid is necessary to inhibit other forms of bacterial activity, and thus preserve the material until such time that it is required (36).

When freshly chopped plant materials are packed into a silo, the living plant cells are not killed immediately. They continue to live as long as they can obtain air and food. As these cells respire, heat is generated, carbon dioxide gas is produced, and the temperature of the fermenting materials rises. The increasing temperatures favor the growth of various microorganisms which are responsible for the many different kinds of organic acids formed during fermentation. As the various microorganisms respire, multiply, and grow, different chemical reactions occur and different acids are formed (6).

Langston and Bouma (36), following a study where the objective was to learn more about the types and occurrence of microorganisms in
silage, concluded that the genera *Streptococcus* and *Leuconostoc* were of prime importance in the production of volatile acids and lactic acid in silage. Included were strains of *Streptococcus faecalis*, *Streptococcus liquefaciens*, *Leuconostoc mesenteroides*, variable *Leuconostoc*, and *Pediococcus*.

Another article by the same authors (37) concluded that the organism mainly responsible for lactic acid production in corn silage is *Lactobacillus plantarum*. Other bacterial species responsible for producing lactic acid in corn silage included *Lactobacillus brevis*, *Lactobacillus brevis* (variable), *Lactobacillus casei*, *Lactobacillus casei* (variable), *Lactobacillus arabinosus*, and branching lactobacilli.

According to Russell (56) the formation of acids during silage making is also considered to be a primary function of plant cell enzymes along with respiration. The identification and determination of relative amounts of volatile acids in corn silage were first made by Dox and Neidig (15). The five aliphatic acids, formic through valeric, were identified quantitatively, with acetic acid comprising about 90 percent of the total. Propionic acid was second in importance while butyric acid was found only in samples characterized by some spoilage.

It is also important that the temperature rise to 27-38 C to ensure that plant cells die as quickly as possible. This not only prevents a buildup of undesirable butyric acid but also enables lactic acid producing bacteria to multiply and grow quicker (6).

Opinions differ as to what conditions determine the final lactic acid concentration. Some say that if enough fermentable carbohydrates
are present, lactic acid will be formed until its weight is equal to about 1.5% of the weight of the silage, and the resulting silage will be successfully preserved (6). Other researchers (37) contend that the carbohydrate source is not always the limiting factor. These workers have put forth various reasons to account for the variability in acid production. They are: 1) variability in sequence changes of microorganisms, 2) antagonism among certain groups of bacteria early in the fermentation process, 3) deficient nutrients in the plant material for bacterial growth, and 4) occurrence of weakened strains of bacteria.

A study by McCullough (41) shows data which illustrates the complex nature of silage fermentation. Since the desired fermentation is a rapid production of lactic acid, the desired changes would be a low pH at four days with a minimum loss of carbohydrates and little change thereafter. By the use of standard partial regressions it became apparent in McCullough's experiment that the factor most highly associated with final pH was crude protein content of the forage while there was an absence of a significant correlation between carbohydrates and pH. McCullough also hypothesized that the high pH usually associated with undesirable silage fermentation was apparently a result of protein breakdown with the resulting detrimental effects of increased buffer capacity. He supports his hypothesis by quoting 1956 data from Nilson which showed that the disintegrated protein in alfalfa forage has a buffer capacity at pH 5 which requires ten times as much acid to reach a pH of 4 as the unfermented forage protein. When this occurs,
fermentation will proceed beyond four days at the expense of the lactic acid previously produced as well as the protein and possibly structural carbohydrates present.

In the same study (41), McCullough conducted feeding trials with lactating dairy cows. These trials were designed with the hope of determining whether the various fermentations of silage resulted in differing dry matter intakes. The association of crude protein and fiber with stage of maturity was found in silages made under many different conditions and these factors were determined to be of great importance in dry matter intake. These results also agree with previously mentioned data (23,40,53) in which a reduction of lactic acid production was found with advancing maturity of corn harvested for silage.

The importance of silage fermentation was upheld in a more recent study of wheat and ryegrass forages by McCullough et al. (44). Their data indicated that fermentation in the silo can result in changes in digestibility of the silage, changes in fermentation patterns in the rumen, and reductions in the rate of intake of the dry matter of the silages. They concluded that such a chain of events can happen and should indicate that the influence of ensiling techniques on animal performance is not a direct cause-and-effect relationship but a complex of interrelationships which must be understood before progress can be made in altering silage fermentation to produce desired changes in animal production.
Composition. According to McCullough (42), three factors are important in silage quality: 1) dry matter content; 2) success of fermentation; and 3) dry matter digestibility. Since the first two factors have previously been covered a discussion of the latter will follow.

In the corn plant, 50% or more of the total nutrients in the resulting silage may be found in the ear (42,43). This makes the corn plant unique in that most of the effects of plant maturity are offset by the proportion of seed that is formed with age. Consequently, digestibility of TDN does not ordinarily decline with age (70). However, factors of decreased fiber digestibility still occur in the aerial portion of the plant due to advancing maturity.

Since ruminants have a digestive system which enables them to utilize fibrous plant material, it follows that the efficiency by which these plant constituents are utilized will vary according to plant maturity and its effect upon the ratios of structural carbohydrates (69). According to McCullough (42), it is the relationship between the structural carbohydrates (cellulose, cell-wall constituents, etc.) and the soluble carbohydrates which is the primary factor influencing the molar percentage of acetic acid. The pH range of six to seven, where acetic acid predominates, is the area where cellulose digesting organisms grow best. Thus the alterations of fiber component ratios in the maturing plant could conceivably effect production of volatile acids and follow with decreased efficiency towards milk production.
Allinson and Osbourn (1) indicated that there are four forage characteristics which may affect voluntary feed consumption: 1) the content of the digestible cell-wall constituents; 2) the content of indigestible cell-wall constituents; 3) the structure of the cell-wall; and 4) the content of cytoplasmic constituents. Van Soest (69) indicated that the cell-wall constituents of plant materials are composed essentially of hemicellulose, cellulose, lignin, and (in the case of heat dried materials) heat damaged protein. Usually, within species and varieties, Allinson and Osbourn (1) point out that significant negative correlations exist between forage lignin content and either forage dry-matter intake or dry-matter digestibility. As forage crops mature the lignin content and yield increases and nutritional value decreases.

According to Morrison (47), lignin is a complex aromatic polymer which occurs in plant cell walls in close association with cellulose and the hemicellulosic polysacharides. Lignin, as isolated from the woody portion of plants, is not a single compound but a group of similar organic substances which contain methoxyl groups, aromatic nuclei, and a carbon-oxygen ratio higher than that of true carbohydrates (54). Gordon (20) stated that chemically, lignin is a co-polymer composed of guaiacyl and syringyl propanes most of which can be ascribed to p-coumaric acid esterified with lignin. This ester linkage with p-coumaric acid and one with ferulic acid has been shown to be characteristic of grass lignins. Morrison (47) also indicates that grass lignins are chemically distinct from wood lignins by
possessing p-hydroxycinnamyl residues as coniferyl and sinapyl moieties found in wood lignins.

Estimates of lignin digestibility vary widely though commonly the lignin complex is assumed to be indigestible (1). Gordon (20) points out that lignin can be enzymatically degraded under aerobic conditions by certain fungi, but no organism has been shown to break down lignin under anaerobic conditions such as exist in the rumen. Porter and Singleton (55) also indicated that in earlier studies and in work of their own on lignin degradation, lignin was demethoxylated in the abomasum of ruminants. They showed a 16% fall in methoxyl content of the lignin between feedstuff and feces and indicated a 19 to 35% reduction in lignin of the diet. Gordon (20) determined that these compositional changes which occur in lignin upon digestion depend on the age and species of the plant involved. Morrison (47) in turn concluded that progressive lignification is the major cause of the decline in digestibility as a forage matures.

Lignin is not only practically indigestible itself, but Patton and Gieseker (54) stated that it also decreases the availability of other nutrient constituents in forages. They indicated that this may result from any of three conditions: 1) the lignin may incrust the other digestible constituents thus prohibiting their contact with enzymatic juices; 2) lignin may combine chemically with other constituents, forming unavailable compounds; and 3) digestion may be retarded through local inhibition of digestive enzymes due to the toxic action of phenolic groups resulting from partial lignin decomposition.
Allinson and Osbourn (1) showed a consistent decline in the digestibility of acid detergent fiber (ADF) and cellulose with increasing maturity of grasses. This decrease in digestibility followed an increase in ADF, cellulose, and lignin content as the forage matured. Similarly, significant negative correlations were obtained between acid detergent lignin (ADL) and dry matter disappearance, voluntary feed consumption, and cellulose digestibility. The ADL fraction was consistently negatively correlated to dry matter disappearance and only slightly less so to cellulose digestibility. Furthermore, the relationships between cellulose digestibility and lignin content suggest that voluntary consumption was related more closely to the percentage of digesta deriving from cellulose than to lignin content. Their work with legume and grass species inferred that it is the nature of the material digested that influences voluntary feed consumption. Overall they found that voluntary feed consumption was more closely related with the percentage of the digesta derived from cellulose than with cellulose or dry matter digestibility. However, the significantly negative correlation between the percentage of digesta deriving from cellulose and voluntary feed consumption was attributed in part to lignin artifact distribution and the inadequacy of cellulose as an index of total cell-wall content.

**Lignin and Brown-Midrib Corn**

**Chemical Composition.** Partially by accident and largely through the use of mutants for examining biosynthetic pathways, the chemical structures and actions of grass lignins have become more understandable.
The structures of major lignin precursors and products are shown in Appendix Figure 1. Kuc and Nelson (33), while studying a recessive mutant of corn as a tool for examining biosynthetic pathways, found that the visual differences of the mutants were caused by abnormal and colored lignins. The mutant, called brown-midrib-1 (bm₁), was characterized by the presence of colored lignins in the cell walls of the leaf midribs which gave them a brownish or reddish appearance in contrast to the grey-green midribs of normal plants. They saw the brown-midrib mutants as possibly being valuable tools in investigation of lignin structure and biosynthesis since it was the first species in which aberrant forms of lignin had been found.

The first chemical difference noted was that the alkali lignin from the normal strain was a greyish tan amorphous powder, but that from the bm₁ strain was deep brownish red and paracrystalline in appearance (33). X-ray diffraction studies, however, have shown that both lignins are amorphous in nature.

Following a systematic series of tests, Kuc and Nelson (33) determined that the plants of the bm₁ strain had somewhat less lignin than nonmutant plants throughout the growing season. Further study of double mutant strains demonstrated greatly reduced lignin contents in mature stalk tissue (33,34). Tests have shown that for either native lignin, dioxane-hydrochloric acid, or pyridine lignin isolates from corn, treatment with potassium hydroxide liberates p-hydroxycinnamic and ferulic acid as the predominant acids. The two liberated acids are apparently bound to the remainder of the lignin molecule by ester
linkages as indicated by results of hydroxylamine tests prior to and following alkaline hydrolysis. Data from Kuc and Nelson (33) show that of the two acids, p-hydroxycinnamic acid is the most plentiful for both strains, and is 2 to 12 times higher in lignin from the normal strain.

In order to further examine the structure of the two lignins, Kuc and Nelson (33) subjected the two alkali lignins to alkaline nitrobenzene oxidation. The major products found are syringaldehyde, vanillin, p-hydroxybenzaldehyde, along with p-hydroxycinnamic, ferulic, p-hydroxybenzoic, vanillic, and syringic acids. The oxidation products recovered from normal and bm1 alkali lignins were found to be in approximately the same ratio, although the yield of phenolic monomers from bm1 lignin was considerably reduced. The oxidation of bm1 lignin produced a lower yield of aromatics, however, the normal strain yielded about three times as much vanillin as syringaldehyde and the ratio of monomers was not the same. Further determinations of the methoxyl content of alkali lignins from 95-day-old normal and bm1 corn plants were 14.6 and 12.3%, respectively, following correction for hemicellulose content.

The use of labeled compounds in the same study (33) indicated a lowered efficiency of incorporation of the phenolic nuclei from phenylalanine and tyrosine in bm1 plants. They determined that the block in the mutant was either in the formation of phenolic building blocks beyond the stage of phenylalanine and tyrosine or in the polymer formation from the lignin building blocks.
A later study by Gee et al. (17) disagrees with the above suggestion that \( \text{bm}_1 \) maize produced an altered lignin core and thus had fewer sites at which p-coumaric acid could be esterified. By structural analyses of dimethylformamide (DMF) lignins of normal and \( \text{bm}_1 \) plants, they dropped the above theory and developed their own. Results of de-esterification and nitrobenzene oxidation of \( \text{bm}_1 \) and normal DMF-lignins are comparable with those found by Kuc and Nelson (33). Similarly, the yield of phenolic aldehydes from normal DMF-lignins was found to be greater than that from \( \text{bm}_1 \) DMF-lignin.

In an effort to determine the carboxyl content of the two strains of lignin, Gee et al. (17) found that while they contain equal amounts of total acidity, \( \text{bm}_1 \) has more carboxyl acidity. They attributed these results to the presence of more base labile bonds, perhaps ester linkages, which result in a larger increase in carboxyl content of the \( \text{bm}_1 \) DMF-lignin. By the use of infrared absorption curves they substantiated the presence of carboxyl groups in DMF-lignins and were able to determine that both strains of maize DMF-lignins show characteristic lignin absorption. In addition, results of hydroxylamine tests indicated that both normal and \( \text{bm}_1 \) DMF-lignin cores have carboxyl groups that are esterified. The presence of the hydroxamic acid derivative of p-coumaric acid following treatment of the DMF-lignins with hydroxylamine hydrochloride indicated that some p-coumaric acid was esterified to hydroxyl groups of the lignin cores.

From their study, Gee et al. (17) concluded that corn lignin cores contain carboxyl groups as an integral part of their structure; more
carboxyl groups being present in the $\text{lignin}_1$ core. They further discussed the possibility that some molecules of p-coumaric acid are doubly esterified linking two lignin cores. It was concluded that such double esterification linking lignin cores might sterically hinder potential sites for further esterification, and thus account for the reduced p-coumaric acid content of $\text{lignin}_1$ DMF-lignin.

Later work by Gordon and Griffith (21) using the nuclear magnetic resonance spectra showed a higher degree of cross-linking of the propane side chains in $\text{lignin}_1$. They concluded that the increased degree of cross-linking of the propane side chain may be a significant factor in determining the effect of lignin on digestibility. By calculation of empirical formulas for the two lignins, they were also able to show that normal lignins have less nitrogen but contain more hydrogen and methoxy groups than the $\text{lignin}_1$ lignins.

Fiber Digestibility. Armed with the knowledge that lignin itself was practically indigestible and had been shown to decrease the availability of other nutrients (54), it was only a short time until studies were initiated comparing the brown-midrib mutants and normal corn.

Digestibility work on the brown-midrib mutants first began with Muller et al. (49). From their studies on structural components of whole corn plants, acid detergent lignin (ADL) differences between the mutants and normal were most notable. The mutants were significantly lower than the normal with the single mutant $\text{bm}_3$ being significantly lower in ADL than $\text{bm}_1$ and normal. The $\text{bm}_3$ mutant tended to be lowest
in ADL for all plant parts. No significant differences in cell-wall contents (CWC) or hemicellulose were found among genotypes but all differed significantly in acid detergent fiber (ADF) concentrations, with normal being highest and \( \text{bm}_1/\text{bm}_3 \) the lowest. Crude protein analysis showed a significantly higher concentration in \( \text{bm}_3 \) than in \( \text{bm}_1/\text{bm}_3 \). Ratios of ADL/ADF and ADL/cellulose presented for stem tissue were consistently lower for the mutants with \( \text{bm}_3 \) and \( \text{bm}_1/\text{bm}_3 \) significantly lower than normal.

A corresponding in vitro study by Lechtenberg et al. (39) indicated that the lignin percentage in \( \text{bm}_3 \) stems was only half that of normal. Leaf blades and sheaths of \( \text{bm}_3 \) were slightly lower in CWC, ADF, and cellulose than normal. The ratio of ADL/ADF was lowest for \( \text{bm}_3 \) which again reflected the low lignin content. In vitro dry matter disappearance (IVDMD) of \( \text{bm}_3 \) was also significantly higher than normal, the \( \text{bm}_3 \) being approximately ten percentage units higher.

Barnes et al. (4) achieved the same IVDMD results on inbred lines. They indicated that the most consistent relationship observed over the leaf, stem, and sheath was the significant negative correlation between ADL and IVDMD. Acid detergent lignin was the single most important variable in predicting IVDMD of stem and sheath tissue, while ADL and cellulose were the most important for predicting dry matter disappearance of the whole plant. They concluded that the reduced lignin content produced in the corn plant by the mutant genes was to a large extent responsible for the improved dry matter disappearance.
Lechtenberg et al. (39) indicated that the \textit{bm}_3 gene is the most effective in reducing ADL. They concluded that their results, along with those reported by Muller et al. (48), indicated that corn silage made from \textit{bm}_3 corn should result in increased production, efficiency of production, or both when the silage is fed to ruminant animals. They cited that yet another advantage of the \textit{bm}_3 gene is its ability to be simply inherited and thus easily incorporated into high yielding corn hybrids.

The problem of consistent inheritance is noted in a digestion study by Gordon and Neudoerffer (22). In this study chopped corn stalks of \textit{bm}_1 and normal plants were supplemented and fed to two groups of three wether sheep. No significant differences in dry matter digestibility were found between the two groups.

The first \textit{in vivo} evaluation of \textit{bm}_3 corn was done by Muller et al. (49). In this study, corn stover silage (whole plants minus ears) of genetically similar normal and \textit{bm}_1 plants was fed \textit{ad libitum} and at 90\% \textit{ad libitum} to two groups of nine ram lambs. Fermentation characteristics were similar for the two silages, however, permanganate lignin (PL) was about 34\% higher in the normal corn silage. A summary of \textit{ad libitum} consumption showed a 29\% greater voluntary intake with \textit{bm}_3 compared with the normal. Although the dry matter intake was greater for \textit{bm}_3, the PL intake was slightly higher for the normal ration. A correlation of -.83 was found between dry matter intake and PL content. Dry matter digestibility was also found to be significantly higher for \textit{bm}_3. Cellulose and hemicellulose digestibilities were also
higher with bm3. Mention of the fact that cellulose and hemicellulose are the major components of CWC and ADF was also made in reference to the digestibility differences of CWC and ADF.

Results of feeding at 90% ad libitum also showed bm3 to be significantly higher in dry matter, CWC, ADF, cellulose, and hemicellulose digestibilities. Results from both trials indicated positive digestibility of lignin. Apparent digestibility of energy was significantly higher for bm3 in both trials.

The above mentioned results led Muller et al. (49) to conclude that the bm3 mutant produced a substantially greater digestible dry matter and energy intake than normal. They attributed this response to the decreased lignin content of bm3 which they said allowed for a faster ruminal degradation rate of cellulose and hemicellulose.

In an effort to test the hypothesis of Muller et al. (49), Lechtenberg et al. (38) conducted a study to determine the effect of lignin concentration on the rate of in vitro CWC and cellulose digestion in corn and to determine if the greater dry matter intake previously observed with bm3 stover silage might be related to a faster rate of digestion. Through the use of digestion rate constants they determined that in vitro disappearance of CWC and cellulose were first-order reactions in which the rate constant was not significantly affected by lignin concentration. They indicated that the amount of lignin in corn tissue does not have a significant effect on the digestion rate constant associated with CWC or cellulose digestion. However, lignin was attributed with affecting the total amount of fiber
digested per unit of time through its effect on the concentration of digestible CWC and cellulose. This means that lignin prevents a portion of the CWC and cellulose from being digested without interfering with the rate of digestion of the remaining CWC and cellulose. They concluded that their results emphasized the importance of lignin in limiting the digestibility of fiber which in turn affects the amount of fiber digested per unit of time.

With the preliminaries of in vitro evaluation and in vivo studies with sheep both demonstrating a greater digestibility of \( \text{bm}_3 \), it was not long before comparative digestion studies were begun on cattle. Colenbrander et al. (9) conducted a multiple trial study which was designed to compare the nutritive value for cattle of whole plant \( \text{bm}_3 \) and normal silages. All animals were individually fed corn silage with a protein supplement added to make the rations isonitrogenous. The \( \text{bm}_3 \) corn silage was significantly higher in crude protein, CWC, ADF, and cellulose and significantly lower in lignin than the normal corn silage. In the first part of their study, two seven-day digestion trials were conducted with four Holstein heifers per silage treatment. Apparent digestibility of \( \text{bm}_3 \) was significantly greater for CWC, ADF, and cellulose.

In the second part of their study, the two silages were fed to 16 Holstein heifers for a period of 52 days. Those animals fed the \( \text{bm}_3 \) silage ration were significantly higher for average daily gain, feed efficiency, and daily intake of digestible CWC. Though not significant, values for daily dry matter intake and daily intake of
digestible dry matter were also higher for heifers fed the \( \text{bm}_3 \) silage.

Another trial by Colenbrander et al. (10) compared \( \text{bm}_3 \) and normal corn stover silages in a feeding and digestion trial. Again, rations were made isonitrogenous with a protein supplement. The \( \text{bm}_3 \) stover silage was significantly lower in lignin, CWC, and ADF but was significantly higher in crude protein. In a 42-day feeding trial with two groups of 10 Holstein heifers, average daily gain, feed efficiency, and all intake measurements were significantly improved for \( \text{bm}_3 \). Two 7-day digestion trials with four Holstein heifers per silage treatment were also conducted. Apparent digestibilities of \( \text{bm}_3 \) were significantly higher for dry matter, C WC, ADF, hemicellulose, and cellulose.

A 1975 cattle feeding trial by Colenbrander et al. (11) showed similar results. Whole plant \( \text{bm}_3 \) and normal corn silages were first evaluated in a 16 week feeding trial with 20 Holstein heifers on each treatment. Later in the trial, digestion trials with replicated seven day collection periods were conducted using four pairs of heifers. The \( \text{bm}_3 \) silage was significantly lower in CWC, ADF, cellulose, and lignin than the normal silage. Results of the feeding trial showed weight gain and daily dry matter intake (% BW) to be significantly greater with \( \text{bm}_3 \). Following the digestion trial, coefficients of apparent digestibility of dry matter, CWC, ADF, hemicellulose, and cellulose were all shown to be significantly higher with \( \text{bm}_3 \) corn silage.
Although several articles have been published concerning the use of brown-midrib silage for sheep and growing cattle, little information is available on the use of the mutant corn for dairy cattle. The only published research has been a short term study by Frenchick et al. (16). In this trial, 24 Holstein cows, past peak lactation, were randomly assigned to two complete diets containing either \( \text{bm}_3 \) or normal whole plant corn silage. The experimental period consisted of a two week segment on a standardization ration, a four week segment on the two experimental rations, and a second two week segment on the standardization ration. Performance during the experimental period was expressed as deviation from standardization. The standardization ration consisted of corn silage from a commercial hybrid. Milk yield was recorded twice daily and milk fat and solids-not-fat were determined weekly. During the last day the cows were on the experimental rations, rumen fluid was collected from all cows and analyzed for pH and volatile fatty acid (VFA) concentration. Composition of the experimental silages varied little in dry matter, crude protein, and crude fiber. However, \( \text{bm}_3 \) was lower in CWC, ADF, and ADL than normal. There were no significant differences in dry matter consumption; however, about 50% of the ration in this study was supplied by ingredients other than silage. Even though intake rates did not differ, cows fed \( \text{bm}_3 \) showed significantly greater body weight gains over the experimental period. Cows fed \( \text{bm}_3 \) produced significantly more milk with a significantly lower milk fat percentage. Milk yield comparisons
on a 4%-fat-corrected basis; however, showed no significant differences between treatments.

The results of rumen fluid analysis showed a significantly lower pH and a significantly higher concentration of total VFA's for cows fed bm-j. No differences were shown in molar concentrations of the various volatile acids between the two silages.

They concluded that the small increases in milk production and in body weight gain may have resulted from improved utilization of bm-j silage. Because the differences in molar proportions of the various VFA's were insignificant, they could not explain the differences noted in milk fat.
MATERIALS AND METHODS

Trial 1

A 1.13 hectare plot of \( \text{bm}_3 \) corn was planted to provide sufficient silage for a short intake and lactation trial, and a digestion study with lactating Holstein cows. A 1.26 hectare plot of genetically similar normal corn was planted as a control. The silages were harvested at 129 days after planting (first frost was two weeks previous to harvesting). The two silages were then placed into two separate bunker silos, packed, and covered with black 4 mm polyethylene tarp. Four months elapsed between ensiling time and initiation of the feeding trial.

The lactation and digestion trial was designed to obtain data on ad libitum intake, digestibility, and milk yield. Ten Holstein cows were paired by previous lactation curve, estimated producing ability (EPA), and number of previous lactations. Paired animals were randomly assigned to either the \( \text{bm}_3 \) or normal silage ration. After calving, cows were placed on a ration consisting of normal corn silage (no hay) and a 22% crude protein grain ration (Table 3). The grain ration was formulated to supply required amounts of protein, vitamins, and minerals according to NRC (50) requirements. Cows assigned to the \( \text{bm}_3 \) ration were switched to their experimental ration one week postcalving. The length of the trial was seven weeks starting the second week postcalving which is hereafter referred to as week one. This time period corresponds to the time of insufficient energy intake in relation to the increasing milk or energy output.
## TABLE 3. Composition of grain rations fed during trial 1.

<table>
<thead>
<tr>
<th>Ingredienta</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolled oats</td>
<td>44</td>
</tr>
<tr>
<td>Ground shelled corn</td>
<td>22</td>
</tr>
<tr>
<td>Soybean meal, (50% CP)</td>
<td>26</td>
</tr>
<tr>
<td>Molasses</td>
<td>5</td>
</tr>
<tr>
<td>Trace-mineralized-salt</td>
<td>1</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>1</td>
</tr>
<tr>
<td>Limestone (Calcium carbonate)</td>
<td>1</td>
</tr>
</tbody>
</table>

aVitamin A, 1200 IU/kg; vitamin D, 120 IU/kg added to grain ration.

Cows were fed individually and offered their rations in two equal portions daily. Both rations were offered at a 60:40 silage:grain ratio (DM basis). Milk yield was weighed and recorded daily and sampled once weekly at two consecutive milkings. Body weights were determined weekly on two successive days. Silages and the grain ration were sampled weekly and frozen for later chemical analyses.

A digestion trial was conducted with four cows on each ration during the 4th to 6th week of the trial. Samples of feed, feed refusal, milk, urine, and feces were collected and weighed daily for a four day period. Representative samples of feces and urine were frozen and later composited according to the proportion excreted daily by each cow. Urine samples were collected with a sterile Bardex Foley urinary catheter.\(^1\) Collected urine was then stored in 22.7 liter containers containing 2 ml of toluene as a preservative.

\(^1\)C. R. Bard, Inc., Murray Hill, New Jersey.
On the last day of the digestion study, rumen samples were collected via stomach tube initially and at 3, 6, 9, and 12 h following silage feeding. Mercuric chloride was added (0.5 ml) to 10 ml of rumen fluid to stop bacterial action. Samples were measured immediately for pH, acidified, centrifuged, and the supernatant was later analyzed for volatile fatty acids (VFA) by gas-liquid chromatography with a neopentylglycol succinate column as described by Baumgardt (5) and analyzed for ammoniacal nitrogen as described by Chaney and Marbach (8).

Samples from the seven week trial and digestion study were dried at 60°C in a forced air oven. The dried portion was analyzed by methods of Goering and Van Soest (19) to determine CWC, ADF, and PL. Total nitrogen content of dry grain and refusals and of wet silage, feces, and urine was determined using the Kjeldahl method (3). Gross energy was determined with a Parr oxygen bomb calorimeter. Silage extracts from weekly samples were analyzed for pH (72), VFA's (5), lactic acid (35), and ammoniacal nitrogen (8).

Weekly milk samples were analyzed for protein via the Kjeldahl method (3). Milk fat was determined by the use of a Milko-tester MK-II3 and Mojonnier total solids was determined as described by Newlander and Atherton (51).

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3 N. Foss Electric, Hillerod, Denmark.
Statistical analyses were performed using the least-squares analysis of variance procedure described by Steele and Torre (59).

**Trial 2.**

Two 1.45 hectare plots of both \( \text{bm}_3 \) and a genetically similar normal corn were planted to provide sufficient silage for five Holstein cows on each ration for an eight week period. Corn was harvested 118 days following planting and within three days of the first frost. Methods of harvesting and storing the silages were similar to those of trial 1. One month elapsed between the time of ensiling and initiation of the feeding trial.

Ten Holstein cows were paired according to previous lactation curve, EPA, and number of previous lactations. Paired animals were randomly assigned to the two rations. After calving, the cows were group fed corn silage and 2.25 kg alfalfa hay per cow daily plus a grain ration fed at the rate of 1 kg to 3 kg milk. Beginning the 5th week post calving, cows were individually fed a ration of normal corn silage ad libitum and a grain ration at the rate of 1 kg grain to 4 kg of milk.

Following this one week preliminary period, cows were started on either the \( \text{bm}_3 \) or normal corn silage ration for an eight week period. Both silages were fed ad libitum with the concentrate twice daily and refusals measured once daily. A 43% crude protein concentrate ration (Table 4) was fed according to the schedule in Table 5. This ration and feeding schedule was calculated to meet the protein, mineral, and vitamin requirements of the cows according to NRC (50) requirements.
Thus, with less daily concentrate intake than in trial 1, a more critical evaluation of the feeding or energy value of the silage could be made.

TABLE 4. Composition of concentrate ration fed during trial 2.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean meal, (47.5% CP)</td>
<td>90.0</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>5.0</td>
</tr>
<tr>
<td>Trace-mineralized-salt</td>
<td>2.5</td>
</tr>
<tr>
<td>Limestone (calcium carbonate)</td>
<td>2.5</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Vitamin A, 3629 IU/kg; vitamin D, 907 IU/kg added to grain ration.

TABLE 5. Method of feeding concentrate according to milk production (trial 2).

<table>
<thead>
<tr>
<th>Milk (kg/day)</th>
<th>Concentrate fed (kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>0.45</td>
</tr>
<tr>
<td>14</td>
<td>1.30</td>
</tr>
<tr>
<td>19</td>
<td>2.15</td>
</tr>
<tr>
<td>24</td>
<td>3.00</td>
</tr>
<tr>
<td>29</td>
<td>3.85</td>
</tr>
<tr>
<td>34</td>
<td>4.70</td>
</tr>
<tr>
<td>39</td>
<td>5.55</td>
</tr>
<tr>
<td>44</td>
<td>6.40</td>
</tr>
</tbody>
</table>

Methods and procedures for the eight week trial were similar to those in trial 1.

Digestibility studies were conducted with four cows from each ration during the 6th or 7th week following ration assignment or 12th
to 13th week postcalving. Methods of collection and analyses were similar to those in trial 1. Rumen samples were collected at 0, 4, 8, and 12 h after silage feeding following the last day of the digestion study.
RESULTS AND DISCUSSION

Trial 1

The fermentation characteristics and composition of the corn silages fed during trial 1 are presented in Table 6. Fermentation was more desirable for the bm3 as evidenced by the lower pH (P < .05) and higher acid concentration. Concentration of propionic acid was higher (P < .10) for bm3. This disagrees with the study by Frenchick et al. (16) which found no difference in molar concentrations of organic acids. Cellulose (P < .05), ADF (P < .05), and PL (P < .01) were all lower while hemicellulose was higher (P < .01) for bm3. Lignin was 24% higher for normal corn silage compared to bm3. These findings generally agree with those reported in earlier studies (9,10,11,16,49). Nitrogen content was lower (P < .05) in bm3 corn silage. Higher nitrogen concentrations were found in two earlier studies by Colenbrander et al. (9,10).

Daily dry matter intakes (DMI) are shown in Table 7. Cows fed the bm3 ration consumed more silage and grain than cows fed the normal ration with total DMI (% BW) being 19% greater (P < .01) on the bm3 ration. Daily DMI (% BW) summarized by week was consistently higher (P < .05) for bm3 (Fig. 1). Since week one corresponds to week two postcalving, bm3 silage may provide a method for high producing cows to consume more feed in early lactation. The increased DMI for bm3 ration agrees with previous studies with sheep (48) and cattle (9,10). However, Frenchick et al. (16) found no difference in DMI by dairy cows.
TABLE 6. Average fermentation characteristics and composition of weekly samples of \( bm_3 \) and N corn silages fed during trial 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ration</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( bm_3 )</td>
<td>N</td>
</tr>
<tr>
<td>( C_2, % ) DM</td>
<td>2.29</td>
<td>1.92</td>
</tr>
<tr>
<td>( C_3, % ) DM</td>
<td>0.16a</td>
<td>0.08b</td>
</tr>
<tr>
<td>( C_4, % ) DM</td>
<td>0.10</td>
<td>0.14</td>
</tr>
<tr>
<td>Lactic acid, % DM</td>
<td>5.53</td>
<td>4.47</td>
</tr>
<tr>
<td>Silage DM, %</td>
<td>32.70</td>
<td>33.55</td>
</tr>
<tr>
<td>CWC, % DM</td>
<td>57.56</td>
<td>57.37</td>
</tr>
<tr>
<td>ADF, % DM</td>
<td>28.11c</td>
<td>31.90d</td>
</tr>
<tr>
<td>PL, % DM</td>
<td>4.89e</td>
<td>6.43d</td>
</tr>
<tr>
<td>Cellulose, % DM</td>
<td>21.88c</td>
<td>24.11d</td>
</tr>
<tr>
<td>Hemicellulose, % DM</td>
<td>29.45e</td>
<td>25.46f</td>
</tr>
<tr>
<td>Nitrogen, % DM</td>
<td>1.68c</td>
<td>1.77d</td>
</tr>
<tr>
<td>pH</td>
<td>4.18c</td>
<td>4.67d</td>
</tr>
</tbody>
</table>

\( ab (P < .10) \)
\( cd (P < .05) \)
\( ef (P < .01) \)

TABLE 7. Daily dry matter intakes of cows receiving \( bm_3 \) and N corn silage rations during trial 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ration</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( bm_3 )</td>
<td>N</td>
</tr>
<tr>
<td>Total DMI, kg</td>
<td>20.15a</td>
<td>18.63b</td>
</tr>
<tr>
<td>Total DMI, % BW</td>
<td>3.15c</td>
<td>2.72d</td>
</tr>
<tr>
<td>Silage DMI, kg</td>
<td>11.94a</td>
<td>10.82b</td>
</tr>
<tr>
<td>Silage DMI, % BW</td>
<td>1.86a</td>
<td>1.58b</td>
</tr>
<tr>
<td>Grain DMI, kg</td>
<td>8.30a</td>
<td>7.81d</td>
</tr>
<tr>
<td>Grain DMI, % BW</td>
<td>1.29c</td>
<td>1.14d</td>
</tr>
<tr>
<td>BW changes, kg (7 wk)</td>
<td>-32.52</td>
<td>-46.60</td>
</tr>
</tbody>
</table>

\( ab (P < .10) \)
\( cd (P < .01) \)
FIG. 1. Daily dry matter intake per week of experiment by cows receiving bm, and normal corn silage rations during trial 1.
DAILY DRY MATTER INTAKE (% BW)

WEEK OF EXPERIMENT

0 1 2 3 4 5 6 7

2.0 2.5 3.0 3.5

BROWN MIDRIB
NORMAL
fed the two silages. Body weight (BW) changes did not differ significantly. An earlier trial (16) with dairy cattle reported significantly higher BW gains by cows fed \( \text{bm}_3 \) silage.

Daily milk and 4% fat-corrected-milk (FCM) yields (Table 8) showed no significant differences between rations other than a higher (\( P < .10 \)) milk fat test for cows fed the \( \text{bm}_3 \) ration. No explanation is apparent for this difference. These results differed from those of Frenchick et al. (16) which reported a significant increase in milk production and a significant decrease in milk fat by cattle fed \( \text{bm}_3 \) silage.

### TABLE 8. Yield and composition of milk from lactating dairy cattle receiving either \( \text{bm}_3 \) or N corn silage rations during trial 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>( \text{bm}_3 )</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk yield per day, kg</td>
<td>31.30</td>
<td>32.90</td>
<td>.66</td>
</tr>
<tr>
<td>FCM per day, kg</td>
<td>33.90</td>
<td>34.00</td>
<td>.92</td>
</tr>
<tr>
<td>Fat, %</td>
<td>4.52\text{a}</td>
<td>4.23</td>
<td>.09</td>
</tr>
<tr>
<td>Protein, %</td>
<td>3.22</td>
<td>3.12</td>
<td>.03</td>
</tr>
<tr>
<td>Total solids, %</td>
<td>13.12</td>
<td>12.91</td>
<td>.09</td>
</tr>
<tr>
<td>Fat per day, kg</td>
<td>1.43</td>
<td>1.39</td>
<td>.05</td>
</tr>
<tr>
<td>Protein per day, kg</td>
<td>1.00</td>
<td>1.02</td>
<td>.02</td>
</tr>
<tr>
<td>Total solids per day, kg</td>
<td>4.12</td>
<td>4.24</td>
<td>.10</td>
</tr>
</tbody>
</table>

\( \text{ab}(P < .10) \)

Data from the digestion study are shown in Tables 9 through 15. No significant differences were found for DMI or DM digested (Table 9) although both were higher for the \( \text{bm}_3 \) ration. Similarly, all intake and digestion parameters for cellulose (Table 10), hemicellulose
### TABLE 9. Dry matter digestion data for cows receiving bm₃ and N corn silage rations during trial 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>bm₃</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total DMI, kg/day</td>
<td>21.28</td>
<td>18.27</td>
<td>1.05</td>
</tr>
<tr>
<td>Total DMI, % BW</td>
<td>3.40</td>
<td>2.81</td>
<td>.20</td>
</tr>
<tr>
<td>Total DMI, g/kg W⁻⁷⁵</td>
<td>17.02</td>
<td>14.20</td>
<td>.96</td>
</tr>
<tr>
<td>Silage DMI, % BW</td>
<td>1.96</td>
<td>1.60</td>
<td>.16</td>
</tr>
<tr>
<td>Silage DMI, g/kg W⁻⁷⁵</td>
<td>9.80</td>
<td>8.07</td>
<td>.75</td>
</tr>
<tr>
<td>Grain DMI, % BW</td>
<td>1.44</td>
<td>1.22</td>
<td>.06</td>
</tr>
<tr>
<td>DM digested, %</td>
<td>65.82</td>
<td>63.95</td>
<td>1.12</td>
</tr>
<tr>
<td>Digestible DMI, kg/day</td>
<td>14.02</td>
<td>11.69</td>
<td>.76</td>
</tr>
</tbody>
</table>

### TABLE 10. Cellulose digestion data for cows receiving bm₃ and N corn silage rations during trial 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>bm₃</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cellulose intake, kg/day</td>
<td>3.39</td>
<td>3.08</td>
<td>.26</td>
</tr>
<tr>
<td>Total cellulose intake, % BW</td>
<td>.54</td>
<td>.47</td>
<td>.04</td>
</tr>
<tr>
<td>Total cellulose intake, g/kg W⁻⁷⁵</td>
<td>2.70</td>
<td>2.39</td>
<td>.20</td>
</tr>
<tr>
<td>Silage cellulose intake, % BW</td>
<td>.41</td>
<td>.37</td>
<td>.03</td>
</tr>
<tr>
<td>Silage cellulose intake, g/kg W⁻⁷⁵</td>
<td>2.06</td>
<td>1.86</td>
<td>.16</td>
</tr>
<tr>
<td>Grain cellulose intake, % BW</td>
<td>.13</td>
<td>.10</td>
<td>.02</td>
</tr>
<tr>
<td>Cellulose digested, %</td>
<td>52.04</td>
<td>48.21</td>
<td>3.37</td>
</tr>
<tr>
<td>Digested cellulose intake, kg/day</td>
<td>1.80</td>
<td>1.54</td>
<td>.21</td>
</tr>
</tbody>
</table>
TABLE 11. Hemicellulose digestion data for cows receiving \textit{bm}3 and N corn silage rations during trial 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ration</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total hemicellulose intake, kg/day</td>
<td>6.42</td>
<td>5.36</td>
<td>.40</td>
</tr>
<tr>
<td>Total hemicellulose intake, % BW</td>
<td>1.03</td>
<td>.83</td>
<td>.08</td>
</tr>
<tr>
<td>Total hemicellulose intake, g/kg W\textsuperscript{.75}</td>
<td>5.15</td>
<td>4.17</td>
<td>.37</td>
</tr>
<tr>
<td>Silage hemicellulose intake, % BW</td>
<td>.60</td>
<td>.46</td>
<td>.05</td>
</tr>
<tr>
<td>Silage hemicellulose intake, g/kg W\textsuperscript{.75}</td>
<td>2.98</td>
<td>2.31</td>
<td>.26</td>
</tr>
<tr>
<td>Grain hemicellulose intake, % BW</td>
<td>.43</td>
<td>.37</td>
<td>.04</td>
</tr>
<tr>
<td>Hemicellulose digested, %</td>
<td>70.95</td>
<td>70.00</td>
<td>1.78</td>
</tr>
<tr>
<td>Digested hemicellulose intake, kg/day</td>
<td>4.59</td>
<td>3.76</td>
<td>.37</td>
</tr>
</tbody>
</table>

TABLE 12. Permanganate lignin digestion data for cows receiving \textit{bm}3 and N corn silage rations during trial 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ration</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total PL intake, kg/day</td>
<td>.90</td>
<td>.94</td>
<td>.06</td>
</tr>
<tr>
<td>Total PL intake, % BW</td>
<td>.15</td>
<td>.15</td>
<td>.01</td>
</tr>
<tr>
<td>Total PL intake, g/kg W\textsuperscript{.75}</td>
<td>.72</td>
<td>.74</td>
<td>.06</td>
</tr>
<tr>
<td>Silage PL intake, % BW</td>
<td>.11</td>
<td>.11</td>
<td>.01</td>
</tr>
<tr>
<td>Silage PL intake, g/kg W\textsuperscript{.75}</td>
<td>.51</td>
<td>.56</td>
<td>.06</td>
</tr>
<tr>
<td>Grain PL intake, % BW</td>
<td>.04</td>
<td>.04</td>
<td>.00</td>
</tr>
<tr>
<td>PL digested, %</td>
<td>41.76</td>
<td>39.53</td>
<td>4.31</td>
</tr>
<tr>
<td>Digested PL intake, kg/day</td>
<td>.38</td>
<td>.38</td>
<td>.05</td>
</tr>
</tbody>
</table>
TABLE 13. Cell wall contents digestion data for cows receiving bm\textsubscript{3} and N corn silage rations during trial 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ration</th>
<th>bm\textsubscript{3}</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total CWC intake, kg/day</td>
<td></td>
<td>11.03</td>
<td>9.60</td>
<td>.63</td>
</tr>
<tr>
<td>Total CWC intake, % BW</td>
<td></td>
<td>1.77</td>
<td>1.48</td>
<td>.12</td>
</tr>
<tr>
<td>Total CWC intake, g/kg W\textsubscript{75}</td>
<td></td>
<td>8.83</td>
<td>7.46</td>
<td>.57</td>
</tr>
<tr>
<td>Silage CWC intake, % BW</td>
<td></td>
<td>1.15</td>
<td>.96</td>
<td>.10</td>
</tr>
<tr>
<td>Silage CWC intake, g/kg W\textsubscript{75}</td>
<td></td>
<td>5.72</td>
<td>4.82</td>
<td>.49</td>
</tr>
<tr>
<td>Grain CWC intake, % BW</td>
<td></td>
<td>.62\textsuperscript{a}</td>
<td>.52</td>
<td>.03</td>
</tr>
<tr>
<td>CWC digested, %</td>
<td></td>
<td>61.81</td>
<td>58.89</td>
<td>1.68</td>
</tr>
<tr>
<td>Digested CWC intake, kg/day</td>
<td></td>
<td>6.86</td>
<td>5.67</td>
<td>.50</td>
</tr>
</tbody>
</table>

\textsuperscript{ab}(P < .01)

TABLE 14. Energy digestion data for cows receiving bm\textsubscript{3} and N corn silage rations during trial 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ration</th>
<th>bm\textsubscript{3}</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total intake, Mcal/day</td>
<td></td>
<td>84.98</td>
<td>73.85</td>
<td>4.30</td>
</tr>
<tr>
<td>Total intake, Mcal/kg BW</td>
<td></td>
<td>.14</td>
<td>.11</td>
<td>.01</td>
</tr>
<tr>
<td>Silage intake, Mcal/kg BW</td>
<td></td>
<td>.08</td>
<td>.06</td>
<td>.01</td>
</tr>
<tr>
<td>Grain intake, Mcal/kg BW</td>
<td></td>
<td>.06</td>
<td>.05</td>
<td>.00</td>
</tr>
<tr>
<td>Gross energy digested, %</td>
<td></td>
<td>64.07</td>
<td>61.77</td>
<td>1.11</td>
</tr>
<tr>
<td>DEI, Mcal/day</td>
<td></td>
<td>54.51</td>
<td>45.62</td>
<td>3.07</td>
</tr>
</tbody>
</table>
TABLE 15. Nitrogen utilization by cows receiving \text{bm}_3\text{ and N corn silage rations} during trial 1.

<table>
<thead>
<tr>
<th>Component</th>
<th>Ration</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>\text{bm}_3</td>
<td>N</td>
</tr>
<tr>
<td>N intake; g/day</td>
<td>502.83</td>
<td>471.68</td>
</tr>
<tr>
<td>N absorbed, g/day(^a)</td>
<td>326.34</td>
<td>325.91</td>
</tr>
<tr>
<td>N excreted, g/day(^a)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feces</td>
<td>176.49</td>
<td>145.77</td>
</tr>
<tr>
<td>Urine</td>
<td>145.38</td>
<td>153.14</td>
</tr>
<tr>
<td>Milk</td>
<td>147.97</td>
<td>143.53</td>
</tr>
<tr>
<td>N retained(^b)</td>
<td>32.99</td>
<td>29.23</td>
</tr>
<tr>
<td>Productive N(^b)</td>
<td>180.96</td>
<td>172.76</td>
</tr>
<tr>
<td>N, % intake</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feces</td>
<td>35.55</td>
<td>30.87</td>
</tr>
<tr>
<td>Urine</td>
<td>29.09</td>
<td>32.53</td>
</tr>
<tr>
<td>Milk</td>
<td>29.85</td>
<td>30.52</td>
</tr>
<tr>
<td>Productive N(^b)</td>
<td>35.36</td>
<td>36.60</td>
</tr>
<tr>
<td>N, % absorbed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urine</td>
<td>46.56</td>
<td>47.04</td>
</tr>
<tr>
<td>Milk</td>
<td>47.13</td>
<td>44.18</td>
</tr>
<tr>
<td>Productive N(^b)</td>
<td>53.44</td>
<td>52.96</td>
</tr>
<tr>
<td>Digested N intake, kg/day</td>
<td>.32</td>
<td>.33</td>
</tr>
<tr>
<td>Apparent N digested, %</td>
<td>64.45</td>
<td>69.13</td>
</tr>
</tbody>
</table>

\(^a\)Absorbed = N intake - N feces

\(^b\)Productive Nitrogen = N milk + N retained
(Table 11), PL (Table 12), and CWC (Table 13) showed no significant differences between rations, although the \textbf{bm}_3 ration digestibility was higher for all components. Although nonsignificant, cows fed the \textbf{bm}_3 ration consumed 19\% more digestible DMI (Table 9) than cows fed the normal ration, an increased consumption of similar magnitude to that previously noted with sheep (49) and cattle (9,10,11). This data does disagree with other research with corn stover (49) and corn silage (9, 10) in which the increased digestibility of \textbf{bm}_3 silage was significant.

Energy digestion data for the two rations (Table 14) showed no significant differences although total energy intake and DEI (Mcal/day) were both higher for \textbf{bm}_3. These results are similar to sheep trials where energy intake and digestibility were significantly greater for \textbf{bm}_3 stover silage (49). Calculated NE values according to methods of Moe et al. (45) are 1.38 and 1.33 Mcal/kg for \textbf{bm}_3 and normal rations.

Nitrogen utilization data is shown in Table 15. Though not statistically significant, nitrogen intake was higher for \textbf{bm}_3, primarily because of the higher total DMI. However, nitrogen absorbed and productive nitrogen were similar for the two rations.

Rumen VFA results (Fig. 2) show that at 0 h (prior to feeding), concentrations of individual and total VFA's were higher for cows fed the \textbf{bm}_3 ration than those fed the normal ration. At 3 h postfeeding, concentrations of butyric and propionic acids were higher for cows fed the \textbf{bm}_3 rations while acetic acid concentration was higher for normal and total VFA concentrations were similar. All individual and total VFA's were higher for cows fed the normal ration at 6 h. At 9 h, the
FIG. 2. Total and individual rumen volatile fatty acid concentrations over a 12 h period for cows fed bmr and normal corn silage rations during trial 1.
trend was reversed and all concentrations were higher for bm₃. At 12 h, total and individual acids dropped for the bm₃ ration while concentrations for cows fed the normal ration remained stable and were higher than for cows fed the bm₃ ration. Frenchick et al. (16) showed significantly higher total VFA levels for cows fed bm₃ silage, but found no differences in individual acid concentrations. In contrast, our study showed trends toward higher concentrations of propionic and butyric acid for cows fed bm₃ silage. In light of 19% greater digestible DMI by cows fed the bm₃ ration, higher concentrations of VFA's would be expected.

Ruminal pH (Fig. 3) was lower at 0, 3, 6, and 9 h with the bm₃ ration. At 12 h, pH levels of both rations were identical. However, the average pH level was not significantly different between rations. This differed from other research (16) which reported a significantly lower ruminal pH from animals fed bm₃ silage.

Rumen ammoniacal nitrogen concentrations (Fig. 3) were lower at all intervals for cows fed the bm₃ ration. Concentrations on the normal ration peaked at 0 h and steadily declined to 9 h before rising at 12 h. Concentrations from cows fed the bm₃ ration peaked at 3 h, declined at 6 h, and rose steadily thereafter. Over all sampling times, ammoniacal nitrogen concentrations were higher (P < .10) for cows fed the normal ration (Appendix Table 3).

**Trial 2**

The fermentation characteristics and composition of the corn silages fed during trial 2 are presented in Table 16. Fermentation
FIG. 3. Rumen pH and ammoniacal nitrogen concentrations over a 12 h period for cows fed bm\textsubscript{3} and normal corn silage rations during trial 1.
The graphs show the changes in pH and ruminal ammonia levels over time.

**Top Graph:**
- **pH** changes from 6.5 to 6.9 over 0 to 12 hours.
- **Bm3** and **NORMAL** lines are shown.

**Bottom Graph:**
- **Ruminal Ammonia** (mg/100ml) changes from 4.5 to 7.0 over 0 to 12 hours.
- **Bm3** and **NORMAL** lines are shown.
TABLE 16. Average fermentation characteristics and composition of weekly samples of bm3 and N corn silages fed during trial 2.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ration</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bm3</td>
<td>N</td>
</tr>
<tr>
<td>C2, % DM</td>
<td>5.40a</td>
<td>2.61b</td>
</tr>
<tr>
<td>C3, % DM</td>
<td>.09a</td>
<td>.17b</td>
</tr>
<tr>
<td>C4, % DM</td>
<td>.11</td>
<td>.21</td>
</tr>
<tr>
<td>Lactic acid, % DM</td>
<td>15.25c</td>
<td>7.40d</td>
</tr>
<tr>
<td>Silage DM, %</td>
<td>27.00c</td>
<td>32.75d</td>
</tr>
<tr>
<td>CWC, % DM</td>
<td>55.57c</td>
<td>60.03d</td>
</tr>
<tr>
<td>ADF, % DM</td>
<td>29.95c</td>
<td>27.87d</td>
</tr>
<tr>
<td>PL, % DM</td>
<td>6.45</td>
<td>6.03</td>
</tr>
<tr>
<td>Cellulose, % DM</td>
<td>21.38a</td>
<td>19.74b</td>
</tr>
<tr>
<td>Hemicellulose, % DM</td>
<td>25.60c</td>
<td>32.16d</td>
</tr>
<tr>
<td>Nitrogen, % DM</td>
<td>2.10c</td>
<td>1.67d</td>
</tr>
<tr>
<td>pH</td>
<td>4.17a</td>
<td>4.39b</td>
</tr>
</tbody>
</table>

*ab*(P < .05)

*cd*(P < .01)
characteristics are more desirable for the \textit{bm}_3 silage in terms of lowered pH (P < .05) and higher lactic acid concentration (P < .01). The lower DM content (P < .01) of \textit{bm}_3 may have been a factor affecting fermentation. Cellulose (P < .05) and ADF (P < .01) levels were higher while CWC (P < .01) and hemicellulose (P < .01) were lower for \textit{bm}_3 silages than for normal. Lignin levels were not significantly different. Results of previous studies (9,10,11,16) are inconclusive upon the level of various fiber components. The higher levels of ADF and cellulose noted here along with alterations in other nutrient components may have been the result of high weed content in the \textit{bm}_3 silage. Nitrogen content was higher (P < .05) in \textit{bm}_3. This disagrees with data from trial 1 but corresponds with two previous studies (9,10).

All parameters of daily DMI (Table 17) were higher (P < .01 and P < .05) for cows fed the \textit{bm}_3 ration. With the exception of week one, daily DMI summarized by week was higher (P < .05) for cows fed the \textit{bm}_3 ration (Fig. 4). Body weight gain for the eight week trial period was higher (P < .01) by cows fed \textit{bm}_3. This is in agreement with a previous study with dairy cattle (16).

Analysis of total milk yields and component yields showed no significant differences between rations (Table 18). These results differ from those of Frenchick et al. (16) which reported significantly higher milk production and significantly lower milk fat percent from cows fed \textit{bm}_3.

Data from the digestion study are shown in Tables 19 through 25. Cows fed \textit{bm}_3 silage had a 23.17% increase (P < .05) in digestible DMI.
TABLE 17. Daily dry matter intakes of cows receiving bm\textsubscript{3} and N corn silage rations during trial 2.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ration</th>
<th>bm\textsubscript{3}</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total DMI, kg</td>
<td></td>
<td>20.69\textsuperscript{c}</td>
<td>17.63\textsuperscript{d}</td>
<td>.28</td>
</tr>
<tr>
<td>Total DMI, % BW</td>
<td></td>
<td>3.52\textsuperscript{c}</td>
<td>3.08\textsuperscript{d}</td>
<td>.04</td>
</tr>
<tr>
<td>Silage DMI, kg</td>
<td></td>
<td>17.62\textsuperscript{c}</td>
<td>14.95\textsuperscript{d}</td>
<td>.26</td>
</tr>
<tr>
<td>Silage DMI, % BW</td>
<td></td>
<td>2.99\textsuperscript{c}</td>
<td>2.61\textsuperscript{d}</td>
<td>.06</td>
</tr>
<tr>
<td>Concentrate DMI, kg</td>
<td></td>
<td>3.08\textsuperscript{c}</td>
<td>2.60\textsuperscript{d}</td>
<td>.06</td>
</tr>
<tr>
<td>Concentrate DMI, % BW</td>
<td></td>
<td>.52\textsuperscript{a}</td>
<td>.47\textsuperscript{b}</td>
<td>.01</td>
</tr>
<tr>
<td>BW changes, kg (8 wk)</td>
<td></td>
<td>49.58\textsuperscript{c}</td>
<td>7.08\textsuperscript{d}</td>
<td>24.07</td>
</tr>
</tbody>
</table>

\textsuperscript{ab}(P<.05) \hspace{1cm} \textsuperscript{cd}(P<.01)

TABLE 18. Yield and composition of milk from lactating dairy cattle receiving either bm\textsubscript{3} or N corn silage rations during trial 2.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ration</th>
<th>bm\textsubscript{3}</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk yield per day, kg</td>
<td></td>
<td>23.39</td>
<td>22.56</td>
<td>.36</td>
</tr>
<tr>
<td>FCM per day, kg</td>
<td></td>
<td>22.69</td>
<td>22.00</td>
<td>.39</td>
</tr>
<tr>
<td>Fat, %</td>
<td></td>
<td>3.82</td>
<td>3.84</td>
<td>.07</td>
</tr>
<tr>
<td>Protein, %</td>
<td></td>
<td>2.87</td>
<td>2.89</td>
<td>.02</td>
</tr>
<tr>
<td>Total solids, %</td>
<td></td>
<td>12.17</td>
<td>12.32</td>
<td>.08</td>
</tr>
<tr>
<td>Fat per day, kg</td>
<td></td>
<td>.89</td>
<td>.87</td>
<td>.02</td>
</tr>
<tr>
<td>Protein per day, kg</td>
<td></td>
<td>.67</td>
<td>.65</td>
<td>.01</td>
</tr>
<tr>
<td>Total solids per day, kg</td>
<td></td>
<td>2.84</td>
<td>2.70</td>
<td>.04</td>
</tr>
</tbody>
</table>
FIG. 4. Daily dry matter intake per week of experiment by cows receiving bm and normal corn silage rations during trial 2.
TABLE 19. Dry matter digestion data for cows receiving bm<sub>3</sub> and N corn silage rations during trial 2.

<table>
<thead>
<tr>
<th>Item</th>
<th>bm&lt;sub&gt;3&lt;/sub&gt;</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total DMI, kg/day</td>
<td>23.46&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17.43&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.91</td>
</tr>
<tr>
<td>Total DMI, % BW</td>
<td>3.52&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.08&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.18</td>
</tr>
<tr>
<td>Total DMI, g/kg WT&lt;sup&gt;75&lt;/sup&gt;</td>
<td>19.78&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15.17&lt;sup&gt;d&lt;/sup&gt;</td>
<td>.81</td>
</tr>
<tr>
<td>Silage DMI, % BW</td>
<td>3.26&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.49&lt;sup&gt;d&lt;/sup&gt;</td>
<td>.09</td>
</tr>
<tr>
<td>Silage DMI, g/kg WT&lt;sup&gt;75&lt;/sup&gt;</td>
<td>16.01&lt;sup&gt;c&lt;/sup&gt;</td>
<td>12.08&lt;sup&gt;d&lt;/sup&gt;</td>
<td>.36</td>
</tr>
<tr>
<td>Concentrate DMI, % BW</td>
<td>.77</td>
<td>.63</td>
<td>.13</td>
</tr>
<tr>
<td>DMI digested, %</td>
<td>59.61</td>
<td>61.45</td>
<td>2.37</td>
</tr>
<tr>
<td>Digested DMI, kg/day</td>
<td>14.07</td>
<td>10.81</td>
<td>.95</td>
</tr>
</tbody>
</table>

<sup>ab</sup>(P < .05)  
<sup>cd</sup>(P < .01)

TABLE 20. Cellulose digestion data for cows receiving bm<sub>3</sub> and N corn silage rations during trial 2.

<table>
<thead>
<tr>
<th>Item</th>
<th>bm&lt;sub&gt;3&lt;/sub&gt;</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cellulose intake, kg/day</td>
<td>3.81&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.66&lt;sup&gt;d&lt;/sup&gt;</td>
<td>.13</td>
</tr>
<tr>
<td>Total cellulose intake, % BW</td>
<td>.65&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.48&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.03</td>
</tr>
<tr>
<td>Total cellulose intake, g/kg WT&lt;sup&gt;75&lt;/sup&gt;</td>
<td>3.20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.33&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.13</td>
</tr>
<tr>
<td>Silage cellulose intake, % BW</td>
<td>.65&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.48&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.03</td>
</tr>
<tr>
<td>Silage cellulose intake, g/kg WT&lt;sup&gt;75&lt;/sup&gt;</td>
<td>3.20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.33&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.13</td>
</tr>
<tr>
<td>Concentrate cellulose intake, % BW</td>
<td>7.93&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.09&lt;sup&gt;d&lt;/sup&gt;</td>
<td>.36</td>
</tr>
<tr>
<td>Percent cellulose digested</td>
<td>47.33</td>
<td>51.80</td>
<td>3.56</td>
</tr>
<tr>
<td>Digested cellulose intake, kg/day</td>
<td>1.83</td>
<td>1.39</td>
<td>.16</td>
</tr>
</tbody>
</table>

<sup>ab</sup>(P < .05)  
<sup>cd</sup>(P < .01)
### TABLE 21. Permanganate lignin digestion data for cows receiving bm3 and N corn silage rations during trial 2.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ration</th>
<th>bm3</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total PL intake, kg/day</td>
<td></td>
<td>1.75a</td>
<td>1.16b</td>
<td>.06</td>
</tr>
<tr>
<td>Total PL intake, % BW</td>
<td></td>
<td>.30a</td>
<td>.21b</td>
<td>.01</td>
</tr>
<tr>
<td>Total PL intake, g/kg W·75</td>
<td></td>
<td>1.47a</td>
<td>.01b</td>
<td>.05</td>
</tr>
<tr>
<td>Silage PL intake, % BW</td>
<td></td>
<td>.28a</td>
<td>.19b</td>
<td>.01</td>
</tr>
<tr>
<td>Silage PL intake, g/kg W·75</td>
<td></td>
<td>1.37a</td>
<td>.93b</td>
<td>.04</td>
</tr>
<tr>
<td>Concentrate PL intake, % BW</td>
<td></td>
<td>.02</td>
<td>.02</td>
<td>.00</td>
</tr>
<tr>
<td>Percent PL digested</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digestive PL intake, kg/day</td>
<td></td>
<td>.59</td>
<td>.37</td>
<td>.07</td>
</tr>
</tbody>
</table>

\(ab(P < .01)\)

### TABLE 22. Cell wall contents digestion data for cows receiving bm3 and N corn silage rations during trial 2.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ration</th>
<th>bm3</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total CWC intake, kg/day</td>
<td></td>
<td>11.21c</td>
<td>9.09d</td>
<td>.35</td>
</tr>
<tr>
<td>Total CWC intake, % BW</td>
<td></td>
<td>1.92a</td>
<td>1.63b</td>
<td>.07</td>
</tr>
<tr>
<td>Total CWC intake, g/kg W·75</td>
<td></td>
<td>9.43c</td>
<td>7.91d</td>
<td>.29</td>
</tr>
<tr>
<td>Silage CWC intake, % BW</td>
<td></td>
<td>1.85a</td>
<td>1.58b</td>
<td>.06</td>
</tr>
<tr>
<td>Silage CWC intake, g/kg W·75</td>
<td></td>
<td>9.11c</td>
<td>7.64d</td>
<td>.26</td>
</tr>
<tr>
<td>Concentrate CWC intake, % BW</td>
<td></td>
<td>.07</td>
<td>.05</td>
<td>.01</td>
</tr>
<tr>
<td>Percent CWC digested</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digestive CWC intake, kg/day</td>
<td></td>
<td>5.90</td>
<td>4.84</td>
<td>.33</td>
</tr>
</tbody>
</table>

\(ab(P < .10)\)

\(cd(P < .05)\)
TABLE 23. Hemicellulose digestion data for cows receiving bm3 and N corn silage rations during trial 2.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ration</th>
<th>SEM^a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bm3</td>
<td>N</td>
</tr>
<tr>
<td>Total hemicellulose intake, kg/day</td>
<td>5.15</td>
<td>4.84</td>
</tr>
<tr>
<td>Total hemicellulose intake, % BW</td>
<td>.88</td>
<td>.87</td>
</tr>
<tr>
<td>Total hemicellulose intake, g/kg W^72</td>
<td>4.33</td>
<td>4.20</td>
</tr>
<tr>
<td>Silage hemicellulose intake, % BW</td>
<td>.86</td>
<td>.84</td>
</tr>
<tr>
<td>Silage hemicellulose intake, g/kg W^75</td>
<td>4.21</td>
<td>4.10</td>
</tr>
<tr>
<td>Concentrate hemicellulose intake, % BW</td>
<td>.03</td>
<td>.02</td>
</tr>
<tr>
<td>Percent hemicellulose digested</td>
<td>51.44</td>
<td>60.77</td>
</tr>
<tr>
<td>Digested hemicellulose intake, kg/day</td>
<td>2.64</td>
<td>2.93</td>
</tr>
</tbody>
</table>

^aStandard error of mean.

TABLE 24. Energy digestion data for cows receiving bm3 and N corn silage rations during trial 2.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ration</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bm3</td>
<td>N</td>
</tr>
<tr>
<td>Total intake, Mcal/day</td>
<td>93.98a</td>
<td>70.57b</td>
</tr>
<tr>
<td>Total intake, Mcal/kg BW</td>
<td>.16a</td>
<td>.13b</td>
</tr>
<tr>
<td>Silage intake, Mcal/kg BW</td>
<td>.13c</td>
<td>.10d</td>
</tr>
<tr>
<td>Concentrate intake, Mcal/kg BW</td>
<td>.03</td>
<td>.02</td>
</tr>
<tr>
<td>Percent energy digested</td>
<td>58.16</td>
<td>60.59</td>
</tr>
<tr>
<td>DEI, Mcal/day</td>
<td>54.81</td>
<td>42.97</td>
</tr>
</tbody>
</table>

^ab(P < .05)
^cd(P < .01)
TABLE 25. Nitrogen utilization by cows receiving bm3 and N corn silage rations during trial 2.

<table>
<thead>
<tr>
<th>Component</th>
<th>Ration</th>
<th>bm3</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>N intake, g/day</td>
<td></td>
<td>689.38c</td>
<td>479.18d</td>
<td>47.88</td>
</tr>
<tr>
<td>N absorbed, g/day</td>
<td></td>
<td>427.80</td>
<td>309.19</td>
<td>49.04</td>
</tr>
<tr>
<td>N excreted, g/day</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feces</td>
<td></td>
<td>261.58g</td>
<td>169.99h</td>
<td>9.83</td>
</tr>
<tr>
<td>Urine</td>
<td></td>
<td>225.22e</td>
<td>154.41f</td>
<td>9.93</td>
</tr>
<tr>
<td>Milk</td>
<td></td>
<td>108.34</td>
<td>117.22</td>
<td>6.33</td>
</tr>
<tr>
<td>N retained</td>
<td></td>
<td>94.24</td>
<td>37.56</td>
<td>45.22</td>
</tr>
<tr>
<td>Productive N (b)</td>
<td></td>
<td>202.58</td>
<td>154.78</td>
<td>43.23</td>
</tr>
<tr>
<td>N, % intake</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feces</td>
<td></td>
<td>38.80</td>
<td>37.62</td>
<td>3.27</td>
</tr>
<tr>
<td>Urine</td>
<td></td>
<td>33.09</td>
<td>33.33</td>
<td>1.82</td>
</tr>
<tr>
<td>Milk</td>
<td></td>
<td>16.22c</td>
<td>25.73d</td>
<td>2.04</td>
</tr>
<tr>
<td>Productive N (b)</td>
<td></td>
<td>28.11</td>
<td>29.06</td>
<td>4.59</td>
</tr>
<tr>
<td>N, % absorbed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urine</td>
<td></td>
<td>55.03</td>
<td>55.10</td>
<td>4.66</td>
</tr>
<tr>
<td>Milk</td>
<td></td>
<td>27.34</td>
<td>42.88</td>
<td>4.39</td>
</tr>
<tr>
<td>Productive N (b)</td>
<td></td>
<td>44.97</td>
<td>44.90</td>
<td>4.66</td>
</tr>
<tr>
<td>Digested N intake, kg/day</td>
<td></td>
<td>.43</td>
<td>.31</td>
<td>.05</td>
</tr>
<tr>
<td>Apparent N digested, %</td>
<td></td>
<td>61.20</td>
<td>62.38</td>
<td>4.63</td>
</tr>
</tbody>
</table>

\(^a\) Absorbed = N intake - N feces

\(^b\) Productive Nitrogen = N milk + N retained

\(^{cd}(P<.10)\)

\(^{ef}(P<.05)\)

\(^{gh}(P<.01)\)
over cows fed normal silage. Although not significant, intake
parameters of individual ration components were all higher by cows fed
the bm3 ration (Tables 20 through 25). Total cellulose (Table 20) and
PL (Table 21) intakes were higher (P < .01) for bm3 fed animals.
Daily CWC intake (Table 22) was also higher (P < .05) by cows fed bm3
than by those fed normal. Hemicellulose intake (Table 23) was not
significantly different between the two rations. Digested hemicellu-
lose intake was 9.9% lower by cows fed the bm3 ration.

Energy digestion data is shown in Table 24. Total energy intake
(P < .05) and silage energy intake (Mcal/kg BW) (P < .01) were both
higher by cows fed bm3. Calculated NE values according to methods of
Moe et al. (45) were 1.22 and 1.30 Mcal/kg for bm3 and normal rations.
Using these values, calculated NE intake was 26% greater by cows fed
the bm3 ration.

Nitrogen utilization data (Table 25) showed that cows receiving
the bm3 ration were less efficient than cows fed the normal ration.
Nitrogen intake was higher (P < .10) by cows fed the bm3 ration, however,
nitrogen contents were also higher in the feces (P < .01) and urine
(P < .05) from cows receiving the bm3 ration. The percentage of
nitrogen ultimately going towards milk production was higher (P < .10)
for cows receiving normal silage.

Rumen VFA results (Fig. 5) show that at all intervals post-
feeding, concentration of all individual and total VFA's were higher
for bm3. This is contrary to the lack of significance noted by
Frenchick et al. (16). The greatest spread between rations occurred
FIG. 5. Total and individual rumen volatile fatty acid concentrations over a 12 h period for cows fed bm3 and normal corn silage rations during trial 2.
with acetic acid and total VFA's at 4 h. Averages of the VFA concentrations (Appendix Table 6) show higher concentrations of butyric (P < .01) and propionic (P < .05) acids and total VFA's (P < .10) for cows fed bm3. These patterns in VFA's appeared consistent with the higher DMI by cows fed the bm3 ration.

Rumen pH levels were consistently lower with bm3 (Fig. 6). Again the greatest spread appeared at 4 h. Average pH levels (Appendix Table 6) did not vary significantly though they were lower for cows fed bm3.

Rumen ammoniacal nitrogen concentrations (Fig. 6) were lower for the bm3 ration at 0 and 4 h postfeeding. At 8 h, ruminal concentration of the normal ration dropped considerably while concentration of bm3 declined slowly. At 12 h, concentrations on the bm3 ration were lower than those on the normal ration.
FIG. 6. Rumen pH and ammoniacal nitrogen concentrations over a 12 h period for cows fed BM3 and normal corn silage rations during trial 2.
GENERAL DISCUSSION

Fermentation characteristics of silages from the two trials are not conclusive. Both trials showed lower pH values (P < .05) for the \( \text{bm}_2 \) silage. An earlier trial (49) showed no difference in pH between silages. Concentrations of silage VFA's varied. Propionic acid concentration was higher (P < .10) in trial 1, but was lower (P < .05) in trial 2 for the \( \text{bm}_2 \) silage. The \( \text{bm}_3 \) silage in trial 2 also had higher (P < .05) concentrations of acetic acid and lactic acid than normal silage. In the study by Muller et al. (49) with stover silage, no significant differences were noted in acid production between silages. A possible explanation for the high acidity of \( \text{bm}_3 \) silage in trial 2 may be the lower (P < .01) DM content of the \( \text{bm}_3 \) silage. Goering et al. (18) found in an earlier study with corn silages of varying DM content that silages with lower DM also had lower pH values.

Composition of fiber in silages also varied between the two trials. Cellulose and ADF levels were both lower (P < .05) for \( \text{bm}_2 \) in trial 1 as anticipated. In trial 2, both were higher (P < .01 and P < .05, respectively). Results from trial 1 also showed less PL (P < .01) and more hemicellulose (P < .01) in \( \text{bm}_3 \) silage. Results from trial 2 showed lower levels of CWC (P < .01) and hemicellulose (P < .01) and no difference in PL. Results from trial 1 are in agreement with previous data (9,10,11,16,49). An explanation for the higher ADF and cellulose levels in \( \text{bm}_2 \) and the lack of difference in PL between silages for trial 2 may be explained by the high population of lambsquarters (Chenopodium album) in the \( \text{bm}_3 \) field plot. Seeds from this
weed were not digested by the cows and were not digested during fiber analyses. Thus, the weights of the seeds probably affected the accuracy of the laboratory analyses and the lignin values. The higher intake of \( \text{bm}_3 \) silage suggests that an altered and possibly lower lignin content did exist on trial 2. The weed seeds may also have resulted in a higher nitrogen value for the \( \text{bm}_3 \) silage. Nitrogen content of \( \text{bm}_3 \) was lower (\( P < .05 \)) in trial 1 and higher (\( P < .01 \)) in trial 2. The digestion of the weed seeds found in trial 2 \( \text{bm}_3 \) silage during the Kjeldahl analysis may have increased the apparent nitrogen content. However, studies by Colenbrander et al. (9,10) noted higher nitrogen in \( \text{bm}_3 \) silage.

Interestingly, intake and digestion data of total DM and various fiber fractions are similar between trials and agree with earlier studies (9,10,11,49). Despite major differences in the proportion of forage to concentrate fed between trials, total and digestible DMI were higher by cows fed the \( \text{bm}_3 \) ration and were similar between trials. Nitrogen intake of \( \text{bm}_3 \) was higher for both trials, however, utilization of nitrogen was lower for cows fed \( \text{bm}_3 \). Increased rates of passage as noted in earlier studies (9,10,11,49) may have allowed the \( \text{bm}_3 \) silage to pass through the rumen before breakdown of nitrogen components could occur. This could also explain the higher (\( P < .01 \)) levels of nitrogen found in the feces of cows fed \( \text{bm}_3 \) silage during trial 2.

In both trials, DMI was higher for the \( \text{bm}_3 \) silage yet digestibilities of nutrients were similar. Some studies (71) have indicated
a decline in digestibility as the level of intake is increased. Other workers (63) have shown that the amount of energy required in excess of maintenance per unit of milk produced does not change with increasing milk production. Tyrrell and Moe (65) have stated that intake is related to a significant depression in digestibility, equivalent on the average to about 4% for each increase in intake equivalent to maintenance. According to NRC (50) maintenance requirements for NE (Mcal/KE), cows fed bm\textsubscript{3} silage consumed 2.9 times maintenance while cows fed normal silage ate 2.4 times maintenance during trial 1. This would have resulted in 2% lower digestibility for bm\textsubscript{3} silage. For trial 2, cows fed bm\textsubscript{3} silage consumed 3.0 times maintenance and those fed normal consumed 2.3 times maintenance. This would have resulted in 2.8% lower digestibility for bm\textsubscript{3} fed cows. When corrected for intake differences, the bm\textsubscript{3} rations were substantially higher in digestibility than the normal rations. The levels of consumption and digestion still should have allowed cows fed the bm\textsubscript{3} rations to produce an additional 6 to 7 kg more milk per day than cows fed normal silage.

Studies (46) have indicated that the rate of depression in digestibility increases as the proportion of grain in the ration increases. This effect of grain on the rate of depression is less pronounced for rations based on corn silage than those based upon hay or haycrop silage. Thus, the difference in type of concentrate ration fed between the two trials should not have significantly affected digestion.
Tyrrell and Noc (64), Van Soest (71) and Smith et al. (58) state that the drop in digestibility with increasing levels of intake is covered by a decrease in digestibility of fibrous components and is almost entirely accounted for by changes in cell wall digestibility. They indicated that the cell wall fraction of the ration, consisting mainly of cellulose and hemicellulose, suffers a greater reduction in digestibility at high levels of intake than does the soluble fraction of the ration. Van Soest (68) continued that as intake of feed increases, cell wall fiber is turned over more rapidly and passes from the rumen before it can undergo digestion. This trend was seen in trial 2 as total CWC intake was higher (P < .05) for bm3 fed cows but the percent of CWC digested was somewhat lower than for cows fed normal silage.

Milk and FCM production were not significantly different in either study, although milk fat percent was higher for bm3 fed cows during trial 1. Frenchick et al. (16) reported no difference in FCM but did show a decrease in milk fat percent and an increase in milk yield. It should be emphasized that both trials 1 and 2 and also the study by Frenchick et al. (16) all covered an insufficient length of lactation to accurately compare the two silages for milk production. As mentioned previously, cows fed the bm3 rations consumed 15 to 20% more digestible and net energy which should have allowed them to produce 6 to 7 kg more milk per day. Interestingly, cows fed bm3 rations in these two studies appeared to direct more energy toward
body weight gain rather than toward increased milk yield. Longer lactation trials with more cows are needed.

Analyses of rumen VFA concentrations for the two trials were also variable per time of collection. However, results of both trials agree with Frenchick et al. (16) in that butyric and propionic acid concentrations were higher for cows fed bm$_3$. Results of the earlier study (16) and trial 2 also indicated higher concentrations of total rumen VFA's. Ruminal pH for both trials was consistently but not significantly lower for cows fed bm$_3$. These results tend to agree with Frenchick et al. (16) as they showed lower (P < .05) pH levels for cows fed bm$_3$ silage. Rumen ammoniacal nitrogen concentrations showed no significant differences, however, hourly fluctuations did vary considerably between trials. Values for both rations were considerably higher during trial 2. Concentrations also peaked earlier and then dropped off at a faster rate in trial 2. The differences in corn hybrid genetics and the lower DM content of silages fed during trial 2 may have promoted increased silage ammoniacal nitrogen concentrations and thus enhanced the higher ruminal concentrations noted in trial 2.
CONCLUSIONS

The conclusions that can be drawn from the results of these investigations are:

1. Silage made from bm⁻³ corn has a lower pH value and a higher acid content than that from normal corn.

2. Silage DM and energy intake is 15 to 20% higher for animals fed bm⁻³ rations, thus bm⁻³ silage offers the potential for greater intake during early lactation.

3. Digestibility of fiber components varies from trial to trial but the percent of CWC digested is usually lower for bm⁻³. This is to be expected with higher intake which usually is associated with lower digestibility.

4. Rumen fluid from cows fed bm⁻³ is consistently higher in butyric and propionic acid concentrations and lower in pH.

5. Nitrogen intake is greater for cows fed bm⁻³ than normal but the amount of feed nitrogen converted into milk nitrogen is similar.

6. Effects of bm⁻³ corn silage upon milk yield cannot be accurately determined until a long term lactation trial comparing the two silages is accomplished, but the greater levels of intake noted in this investigation and others indicates that higher milk yield should be obtained from cows fed bm⁻³ silage.
REFERENCES


56 Russell, E. J. 1908. The chemical changes taking place during the ensilage of maize. J. Agric. Sci. 2:392.


APPENDIX
APPENDIX TABLE 1. Acid detergent fiber digestion data for cows receiving \( \text{bm}_3 \) and N corn silage rations during trial 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>( \text{bm}_3 )</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total ADF intake, kg/day</td>
<td>4.62</td>
<td>4.24</td>
<td>.34</td>
</tr>
<tr>
<td>Total ADF intake, % BW</td>
<td>.73</td>
<td>.66</td>
<td>.06</td>
</tr>
<tr>
<td>Total ADF intake, g/kg W( \cdot .75 )</td>
<td>3.68</td>
<td>3.29</td>
<td>.27</td>
</tr>
<tr>
<td>Silage ADF intake, % BW</td>
<td>.55</td>
<td>.50</td>
<td>.05</td>
</tr>
<tr>
<td>Silage ADF intake, g/kg W( \cdot .75 )</td>
<td>2.74</td>
<td>2.51</td>
<td>.24</td>
</tr>
<tr>
<td>Concentrate ADF intake, % BW</td>
<td>.19</td>
<td>.15</td>
<td>.03</td>
</tr>
<tr>
<td>ADF digested, %</td>
<td>48.56</td>
<td>43.59</td>
<td>2.95</td>
</tr>
<tr>
<td>Digested ADF intake, kg/day</td>
<td>2.26</td>
<td>1.92</td>
<td>.24</td>
</tr>
</tbody>
</table>

APPENDIX TABLE 2. Summary of apparent digestibilities of various nutrient components of \( \text{bm}_3 \) and N corn silage rations during trial 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>( \text{bm}_3 )</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter</td>
<td>65.82</td>
<td>63.95</td>
<td>1.12</td>
</tr>
<tr>
<td>Energy</td>
<td>64.07</td>
<td>61.77</td>
<td>1.11</td>
</tr>
<tr>
<td>Cellulose</td>
<td>52.04</td>
<td>48.21</td>
<td>3.37</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>70.95</td>
<td>70.00</td>
<td>1.78</td>
</tr>
<tr>
<td>Permanganate lignin</td>
<td>41.76</td>
<td>39.53</td>
<td>4.31</td>
</tr>
<tr>
<td>Acid detergent fiber</td>
<td>48.56</td>
<td>43.59</td>
<td>2.95</td>
</tr>
<tr>
<td>Cell wall contents</td>
<td>61.81</td>
<td>58.89</td>
<td>1.68</td>
</tr>
</tbody>
</table>
APPENDIX TABLE 3. Rumen volatile fatty acid, pH, and ammoniacal nitrogen concentrations for cows fed bm_3 and N corn silage rations during trial 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ration</th>
<th>bm_3</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid, µM/ml</td>
<td>bm_3</td>
<td>49.68</td>
<td>52.92</td>
<td>2.17</td>
</tr>
<tr>
<td>Propionic acid, µM/ml</td>
<td>N</td>
<td>14.00</td>
<td>13.26</td>
<td>.70</td>
</tr>
<tr>
<td>Butyric acid, µM/ml</td>
<td>bm_3</td>
<td>4.05</td>
<td>3.81</td>
<td>.19</td>
</tr>
<tr>
<td>Total VFA's, µM/ml</td>
<td>N</td>
<td>70.37</td>
<td>73.24</td>
<td>3.08</td>
</tr>
<tr>
<td>pH</td>
<td>bm_3</td>
<td>6.67</td>
<td>6.75</td>
<td>.03</td>
</tr>
<tr>
<td>Ammoniacal nitrogen</td>
<td>N</td>
<td>5.12</td>
<td>6.03</td>
<td>.24</td>
</tr>
</tbody>
</table>

ab (P < .10)

APPENDIX TABLE 4. Acid detergent fiber digestion data for cows receiving bm_3 and N corn silage rations during trial 2.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ration</th>
<th>bm_3</th>
<th>N</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total ADF intake, kg/day</td>
<td>bm_3</td>
<td>6.06</td>
<td>4.26</td>
<td>.22</td>
</tr>
<tr>
<td>Total ADF intake, % BW</td>
<td>N</td>
<td>1.04</td>
<td>.77</td>
<td>.05</td>
</tr>
<tr>
<td>Total ADF intake, g/kg W·75</td>
<td>bm_3</td>
<td>5.10</td>
<td>3.71</td>
<td>.20</td>
</tr>
<tr>
<td>Silage ADF intake, % BW</td>
<td>N</td>
<td>1.00</td>
<td>.72</td>
<td>.04</td>
</tr>
<tr>
<td>Silage ADF intake, g/kg W·75</td>
<td>bm_3</td>
<td>4.90</td>
<td>3.54</td>
<td>.18</td>
</tr>
<tr>
<td>Concentrate ADF intake, % BW</td>
<td>N</td>
<td>.04</td>
<td>.04</td>
<td>.01</td>
</tr>
<tr>
<td>ADF digested, %</td>
<td>bm_3</td>
<td>40.31</td>
<td>44.38</td>
<td>3.87</td>
</tr>
<tr>
<td>Digested ADF intake, kg/day</td>
<td>N</td>
<td>2.50</td>
<td>1.91</td>
<td>.28</td>
</tr>
</tbody>
</table>

ab (P < .05)

cd (P < .01)
APPENDIX TABLE 5. Summary of apparent digestibilities of various nutrient components of bm and N corn silage rations during trial 2.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ration</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bm</td>
<td>N</td>
</tr>
<tr>
<td>Dry matter</td>
<td>59.61</td>
<td>61.45</td>
</tr>
<tr>
<td>Energy</td>
<td>58.16</td>
<td>60.59</td>
</tr>
<tr>
<td>Cellulose</td>
<td>47.33</td>
<td>51.80</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>51.44</td>
<td>60.77</td>
</tr>
<tr>
<td>Permanganate lignin</td>
<td>32.59</td>
<td>32.67</td>
</tr>
<tr>
<td>Acid detergent fiber</td>
<td>40.31</td>
<td>44.38</td>
</tr>
<tr>
<td>Cell wall contents</td>
<td>45.53</td>
<td>53.03</td>
</tr>
</tbody>
</table>

APPENDIX TABLE 6. Rumen volatile fatty acid, pH, and ammoniacal nitrogen concentrations for cows fed bm and N corn silage rations during trial 2.

<table>
<thead>
<tr>
<th>Item</th>
<th>Ration</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bm</td>
<td>N</td>
</tr>
<tr>
<td>Acetic acid, µM/ml</td>
<td>64.60</td>
<td>51.20</td>
</tr>
<tr>
<td>Propionic acid, µM/ml</td>
<td>22.81c</td>
<td>16.17a</td>
</tr>
<tr>
<td>Butyric acid, µM/ml</td>
<td>8.32e</td>
<td>6.05c</td>
</tr>
<tr>
<td>Total VFA's, µM/ml</td>
<td>102.61a</td>
<td>78.19b</td>
</tr>
<tr>
<td>pH</td>
<td>6.55</td>
<td>6.65</td>
</tr>
<tr>
<td>Ammoniacal nitrogen, mg%</td>
<td>8.34</td>
<td>7.63</td>
</tr>
</tbody>
</table>

ab(P < .10)

bc(P < .05)

cd(P < .01)
APPENDIX FIG. 1. Structures of major lignin precursors and products.