ANHYDROUS AMMONIA VERSUS UREA IN CORN SILAGE FOR DAIRY ANIMALS

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ODON P. SANTANA

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ABSTRACT

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By

Odon P. Santana

Corn silage was ensiled alone or with additions of urea or ammonia and several criteria were used to evaluate these chemical additives.

In a series of feeding trials over a two-year period the NPN-treated corn silages containing 32.6 to 52.4% dry matter (D.M.) were fed as the only forage to Holstein heifers and lactating Holstein cows to compare their nutritive value.

Effects of drying temperatures and time of exposure to the barn atmosphere on nitrogen concentration of corn silages were also studied.

The crude protein equivalent of the urea-treated silages (0.5 and 0.75%) at 36 and 52% D.M. increased

4.1 and 4.2 percentage units on a dry basis. Silages containing ammonia (0.28%) increased in crude protein equivalent by 3.6 and 1.8 percentage units on a dry basis, for the 36 and 41% D.M. levels, respectively.

Heifers fed ammoniated silage as the sole feed in which ammonia furnished 31.7% of the total ration nitrogen made adequate body weight gains. Feed intakes were higher ($P < 0.01$) for the ammonia-treated than for the control silage.

In the first lactation trial, 35 lactating cows were divided into 5 groups and fed control, urea- or ammonia-treated corn silage for 9 weeks. Concentrate mixtures containing 8.4, 12.9 and 18.6% crude protein were fed at 1 Kg/3 Kg of milk. Milk yields, persistencies and body weight gains for the negative control group were lower ($P < 0.05$) than cows on medium and high protein diets. Dry matter intakes were markedly improved ($P < 0.05$) by either the high level of protein in the concentrate or by the addition of urea or ammonia to the silage. Inadequate nutrient intake contributed to the poor performance of the negative controls. No differences were observed among silages in palatability when dietary protein was adequate.

In the second lactation trial, three groups of 6 cows received: urea-treated silage (36% D.M.); urea-treated silage (52% D.M.); or ammonia-treated silage (42% D.M.) as the sole forage for 7 weeks. A concentrate mixture containing approximately 10% crude protein was fed to all groups at the same ratio as in the first lactation trial. At the higher dry matter levels (52 to 42%), the urea and ammonia groups performed similarly, but milk persistencies and intakes were greater for the cows fed 36% D.M. silage treated with urea.

There were no differences in apparent digestibility of dry matter, crude protein and non-protein dry matter due to silage treatment. Inadequate nitrogen intake resulted in negative nitrogen balance for all treatments. The 36% D.M. group excreted 140% of its digested nitrogen as milk and urine, while 113 and 106% were obtained for the 52 and 42% D.M. treatments, respectively.

Corn silages were treated with urea plus ammonium polyphosphate or with ammonia at the time of ensiling and set at temperatures ranging from 20°C to 75°C for 10 hours. Untreated and silages treated with urea at the time of feeding were exposed to the barn conditions for 20 hours, either in the manger (fed to cows) or in open buckets. No loss of nitrogen was noted due to heating or exposure of the silages. The pH values increased slightly with increasing temperature.

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Odon P. Santana

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INTRODUCTION

There is already a shortage of adequate protein for man and for animals throughout the world and the situation is likely to become more critical in the years ahead.

Kolari (59) has reviewed the problem and said: "The most serious food shortage in the future will be protein of high quality." Undoubtedly, this will be of major concern as the world population continues to increase.

With growing competition between man and animal for protein sources, oil meal supplementation of ruminant rations will become increasingly less economical.

Man depends greatly on animal protein sources, and meat and milk are essential dietary components for many peoples.

Extensive studies had been conducted in many parts of the world on the utilization of non-protein nitrogen (NPN) for ruminants by the mid-1930's (8).

It was observed that ruminants could use simple nitrogenous compounds through the action of the rumen microorganisms which form protein for the host animal. With this foundation, there have been many studies on factors affecting the utilization of NPN by ruminants. Specific problems investigated have been: 1) level of NPN that can replace natural protein without adversely affecting animal performance; 2) palatability and ration intake; and 3) possible side-effects due to prolonged feeding of NPN compounds.

Urea is the main NPN compound fed commercially to ruminants. Other simple nitrogenous compounds such as biuret, diammonium phosphate, ammonium bisulphate (100) and ammonium bicarbonate (33), have been suggested as possible substitutes for natural protein in ruminant rations. However, none except urea has made any substantial impact in the animal feeding industry.

Urea has been included as an additive to dry grain as a part of the total nitrogen in the ration, but decreased intakes generally resulted when urea comprised over 2% of the concentrate (99). Perhaps a more satisfactory method of including urea is adding it to corn silage at ensiling time because corn silage has certain advantages for incorporating urea into the ruminant's diet.

Corn silage is one of the most widely accepted feeds for dairy and beef cattle. Corn silage is indeed the best energy crop per acre of land in many areas. A large part of this energy is in the form of starch, which is essential for the efficient conversion of urea to bacterial protein (100). Corn silage has become the principal forage for dairy cattle in many parts of the USA. This feedstuff is higher in available energy and lower in crude protein, compared to legume forages.

Urea added to corn silage at the time of ensiling is partially broken down to ammonia and this ammonia has an important role in the fermentation process. Ammonia increases the corn silage pH and tends to lengthen the fermentation time. A significant increase in organic acid concentrations, primarily ammonium lactate (46, 88), also results from treating corn silage with urea.

The optimum amount of urea that should be added to corn silage for best results is still questionable. However, 0.5 to 0.75% has given good results.

This study was a comparative evaluation of corn silages treated with anhydrous ammonia or urea.

Anhydrous ammonia is a volatile alkaline gas (NH_3) extremely soluble in water. It combines with acids to form a number of salts. Ammonia is the principal source of fixed nitrogen used in the manufacture of fertilizers (82% nitrogen).

Douglas et al. (27) stated that the ammonia production in the USA for the fiscal year 1963-1964 was 5.8 million tons and that about 74% of this production was utilized as fertilizer, thus, the importance of ammonia for agricultural applications is obvious.

In the March, 1969 edition of Oil Plant and Drug Reporter (75), prices for feed grade urea (45% nitrogen) ranged from \$84 to \$88 per ton and \$50 to \$92 per ton for anhydrous ammonia (82% nitrogen). Most recent comparisons have shown that the price of anhydrous ammonia is usually lower than that of urea. This cost advantage is further magnified by the fact that anhydrous ammonia contains 82% nitrogen compared to 45% for feed grade urea.

Methods for including anhydrous ammonia in animal feeds are more complicated than for urea (32). This is because the ammonia is available as a liquefied gas maintained under high pressures.

To date, very little research has been reported on adding anhydrous ammonia to corn silage. It would seem that silage should serve as a desirable vehicle for carrying the ammonia because of its acid nature which would enhance formation of ammonium salts and prevent volatilization of the gas.

REVIEW OF LITERATURE

Use and Advantage of Silage in Cattle Feeding

The history of the feeding of the silage dates back to antiquity. The silo has been used for many years to assure a satisfactory conservation of crops. Miles (68) in 1889 reported that "The preservation of green fodder for winter feeding has for many years engaged the attention of practical men as a matter of great economic interest , ..." As early as 1895 Woll (110) stated that: "A German agricultural writer predicted the day as likely to come when dry hay would only be obtainable in drug stores."

Corn silage has merits not commonly observed in most dry roughages. It is a low cost feed, of high palatability and usually yields more energy per acre than other crop alternatives (23, 73), especially when harvested in the hard dough (32-37% dry matter) stage where maximum yields are obtained (43).

Relative Feeding Value of Corn Silage for Lactation

Numerous reports (2, 30, 104, 105, 106, 107) have discussed the use of corn silage for dairy cows. Carroll (17) showed a higher milk and fat production of cows on the corn silage ration than those which received hay and additional grain. A sudden increase in milk yield was observed by Bartlett (2) when a dairy cow ration consisting of hay and a mixture of cottonseed meal, bran and corn meal was partially replaced with corn silage for about two months. A significant decrease in production was observed when the additional silage was taken from the ration.

An early report by Williams (109) claimed that 35 pounds of low-quality corn silage could replace 10 pounds of alfalfa hay in the dairy ration. Another study by Bechdel (5) demonstrated that corn silage was superior to silage made of Canada field peas and oats.

Corn silage has also been shown to be equal or superior for dairy cows to alfalfa-brome grass silage (103); sunchoke silage (26); and meadow crop silage (72).

In more recent reports (14, 60, 76) corn silage was shown superior to sorghum silages.

Feeding of corn silage as the sole roughage has been suggested by some research workers. Good results were found by the Ohio Experiment Station (71) when cows were fed corn silage continuously during a period of approximately 5 months. The cows maintained normal milk and butterfat production with good health and satisfactory body weight gain. Porter (81) paired 22 Holstein heifer calves at birth. One calf of each pair was fed corn silage as the only roughage, and the other calves were initially fed hay for about 6 months and then both hay and silage, subsequently. No appreciable differences between groups were shown for breeding efficiency or milk and butterfat production. Records for the first and second lactations indicated that the milk and fat yields for the corn silage and the hay plus silage treatments were 12,876, 422; 14,369, 471; and 11,511, 399; 12,567, 421 pounds, respectively. In a later study Converse (22) reported that dairy cows receiving only corn silage and concentrates maintained about the same level of production as those cows fed corn silage, hay and concentrates when the total levels of nutrients were the same.

A progress report was conducted at the Connecticut Experiment Station by Pratt and White (82) comparing light or heavy amounts of silage in dairy rations. The results indicated that high silage ration resulted in slightly greater dry matter consumption and milk production.

Huffman and Duncan (48) fed one group of cows on all-hay and another group on hay-corn silage rations. They reported that when part of the total digestible nutrients (TDN) of an all-hay ration was replaced by an equal amount of TDN from the silage, an increase in Fat-Corrected Milk (FCM) occurred in 22 of 23 trials. The valuable quality of the TDN in the corn silage was attributed to the presence of an unidentified grain factor(s) in the corn which was needed to balance the TDN in the roughage diet.

Corn silage and recombined corn silage were studied by Dunn _et al_. (28). The amount of corn and cob meal fed in the recombined corn silage was equivalent to the amount of corn in the normal corn silage. No significant differences were observed in FCM production, body weight gains and amount of digestible protein ingested during the feeding periods. The authors concluded that the grain in corn silage was of the same nutritive value as dry corn and cob meal.

Some studies have suggested that forages other than corn silage are more valuable as a roughage for milk production. Hinton et al. (38) treated first-cut alfalfa and Lespedeza sericea silages with a molasses-phosphoric acid mixture and compared their feeding value with corn silage. Twelve lactating cows were divided into three groups which received twenty pounds of silage each. Ground alfalfa hay was offered ad libitum and 10 pounds of a grain mixture. The results, over a period of 120 days, showed that the body weight and production of all groups were normal, but a higher production of alfalfa silage than of the corn silage groups was observed. In Mississippi (12) corn silage was compared with silages from NK 300 (an intermediate forage-type grain sorghum) and with RS 610 (a combined grain sorghum). All cows recieved silage ad libitum and 0.5 pounds of alfalfa hay per 100 pound body weight daily. A grain mixture with 15.5% crude protein was also fed according to NRC standards. The average persistency of production was 80.5, 78.0 and 117.5% for the respective treatments.

Corn silage was compared with oats and vetch and sunflower silages (51). Three trials were conducted at the Oregon Experiment Station which involved 32 dairy animals. The results favored oats and vetch silage as producing the largest amount of milk with the corn and sunflower silage following in that order. Another experiment was conducted by Jones and Brandt (50) comparing the feeding value of kale and corn silage. In three of the four trials, kale feeding resulted in slightly higher milk yields, but a slightly lower butterfat production. Nevertheless, a higher body weight gain was observed in three of the four trials by the cows fed corn silage.

In Utah (4), wet beet pulp was compared to corn silage for four consecutive winter feeding periods. Twenty-two Holstein cows were divided into two groups. One group was fed 57.5 pounds of corn silage and the other 93.8 pounds of beet pulp. The average dry matter content of the corn silage and beet pulp were 26 and 11.5%, respectively. The daily production per cow during the four winter periods averaged 23.5 pounds milk, with 0.77 pounds of butterfat for the corn silage cows, and 27.9 pounds of milk containing 0.91 pounds butterfat for the pulp group.

The unfavorable results obtained with corn silage as the main forage for milk production may be attributed to several factors. These are: ecological conditions, quality and dry matter content of the silage, amount and quality of supplemental concentrate and mineral supplementation.

Despite the conclusions that, under certain conditions, corn silage may not be more valuable than some other roughages for cattle feeding, one cannot deny the importance that corn silage plays in the feeding of ruminants. This is justified by the rapid and tremendous adoption of corn silage in the ration of dairy cows.

In 1952, Converse and Wiseman (22) stated that the amount of silage made in this country primarily from corn and sorghum had increased to an estimated 40 million tons annually. In a more recent report, Hoglund (39) concluded that from 1960 to 1965 corn silage acreage per farm in Southern Michigan increased by 50 and 20% for the farms with less than 50 and with 50 or more cows, respectively. In an excellent review on corn silage in the ration of dairy cattle, Coppock and Stone (23) stated that there has been a marked increase of the number of hectares of corn harvested as corn silage in the United States during the last two decades. But in contrast to this, about a 25% decrease has been observed in the number of hectares harvested as corn grain.

Many comparative feeding trials (23) with corn silage have shown the merit of this forage as a source of energy for cattle; especially when made from the well matured corn plant, which is equal to the best forages or combinations of forages.

The corn plant is relatively low in crude protein. Various approaches have been tried to increase its nitrogen content. In 1944, Woodward and Shepherd (111) studied the feeding value of corn silage treated with 0.5% urea. This silage was fed with a low-protein concentrate and hay to a group of lactating cows. Another group received an identical treatment, except that the urea was mixed with the concentrate. Both treatments maintained comparable milk production. In Michigan, Huber <u>et al</u>. (46) fed corn silages <u>ad libitum</u> to 54 lactating cows for an 80-day feeding period. The corn was cut at different maturities and contained 30, 36 and 44% dry matter. The silages were treated with urea (0 or 0.5%) at the time of ensiling and fed to nine groups of six cows each. Untreated silage was fed to six groups, three of which were fed a 13.8% crude protein concentrate while the other three received an 18.7% mix. The groups fed urea-treated silage received the 13.8% concentrate. At the two earlier maturities, the urea silage did not affect the milk production but a decrease occurred when urea was added to 44% dry matter silage resulting in a significant interaction between urea-treatment and silage maturity.

In a two-year study conducted by Polan _et al_. (79) corn silages were fed as the sole forage to dairy cows. For the first year silages were treated with 0, 0.5 and 0.75% urea, while levels added during the second year were 0, 0.5 and 0.85%. It was calculated that the high urea treatments furnished 27 and 38% of the ration nitrogen during the successive years. Treatments lasted 70 and 63 days, respectively. The rations were approximately isocaloric and isonitrogenous. Milk yields during the treatment periods averaged 20-25 kg. daily. No significant depressions in production or feed consumption resulted from urea-treatment of silages. A nitrogen balance trail conducted during the second year of the study showed that the nitrogen excretion exceeded the intake at the highest urea level.

Addition of Urea to Concentrate Mixtures

Ward *et al*. (102) compared the milk-producing value of a low-protein roughage supplemented with two experimental mixtures. These were corn with 2% urea and soy bean oil meal. Under the conditions of this experiment, urea plus corn and soy bean oil meal were considered to be of similar feeding value, since maintenance of body weight and milk production did not show any significant differences. At the Virginia Station (94), during a 3-year period, three trials were conducted involving 3 groups of 4 cows each. Hay, corn stover and corn silage were the roughages fed in Trial l. In Trials II and III no stover was included. The concentrates contained corn and cob meal, ground oats, bone meal and salt. The authors concluded that urea plus corn and cottonseed meal were of similar value for milk production.

They also noted that the addition of corn cobs did not alter milk production or digestibility.

An outstanding herd was used for a feeding test in 1944 (34). Seven cows of this herd were selected as the experimental group to be compared with 15 other representative cows as the control group. Alfalfa hay and corn silage were fed with one of two concentrates of 20.6% crude protein content. Concentrate fed the control group contained a small amount of urea, while sufficient urea was added to the test concentrate to equal as much as 43% of the total ration nitrogen. The results obtained over a 210-day period indicated that milk production was about the same for test and control concentrates, so the author concluded that urea was effectively used. However, it is doubtful that dietary protein was low enough initially to evaluate the benefit of the added urea.

In Virginia, Huber et al. (42) conducted two trials with 40 lactating Holstein cows for 12 weeks. All groups received corn silage ad libitum as the only forage. The forage was supplemented on an equal nitrogen basis, with the following: 1) a concentrate mixture with 15% crude protein fed at 1 pound per 3.5 pounds of milk;

2) soybean or cottonseed meal; 3) oil meal plus urea (each furnished equal nitrogen); and 4) urea. In the first trial, the silage dry matter intake for these four groups were: 1.78, 2.31; 2.30 and 2.30% of body weight, respectively. The milk yields for the respective treatments were: 51.3, 48.7, 43.6 and 36.0 pounds per day. The persistency of production (as a percent of the standardization period) followed a trend similar to milk yields. In Trial II the group supplemented with only urea was significantly lower in milk yields and dry matter intake than the other three groups. Little difference in performance was noted between groups 1, 2 and 3. The reason for the different results between the two trials was probably because production levels were lower and cows were later in lactation in Trial II than I. This study showed very clearly that milk yields could not be maintained with only corn silage and urea, but conclusions concerning the replacement value of urea for natural protein would be biased because the rations were not balanced for their energy content.

In another report, Virginia researchers (45) added varying amounts of urea at the time of feeding to rations for high producing dairy cows. Ninety-one lactating cows were involved in three experiments. Corn silage was fed ad libitum as the sole forage. Urea supplied from 0 to 48% of the total dietary nitrogen. No adverse effect on milk production was observed when 11% of the nitrogen came from urea. However, when urea furnished 21 to 23%, milk yields were significantly decreased. A more radical depression in milk production was noted when urea supplied 38 and 48% of the ration nitrogen. Corn silage intake was not decreased by the addition of urea, but the silage consumption was depressed on high-concentrate rations containing urea. From these studies the authors concluded that the maximum urea that can be added to concentrate for high producing cows without depressing milk yields is about 180 g/day. They further suggested that the old recommendation of furnishing about 1/3 of the dietary nitrogen as urea is not applicable to cows at high production levels where protein needs are greatly increased. Holter and co-workers (40) reported that no significant differences in dry matter intake and ration utilization resulted from the addition of 1.25, 2.0 and 2.5% urea to concentrate for dairy cows on isonitrogenous rations with corn silage as the only forage. However, nitrogen retention was significantly depressed by the addition of urea to the concentrate mixtures.

In a field study reported by New Hampshire workers (41) fifty-six high-producing cows were allotted to two groups and individually fed hay and corn silage <u>ad libitum</u>. A premium commercial concentrate was fed to one group during the testing period. The other group received a similar concentrate in which corn and 1.5% urea replaced part of the oil meal on an isonitrogenous basis. The maximum urea intake was 0.17 kg. daily. Milk and butterfat production for urea and non-urea groups were: 8,028, 299 and 8,059, 308 kg., respectively. The urea level fed to the cows in this study appeared to be acceptable even to cows producing up to 30 kg. milk daily.

Van Horn <u>et al</u>. (99) reported that addition of 2.2 and 2.7% urea to concentrate mixtures reduced concentrate intake significantly. Milk yields were less from cows on urea treatments, which suggested that milk production was directly affected by the amount of concentrate eaten. In another experiment the cows were allotted to three groups. Group 1 was the control, and groups 2 and 3 received urea-treated corn silage (5.0 kg. of urea per metric ton at the ensiling time). The third group was fed a concentrate with 1% urea added. All groups were offered 27 kg. silage and about 3.0 kg. alfalfa hay daily. No significant differences in milk yields and feed intake were noted between the treatments.

Colovos et al. (19, 20) reported the results of two experiments showing the effects of different levels (0, 1.25, 2.0 and 2.5%) of urea (42% nitrogen) in concentrate mixtures. In the first experiment, the concentrate fiber levels were 5 and 8%. Fair quality timothy hay was offered as the sole forage at 2% of body weight. In the second experiment concentrates averaged 6.64% fiber and good quality timothy hay were fed as described previously. The authors concluded that urea in concentrates did not significantly affect ration intake and milk production. Digestibility of fiber was significantly increased by urea when added to low fiber concentrate. However, an adverse effect resulted from the addition of urea to the high fiber concentrate. In another study, urea was compared to linseed oil meal for milk production (86). Corn silage and timothy hay comprised the roughages. A basal concentrate mixture containing about 10% protein was treated with urea or linseed meal. Urea nitrogen constituted 27% of the total nitrogen in the ration. Data on milk production did not indicate significant differences among treatments.

Reid (84) reviewed the use of urea as a protein supplement and stated that urea could effectively substitute for plant protein when fed at levels of not more than 27% of the total ration nitrogen. The use of urea and other non-protein nitrogen compounds was reviewed by Stangel (91). He listed more than 1500 citations. Numerous experiments summarized by Stangel suggested that urea was successfully used as a nitrogen extender when the urea-nitrogen did not furnish more than one-third of the protein-equivalent in ruminant rations. However, recent data show that this may not be true for high producing cows, particularly when the urea is fed through the concentrate.

High Levels of Urea for Dairy Cows

Early work at the Hawaii Agricultural Experiment Station (108) suggested that urea can function as a source of nitrogen for ruminants but not as efficiently as nitrogen of plant origin. Depressions in milk yields were observed when either 19 or 36% of the total crude protein equivalent was furnished by urea.

Conrad and Hibbs (21) fed corn silage containing 0.7% urea as the only feed for milking cows in late lactation, but results were inferior to a conventional alfalfa hay-grain ration.

Lactating cows were fed silages treated with 0.5 and 0.75% urea, or 1% diammonium phosphate (90). Nitrogenous additives did not significantly affect milk production but lower intakes were noted for cows fed silages containing 0.75% urea or 1% diammonium phosphate.

As already mentioned, promising results were observed by Polan _et al_. (79) when 0.85% urea was added to corn material at the ensiling time which furnished 38% of the dietary nitrogen; but marked depressions in milk production were reported by Huber _et al_. (45) when 38 to

48% of the ration nitrogen was supplied by urea. A comparison of these studies indicates that treating corn silage with urea allows for intake of higher urea levels without depressing milk yields compared to the conventional method of adding all the dietary urea to the concentrate.

Urea in Beef Cattle and Sheep Studies

Cullison (24) added 10 pounds of urea per ton to sweet sorghum silage for beef cows. The group fed urea-treated silage maintained body weight during the feeding period, while the negative control group lost an average 47 pounds per head. Urea addition also made the sorghum silage more palatable and higher in carotene content.

Blaylock *et al*. (7) fed 0, 23, 45, 68, 91, 113, 136, 159 and 181 gm. urea per steer daily for a 112-day feeding period to 108 steers (9 per treatment). Animals were fed ground ear corn *ad libitum* and 907 g. hay/day in addition to a protein supplement which contained 32 to 62% crude protein equivalent. Daily gains did not significantly differ between treatments and averaged 1.21, 1.25, 1.37, 1.29, 1.32, 1.37, 1.39, 1.34 and 1.34 kg., respectively.

In 1947, Briggs et al. (9) studied the value of urea as an extender of protein for beef cattle. Crystalline urea and pelleted feeds containing urea were used in the digestion trials and feeding experiments. The nitrogen furnished by urea in the different supplements varied from 25 to nearly 100% of the total in the various rations. Low grade prairie hay as the basal ration was fed to appetite along with the supplements. Pellets containing not more than 50% urea nitrogen were comparable to cottonseed meal in providing the nitrogen storage. Urea alone was considered a poor supplement to prairie hay. In this study urea was fed at relatively high levels but toxic effects were observed.

Perry et al. (78) compared the feeding value of urea supplements to those of natural protein in seven different trials. In six of these trials the cattle received a 64% crude protein supplement and for the seventh trial, supplements of 80 and 96% crude protein were fed. Urea content of the supplements was 21-22, 28 and 35%, respectively. High moisture ground ear corn and a limited amount of corn silage were fed in the fattening rations. For the growing rations, corn stover silage or corn silage plus the experimental supplements were fed. Growth on the natural protein rations was not significantly different from those containing urea. In one fattening trial, however, the natural protein group was significantly higher than the higher urea group.

Lowrey and McCormick (62) recently showed that steers and yearling calves could utilize concentrate rations when most of the supplemental nitrogen came from urea. However, the body weight gains in yearlings averaged somewhat less on all high-urea treatments. At high urea levels, nitrogen digestibility was higher and feed intakes lower for both the yearlings and steers.

Raleigh and Wallace (83) used 30 Hereford steer calves in an attempt to establish an adequate level of protein supplementation for meadow-hay (5.5% crude protein). Nitrogen supplements compared were urea, cottonseed meal or a mixture of both urea and cottonseed meal. Salt and monosodium phosphate were added at 1% and chromic oxide (as an indicator) at 0.5% of the total diet. The hay was mixed with the other ration components and pelleted. The percent urea in the experimental diets ranged from 0 to 2.52. Urea and/or cottonseed meal raised the crude protein levels of rations from 5.5 to 6.0; 9.0 and 12.0%. Data on gains, feed intake and feed efficiency were significantly higher at 9 and 12% crude protein levels than 6% or hay alone. Nitrogen source has a significant effect on gains with better performance on the plant protein than on the plant protein plus urea or the urea alone. Urea was inferior to plant protein at both 9 and 12% protein diets. Toxicity was noted at the highest level of urea.

Feeding Value of Urea for Growing Dairy Cattle

Bartlett and Cotton (3) reported satisfactory results over a 142-day feeding period with 21 dairy heifers when 0.127 pounds of urea was added to low-protein rations.

Hart *et al*. (33) reported that growing calves (250-290 pounds) fed rations in which urea supplied 43%

of the nitrogen had slightly less growth than calves fed 66% of the ration nitrogen as casein. Data reported in this experiment also indicated that nitrogen not only from urea, but also that furnished by ammonium bicarbonate was utilized by calves.

Lassiter et al. (61) fed ground corn cobs as the only roughage to 24 growing dairy heifers in a 150-day trial. Three experimental mixtures were offered in which 30, 50 and 70% of the ration nitrogen came from urea. Daily gains were significantly depressed as urea nitrogen increased. Brown et al. (10) showed that dairy calves fed an experimental starter (15.1% protein equivalent) with 54.2% of the nitrogen as urea grew at about the same rate as those fed a natural protein supplement (15.2% protein). These two groups were significantly superior to a third group fed a low protein diet (6.7% protein). The data showed that 6-7 week old calves could utilize urea as a nitrogen source.

The frequency of feeding seems to affect urea utilization. A study by Campbell et al. (16) showed similar growth results when they fed conventional protein and urea nitrogen to dairy heifers six times daily, but gain was significantly reduced when the urea-supplemented group was fed only twice a day.

Antibiotics such as chlortetracycline have been used to promote the utilization of urea by young dairy calves. In a Kentucky study (11), urea was fed at 30.8, 46.3 and 57.5% of the ration nitrogen. Crude protein equivalent in these diets ranged from 6.5 to 15.3%. The urea-supplemented animals fed the 12.1% crude protein equivalent ration with chlortetracycline gained significantly more than those on the 6.5 or 9.4% rations. The authors suggested that as early as 3 weeks of age some urea nitrogen was utilized by the young calves.

The Ohio workers (6) added 17, 20 and 25 pounds of urea per ton to chopped corn at the ensiling time and noted that a large part of the added urea was hydrolyzed to ammonia during the ensiling process. In fact, most of the added urea nitrogen was retained as ammonium salts of organic acids. In digestion trials with sheep, it was observed that the urea nitrogen was utilized as efficiently as the nitrogen supplied from soybean meal. The palatability and feeding value of the urea-treated silage were studied in three cattle-feeding experiments.

Results of two trials with a limited number of steers showed the treated silage to be a safe and palatable feed. The third experiment indicated the feeding value of the urea-treated corn silage was comparable to that of corn silage and soybean oil meal.

Urea Versus Biuret for Ruminants

Excessive ammonia nitrogen from urea or ammonia salts is easily wasted by the animal. Other non-protein nitrogenous compounds, such as biuret, may be less toxic than urea and could have economic importance as a nitrogen source for ruminants.

Several studies have investigated biuret as a non-protein nitrogen addition for ruminant animals (29, 35, 49, 66).

Meiske *et al*. (67) added either urea, biuret, crude biuret or soybean meal to a basal ration containing 7.13% crude protein for 50 fattening lambs. The crude protein levels of the lamb rations after the NPN additions were: 9.11, 9.08, 9.10 and 9.69%, respectively.

Feed efficiency and body weight gains were markedly increased by the added nitrogen regardless of source.

Urea and biuret were compared as a nitrogen source in a series of experiments by Karr et al. (52). Results from two of the three metabolism trials indicated that biuret significantly improved nitrogen retention when added to basal corn silage which was fed to fattening lambs. Nitrogen retentions were consistently lower in the urea than the biuret fed groups. A 26% increase in gains resulted from addition of urea or biuret to the basal diet.

In South Africa, Clark et al. (18) showed that biuret was more satisfactory than urea as a nitrogen supplement for sheep fed high fiber, low protein roughages. Such results should be expected from adding biuret to a high fiber ration because of its slower rate of hydrolysis and lack of effect on palatability.

Studies by Hatfield et al. (35) compared biuret and urea in metabolism, toxicity, growth and reproduction tests with sheep and beef cattle, and showed that biuret could safely supply a large portion of the nitrogen required by those ruminants. One report has indicated, however, contradictory results on the feeding value of biuret. Schaadt et al. (89) reported lower gains and a failure of sheep to readily adapt to biuret-containing rations. They also suggested that the main site of biuret hydrolysis and metabolism was probably not within the rumen, but in other tissues of the animal.

There are only a limited number of trials on biuret in milking cows. In 1968 two experiments were conducted in Scotland by Waite et al. (101) involving 39 cows to compare the feeding value of biuret and urea as a total substitute for the nitrogen supplied by the oil cake in concentrates. Urea and biuret replaced 52 and 43% of the total nitrogen in the concentrate mixtures used in the first and second experiments, respectively. Good quality hay was fed as the only roughage. No differences in milk yields between biuret and urea treatments were noted. However, production by the urea- and biuret- supplemented groups was lower (10%) than that of the control treatment.

Ammoniation of Industrial By-Products for Livestock

Many industrial by-products have long been utilized as livestock feeds. Cane molasses, condensed distillers molasses solubles, blackstrap molasses, citrus pulp, sugar beet pulp, are some common by-products used in ruminant rations.

In general, most of these feeds are low in protein, so attempts have been made to increase their nitrogen content.

A considerable number of reports in the literature (25, 55, 57, 63, 64, 65, 70) have demonstrated that after ammoniation these materials might serve as sources of nitrogen for ruminants.

In 1941, Millar (69) treated air-dry sugar beet pulp with anhydrous ammonia resulting in the fixation of ammonia nitrogen. An increase of 2.4% nitrogen occurred without external heat, or prolonged ammoniation. However, to secure a product having a higher percentage of ammonia nitrogen, increases of temperature, pressure and time of ammoniation were required. Under a pressure above 1000 pounds per square inch, at 232°C for two hours, nitrogen content of the beet pulp was raised from 1.6% (in the original material) to over 10%. The feed color became progressively darker with increased ammoniation temperatures. The major part of the nitrogen fixed at increased temperatures was water-insoluble. However, when the ammoniation was accomplished without external heat and at low pressures, 96.44% of the added nitrogen was water-soluble.

A small portion of corn silage was also ammoniated under conditions similar to those used for beet pulp. This study represents one of the few references found on ammoniation of corn silage in the literature. No nitrogen losses were detected from ammoniated silage samples stored for 5 months.

Intakes by sheep and dairy cattle decreased as ammonia content of the beet pulp or corn silage increased. In case of the pulp, the author suggested for a suitable protein supplement the nitrogen content should be limited to 6%.

An increase of about 1.5% nitrogen was obtained when corn silage (67% moisture) was ammoniated at low pressure. Higher pressure (155 psi) and temperature

(108°C) were required for an increase of 2.0% nitrogen. The physical appearance, odor and palatability of the silage so ammoniated were considered undesirable.

Stiles (93) also ammoniated forage-type materials with the objective of fixing the ammonia nitrogen through chemical combinations that release in the rumen at a rate adequate for microbial protein synthesis.

Ammoniated Products for Dairy Cattle

In Pennsylvania, Knodt et al. (56) conducted a series of growth studies in which ammoniated cane molasses, ammoniated inverted cane molasses and ammoniated condensed distillers molasses solubles replaced soybean meal and oats nitrogen in rations for dairy calves. They demonstrated that when the ammoniated products were fed to calves over 12 weeks of age, gains of nearly 2.0 pounds daily were obtained. However, younger calves did not grow well on the ammonia nitrogen.

Ammoniated cane molasses and urea were fed to dairy heifers as replacements for the nitrogen of cottonseed meal by the Louisiana workers (77). The concentrate mixtures used contained 12.4, 12.6 and 13.1% crude protein. Urea and ammonia replaced 30% of the protein equivalent in the experimental rations. Daily gains averaged 1.23, 0.92 and 1.04 pounds for cottonseed meal, urea and ammoniated molasses treatments, respectively. The ammoniated molasses was quite palatable in this feeding trial. The highest intake per pound of gain was required by the urea-supplemented animals.

Magruder et al. (63) reported that ammoniated cane molasses fed to milking cows at 10% of the grain ration was well utilized for milk production and body weight gains. These researchers also fed ammoniated wood molasses (Masonex) to growing dairy heifers at 10% of the total ration and obtained favorable results.

Ammoniated citrus pulp was fed to dairy cattle as a carbohydrate and crude protein supplement (25). Satisfactory results were reported when 30 to 40% of the total digestible nutrients, and 15 to 20% of the ration nitrogen was supplied by the ammoniated citrus pulp.

Inverted cane molasses which had been highly ammoniated (38% crude protein equivalent) was fed at 10% of the grain ration containing 18% protein as a cottonseed meal substitute (87). Satisfactory growth was made by the dairy steers on the experimental ration. However, the treated molasses when fed ad libitum, along with hay and grain, was not palatable. This lack of palatability was attributed to the high alkalinity (pH 8.5) of the feed.

Ammoniated Products for Beef Cattle and Sheep

Several ammoniated by-products have been evaluated in fattening and wintering rations for beef cattle. In 1951, Tillman and Kidwell (95) reported the value of ammoniated condensed distillers molasses solubles as a protein source and carbohydrate extender. Gains were comparable for all groups, but slightly lower for the lots fed the highest level of ammoniated material.

Four experiments were conducted by McCall and Graham (65) comparing ammoniated cane molasses, ammoniated citrus pulp and furameal with natural proteins. The study involved 251 fattening steers. The protein equivalent levels were 24% for the ammoniated molasses and ammoniated citrus pulp; and 35% for the furameal. Steers fed a protein supplement in which furameal supplied about one-fifth of the nitrogen gained slightly more than those on the diet in which urea replaced a similar amount of protein. When ammoniated molasses replaced one-sixth of the protein in the supplement gains were exactly the same as the control, but slightly less when fed to replace one-fifth of the supplemental protein. Furameal and ammoniated molasses were combined with each supplying one-fifth of the supplemental protein. The ration produced slightly higher gains than the control with about the same feed efficiency. The ammoniated citrus pulp diet gave gains comparable to the controls, with about the same feed consumption. The authors concluded that the ammoniated products were satisfactory protein substitutes for fattening steers when fed to the level of 40% of the protein supplement.

In Florida, Kirk et al. (53) measured the nutritional value of ammoniated citrus pulp in fattening rations. Pangola-grass hay, cottonseed meal, plain citrus pulp and citrus molasses were used in the feeding trials. Ammoniated citrus pulp containing 12.9% crude protein equivalent, replaced most of the plain pulp and part of the cottonseed meal. Average daily gains by cattle fed ammoniated citrus pulp was lower than that of the control lots. The workers suggested that a lack of palatability of the experimental rations would explain the low gains.

In Oklahoma, Pope et al. (80) found that ammoniated cane molasses (17% crude protein equivalent) successfully replaced one-third of the cottonseed meal on a protein equivalent basis in wintering beef cows. Cows fed a combination cottonseed meal and ammoniated molasses gained significantly more than those fed cottonseed meal alone.

Nine trials on ammoniated cane molasses (16 to 33% crude protein equivalent) and ammoniated furfural residue (34.4% crude protein equivalent) were reported by Tillman et al. (97). The results generally indicated that the ammonia nitrogen in these products was not well utilized. Ammonia treated molasses gave results comparable to urea only in the wintering trials. An unusual behavior was observed among steers fed 2 pounds daily of high-ammoniated cane molasses (32.2% protein equivalent).

This was characterized by short periods of violence, running into or jumping fences in a highly excited manner.

In digestion and nitrogen balance studies with sheep, Tillman and Swift (96) found that ammoniated cane molasses (ACM) was inferior to both soybean oil meal and urea when these supplements furnished 17% of the total ration nitrogen. But with respect to palatability, the trial showed that both ammoniated condensed distillers molasses solubles and ammoniated cane molasses (ACM) were acceptable to animals when fed at 10% of the total ration. In a more recent report, Tillman et al. (98) added a high-ammoniated cane molasses to low and medium protein control diets in order to supply 49 and 38% of the total ration nitrogen. Nitrogen digestibility (calculated by difference) was 50 and 42% for the respective rations. In a fattening ration, ACM gave unfavorable results and sheep on the supplemented rations presented endocardial hemmorhage condition.

Hershberger et al. (37) and Ferguson and Neave (31) have also reported unimpressive or negative results from digestion and nitrogen balance trials with sheep fed ammoniated by-products.

Other investigators have also reported unusual behavior in cattle fed ACM (1, 85). Sheep fed a high level of ACM exhibited mild to extreme excitement (98). Because of these pathological signs, Tillman *et al*. (97) stated:

> Apparently the stimulatory agent is concentrated to a greater extent in the ammoniated high-test molasses product than in the ammoniated cane molasses (16 and 38%). Because of their violent response, animals stimulated by these products may not only injure themselves, but also become a hazard to personnel.

Resume

The excellent quality of corn silage as a source of energy for dairy cattle has been substantiated by many feeding trials. Corn silage when adequately prepared is one of the most productive forages from both an acreage yield and total digestible nutrients standpoint. However, because of the relatively low crude protein content of corn silage it should be supplemented with a satisfactory source of nitrogen. Urea treated corn silage as the only forage for lactating dairy cows has been successfully reported by several investigators.

Studies have demonstrated good performance in lactating cows fed corn silage treated with 10 to 17 pounds per ton of urea at ensiling time. Nutrient digestibilities and nitrogen retention of low-protein basal rations are increased by the addition of urea. Urea treatment at ensiling time lengthens fermentation time and increases organic acid concentration in silages.

Urea added to concentrate at 2% has been shown to decrease palatability of rations. Milk production in high-producing cows was depressed when 21 to 25% of the total ration nitrogen was supplied by urea in the concentrate. Marked decreases in milk yields resulted when urea in the concentrate furnished 38% of the total ration nitrogen. Urea fed at very high levels has been fatal even for adapted animals. However, much lower intakes are toxic to unadapted animals.

Calves can utilize urea as early as 6 weeks of age. In some studies, urea-supplemented calves grew at comparable rates to conventional-protein groups.

Biuret, another NPN compound, was found to be comparable to urea as a nitrogen source for ruminants. Biuret can safely supply a considerable quantity of the nitrogen required by sheep and cattle. Biuret appears to be less toxic and more palatable than urea in the diet of ruminants. However, its use in milking rations in the U.S.A. is presently forbidden because of its appearance in milk of cows fed the compound.

Many industrial by-products have been used as livestock feeds. Several research reports have shown that the low crude protein content of these products may be considerably increased by addition of urea or anhydrous ammonia. Ammoniation of these feeds can be accomplished in an economical and practical way at room temperature. Higher ammonia nitrogen fixation is possible under high pressure and high temperature. Palatability of ammoniated feed for sheep and cattle is decreased as feed undergoes higher pressures and higher temperatures for nitrogen fixation. Ammonia nitrogen fed to calves over 12 weeks of age was satisfactorily utilized. Dairy heifers on ammoniated rations gained slightly better than those on a urea diet. Dairy cows fed ammoniated cane molasses at 10% of the grain responded favorably in milk production and body weight gains. Ammoniated products added to fattening and wintering-type rations gave satisfactory results when compared to the conventional rations. Abnormal behavior was observed in cattle and sheep fed high amounts of ammoniated products.

EXPERIMENTAL PROCEDURE

The present research covers a two-year study with hybrid corn harvested as silage during the 1967 and 1968 crop years on Michigan State University dairy farms.

Experiment I

Whole plant corn (excluding roots) of the Michigan 400 variety was harvested with a two row silage harvester. The corn plant material, fine chopped, was transported to the Michigan State University dairy barns in self-unloading wagons, and weighed prior to ensiling. Two vertical, concrete stave silos (3.66 x 6.71 and 3.01 x 12.19 m) were filled with approximately 32 and 50 tons of the fresh material containing 39 and 35% dry matter (D.M.). At the time of ensiling, randomized samples of the green chopped corn were collected for subsequent chemical analyses.

Addition of Anhydrous Ammonia to Green Chop Corn

A high-pressure tank equipped with a relief valve, pressure gauge, and a liquid withdrawal valve, of 200-gallon capacity was used for application of ammonia. By setting the relief valve the ammonia was added to the silage at a rate of 2.8 kg per metric ton of chopped corn. A plastic line from the ammonia tank was connected to a water hose, set to deliver at the blower 30 kg of water per metric ton of green material. Mixing occurred as the dissolved ammonia was blown into the silo. The other silo (35% D.M.) was filled with untreated material and used as control silage.

Fresh corn samples were collected from both lots just prior to entering the blower. One sub-sample was immediately analyzed for dry matter content. The other was placed in a plastic bag and stored at -3°C for future determinations.

Dairy Heifer Feeding Trial

The experimental silage was fed to dairy heifers primarily to determine the effects of its palatability on intake, but some indication of its value for growth was also of interest. Twenty-one Holstein heifers weighing 354 to 485 kg were allotted to two uniform groups on the basis of body weights. The heifers were individually fed once daily. Each group was fed corn silage *ad libitum* as the only forage, in order to evaluate more clearly the effect of the nitrogenous additive on appetite. Silage offered and weighed back was recorded for each heifer daily. The animals were weighed at the beginning and at the end of the 16-day feeding period for two consecutive days. Samples of silage were taken three times a week, on alternate days, for dry matter and nitrogen analyses. The only supplement fed to heifers was a 50/50 mixture of dicalcium phosphate and trace mineralized salt, which was supplied at approximately 50 gm per heifer daily.

Experiment II

In a second experiment, hybrid corn from the same field was harvested and ensiled from October 2 to October 11, 1967, in a similar manner as described for Experiment I. The dry matter content of the whole plant corn silage ranged from 37.8 to 39.2%. Approximately 40 metric tons of silage was treated with 0.5% urea and ensiled in a concrete-stave, upright silo (3.01 x 12.19 m). A second silo was filled from alternate loads, but was not treated with urea. The ammoniated corn silage from Experiment I was also used in the trial.

Silage treatments were as follows: A) Silo 5, control corn silage; B) Silo 4, corn silage plus 5.0 kg urea per metric ton; C) Silo 10, corn silage plus 2.8 kg of ammonia per metric ton.

The relative value of ammoniated and urea-treated silages were determined for milk production and dry matter intake.

Lactation Study

Thirty-five Holstein cows were allotted to five treatments on the basis of milk production during a 3-week standardization period, in which control silage and alfalfa hay were fed free choice. Grain was fed at 1 kg per 3 kg milk. During the experimental period which lasted 9 weeks, control silages were fed to two of the five groups. A low protein concentrate (8.4%) was offered to one control group, while the protein content of the grain fed to the other group was 18.6%. The cows on control silage plus low protein grain served as negative control for a better evaluation of the possible effects of the added ammonia and urea. Two groups were fed urea-treated silage. Crude protein in the concentrate offered to one group on urea silage was 8.4% and the other group received a concentrate containing 12.9% crude protein. The fifth group was fed ammoniated corn silage and the same concentrate (12.9% crude protein) furnished to one of the urea-supplemented groups. All cows were fed the various silages *ad libitum* once daily as the sole forage, and concentrates were supplied twice daily at 1 kg per 3 kg milk. Daily milk weights were recorded for all cows. A daily composite sample of milk was collected weekly and was tested for fat content by the Babcock procedure. Animals were weighed on two consecutive days, 7 days after the beginning and at the end of the experimental period. Samples of silages were taken on Mondays, Wednesdays and Fridays of each week and analyzed for dry matter. Subsamples were frozen in plastic bags and saved for nitrogen analyses. Samples of the different concentrates were also collected at various times throughout the feeding period for dry matter and nitrogen determinations.

Experiment III

In October, 1968, hybrid silage corn was harvested at approximately 37, 41 and 52% D.M. with a self-propelled Super-D Fox Chopper. The chopped corn was transported and ensiled as described for the first and the second experiment. Nearly 58 tons (37% D.M.) and 25 tons (52% D.M.) of whole plant corn silage were treated with urea at 0.5 and 0.75% levels, respectively, at the ensiling time in a similar manner as in Experiment II. Approximately 35 tons of fresh material (41% D.M.) were treated with anhydrous ammonia at the filling time by the process already described in Experiment I. Through 2-inch holes in the silo doors, samples were removed with an auger during the fermentation period of the 41 and 52% D.M. silages for pH determination. All sampling and tests for silage samples were the same as outlined previously. The silages were evaluated in two animal performance trials, consisting of a lactation and a nitrogen balance study.

Lactation Study

Eighteen Holstein cows were grouped into three comparable lots, on the basis of milk production during a 21-day standardization period. The standardization ration was the same as described in the previous experiment. During treatments three groups of 6 cows each received the following rations: urea-treated corn silage (36% D.M.); urea-treated corn silage (52% D.M.); and ammonia-treated corn silage (42% D.M.). The length of the feeding trial was 7 weeks following 10 days for adjustment to rations. Cows on ammoniated silage and 36% D.M. silage treated with urea continued on treatment until 11 weeks. The silages were fed *ad libitum* with a concentrate mixture formulated to contain approximately 10% crude protein. The grain was fed to all cows at the same ratio (1:3) as during standardization. Changes of the amount of grain supplied were made based on the mean persistencies of each group. During the experimental period, daily feed consumption and milk production were recorded as in the previous experiment. Likewise, all milk and all feed sampling procedures were similar to those previously reported.

Digestibility and Nitrogen Balance Study

A digestibility and nitrogen balance trial was conducted immediately after the 7-week feeding period on all cows used during the lactation study.

The system employed for urine collection was developed by Dr. Clifford Beck of the Michigan State University Veterinary Science Faculty. It consisted of a plastic funnel-like apparatus, surgically sutured to the skin surrounding the vulva. Branding cement was applied to make the device spillage-free. Urine excreted was directed through a tube into a storage container. Feces were collected in galvanized, stainless steel pans set in the gutter behind the cows. This type of pan is characterized by a high back in order to prevent possible losses.

The collection period for all groups was originally designed to last 7 days, but because of a lack of good-quality silage, cows on silo 12 (52% D.M.) were terminated after 5 days. The other groups continued to 7 days. Two days were allowed for adjustment to the collection apparatus. Feed, orts, urine and feces were individually weighed at 24-hour intervals. One percent of the daily urine volume, five percent of the feces weight and 20 to 100% of the orts were frozen daily. Samples for the total period from each cow were thawed and composited for analyses. Milk weights were recorded for each cow and a daily composite sample was collected for three alternate days. Milk samples were treated with formaldehyde during the collection period, as a preservative and kept at 4°C until analysis. Fecal, urinary and milk nitrogen were determined by the Kjeldahl method on fresh samples. Dry matter on feces was analyzed as previously described.

Experiment IV

Samples of untreated, urea-treated and ammoniated corn silages were used for this experiment. This was an attempt to detect possible nitrogen losses from samples of silage exposed to different temperatures for varying lengths of time. Anhydrous ammonia was added to the green-chopped corn only at the time of ensiling; but in case of the urea-treated silage, some was treated either at the time of ensiling or at the time of feeding. Some control and urea silages were sampled immediately after the removal from the silo by the silo unloader. Samples were sealed in plastic bags. The ammonia silage was taken four feet below the top surface of the silage. All samples were handled in such a way as to minimize nitrogen losses and air exposure. The urea-treated silage was divided into 5 portions. One portion was immediately analyzed for dry matter and total nitrogen. Another was exposed to the barn temperature (average 20°C) for 10 hours. The three remaining portions were placed in three different ovens, set at 31°, 45° and 52°C for 10 hours. Following the 10-hour period, samples were ground and analyzed for nitrogen and dry matter.

Another untreated corn silage sample was taken directly from the top of the silo immediately after mechanical unloading of 420 kg of silage. Exactly 190 kg of that silage were treated with 0.71% feed grade urea (45% nitrogen) and 0.75% ammonium polyphosphate (AMP). One sample was collected after the chemical treatment.

Two Holstein cows were offered 45.4 kg of silage. One cow received control silage and the other was offered urea-AMP-treated silage. Additionally, 9 kg of each silage were not fed but were placed in two galvanized bushel containers exposed to the barn conditions in order to compare the effect on the silage of feeding conditions (such as contamination by saliva, water and dirt from the cow). The barn temperature was measured with a thermometer placed approximately 10 cm above the silage buckets. The "fed" and "not fed" silages were exposed to the stated conditions for 20 hours. Sub-samples were taken after 10 hours and at 20 hours. Barn temperature during the period averaged 21°C. All samples were ground and analyzed for moisture, pH and nitrogen.

The ammoniated silage was ground in a Wiley mill using a 3/8" coarse screen. One portion of the ground silage was analyzed as described. The remainder was placed in the cooler at 3°C. A sub-sample of 500 gm of the remaining silage was taken daily from the sealed plastic sack and placed immediately into a hot air oven for 10 hours. Temperatures of 35°, 52° and 75°C were compared for three successive days. During the drying process the forage sample was spread in a thin layer of approximately half inch depth in a shallow tray. After 10 hours at the different temperatures the forage was removed from the oven, placed immediately in glass jars and stoppered firmly for future determinations.

CHEMICAL ANALYSIS

Dry Matter, pH, Total Kjeldahl Nitrogen, Crude Protein Equivalent

Dry matter content of green chopped corn, corn silage, orts and feces were determined in duplicate by drying in a forced-air oven at 80°C for 48 hours. Dry matter content of the ground grain was measured by drying in a hot-air oven at 100°C for 5 hours.

The pH was determined with a Beckman pH meter, by placing the external glass electrode of the Beckman into a mixture of approximately 5 gm of wet silage and 20 ml of distilled, deionized water at room temperature.

Total nitrogen was analyzed by the Kjeldahl method in triplicate for all feed and fecal samples, but air-dried ground grain samples were analyzed only in duplicate. Crude protein equivalent was obtained by multiplying the total nitrogen value of each sample by the factor 6.25.

RESULTS

Chemical Composition of Silages and Concentrates

Dry Matter

The average dry matter content of silages fed in Experiments I, II and III are presented in Table 1. Silages which received no additive fed only in trials I and II, averaged 32.6 to 35.7% dry matter (D.M.), while the two silages treated with ammonia contained 35.9 and 41.9% D.M. Urea-treated silages ranged from 35.8 to 52.4% D.M.

Differences in dry matter levels were related to date of harvest. Harvest was intentionally delayed in order to obtain the high dry matter levels (52%) of a urea-treated silage in Experiment III.

Grain dry matter levels (Table 2) averaged 86.3% with a range of 86.0 to 86.7%.

pH

Data on pH were not analyzed statistically because of the limited number of observations. Values of between 3.64 (for the ammoniated silage, 41% D.M.) and 4.63 (for the urea-treated silage, 52% D.M.) were observed. Under the conditions of this study, neither urea nor ammonia additions appeared to have a consistent effect on pH. The lack of effect due to the additives may have been partially due to variations in dry matter, however, urea-treated silage having the highest dry matter level (52%) also exhibited the highest pH (4.63).

Crude Protein

All of the nitrogen additives markedly increased the crude protein equivalent of the silages above that of comparable controls (Table 1).

TABLE 1.--Chemical composition and pH of experimental silages fed during the three experiments

Silage treatment	Dry matter	Ash	Crude fiber	Ether extract	Crude protein	Nitrogen free extract	pH
	(%)						
Experiment I							
None	32.6	4.5	22.1	1.5	9.3	63.4	4.09
0.28% ammonia	35.9	4.0	21.8	1.7	11.4	62.8	4.22
Experiment II							
None	35.7	4.3	20.8	2.1	8.3	64.5	4.08
0.5% urea	35.8	4.3	19.5	2.3	12.8	62.2	4.08
0.28% ammonia	35.9	4.0	21.8	1.7	11.4	62.8	4.22
Experiment III							
0.5% urea	36.2	4.3	16.3	2.6	11.6	66.5	3.81
0.75% urea	52.4	4.1	18.4	1.9	11.3	66.5	4.63
0.28% ammonia	41.9	4.6	17.6	2.1	9.3	67.2	3.64

Urea was added to the high dry matter silage (52%) in such amount (0.75%) as to furnish approximately equal nitrogen on a dry basis, as the lower dry matter silage treated with 0.5% urea. Ammonia was added to the silages at 2.8 kg per metric ton, which was equivalent to 0.5% urea. Silage analyses showed that ammonia supplied approximately 31.7 and 23.0% of the total nitrogen of silages harvested during 1967 and 1968, respectively.

In 1967-68 added ammonia accounted for 31.7 of the total ration nitrogen fed the heifers and 20.1% furnished to the cows in the lactation study. In Experiment III the percentage of the total ration that came from ammonia was 9.2%.

Urea nitrogen accounted for approximately 21.7 and 19.0% of the total nitrogen fed with low- and medium-protein rations during the Experiment II. About 20.4 and 16.4% of the total ration nitrogen was supplied by urea in the low and high dry matter silages fed in Experiment III.

TABLE 2.--Formulas and chemical composition of experimental concentrate mixtures used in Experiments II and III

Ingredients	Experimental Grains[1]			
	D-53	D-54	D-55	D-68
Ground shelled corn (kg)	816.3	589.7	725.8	771.1
Soybean meal - 50% C. P. (kg)	-	226.8	90.7	45.4
Molasses (kg)	68.0	68.0	68.0	63.5
Dicalcium phosphate (kg)	15.4	15.4	15.4	13.6
Trace mineralized salt (kg)	9.1	9.1	9.1	9.1
Vitamin A (IU/453.6 gm)	3000.0	3000.0	3000.0	-
Vitamin D (IU/453.6 gm)	1000.0	1000.0	1000.0	-
Limestone (kg)	-	-	-	4.5
Chemical constituents	(%)			
Dry matter	86.1	86.7	86.0	86.5
Crude protein	8.4	18.6	12.9	11.1
Ether extract	4.5	2.8	3.3	4.0
Crude fiber	2.9	2.1	2.2	2.3
Ash	3.4	4.7	4.1	5.5
Nitrogen free-extract	66.9	58.5	64.5	77.1

[1]D-53, 54 and 55 were used in Experiment II and D-68 was fed to all groups in Experiment III.

Other Constituents

In general, the addition of either urea or ammonia did not alter the proximate constituents of silages other than the crude protein content.

Table 2 shows the ingredient composition and chemical analyses of the concentrates used throughout the feeding trials.

Heifer Growth Trial (Experiment I)

Data from this trial are shown in Table 3. The statistical analysis employed was the Student t-test (92).

TABLE 3.--Intake and growth of dairy heifers fed ammoniated corn silage

Item	Treatment	
	Control	Ammonia (0.28%)
Number	10	11
Dry matter intake (% of B.W.)[a]	0.94*	1.06
Average daily gain (kg)	1.06**	1.18
Feed utilization (kg D.M./kg gain)	8.51	8.46

[a]B.W. = body weight
*Significant lower ($P < 0.01$).
**Nonsignificant ($P < 0.10$).

Dry matter consumption was significantly lower ($P < 0.01$) for heifers fed the control than the ammonia-treated silage. Heifers fed the ammoniated silage also had greater body weight gains (0.12 ± 0.12 kg per day difference, $P < 0.15$). Feed utilization (kg D.M. per kg gain) was not significantly different, but the treated group had a slightly higher feed utilization than the control.

First Lactation Study (Experiment II)

In Table 4 are presented the feed consumption data collected from all cows during the feeding period. Orthogonal contrast (92) was the technique used for testing differences among treatments.

The silages were of good quality as indicated by the silage dry matter intakes. However, intakes were significantly depressed ($P < 0.05$) when the low protein concentrate (8.4% C.P.) was fed. The depressed consumption was due to the low protein content of the rations, rather than any silage characteristic. Total dry matter

TABLE 4.--Dry matter intakes of cows as influenced by additions of urea and ammonia to corn silages fed with grain at various protein levels.

Item	Silage Treatment				
	Control 8.4[a]	Control 18.6	Urea 8.4	Urea 12.9	Ammonia 12.9
Corn silage (% of B.W.)	1.10^{b}	1.59^{d}	1.27^{bc}	1.55^{cd}	1.53^{cd}
Total (% of B.W.)	2.36^{b}	2.77^{cd}	2.49^{bc}	2.93^{d}	2.79^{cd}
Milk yield/kg D.M.	1.54	1.40	1.56	1.64	1.46

[a] C.P. in concentrate: %

[bcd] Means not sharing a common superscript are significantly different ($P < 0.05$).

intakes followed a trend similar to that observed for corn silage intakes except that the group receiving urea-treated silage and medium-protein concentrate exhibited highest intakes but differences were not significant from the other two rations containing approximately equal levels of nitrogen.

Milk yields per kg dry matter intake among all groups were not significantly different ($P < 0.05$).

Production performance and body weight gain data are presented in Table 5. Because of lower protein consumption, the negative control group produced significantly less ($P < 0.05$) than all other groups, except the low-protein group fed urea-treated silage which approached significance ($P < 0.05$). Average production of cows fed urea-treated and ammonia-treated silages with the medium-protein concentrate was about the same as those on positive control silage. Because of similar production during standardization, persistencies followed a pattern similar to that for milk yields.

Body weight changes were significantly lower ($P < 0.05$) for the negative controls than the three groups receiving adequate protein. Gains on urea silage and

TABLE 5.--Milk and fat yields and body weight changes of cows fed high corn silage rations treated with urea and ammonia

Item	Silage Treatment				
	Control 8.4[a]	Control 18.6	Urea 8.4	Urea 12.9	Ammonia 12.9
Milk yields:					
Standardization (kg/day)	28.0	27.7	28.6	27.5	28.2
Treatment (kg/day)	19.4^{b}	25.6^{cd}	23.0^{bc}	26.6^{cd}	24.9^{cd}
Persistency $\frac{\text{Treat.}}{\text{Std.}} \times 100$	70.8^{b}	91.1^{c}	83.5^{bc}	98.2^{c}	91.4^{c}
Milk fat (gm/day)	601.0	870.0	621.0	745.0	697.0
Milk fat (%)	3.1	3.4	2.7	2.8	2.8
Body weight gain (kg/day)	-0.34^{b}	$+0.33^{c}$	-0.12^{bc}	$+0.18^{c}$	$+0.18^{c}$

[a]Crude protein in concentrate (%).

[bcd]Means not sharing a common superscript are significantly different ($P < 0.05$).

low-protein concentrate were intermediate and not significantly different from any of the treatments.

Second Lactation Study (Experiment III)

Corn silage and total feed intakes, expressed as a percentage of live weight, were higher ($P < 0.05$) for the cows on treatment A than the B and C (Table 6). Milk yield per kg dry matter intake was significantly higher ($P < 0.05$) for cows on B than for those on A but not significantly different from C.

Average milk yields did not vary significantly but persistencies were higher for groups receiving urea-treated than ammonia-treated silages (Table 7). Differences between the lower dry matter urea-treated and the ammonia-treated silages were significant ($P < 0.05$).

Milk fat production was significantly higher ($P < 0.05$) for treatment A than B and C, but there was no significant difference in milk fat percentages among the three groups. Gains were about equal in group A and C, but B was lower ($P < 0.05$) than A.

TABLE 6.--Dry matter intakes of cows as affected by added ammonia and urea to corn silages (7-week averages)

Item	Silage Treatment		
	A (Urea-36% D.M.)[c]	B (Urea-52% D.M.)	C (Ammonia-42% D.M.)
Corn silage (% of B.W.)	1.66[a]	1.24[b]	1.19[b]
Total (% of B.W.)	3.21[a]	2.68[b]	2.57[b]
Milk yield/kg D.M.	1.47[a]	1.62[b]	1.56[ab]

[ab]Means not sharing same superscript are significantly different ($P < 0.05$).

[c]D.M. = dry matter.

TABLE 7.--Milk yields and body weight changes of cows as influenced by additions of urea and ammonia to corn silages[a]

Item	Treatment		
	A (Urea-36% D.M.)	B (Urea-52% D.M.)	C (Ammonia-42% D.M.)
Milk yields:			
Standardization (kg/day)	33.3	33.3	33.2
Treatment (kg/day)	27.3[b]	25.6[b]	24.4[b]
Persistency: Trt./Std. (x100)	82.6[b]	77.0[bc]	73.3[c]
Milk fat (gm/day)	928.0[b]	717.0[c]	610.0[c]
Milk fat (%)	3.4	2.8	2.5
Body weight gain (kg/day)	+ 0.46[b]	+ 0.05[c]	+ 0.30[bc]

[a]Six cows per group for 7 weeks.

[bc]Values not sharing a common superscript are significantly different ($P < 0.05$).

Dry matter intakes for Groups A and C for the total period of 11 weeks are given in Table 8. Silage intake and total dry matter intake expressed as a percentage of bodyweight were significantly higher ($P < 0.005$ and $P < 0.025$, respectively) for treatment A. There was no significant difference in milk yield per kg of dry matter intake between the groups.

TABLE 8.--Dry matter intake of cows as affected by added ammonia or urea to corn silages (11-week average)

Item	Treatment	
	A (Urea-36% D.M.)	C (Ammonia-42% D.M.)
Corn silage (% of B.W.)	1.73*	1.23
Total (% of B.W.)	3.19**	2.53
Milk yield/kg D.M.	1.43	1.50

*Significantly higher ($P < 0.005$)

**Significantly higher ($P < 0.025$)

Milk production and persistency were significantly higher ($P < 0.05$), for the cows that were fed the silage treated with urea. Fat production and percentage of fat in the milk were also higher ($P < 0.01$ and $P < 0.10$, respectively) for group A (Table 9). Body weight changes showed no significant differences between treatments.

Digestibility and Nitrogen Balance Studies

Immediately after the 7-week feeding period all the cows were used in a digestibility and nitrogen balance study. The results of this trial are given in Tables 10, 11, and 12. All three groups were in negative nitrogen balance; group C only slightly but the urea-fed groups to a greater extent (Table 10).

The proportion of the ingested nitrogen appearing in the milk was 46, 45 and 39% for the respective rations. Nitrogen excreted in the urine made up 26, 23 and 21% of the total nitrogen ingested. The proportion of ingested nitrogen excreted in the feces ranged from 40 to 48%. The analysis of variance of the percent of ration nitrogen secreted in milk, urine and feces failed to detect any significant differences even at the 10% probability level among treatments.

TABLE 9.--Milk and fat yields and weight changes of cows as affected by additions of urea and ammonia to corn silages[a]

Item	Treatment	
	A (Urea-36% D.M.)[b]	C (Ammonia-42% D.M.)
Milk yields:		
Standardization (kg/day)	33.3	33.2
Treatment (kg/day)	26.3*	23.1
Persistency Trt./std. (x100)	79.8*	69.7
Milk fat (gm/day)	920.5**	600.6
Milk fat (%)	3.5	2.6
Body weight gain (kg/day)	+ 0.46	+ 0.30

[a]Six cows per group for 11 weeks.

[b]D.M. = dry matter.

*Significantly higher ($P < 0.05$).

**Significantly higher ($P < 0.01$).

TABLE 10.--**Fate of** ingested nitrogen in cows fed ammoniated- and urea-treated corn silages

Item	Treatment			
	A (Urea-36% D.M.)	B (Urea-52% D.M.)	C (Ammonia-42% D.M.)	Std. error
Nitrogen intake (gm/day)	330^{a}	252^{b}	242^{c}	-
Nitrogen secreted (%):				
in milk	46	45	39	±1.9
in urine	26	23	21	±1.4
in feces	48	40	43	±1.7
Total	120	108	103	-
Nitrogen balance (gm/day)	-58	-20	- 8	-

[abc]Means not sharing a common superscript are significantly different ($P < 0.05$).

TABLE 11.--Digestion coefficients of high corn silage rations as influenced by addition of ammonia and urea

Item	Silage Treatment		
	A (Urea-36% D.M.)	B (Urea-52% D.M.)	C (Ammonia-42% D.M.)
	%		
Dry matter	62.0	61.6	62.0
Crude protein	58.4	59.7	57.1
Non-protein dry matter	62.3	61.8	62.2

TABLE 12.--Fate of digested nitrogen of cows receiving ammoniated- and urea-treated corn silages

Item	Silage Treatment		
	A (Urea-36% D.M.)	B (Urea-52% D.M.)	C (Ammonia-42% D.M.)
Digested nitrogen (gm/day)	146	150	138
As milk (%)	89^{a}	75^{b}	68^{b}
As urine (%)	51^{a}	38^{b}	38^{b}
Total (%)	140	113	106

[ab] Means not sharing a common superscript are significantly different ($P < 0.05$).

No significant difference was observed in nitrogen balance between the three diets. Nitrogen intakes were highest on treatment A, followed by B and then C. Mean differences in nitrogen intake were significant ($P < 0.05$).

Coefficients of digestibility of dry matter, crude protein and non-protein dry matter were similar in all treatments (Table 11).

Cows on ration A secreted a higher percentage ($P < 0.05$) of the total digested nitrogen in both milk and urine than the other two groups ($P < 0.05$, Table 12). The percentage of the digested nitrogen in milk for group B was greater than that observed for the ammonia treatment, but differences were not significant ($P < 0.05$).

Study on Nitrogen Losses from Corn Silages Treated with Various NPN Sources

No consistent losses of nitrogen resulted from the drying temperatures or methods of exposure imposed on the urea-AMP-treated silage (0.72% urea and 0.75% AMP), or ammoniated silage (0.28%).

Concentrations of Kjeldahl total nitrogen (on a dry matter basis), dry matter percentages and pH values for the silages measured at varying temperatures are presented in Tables 13 and 14.

The addition of urea and AMP to the control silage (0.71 and 0.76%, respectively) at the time of feeding increased the nitrogen concentration of the silage which did not change for 20 hours under barn conditions (either sitting in an open bucket or in front of the cow).

Addition of urea and AMP to the control silage at the time of feeding produced a slight rise in pH compared to the control when the silage was exposed to the barn temperature for several hours. A trend toward increased pH was detected as temperatures increased from 20°C to 75°C but this was not consistent for all treatments.

TABLE 13.--Nitrogen and dry matter content and pH values of urea plus AMP- and ammonia-treated corn silages dried at various temperatures

Treatment	Original	Drying temperature for 10 hours					
		20°C	31°C	35°C	45°C	52°C	75°C
Urea + AMP-treated silage[a]							
Nitrogen (% of D.M.)[b]	2.115	2.258	2.194	-	2.263	2.114	-
Dry matter (%)	37.49	46.23	45.44	-	64.30	55.49	-
pH	3.84	4.06	4.16	-	4.26	4.12	-
Ammoniated silage[c]							
Nitrogen (% of D.M.)	1.511	-	-	1.488	-	1.483	1.472
Dry matter (%)	41.56	-	-	65.54	-	88.94	96.20
pH	4.08	-	-	4.18	-	4.23	4.17

[a]0.72% urea and 0.75% ammonium polyphosphate added at time of ensiling.

[b](D.M.) = dry matter.

[c]0.28% anhydrous ammonia added at time of ensiling.

TABLE 14.--Effects of time of exposure to the environmental barn conditions on nitrogen content and pH of untreated and urea-AMP-treated corn silages

Sample designation	Time of exposure (hour)		
	0	10	20
Untreated silage (not fed)[a]			
Nitrogen % (D.M.)[c]	1.192	1.199	1.173
Dry matter (%)	37.33	38.38	38.71
pH	3.83	3.92	3.94
Ort from untreated silage (fed)[b]			
Nitrogen % (D.M.)	1.192	1.260	1.229
Dry matter (%)	37.33	37.85	36.79
pH	3.83	3.85	3.83
Treated silage (not fed)			
Nitrogen % (D.M.)	2.296	2.150	2.218
Dry matter (%)	37.46	38.32	38.37
pH	3.90	3.94	3.96
Ort from treated silage (fed)			
Nitrogen % (D.M.)	2.296	2.273	2.308
Dry matter (%)	37.46	39.03	41.03
pH	3.90	3.94	4.02

[a]Not fed = exposed in a bucket in front of the cow.

[b]Fed = silage fed to a cow.

[c]D.M. = dry matter. Treated with 0.72% urea and 0.72% AMP at the time of feeding.

DISCUSSION

Urea increased the crude protein equivalent of silages at 36 and 52% D.M. by 4.1 and 4.2 percentage units on a dry matter basis, which represented 35.3 and 37.2% of the total nitrogen. Crude protein equivalent of silage increases in proportion to the amount of urea added (6, 54). However, because of the difference in dry matter content of the urea silages (36 and 52%) fed in the second lactation study, 7.5 Kg per metric ton of urea were added to 52% D.M. silage to obtain crude protein equal to that furnished by the addition of 5.0 Kg of urea to the 36% D.M. silage.

The crude protein content of the silages treated with 2.8 Kg of ammonia per metric ton was increased by only 3.6 and 1.8 percentage units on a dry matter basis for the 36 and 41% D.M. silages, respectively. Prior to treatment, the 36% D.M. corn silage (harvested in 1967) contained 1.25% nitrogen on a dry matter basis. Nitrogen content was increased to 1.83% by ammonia treatment. In the case of 42% D.M. silage (harvested in 1968) the increase was from 1.20% to 1.48% on a dry matter basis. The magnitude of increase in nitrogen by ammoniation is within the range of that reported by Millar (69). Ammoniation of several by-products (molasses, citrus pulp, beet pulp, etc.) has been conducted by different processes. For instance, the process of ammoniating corn silage reported by Millar differed from the process employed in this study. Ammoniation of corn silage at 155 pounds pressure and 108°C increased the nitrogen content 2.0 percent; however, the quality of the feed was adversely affected (69). From the data in this work it appears that the dry matter content of the silage has an influence upon the amount of total nitrogen fixed from anhydrous ammonia added through water. One improved method for ammoniating silage has been developed at the Michigan State University Experiment Station (36). It involves the use of cane or wood molasses as a carrier for the gas.

In the growth trial, heifers made good weight gains when fed both control and ammoniated silage. The heifers receiving the silage with ammonia showed better feed intake expressed as a percentage of liveweight ($P < 0.01$). The improved performance on ammoniated silage was due to the increased crude protein equivalent of the silage. Many investigators: Millar (70), Knodt et al. (55, 56), Magruder et al. (63), McCall and Graham (65), Magruder and Knodt (64), and Parham et al. (77) have reported satisfactory body weight gains in cattle and sheep with ammoniated products. In the previous trials additional sources of protein and energy were supplied, but in this study corn silage was offered as the sole source of protein and energy. Under this feeding regime, even the heifers on the control silage gained an average of 1.06 Kg per day which is quite satisfactory for herd replacements averaging 424 Kg liveweight. Schmutz (90) reported reasonable weight gains of heifers on corn silage as the only feed. In the present study, the good gains of heifers on the untreated corn silage may be explained by the excellent quality of the silage and by its relatively high crude protein level (9.3%). Daily intake of silage on wet basis averaged 27.4 Kg (32.6% D.M.) and 26.2 Kg (35.9% D.M.) for the control and ammoniated silages, respectively. Intakes of total crude protein daily were approximately 865 gm for the control and 1063 gm for the experimental group. Both groups were fed more than the total protein allowance of the National Research Council (74). The ammoniated silage was found to be very palatable. In this study ammonia contributed approximately 31.7% of the total ration nitrogen consumed. The higher crude protein content of the ammoniated silage was probably the reason for the increase in feed intake.

The heifer experiment was of a very short length of time; therefore, any considerations of practical application should be taken with caution. Undoubtedly an experiment of longer duration would be necessary to more properly evaluate the ammoniated silage for heifer growth.

Corn silage and concentrate mixtures were the only nutrients fed to cows during the lactation studies. In the first trial, the animals fed low-protein concentrate (8.4%) with control silage or with urea-treated silage (0.5%) exhibited lower silage dry matter intakes than treatments of higher protein content. The highest intake of silage was noted for the positive control group, followed by urea-treated and ammonia-treated silages fed with medium-protein concentrate (12.9%); however, these differences were not significant. It is interesting to note that the highest total dry matter intake was observed for cows on urea-treatment, followed by ammonia-fed group and the positive control group. Silage treated with 0.5% urea when fed with a medium-protein concentrate, the animals consumed more than those on the same silage fed with a low level of protein concentrate. The most dramatic evidence of effect of total nitrogen intake on feed consumption was shown by the very low intakes of the negative control cows. An improvement in dry matter intake by addition of urea to corn silage was also reported by Huber et al. (46). This response appears to be due primarily to an improvement in the protein status of the cows through increased nitrogen intake.

No significant treatment differences were observed in efficiency of production per Kg of dry matter intake. Treatment differences in milk production, persistencies and body weight gains can be partially explained by the low nutrient intakes by the low-protein groups. Both additives had a small depressing effect on the percentage of milk fat. Low milk fat percentage has also been reported by Holter et al. (40) in cows on concentrates containing various levels of urea; however, the authors suggested that the low milk fat content was due to the low dry matter content of the corn silage.

In the second lactation trial, one reason for the poor production performance of cows on the higher dry matter silages treated with urea or ammonia was again related to the low intakes. The ammoniated silage contained only 9.3% crude protein. The ammonia-nitrogen fixation was presumably limited by the high dry matter content of the silage which resulted in lower added nitrogen per unit of dry matter. Moreover, to fully challenge the NPN sources added to silage, a low-protein concentrate was fed (10% C.P.). Poor response by cows to urea-treated corn silage of high dry matter content was previously reported by Huber et al. (46). Another possible reason for the lower production when either NPN source was added to the higher dry matter silages was an inferior quality of the silages, this was particularly true for the 52% D.M. treated silage which exhibited visible spoilage.

As already reported, 0.75% urea was added to the high dry matter silage to supply approximately the same amount of nitrogen (on a dry basis) as 0.5% urea added to silage with 36% D.M. material. In the case of the ammonia-treated silage, the nitrogen added per unit of dry matter was only 88% that of the urea-treated silage and that retained was much lower, probably because of the higher dry matter content of the crop. Corn plant material with about the same percent dry matter as the above-mentioned ammoniated silage was treated with 0.55% ammonia (equivalent to 1.0% urea). Nitrogen levels in the resulting silage were only slightly higher than those of silage treated with 0.28% ammonia. This observation supports the claim that dry matter content of the chopped corn has a marked effect on the uptake of the anhydrous ammonia by the silage. As reported by Millar (69) the nitrogen fixation can be easily increased by adding larger amounts of ammonia to a moist product. However, for a very high level of ammonia fixation increased temperature and pressure must be applied.

On the basis of these data one might hypothesize that urea-treated or ammonia-treated corn silages harvested at high dry matter content are not adequately consumed by lactating cows for high level production. All the reasons for this poor response by the animals to the NPN treated silage with high dry matter content still need clarification. However, poor intake has been shown as a major problem.

In the digestion study, no significant differences were noted in the apparent digestibilities of dry matter, crude protein or non-protein dry matter among treatments. Apparent digestion of crude protein in this trial was comparable to that reported by other investigators (44), when urea comprised 0.6% of the silage; but higher than when 0.85% urea silage was fed. Digestibilities in the present study were lower than those reported by Huber *et al*. (45) when corn silage rations were fed with concentrates containing varying levels of urea. The low dry matter digestibilities (DMD) may have been due to two factors: low protein rations and dry matter content of silage. There is a general trend toward lower DMD with higher dry matter silages; but there is also a trend toward lower DMDs in rations which are deficient in protein (47).

It is possible that not only the low protein intake but also an inferior quality of the silage in Experiment III contributed to lower milk production. Nitrogen intake by cows on low dry matter silage was higher ($P < 0.05$) than the two remaining groups. Of the ingested nitrogen, the percentages recovered in either milk, urine or feces were not significantly different among rations (Table 10). It is interesting to compare the amounts of crude protein fed with the minimum requirement established by the NRC feeding standard (74). According to NRC all groups were severely underfed with respect to crude protein. One might suggest that the feeding of rations inadequate in protein was the major factor for the poor production performance, namely by the cows on ammoniated silage. The addition of nitrogen as urea or ammonia to these low protein rations should have improved digestibility of the dry matter. Several researchers have shown increases in dry matter digestibility of low nitrogen rations after the addition of urea (13, 15, 47, 58).

All three groups were in negative nitrogen balance. The highest loss of metabolic nitrogen was observed in cows on 36% D.M. silage treated with urea. The low nitrogen intake is a possible explanation for the negative balances; however, the highest percentage of dietary nitrogen secreted in milk and urine (resulting in the largest negative balance) was exhibited by the group producing the most milk which actually consumed more nitrogen than the other groups (B and C). Expressed as a percentage of the ingested nitrogen, urinary nitrogen losses were 26, 23 and 21%, for rations A, B and C, respectively. These percentages are lower than those reported by Huber et al. (45) and Holter et al. (40). Balance results showed that the group A secreted 140% of its digested nitrogen as milk and urine, while groups B and C averaged 113 and 106%. Huber and Thomas (47) have recently reported that as high as 142% of the digested nitrogen was recovered in the milk and urine from cows on control silage fed 8.4% crude protein concentrate.

Some attention was directed to possible non-protein nitrogen losses during the handling of the silage. As previously reported, corn silage treated with urea and AMP (7.2 Kg and 7.5 Kg per metric ton) at the ensiling time, when placed under various temperatures (ranging from 20°C to 75°C, Table 13), did not undergo any significant decrease in nitrogen, neither did exposure of corn silage treated with urea and AMP at barn temperature affect the nitrogen content of the silage (Table 14). Small and inconsistent differences noted among treatments regarding nitrogen levels might be due to: 1) lack of complete uniformity in the different portions of silage subjected to the various temperatures or method of exposure, and 2) the techniques for determining nitrogen losses were not sufficiently precise to differentiate among very small changes that might have occurred. In other words, the results are within the limits of experimental error. A trend toward increased pH due to barn exposure and higher temperatures was noted in most of the treatments, but this was not consistent. The rise in pH with increasing temperature or length of exposure time may be explained by the loss of volatile organic acids.

SUMMARY AND CONCLUSIONS

Holstein heifers and lactating cows were used to compare the nutritive value of ammoniated corn silage to silage treated with urea.

The dry matter content in the silage appears to be more responsible for changes in pH than the addition of urea or ammonia at the levels used in this study. The highest pH measured (4.63) was in high dry matter silage (52%) to which 7.5 Kg of urea were added per metric ton.

The crude protein equivalent of the urea-treated silages at 36 and 52% D.M. increased by 4.1 and 4.2 percentage units on a dry matter basis. Silages treated with anhydrous ammonia (0.28%) increased in crude protein equivalent by 3.6 and 1.8 percentage units on a dry matter basis at 36 and 41% D.M., respectively. In contrast to conclusions by Millar (69), it appears that the dry matter content of the silage has a marked influence on the amount of nitrogen fixed by application of ammonia in the aqueous form.

The process for ammoniating corn silage employed in the present study has been recently improved through using molasses as a carrier.

In the heifer trial, intakes and gains of the ammoniated-silage group were better than the control group, probably because of the increased nitrogen content.

In the first lactation study, total dry matter and silage dry matter intakes, milk yields, persistencies and body weight gains of cows on the negative control ration were significantly lower ($P < 0.05$) than the groups on normal protein diets. The group on urea silage plus low-protein concentrate was lower ($P < 0.05$) in silage dry matter intake than the positive control, and lower in total dry matter intake than the group on urea-silage fed with a medium protein grain. On the basis of these data it was concluded that dry matter intakes were significantly improved either by a higher level of protein in the concentrate or by addition of urea or ammonia to the silage. The poorer performance of the low protein rations was partially due to reduced nutrient intake. The ammoniated silage was as palatable as the control or urea-treated silages.

In the second lactation trial, fixation of anhydrous ammonia (with water as a carrier) was decreased by the high dry matter content of the silage. Lower intakes and milk yields resulted from feeding NPN-treated silages (either urea or ammonia) which were higher than 40% in dry matter. The decreased nitrogen fixation by the ammoniated silage resulting in a ration of lower protein content (than groups receiving urea-treated silages) may have been partially responsible for the poor performance of this group. Based on these findings, one may conclude that urea- or ammonia-treated silage containing a high level of dry matter is not sufficiently consumed by lactating cows to maintain high milk yields. However, data are not sufficient to explain the reason for the poor intakes by cows fed urea or ammonia silages of high dry matter content.

Dry matter digestibilities among treatments were somewhat lower than those reported in some previous studies (45, 47). Additions of ammoniated products to rations have adversely affected the digestibility of many components in the ration (96); but when this occurred, ammoniation was under conditions of high temperature and pressure.

NPN-treated silages were subjected to various temperatures but no consistent losses of nitrogen were noted. On the basis of this trial it appears that untreated or treated silages can be exposed to the barn atmosphere for a prolonged time without loss of nitrogen.

Based on the findings in this study, it is concluded that:

1) On an equal-nitrogen basis anhydrous ammonia added to corn silage is used for milk production and heifer growth as effectively as urea, but it must be added to silage of less than 40% dry matter for optimum results.

2) When either urea or ammonia is added to silage which is in excess of 40% D.M., poor performance results.

3) Loss of nitrogen from ammonia-treated or urea-treated silages under barn conditions, before

the cow, or due to heating up to 75°C are insignificant.

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