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Influence of Urea on the Fermentation Pattern & Nutritive Value of Corn Silage

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ABSTRACT

INFLUENCE OF UREA ON THE FERMENTATION PATTERN AND NUTRITIVE VALUE OF CORN SILAGE

The effects of chemical additives on the fermentation pattern and subsequent feeding value of corn silage was investigated over a two year period. Corn plants harvested in August 1967 (Experiment I) were ensiled with no additive, 0.50 per cent urea, or urea-mineral mix supplying an equal amount of urea. Those harvested in August 1968 (Experiment II) were ensiled with no additive, 0.50 per cent urea, or 0.75 per cent urea. The nutritive value of these silages was evaluated chemically and by lactation trials.

The addition of urea alone, or in combination with minerals elevated the initial pH and buffered against reduction of pH during fermentation. Urea-mineral combination exhibited a stronger buffering action than urea alone.

Data obtained during the first 25 days of fermentation in Experiment II indicated that acetic acid production was essentially completed after 5 days. Lactic acid production continued throughout the 25-day period. The production of propionic, butyric, and lactic acids was significantly

increased by increased amounts of urea ($P<.01$). Acetic acid production was significantly increased ($P<.01$) by the addition of 0.75 per cent urea but was slightly, although not significantly, depressed by the addition of 0.50 per cent urea.

In both experiments the treated silages tended to have less crude fiber, ether extract, and nitrogen-free-extract, but more ash and crude protein than the control silages. The crude protein content appeared to be elevated in an amount corresponding to the amount of urea added.

The effects of fermentation on urea were studied in Experiment II. Approximately 72.7, 65.3, and 66.6 per cent of the initial nitrogen as urea in the control, 0.50 per cent urea, and 0.75 per cent urea silages, respectively, was converted to other forms. The increase in NH_3-N accounted for 22.8, 44.4, and 24.8 per cent of this decrease in urea-N in the control, 0.50 per cent urea, and 0.75 per cent urea silages, respectively.

In the lactation trials, 24 Holstein cows were arranged in a 3 x 3 Latin Square design. Experimental silages were fed ad libitum. The diets were isonitrogenous and isocaloric. No significant difference was noted in milk production, silage consumption, and body weight change between cows fed the control and 0.50 per cent urea silages in both experiments. Cows fed the urea-mineral silage in Experiment I, produced significantly less milk, consumed significantly less silage, and gained significantly less body weight than did

cows fed the control and 0.50 per cent urea silages (P<.01, P<.01, P<.05, respectively). In Experiment II, cows fed the control and 0.50 per cent urea silages consumed significantly more silage dry matter than cows fed the 0.75 per cent urea silage (P<.01). Cows fed the control silage gained significantly more weight than did those fed the 0.75 per cent urea silage (P<.05), whereas, cows fed 0.50 per cent urea silage were not different from either the control or 0.75 per cent urea group in this respect. No significant differences in FCM production were noted among treatment groups.

TABLE OF CONTENTS

Page

INTRODUCTION 1

REVIEW OF LITERATURE 3

The addition of chemical compounds to corn silage 3
Urea 4
Hydrogen ion concentration and acid production in urea treated corn silage 5
Distribution of nitrogen in urea treated silage 7
Relative feeding value of urea-corn silage 9
Urea-mineral 15
Effects of urea-mineral mix on the pH and organic acid production in corn silage 15
Relative feeding value of urea-mineral corn silage 18

EXPERIMENTAL PROCEDURE 20

Experiment I 20
Lactation trial 21
Experiment II 22
Lactation trial 23
Computation of data--Production trials 25
Chemical analyses 25
Hydrogen ion concentration 25
Moisture 25
Proximate analysis 26
Organic acid determinations 26
Determination of nitrogen fractions 27
Urea-nitrogen plus ammonia-nitrogen 28
Ammonia-nitrogen 28
Urea-nitrogen 29
Analysis of data 29

Page

RESULTS AND DISCUSSION 30

Chemical data 30
pH and organic acid production 30
Chemical composition 36
Crude protein equivalent 36
Nitrogen distribution 39
Lactation trials 42
Experiment I 42
Experiment II 45

SUMMARY 48

LITERATURE CITED 51

VITA 56

LIST OF TABLES

Table | Page
1. Effect of chemical additives on final pH and organic acid content of corn silage (Experiment I) 31

2. Effect of urea on pH of corn silage during fermentation 32

3. Organic acid content of experimental silages at intervals after ensiling . . . 34

4. Effect of urea on the final pH and organic acid content of corn silage (Experiment II) 35

5. Chemical composition of the experimental silages 37

6. Per cent theoretical and analyzed crude protein equivalent in experimental silages 38

7. Milligrams of NH_3-N and urea-N per 100 grams of dry matter in Experiment II silages at intervals after ensiling . . . 40

8. Feed intake, milk production, and body weight change of cows during Experiment I 43

9. Feed intake, milk production, and body weight change of cows during Experiment II 46

INTRODUCTION

In recent years it has been well established that corn silage is a highly palatable and economical source of energy for dairy cattle. On the other hand, it is known to be deficient in protein, calcium, and phosphorus. Recent work with corn silage, as reviewed by Coppock and Stone (12), shows that, when properly supplemented, it can be used as the sole roughage in a dairy operation for extended periods without suffering diminution of appetite or production. In an attempt to increase the protein value of corn silage, several non-protein nitrogen compounds have been used. The most prominent among these is urea, which can be utilized by the rumen microorganisms to synthesize both essential and non-essential amino acids, providing a suitable carbon-chain source is available (34). The optimum level of urea to add is given as 0.5 per cent, however, there are some indications that higher levels can be used without detrimental effects.

Calcium carbonate addition to corn silage at the time of ensiling has been studied by various investigators with inconsistent results as to intake and milk production (6, 20, 28, 35, 43, 44). However, it is generally agreed that calcium carbonate provides a buffering action as shown by the

higher pH and increased concentrations of acetic and lactic acids in treated silage.

The investigation reported herein was conducted to more accurately determine the optimal urea level in corn silage and to investigate the use of a urea-mineral mix. Data are presented on the chemical composition and feeding value of corn silages ensiled with three levels of urea and urea in combination with minerals.

REVIEW OF LITERATURE

Since the mid-1950's much research has been done in an attempt to correct the inherent deficiencies of corn silage. A majority of this work has centered on the use of chemical additives such as dicalcium phosphate and calcium carbonate to correct mineral deficiencies and diammonium phosphate, biuret, urea, and just recently anhydrous ammonia to enhance the crude protein content of corn silage. Of the non-protein nitrogen compounds used, urea has been most prevalent. In this research, sheep, beef cattle, and dairy cattle have all been utilized. However, this review will be primarily concerned with work done with dairy cattle and will only delve into research on beef cattle and sheep when necessary to clarify or bring out those points where research is scarce or lacking with dairy cattle.

The Addition of Chemical Compounds to Corn Silage

A review of recent investigations involving corn silage reveals a renewed interest in the use of chemical compounds to increase the nutritive value of corn silage. In this report urea and urea-mineral combinations will receive primary attention.

Urea

Experiments concerning the use of urea in corn silage for dairy cattle were recently reviewed by Huber et al. (21). The factors affecting utilization of urea were reviewed by Chalupa (7). Conrad and Hibbs (10), Tillman and Kirpal (48), and Waldo (54) have recently reviewed the literature concerning nitrogen utilization by ruminants and nitrogen metabolism in ruminants.

Maximum utilization of urea for complete replacement of natural protein supplements appears to be dependent on controlling its rate of hydrolysis to ammonia and identification of specific rumen microbial factors for enhancing conversion to microbial protein.

The addition of urea to corn silage at the time of ensilation seems to have some advantages over the addition of urea to either the concentrate or to the silage as fed. Huber et al. (21) suggested that some benefits of adding urea at ensilation might be to: (a) mask the undesirable taste of the urea; (b) allow a more even intake of urea over the whole day and minimize possible ammonia excesses in the blood; and (c) take advantage of automated silage feeding systems. These and other considerations have prompted several investigators (3, 12, 14, 18, 23, 29, 50) to suggest that urea be added at time of ensilation.

Hydrogen Ion Concentration and Acid Production in Urea Treated Corn Silage

It is generally accepted that during the silage fermentation process anaerobic microorganisms use the soluble carbohydrates of the ensiled material to produce organic acids. It is also known that the activity of these anaerobes decreases as the pH drops below 4.5 and the silage keeping quality is decreased if the pH remains above 4.8 for an extended period. Most good quality corn silage has a final pH of about 3.8 (14).

Certain chemical additives, such as dolomitic limestone, calcium carbonate, and diammonium phosphate, when ensiled with corn silage, increase its pH and organic acid content (6, 30, 31, 35, 43). This buffering action has also been demonstrated with urea.

Huber *et al*. (24) treated corn silage of three different dry matter contents (30, 36, and 44 per cent) with 0.0 or 0.5 per cent urea at ensiling time. The respective pH values for each dry matter content and level of urea were 3.89, 3.91; 3.97, 3.95; and 3.87, 4.01. The corresponding lactic acid values (grams per 100 grams dry matter) were 8.72, 10.23; 7.83, 8.44; and 5.68, 6.99. Corn silages containing 0.0, 0.5, or 0.75 per cent urea were observed by Polan *et al*. (42) to have final pH values of 3.8, 4.5, and 4.8, respectively. No attempt was made to determine the organic acid content. Schmutz *et al*. (43) observed a slight increase in pH values of urea treated silage over the control

silage and also an increase in the organic acid content. However, he noted that $CaCO_3$ stimulated greater acid production (lactic and acetic) than did urea. The results of two trials concerning the effects of calcium sources and urea on corn silage fermentation in laboratory silos were reported by Owens (40) in 1969. Two levels of urea (0.0 and 0.5 per cent) were studied. The urea was added to 45 per cent dry matter corn material at time of ensilation and allowed to stand for a 60-day period before observations were made in Trial 1. Similar conditions existed in Trial 2 with the exception of a 90-day fermentation period. The final pH values for the Trail 1 silages were 3.98 for the 0.0 level and 4.64 for the 0.5 per cent level of urea. Corresponding values for acetic and lactic acid were 0.78, 4.22, and 0.22, 7.50 (expressed as per cent of dry matter). In Trial 2 the 0.0 and 0.5 per cent levels of urea resulted in final pH values of 4.38 and 4.68, respectively, with acetic and lactic acids levels (expressed as per cent of dry matter) of 1.05, 1.48, and 1.14, 2.94, respectively. Analyses of these data showed that urea additions resulted in significantly higher ($P<.05$, $P<.01$) final pH values in Trials 1 and 2. Urea caused a significant increase ($P<.05$) in lactic acid content in Trial 1. This increase was highly significant ($P<.01$) in Trial 2. It should also be noted that the addition of urea depressed the acetic acid content, which conflicts with the data of Schmutz _et al_. (43). Using conventional silos, they

(43) reported an increase in acetic acid levels with the addition of 0.5 per cent urea and still a greater increase when 0.75 per cent was used. It should be noted that Schmutz et al. (43) were using silage materials of 27 to 28 per cent dry matter. Dry matter content greatly influences the effects of urea and other chemical compounds on the fermentation of corn silage. As the corn plant matures, fermentation of the resulting silage changes somewhat. Johnson et al. (26) reported that acetic acid content was highest (6 to 7 per cent of dry matter) at the blister stage, decreased significantly ($P<.01$) at the early milk stage, and gradually decreased to about 1.0 per cent of dry matter in later stages. Lactic acid was highest (16 per cent of dry matter) at the early milk stage and then gradually declined ($P<.01$) to about 4 per cent of silage dry matter.

Distribution of Nitrogen in Urea Treated Silage

Work by Klosterman et al. (29) indicated that urea was more efficiently utilized as a nitrogen source by ruminants when added to corn plant material at the time of ensilation, rather than when added in mixture with corn and silage at feeding time. These observations along with previous data (3) caused speculation that the ammonia derived from ensiling urea was bound to the organic acids produced during fermentation, thus less easily released in the rumen. Johnson et al. (27) reported that this may not be the true

picture. Their results indicated that the amount of nitrogen as urea and ammonia in the ensiled product may be even higher than expected after fermentation. They suggested that the increased utilization of the added urea may be the result of the low pH of silage coupled with the rapid fermentation of lactic acid in the rumen. The two situations together would (a) produce and maintain a lower pH in the rumen, under which conditions the NH_4^+ ion is not rapidly absorbed through the wall, or (b) cause more rapid utilization of the ammonia through lactate fermentation.

The extent to which urea is hydrolyzed to ammonia, enzymatically and chemically, has been studied by several investigators. Johnson et al. (27) reported that urea was only partially broken down to ammonia. Polan et al. (42) presented values for urea-N and NH_3-N content of control (no additive), 0.5 per cent urea corn silage, and 0.75 per cent urea corn silage of 0.02, 0.02; 0.05, 0.18, and 0.13, 0.23 (expressed as per cent of as fed material), respectively. The corresponding dry matter contents were 38.0, 36.0, and 37.8 per cent. Huber et al. (24) in a Michigan study used corn silage with dry matter contents of approximately 30, 36, and 44 per cent with urea added at ensiling time in the amounts of 0.0 or 0.5 per cent for each stage of maturity. The NH_3-N and urea-N fractions (expressed as per cent of total nitrogen) in the control and urea silages for the three stages of maturity (30, 36, and 44 per cent dry matter) were

7.2, 3.9, and 21.1, 16.3; 6.4, 4.0, and 19.4, 12.8; and 6.5, 3.4 and 15.4, 12.0, respectively. These results indicate that a greater conversion of urea to ammonia occurred in the high dry matter silage than in the less mature silages, assuming that unrecovered nitrogen escaped as volatile ammonia. Owens et al. (40) reported that the addition of non-protein nitrogen (feedgrade urea) at ensiling time increased the crude protein content, the final wet silage ammonia content, and the soluble NPN content of corn silage. He also noted that the final urea concentrations of the silages studied did not reflect amounts of urea which had been added at ensiling time. Polan et al. (41) indicated that pH might be a significant factor in determining the amount of hydrolysis urea undergoes during the ensiling process. Using silages of 30 to 32 per cent dry matter and 37 to 44 per cent dry matter with respective pH values of 3.8 and 4.5 to 4.9, they noted that 80 per cent of the urea nitrogen was recovered as intact urea in the lower pH silage while in the higher pH silage ammonia accounted for 65 to 80 per cent of the non-protein nitrogen.

Relative Feeding Value of Urea-Corn Silage

Corn silage is a highly palatable source of energy but is inherently low in crude protein. When corn silage is fed as the sole roughage a series of protein levels is theoretically required to meet each animals requirements according to their production level. This presents a difficult situation

to most dairymen who would prefer to feed one concentrate mix. One way to supplement the forage protein level is to use a combination forage program of corn silage plus alfalfa hay. A second and less expensive way is to add urea to the corn silage. When corn silage is the only forage fed the addition of urea alleviates the high protein level theoretically required by the low producing cow, because a larger proportion of the digestible protein requirements can be obtained from the forage (11).

The present accepted standards for urea additions are (a) 0.5 per cent urea added to corn silage at ensiling time or (b) not more than 3 per cent of the concentrate (5). After reviewing the literature Hillman (19) further stated that the upper limit of adding urea approximates 0.027 pounds per 100 pounds of body weight, at least until further developments have evolved from research. This amounts to limiting the urea content to 1.5 per cent of concentrate rations, or 0.5 per cent urea ensiled with corn silage fed as the only forage. Corn silage ensiled with 0.5 per cent urea has been shown to be equal (24, 42), superior (18), and inferior (9, 18) to natural protein sources for milk production. These investigators also noted that intake was not affected by the use of urea at this level.

The possibility of using higher levels of urea has been recently investigated (22, 23, 42, 43, 52). Van Horn et al. (52) reported the results of 3 experiments in which

lactating dairy cows were fed levels of urea ranging from 0.0 to 423.0 grams of urea per cow daily. In Experiment 1, 24 Holstein cows were used in a 70-day continuous feeding trial employing a 4 by 3 factorial design with four levels of urea (0, 82, 160, and 232 grams of urea per cow daily) and three levels of crude protein (average of 2.5, 2.2, and 1.7 kilograms crude protein per cow daily). Urea was added to both the corn silage and the grain mix. Feed intake, milk production, milk composition, and body weight gains were not affected by treatments. In Experiment 2, 12 Jersey cows in a switchback design were fed corn silage and ground shelled corn with and without urea (179 grams per cow daily). The addition of urea increased milk production and body weight gains ($P<.01$) as compared with no added nitrogen. The addition of urea (423 grams of urea per cow daily) to an all corn silage and ground shelled corn ration fed to Holstein cows in Experiment 3 reduced milk production and body weight gains. However, in Experiment 3, pelleting of one concentrate and not the other and the use of a liquid supplement in one and not the other are confounded in the results. A Virginia study (23) involving 91 lactating Holstein cows fed corn silage as the sole roughage with urea added at time of feeding resulted in decreased milk production when urea furnished as much as 21 to 23 per cent of the total dietary nitrogen. This is contrary to the results of Van Horn et al. (52) who showed no decreased production when urea furnished as much as 29.5 per cent of the total dietary nitrogen. In

this study (52) part of the urea was added to the corn silage at ensiling time. It was also noted (23) that, in general, voluntary intake of corn silage was not adversely affected by urea additions, although silage consumption was depressed by high-concentrate rations which contained urea. A similar trial in which three levels (0.0, 0.5, or 0.75 per cent) of urea were added to the corn plant material at ensilation rather than at time of feeding was conducted by Polan et al. (42). Twenty-four cows were divided into eight outcome groups based on milk production during a two-week standardization period. One member of each group was randomly assigned to one of the three treatments. During the standardization period all cows were fed control (no additives) corn silage and pelleted concentrate. Corn silage of 38.0, 36.0, and 37.8 per cent dry matter containing 0.0, 0.5, or 0.75 per cent urea, respectively, were offered ad libitum during the 70-day treatment period. Two weeks were allowed for cows to adjust to treatments. Concentrates were fed to balance nitrogen and energy in the diets. Milk production and total or silage dry matter intakes were not affected by treatments. However, lower weight gains were noted for the groups fed the highest level of urea. Similar results were obtained in a second experiment (42) in which corn silage of 43.5, 36.6, and 31.7 per cent dry matter were ensiled with 0.0, 0.6, or 0.85 per cent urea, respectively. The authors suggested that the lower weight gains experienced by the cows on the highest levels of urea (0.75 and 0.85 per cent) might indicate the need for an adaptation

period longer than the 30 days for sheep, as advanced by Virtanen (53). Huber *et al*. (22) also reported no difference in milk production and total or silage dry matter intake between corn silages of 38.3, 42.9, and 35.4 per cent dry matter with 0.0, 0.5, or 0.75 per cent urea added at ensilation when fed as the sole roughage to lactating Holsteins. The results of two trials in which lactating cows were fed silages (27 to 29 per cent dry matter) treated with 0.0, 0.5, and 0.75 per cent urea were reported by Schmutz *et al*. (43). Milk production, expressed as 4 per cent FCM, was not affected by treatments. However, contrary to the data of others (22, 42) silage intake was depressed by the addition of 0.75 per cent urea. Conrad and Hibbs (9) also noted that addition of 0.70 per cent urea to 26.6 per cent dry matter corn silage depressed silage intake. They (9) also noted a lower milk production for cows fed urea treated silage (0.70 per cent) when compared to cows fed alfalfa hay and grain. These contrasting results are probably due, in part, to the differences in dry matter content of the silages involved. The corn silages of 26 to 29 per cent dry matter would contain a much lower level of starch than silage harvested at 35 to 40 per cent dry matter. As suggested by several workers (8, 9, 10, 43) urea utilization depends to some extent on the amount of readily available carbohydrates present. Conrad and Hibbs (10), after reviewing available research data, stated that the success of urea feeding is decisively dependent on the composition of the carbohydrates fed. They

suggested that the quantity needed approximates one kilogram of readily fermentable carbohydrate per 100 grams of urea in an adapted cow. They further stated that about two-thirds of the readily fermentable carbohydrates should be starch. Huber et al. (24) investigated the response of lactating cows fed urea-treated corn silage harvested at 30, 36, and 44 per cent dry matter. Each silage was treated with either 0.0, or 0.5 per cent urea at ensilation. Responses were measured over an 80-day treatment period involving nine groups of lactating cows (6 per group). A significant interaction was shown between the concentration of urea and the stage of maturity at which the corn was ensiled. Milk persistencies were higher for cows fed urea-treated silage than for cows fed control silage at the early (30 per cent dry matter) and medium (36 per cent dry matter) maturities, but markedly lower for the late-maturity (44 per cent dry matter) silage. Silage dry matter intake was significantly higher ($P<.01$) for urea-treated than for control silages. There was a trend toward lower intakes on the 44 per cent dry matter silage. Similar results were reported by Van Horn et al. (51) when comparing 32 per cent dry matter silage and 48 per cent dry matter silage ensiled with 0.5 per cent urea. However, in this report feed intake was significantly lower ($P<.01$) on the 48 per cent dry matter silage. They (51) also fed a 1.0 per cent urea concentrate along with the silage. From these reports, it appears that urea should be added to corn silage with a dry

matter content in the range of 32 to 40 per cent for optimum urea utilization.

Research pertaining to the use of non-protein nitrogen as the only or primary source of nitrogen in diets for ruminants was recently reviewed by Oltjen (38). He pointed out, in summary, that growth, feed efficiency, and nitrogen retention were reduced 35 per cent by protein-free diets. He also noted that a moderate milk production was possible when cows were fed diets devoid of protein and the composition of the milk was essentially similar to the milk produced from cows fed natural diets.

Urea-Mineral

The fact that corn plant material is inherently low in both crude protein and some minerals, especially calcium and phosphorus, has stimulated some interest in ensiling a urea-mineral mix with the whole corn plant.

Effects of Urea-Mineral Mix on the pH and Organic Acid Production in Corn Silage

When ensiled with corn silage, calcium carbonate has been shown (6, 30, 31, 36, 43) to maintain a higher pH and increase organic acid production. This same buffering action, to a lesser extent, has been accredited to urea (24, 40, 42, 43). Various workers (27, 31, 40, 43) have studied the effects of a combination of the two on corn silage fermentation. Klosterman *et al*. (31) reported that corn silage

containing 0.5 per cent high calcium ground limestone plus 0.5 per cent urea had a higher final pH (4.48) than untreated silage (3.86) and a greater concentration (per cent dry matter basis) of acetic and lactic acids (1.44, 5.86). Dry matter contents of the treated and untreated silages were 33.4 and 31.5 per cent, respectively. The effects of 0.5 per cent urea plus 0.5 per cent limestone on silage fermentation was investigated by Johnson et al. (27) for silages of six dry matter contents ranging from 19.9 to 47.2 per cent. In this study, urea-limestone significantly ($P<.01$) increased acid production during fermentation. Higher pH values were also reported for the treated silages. Schmutz et al. (43) ensiled corn silage of 27 to 29 per cent dry matter alone and with additions of limestone, urea, and diammonium phosphate, as well as with limestone combined with either urea or diammonium phosphate. The pH of the control silage was slightly lower than that noted with single chemical additives or any combination of additives ($P<.01$). The pH of silages receiving a combination of additives was higher than the pH of single additive silages. All added compounds produced an increase in the concentration of organic acids in the treated silage compared to the control silage. The addition of $CaCO_3$ singly and in combination with urea or diammonium phosphate significantly increased lactate production but did not produce a significant increase in acetate levels. Using laboratory silos, Owens et al. (40) found that the addition of 0.50 per cent $CaCO_3$ and 0.50 per cent urea increased

acetic acid content, whereas, addition of either alone depressed acetic acid content. In an earlier investigation Owen et al. (39) reported that 1.0 per cent limestone added to corn plant material in laboratory silos appeared to have no influence on the production of lactic, acetic, propionic, and butyric acid. Whereas, the addition of 0.5 per cent urea and 0.5 per cent limestone appeared to increase the concentration of lactic, propionic and butyric acids as compared to the non-treated silages. The acetic acid concentration (0.6 grams per 100 grams of dry matter) was lower for the treated silage than for the untreated silage (0.8 grams per 100 grams of dry matter). It should be noted here that when comparing the effects of chemical additives on the fermentation of corn silage one should use silages of approximately the same dry matter because as the plant matures, the fermentation pattern changes somewhat. As reported by Johnson et al. (27) the acetic acid content is highest in silage made from corn harvested at the blister stage, decreases significantly ($P<.01$) at the early milk stage, and thereafter gradually declines to about 1.0 per cent of dry matter in latter stages. The lactic acid is highest in silage made from corn harvested at the early milk stage and then gradually declines ($P<.01$) to about 4.0 per cent of dry matter.

Relative Feeding Value of Urea-Mineral Corn Silage

The addition of 0.5 per cent urea to corn silage at ensilation has been shown to maintain milk production and feed consumption as well as or better than does untreated silage (22, 23, 24, 42, 43). The results of available research concerning the addition of calcium carbonate or limestone at ensiling time to corn silage are inconsistent with respect to intake and milk production (6, 20, 28, 35, 43, 44). Byers *et al.* (6) reported no difference in dry matter consumption, milk production, milk fat per cent, or change in body weight between cows fed 1.0 per cent limestone treated silage, control silage, or control silage with 1.0 per cent limestone added at time of feeding. Similar results were reported by Huber *et al.* (20) and Schmutz *et al.* (43). McCullough *et al.* (35) group-fed corn silage (31.0 per cent dry matter) containing 1.0 per cent $CaCO_3$ added at ensilation to groups of Guernsey cows for a 28-day period. Contrary to Byers *et al.* (6), Huber *et al.* (20), and Schmutz *et al.* (43), but in agreement with Kesler *et al.* (28) and Simkins *et al.* (44), McCullough found that $CaCO_3$ reduced feed intake and milk production.

Very little work has been done with urea-mineral corn silage as the sole roughage for dairy cattle. Schmutz *et al.* (43) found no difference in milk production and feed consumption between cows fed corn silage treated with 0.5 per cent urea plus 0.5 per cent $CaCO_3$ and cows fed untreated,

0.5 per cent urea, or $CaCO_3$ silage. They concluded that the nutritive value of corn silage was not increased by ensiling with limestone. Studies with beef cattle (14. 31) have shown limestone treated silage to be superior to untreated silage in efficiency of utilization.

EXPERIMENTAL PROCEDURE

The experiments described herein involved two years' work with whole plant corn silage (excluding roots).

Experiment I

During the latter part of August 1967, each of three metal silos (13.6 by 35 feet) was filled with approximately 80 tons of fresh material harvested in the well dent stage of maturity. The experimental treatments were: Silo 1, control (no additives); Silo 2, urea (42 per cent nitrogen) added at the rate of 10 pounds per ton of fresh material; and Silo 3, urea-mineral mixture (Grace Chemical Company product) added at the manufacturer's recommended level of 25 pounds per ton of fresh material. The amounts of urea added to silos 2 and 3 increased the theoretical protein equivalent level of the silage from 2.8 to 4.2 per cent.

During the filling process each load of silage was weighed and the corresponding amount of urea or urea-mineral mix was spread on top of the load. After each load was blown into the silo it was leveled and a sample was taken. These

load samples were composited for each silo and frozen for chemical analysis.

Lactation Trial

Following a fermentation period of approximately 90 days the experimental silages were fed to lactating Holstein cows and their nutritive value assessed on the basis of feed consumption, milk production, and body weight change. A 3 by 3 Latin Square design with three 21-day periods was employed for these comparisons. Twenty-four cows were grouped into eight blocks. Each block contained three cows which were as nearly alike as possible in milk production, body weight, and stage of lactation. Each cow within a block was randomly assigned to one of the three experimental treatments for each 21-day period. Silage was fed ad libitum to insure approximately 10 per cent excess daily. To equalize the treatments as to crude protein and TDN, soybean oil meal (44 per cent crude protein) was added to the control silage at the rate of 0.3 pound per 10 pounds of silage consumed, whereas, an equal amount of corn was added to the urea-treated silages. At the beginning of the trial a 16 per cent crude protein grain mix was fed according to average TDN and protein requirements of the cows (37) within each block. The level of grain fed was decreased at the rate of 8 per cent at the end of each 21-day period. All uneaten feed was removed and weighed daily. Milk-O-Meters were used to record daily milk weights and to collect samples for weekly butterfat tests. All cows were

weighed at 24-hour intervals for three consecutive days of each week to indicate gain or loss in body weight. Samples of silages, grain mix, soybean oil meal, and corn were taken weekly and composited by periods for chemical analyses. The moisture, total nitrogen, ash, crude fiber, ether extract, and nitrogen-free extract (NFE) were determined on each of these samples. The silage samples were further analyzed for hydrogen ion concentration, volatile fatty acids, and lactic acid.

Experiment II

Whole plant corn silage containing approximately 38 per cent dry matter was ensiled during the period of August 23 to August 28, 1968. The silage was chopped with a two-row chopper, collected in a wagon, and weighed. The appropriate amount of urea on a fresh weight basis was spread over the top of each load immediately before it was blown into the silo. Mixing occurred during the filling process. Approximately 72 tons of the fresh material was placed into each of three 13.6 by 25 foot silos. Dry matter determinations were made daily during the ensiling period. Silo contents and filling dates were as follows: Silo 1, control corn silage, August 23 and 24; Silo 2, corn silage plus 0.5 per cent urea (45 per cent nitrogen), August 27 and 28; Silo 3, corn silage plus 0.75 per cent urea (45 per cent nitrogen),

August 26 and 27. After each load was blown into the silo, it was leveled and a sample was taken. These load samples were composited by silos and frozen until analyzed.

Samples were removed for chemical analyses on day 5, 10, 15, 20, and 25 after ensiling. This represents most of the fermentation period. Sampling was done by boring a 2-inch hole in a door and removing the sample with an auger. The holes were resealed with rubber stoppers to prevent spoilage in the immediate area. The samples were placed in polyethylene bags, tagged, and frozen for future chemical analyses. The hydrogen ion concentration and the concentration of volatile fatty acids and lactic acid were determined on each of these samples.

Lactation Trial

Twenty-four cows between the 45th and 120th day of lactation were selected for use in the trial. This was done to insure that each cow had reached peak production but was not so far into lactation that she would markedly decline in production or begin the dry period during the trial. The experimental design used to measure animal performance was similar to the one employed in Experiment I.

Silage was fed ad libitum to insure approximately 10 per cent excess daily. The amount of silage initially fed was based on the assumption that Holstein cows will consume 5 pounds of fresh silage per 100 pounds of body weight per day. This figure was derived from previous knowledge of

consumption rates on 32 per cent dry matter silage and adjusted to a 38 per cent dry matter basis. The unconsumed silage was weighed daily and the amount fed increased or decreased to maintain a 10 per cent excess.

To equalize treatments as to crude protein and TDN, ground shelled corn and soybean oil meal (44 per cent crude protein) were added to the experimental silages in the ratio required to meet requirements for maintenance and milk production. Nutrient requirements were based on each experimental group's average body weight, milk production, and butterfat test of 3.5 per cent. The nutrient requirements were initally calculated from the results of a 15-day preliminary trial. At the end of each 28-day period, they were recalculated using the data obtained during the last 7 days of that period.

With the exception of body weight, animal performance data were collected as in Experiment I. All cows were weighed at 24-hour intervals for three consecutive days at the beginning of each period and twice per week during the period. All sampling and chemical analyses of the experimental silages, ground shelled corn, and soybean oil meal were carried out as in Experiment I with the exception that silage samples were taken at 2-day intervals.

Computation of Data--Production Trials

All feed consumption data were computed on both a fresh and dry matter basis. Milk production was expressed on a 4.0 per cent fat-corrected basis using the following equation: 4 per cent F.C.M. = 0.4 (pounds of milk production) + 15 (pounds of fat).

Chemical Analyses

Hydrogen Ion Concentration

Distilled water was added to silage samples in a 2:1 (water to silage) ratio. After thorough mixing the samples were allowed to sit for 30 minutes. The supernatant was collected and analyzed with a Beckman pH meter equipped with an external glass electrode. Sample sizes varied from 10 grams for the fermentation samples to 25 grams for all other samples.

Moisture

Silage samples (100 grams) were placed in a hot air oven at 100 to 110 degrees centigrade for 48 hours. The per cent moisture was determined directly by substracting the dry weight from the wet weight. The toluene distillation method for moisture determination was also used. Values obtained from the two methods were very close.

Proximate Analysis

Total nitrogen, ether extract, crude fiber, ash, and nitrogen-free extract were determined by the proximate analysis procedure outlined by the Association of Official Agricultural Chemists (1). The total nitrogen values from each sample were multiplied by 6.25 to obtain the crude protein equivalent values on a fresh basis.

Organic Acid Determinations

The volatile acids (acetic, propionic, and butyric) and the non-volatile acid (lactic) were extracted from the experimental silages with 0.4 normal H_2SO_4. Fifty grams of fresh material were mixed with 75 milliliters of acid, incubated at 37 to 39 degrees fahrenheit for 72 hours, then strained through a double layer of cheese cloth. The filtrate was centrifuged at 2,000 revolutions per minute for 5 minutes to remove any remaining sedimentable material. The supernatant was removed and stored under refrigeration with Thymol as a preservative. Samples taken during the first 25 days after ensiling were extracted as above with the exception that 10 grams of silage were mixed with 20 milliliters of acid. This was done because of small sample size.

The concentrations of acetic, propionic, and butyric acid present in the experimental silages were determined with a Varian Aerograph Series 204B Gas Chromatograph equipped with hydrogen flame detectors and a manual temperature programmer. The column material used was 15 per cent FFAP on

chromosorb "W" (Varian Aerograph, Walnut Creek, California). A 10-microliter sample of the extract was analyzed using a column temperature of 130 degrees centigrade and a gas flow rate of 25 milliliters per minute. A standard solution of acetic, propionic, and butyric acid was run at five different concentrations for comparison. In preparing the standards, 3.0 grams of barium acetate, 1.0 gram of sodium propionate, and 1.0 gram of sodium butyrate were added to 70 milliliters of distilled water and acidified with concentrated H_2SO_4 to precipitate the barium and sodium. Distilled water was added to bring the total volume to 100 milliliters. The precipitate was removed and the supernatant placed in a glass stoppered flask to be used as stock solution. The five standards were made by placing 1.0 milliliter of stock solution in each of five 10-milliliter flasks containing 0.0, 2.0, 3.0, 4.0, and 6.0 milliliters of distilled water, respectively.

The amount of lactic acid present was determined by the Barker and Summerson Colorimetric Method (2).

Determination of Nitrogen Fractions

Total nitrogen was determined by the standard Macro-Kjeldahl Method (1). The amount of ammonia and urea nitrogen was determined by the procedure outlined by Folin and Bell (16) and Folin and David (17) as modified by Toman (49).

Samples for both ammonia and urea-nitrogen determinations were prepared by blending 10 grams of fresh silage with 100 milliliters of 0.05 molar phosphate buffer solution

(pH 7.0) and centrifuging at 6,000 revolutions per minute for 30 minutes. The supernatant was decanted through four layers of cheese cloth and the filtrate retained for analysis.

Urea-Nitrogen plus Ammonia-Nitrogen. One milliliter of the silage extract was placed in a 50-milliliter volumetric flask. Urease solution (1.0 milliliter of a 1.0 per cent filtrate) and several milliliters of 0.005 molar phosphate buffer were added. After standing for 15 minutes, the mixture was Nesslerized by adding 1.0 milliliter of ethylenediaminetetraacetic acid (EDTA), diluting to approximately 15 milliliters with distilled water, and adding 1.0 milliliters of commercial Kock and McMeekin Nessler's reagent. The solution was brought to volume with distilled water, allowed to stand for 20 minutes, and its absorbance read at 420 nanometers with a Bausch and Lomb Precision Spectrophotometer.

Ammonia-Nitrogen. One milliliter of the silage extract was pipetted into a 50-milliliter beaker and diluted with a few milliliters of distilled water. One gram of ion exchange resin (Permutit) was added and the mixture allowed to stand at least 5 minutes with frequent swirling. This mixture was decanted and washed with distilled water at least three or four times. Two milliliters of 10 per cent NaOH were added to the resin along with a few milliliters of distilled water. The mixture was swirled several times during a 5-minute period then decanted quantitatively into a 50-

milliliter volumetric flask and Nesslerized. Absorbance was read at 420 nanometers.

Urea-Nitrogen. The amount of urea-nitrogen was determined by subtracting the NH_3-nitrogen fraction from the NH_3-nitrogen plus urea-nitrogen fraction.

Analysis of Data

The data were analyzed according to Steel and Torrie's method for Latin Square designed experiments with more than one block (47).

RESULTS AND DISCUSSION

Chemical Data

pH and Organic Acid Production

In Experiment I (TABLE 1), the addition of urea increased the amount of lactic acid produced, but appeared to have no consistent effect on acetic acid production. The concentrations of both acetic and lactic acids were increased by the addition of urea plus mineral at the time of ensiling. These results are in general agreement with those of Schmutz *et al*. (43) and Owens *et al*. (40). The level of butyric acid was highest in the urea-mineral silage. This would be expected since the final pH of 5.4 was well above that required to retard microbial activity (32). This silage was of low quality as evidenced by the high concentration of butyric acid along with the high pH. Physical indicators of low quality silage such as foul odor, off color, and somewhat slick texture were noted.

When ensiled with corn plant material, urea has been shown to maintain a higher pH and increase organic acid production as compared to control corn silage (24, 40, 42, 43). In order to study the buffering action of urea, samples of the

silages from Experiment II were taken at 5-day intervals during the first 25 days after ensiling and during the feeding trial. The first 25 days in the silo included most of the fermentation period as indicated by changes in pH and organic acid content.

TABLE 1. Effect of chemical additives on final pH and organic acid content of corn silage (Experiment I).

Item	Treatment		
	Control	0.50% urea	urea-mineral
pH	4.4	4.5	5.4
Organic Acid content[a]			
Acetic	1.66	1.64	2.49
Propionic	0.04	0.04	0.16
Butyric	0.17	0.11	0.94
Lactic	2.12	4.26	6.20

[a]Expressed as per cent of dry matter.

The results of the pH analyses (TABLE 2) indicated that the addition of urea both elevated the initial pH and buffered against reduction of pH during fermentation. This buffering action of urea is attributed to its degradation product, ammonia. Urea, itself, is a very weak base ($K_b = 1.5 \times 10^{-14}$ at 25 degrees) and would have little buffering capability. These data tend to substantiate the results of Huber et al. (24), Owens et al. (40), Polan et al. (42), and Schmutz et al. (43).

TABLE 2. Effect of urea on pH of corn silage during fermentation.

Day after ensiling	Treatment		
	Control	0.50% urea	0.75% urea
0	5.2	6.2	6.3
5	4.0	5.0	5.5
10	3.9	4.6	4.4
15	3.9	4.5	4.4
20	4.0	4.3	4.4
25	3.8	4.2	4.2

Organic acid production data (TABLE 3) indicated that acetic acid production was essentially completed in 5 days after ensilation. Similar results were reported by Langston *et al*. (33). The concentration of lactic acid increased throughout the 25-day period in both urea treated silages but appeared to be maximum in the control silage by the 10th day. This would be expected since the pH of the control silage at the 10th day of fermentation was 3.9, well below that required for retardation of microbial activity. Corresponding pH values for the 0.50 per cent urea silage and the 0.75 per cent urea silage were 4.6 and 4.4, respectively. Thereafter, only a slight increase in lactic acid content was noted in the low level urea silage, whereas, the amount of lactic acid in the high level urea silage almost doubled from the 10th to the 25th day. The changes in pH of these two silages during this interval were somewhat similar. The pH of the low level urea

silage steadily declined throughout, whereas, it was maintained at 4.4 until day 20 in the high level urea silage. Both silages had a pH of 4.2 at the 25th day after ensilation. It is worthy of note that the largest decrease in pH of the 0.75 per cent urea silage occurred between the 5th and 10th day of fermentation, while the largest decrease in pH occurred during the first 5 days in the 0.50 per cent urea silage.

Statistical analyses of the data in TABLE 3 showed that the concentrations of propionic, butyric, and lactic acids were significantly increased by increased amounts of urea ($P<.01$). Compared to control, acetic acid production was slightly but non-significantly depressed by the addition of 0.50 per cent urea, but was significantly increased by the addition of 0.75 per cent urea ($P<.05$). These results tend to substantiate the data of Owens et al. (40), but contradict the results of Schmutz et al. (43). They (43) found acetic acid production to be increased by both the addition of 0.50 per cent urea and 0.75 per cent urea, however, they used corn plant material of 27 to 28 per cent dry matter. Owens et al. (40) did not study the higher level of urea.

The final pH and organic acid concentrations of the silages in Experiment II are shown in TABLE 4. The pH of the control silage did not change after the 25th day, however, an increase in acetic and butyric acids and a decrease in lactic acid occurred after the 25th day of ensilation. These changes are indicative of the action of putrefaction microbes (33),

TABLE 3. Organic acid content of experimental silages at intervals after ensiling.

Days after ensiling	Per cent urea added	Organic acids			
		Acetic	Propionic	Butyric	Lactic
		% of dry matter			
	0.0	2.00	0.10	0.09	2.74
5	0.50	1.44	0.11	0.13	4.66
	0.75	1.96	0.26	0.29	4.23
	0.0	1.05	——[a]	——[a]	4.35
10	0.50	1.06	0.09	0.12	4.66
	0.75	1.77	0.16	0.21	5.97
	0.0	1.26	0.02	0.08	4.35
15	0.50	0.86	0.16	0.17	5.09
	0.75	1.65	0.08	0.09	8.90
	0.0	1.33	0.02	0.05	3.82
20	0.50	2.06	0.16	0.17	5.11
	0.75	2.74	0.28	0.30	9.02
	0.0	1.93	0.03	0.17	4.89
25	0.50	1.26	0.12	0.13	5.91
	0.75	2.86	0.27	0.29	10.46

[a]Concentration too low to measure.

although the silage appeared to be of good quality. Similar changes in acid content were noted in the urea treated silages, with the most pronounced changes occurring in the silage containing 0.75 per cent urea. The concentration of lactic acid in the 0.75 per cent urea silage decreased from 10.46 to 5.38 per cent of dry matter after the 25th day of ensilation. This resulted in a slight increase in pH (4.2 to 4.3). The reason for this large decrease in lactic acid content is not apparent.

TABLE 4. Effect of urea on the final pH and organic acid content of corn silage (Experiment II).

Item	Treatment		
	Control	0.50% urea	0.75% urea
PH	3.8	4.0	4.3
Organic acid content[a]			
Acetic	4.15	1.46	3.12
Propionic	0.06	0.06	0.09
Butyric	1.56	0.08	0.45
Lactic	3.38	4.24	5.38

[a]Expressed as per cent of dry matter.

The levels of acetic and butyric acid in the control and 0.75 per cent urea silages (TABLE 4) were higher than normal for good quality silage. However, the pH and physical characteristics of the silages were indicative of good quality silage. A factor that might have influenced the final

concentrations of organic acids was an undetected freezer malfunction that allowed the sample to thaw over a 3-day period. The effect of this on the acid content of the sample is not known.

Chemical Composition

The results of the proximate analyses of the experimental silages used in both Experiment I and II are shown in TABLE 5. These data were not subjected to statistical analysis. However, some trends can be noted. In Experiment I, the silages containing urea alone or with minerals tended to have less crude fiber, ether extract, and nitrogen-free extract (NFE), but more ash and crude protein than the control silage. These same general trends were noted in Experiment II.

The lower amounts of crude fiber and ether extract in the treated silages may have resulted from the sustained microbial activity. Whether or not this is true is a point of conjecture and needs further investigation. The decrease in NFE would be expected as it is obtained by subtraction, thus, directly influenced by the increase in crude protein. The increase in ash content of the treated silages can be partially attributed to the urea and mineral additives. The increase in crude protein is a reflection of the added nitrogen and is discussed in the following section.

Crude Protein Equivalent

The theoretical and analyzed protein content of the silages used in both experiments are shown in TABLE 6. The

TABLE 5. Chemical composition of the experimental silages.

Item	Dry matter	Ash	Crude fiber	Ether extract	Crude protein	Nitrogen free extract
	%	% of dry matter				
Experiment I						
Control	34.2	4.5	22.4	3.5	8.2	61.4
0.50% urea	35.2	4.9	21.0	2.8	11.4	59.9
Urea-mineral	33.5	5.3	21.4	3.0	13.4	56.9
Experiment II						
Control	37.2	4.3	21.5	1.5	8.3	64.4
0.50% urea	39.9	5.0	20.2	1.4	11.8	61.7
0.75% urea	39.0	4.6	20.3	1.4	14.1	59.6

theoretical crude protein equivalent values were computed with the following considerations. The crude protein of the control silage dry matter times the dry matter of the treated silage would give the crude protein of the treated silage before urea was added. The pounds of added urea times the per cent crude protein equivalent of the urea (262.5 for Experiment I and 281.25 for Experiment II) would give the pounds of crude protein equivalent added to the treated silage. The sum of both crude protein equivalent values (natural plus added urea) would give the theoretical crude protein in the treated silage on a fresh basis. The per cent crude protein equivalent of the urea-mineral mix used in Experiment I was approximately 120.

TABLE 6. Per cent theoretical and analyzed crude protein equivalent in experimental silages.

Item	Treatment							
	Control		0.50% urea		0.75% urea		urea-mineral	
	A[a]	B[b]	A	B	A	B	A	B
Experiment I								
Fresh basis	2.8	2.8	4.2	4.0			4.2	4.5
Dry basis	8.2	8.2	11.9	11.4			12.5	13.4
Experiment II								
Fresh basis	3.1	3.1	4.7	4.7	5.4	5.5		
Dry basis	8.3	8.3	11.8	11.8	13.5	14.1		

[a]Theoretical values.

[b]Analyzed values representing the mean of a composite sample taken at ensiling time and three composite samples taken during the feeding trial.

The small differences between the theoretical and analyzed values indicated that little or no loss of added nitrogen occurred. The analyzed values were slightly higher than the theoretical values in the silages receiving 0.50 per cent urea and urea-mineral in Experiment I and the silage receiving 0.75 per cent urea in Experiment II. This could partially have been due to differences in crude protein content (natural) of the corn plant materials used and partially due to sampling error. The data indicated that the addition of urea elevated the crude protein content of corn silage in an amount corresponding to the level of urea added. This agrees with other investigators (12, 15, 18, 24, 43).

The crude protein of the silages is an expression of total nitrogen and includes both true protein and non-protein nitrogen. Whether the added urea remained intact, or was converted to microbial protein and other forms of non-protein nitrogen is not evident from these data.

Nitrogen Distribution

The effects of fermentation on urea were studied in Experiment II. Samples taken during the first 25 days after ensilation and during the feeding trial were analyzed for ammonia-nitrogen (NH_3-N) and urea-nitrogen (urea-N). The results of these analyses are presented in TABLE 7. In general, the concentration of NH_3-N increased and the concentration of urea-N decreased in all silages during fermentation. Approximately 72.7, 65.3, and 66.6 per cent of the

initial nitrogen as urea in the control, 0.50 per cent urea, and 0.75 per cent urea silages, respectively, was converted to other forms. These results are in general agreement with those of Huber _et al._ (24) and Polan _et al._ (42).

TABLE 7. Milligrams of NH_3-N and urea-N per 100 grams of dry matter in Experiment II silages at intervals after ensiling.

Day after ensiling	Treatment					
	Control		0.50% urea		0.75% urea	
	NH_3-N	Urea-N	NH_3-N	Urea-N	NH_3-N	Urea-N
0	53.76	502.69	140.35	786.97	350.00	1190.00
5	77.96	101.88	451.13	616.54	810.26	864.10
10	150.54	0.00	463.66	97.74	350.88	348.72
15	150.54	0.00	——[b]	——[b]	202.56	400.00
20	69.89	43.01	280.70	431.08	561.54	335.90
25	77.89	72.58	320.80	576.44	——[b]	——[b]
As fed[a]	137.10	137.10	368.42	273.18	546.15	397.44

[a]Encompasses days 90 through 180. Values represent mean of three composite samples.

[b]Values not obtained.

The increase in NH_3-N accounted for 22.8, 44.4, and 24.8 per cent of the decrease in urea-N in the control, 0.50 per cent urea, and 0.75 per cent urea silages, respectively. The remainder was probably incorporated into microbial protein or lost as gaseous ammonia. The similarity of the theoretical

and analyzed crude protein contents of the experimental silages indicated that little loss of added nitrogen occurred. The amount of urea-N incorporated into microbial protein was not determined in the present experiment. However, Coppock and Stone (12) noted, after reviewing the literature, that urea appears to increase the true protein content of corn silage. Part of this increase resulted from microbial synthesis of protein from the added urea and part from the protein sparing action of urea.

In general, the data (TABLE 7) fit together well except for the control urea-N level at time of ensilation. This value was quite high relative to the amounts found in later samples. To substantiate that this value was non-representative of the amount expected in corn plants, corn plant material harvested in mid-August 1969 was found to be much lower in urea-N (31 milligrams per 100 grams of dry matter) than the reported amount (502.69 milligrams per 100 grams of dry matter). The reason for this high concentration of urea-N is not apparent. Possible explanations include sampling error and contamination with urea.

The literature contains several reports (24, 40, 41, 42) evaluating the degree of urea hydrolysis, but little information concerning the hydrolytic agent(s) involved is available. Hunter (25) postulated that the formation of ammonia was due to both plant enzymes and microbial enzymes.

Unpublished work by Skean *et al.* (45) indicated that

urease positive microorganisms do not play a major role in the breakdown of urea during ensilation. They used a differential medium to enumerate microbes that degrade urea among high populations of microbes that do not. Attempts were made to enumerate the populations of microbes degrading urea during the ensilation of corn containing 0.0, 0.50, or 0.75 per cent added urea. Data obtained from triplicate enumerations of triplicate samples taken at 5-day intervals during the 25-day ensilation period did not indicate that added urea affected the populations of urea-degrading microbes in the silage. The data did indicate that the silage contained urea-degrading microbes in populations too low for differential enumeration among the total populations. Silage bearing 10^4 to 10^7 elutable microbes per gram generally bore fewer than 10^3 elutable urea-degrading microbes per gram.

Further work is needed in this area to determine the relative importance of microbial urease, corn plant urease, and chemical factors in the degradation of urea during ensilation.

Lactation Trials

Experiment I

Animal performance data (TABLE 8) indicated a preference for the control and urea-treated silage over the urea-mineral silage ($P<.01$). These observations are in general agreement with previous work reported by Kesler et al. (35),

and Simkins et al. (44). However, Schmutz et al. (43), Byers et al. (6), and Huber et al. (20) reported little or no influence of the added mineral on silage consumption. The lower consumption rate of cows fed the urea-mineral silage was attributed to its low quality as indicated earlier. No significant difference in average daily consumption rate was noted between the control and urea-treated silages. Similar results have been observed by other investigators (22, 23, 24, 42, 43).

TABLE 8. Feed intake, milk production, and body-weight change of cows during Experiment I.

Performance criterion	Treatment		
	Control	Urea	Urea-mineral
Feed intake (lb/day)			
Silage (fresh)	77.3	73.6	68.7
Silage (dry)	26.4[b]	25.9[b]	23.0[d]
Corn or soybean meal	2.4	2.4	2.3
Grain mix[a]	12.8	12.8	12.8
Milk production (lb/day)			
Actual	46.6[b]	46.1[b]	44.1[d]
4% fat corrected milk	43.1[b]	42.6[b]	40.1[d]
Milk fat (%)	3.5	3.5	3.4
Body weight change per period (lb)	+8.0[b]	+5.0[b]	-22.0[c]

[a]16 per cent protein.

[b,c,d]Treatment means of a given variable with different superscripts are statistically different, b>c ($P<.05$) b>d ($P<.01$).

Milk production followed the same general trend as silage consumption. The small difference in milk production between cows fed control and urea silages was not significant, but cows in both treatment groups produced significantly more milk than cows in the urea-mineral group ($P<.01$). This difference in milk production is probably associated with the difference in silage consumption previously noted. The similarity in production of cows fed control and urea silages indicated good utilization of the urea nitrogen since all silages were fed on an equal nitrogen and energy basis per pound of silage consumed. This was accomplished by supplementing the control silage with soybean meal and the treated silages with an equal amount of corn per unit of silage consumed. Body weight change data indicated that cows in the control and urea groups were slightly over-fed in energy, whereas, cows in the urea-mineral group were under-fed. The change in body weight experienced by cows fed control and urea silages were not significantly different, however, both gained significantly more weight than cows fed the urea-mineral silage ($P<.05$). This difference is attributed to the lower consumption rate of cows in the urea-mineral group. The similar change in body weight of cows fed control and urea silage further indicated good utilization of the added urea-nitrogen.

Experiment II

Several workers (22, 42, 43, 52) have indicated that higher levels (greater than 0.50 per cent) of urea can be utilized by the lactating dairy cow without ill effects if properly supplemented. Schmutz et al. (43) further implied that higher levels of urea might be better utilized when added to silage containing around 38 per cent dry matter as compared to 26 per cent dry matter silage. The higher dry matter silage would contain more readily available carbohydrates which, in turn, influences urea utilization (8, 9, 10, 43).

To test these observations, three levels of urea, 0.0, 0.50, or 0.75 per cent, were added to whole corn plant material at ensiling time. The ensiled material was approximately 38 per cent dry matter. Animal performance data (TABLE 9) indicated a lack of preference between control and 0.50 per cent urea silage. While both control and low level urea (0.50 per cent) silages were highly preferred over the high urea (0.75 per cent) silage ($P<.01$). This difference in consumption rate is possibly a reflection of the silage feeding order followed. The high level urea silage was almost always fed last thus allowing less exposure time. The urea-adaptation period noted by Polan et al. (42) might have been a factor involved in the decreased consumption rate of the silage treated with 0.75 per cent urea. These observations support the data of Conrad and Hibbs (9) and Schmutz et al.

(43), but contradict the results of Polan et al. (42) and Huber et al. (22). These investigators (22, 42) found no significant difference in consumption rate among levels of urea up to 0.85 per cent.

TABLE 9. Feed intake, milk production, and body-weight change of cows during Experiment II

Performance criterion	Treatment		
	Control	0.50% urea	0.75% urea
Feed intake (lb/day)			
Silage (fresh)	64.93	60.38	57.08
Silage (dry)	28.19[a]	28.13[a]	25.76[c]
Corn	7.01	9.94	10.78
Soybean meal	4.02	1.10	0.30
Milk production (lb/day)			
Actual	45.12[a]	45.61[a]	44.41[a]
4% fat corrected	40.4 [a]	40.9 [a]	39.7 [a]
Milk fat (%)	3.3	3.3	3.3
Body weight change per period (lb)	39.0[a]	23.9[ab]	15.6[b]

[a,b,c]Treatment means of a given variable with different superscripts are statistically different. a>b ($P<.05$) a>c ($P<.01$)

Milk production, unlike consumption rate, was not significantly affected by treatments. This is in general agreement with Polan et al. (42), Huber et al. (22), and Schmutz et al. (43) but contrary to Conrad and Hibbs (9). All treatment groups registered positive body-weight gains. However, cows fed 0.75 per cent urea silage gained significantly less than cows fed control silage ($P<.05$). Cows in the 0.50 per cent urea group were between cows in the other

two groups and were not significantly different from either. The fact that milk production was essentially the same for cows on all treatments and that cows in all treatment groups had positive weight gains indicated that the consumption rates were sufficient to meet nutrient requirements for maintenance and milk. These results further indicated that non-protein nitrogen in the form of urea is at least equal to natural protein sources for maintenance and milk production. The significance of this lies in the fact that urea is a less expensive source of protein than natural sources as the soybean meal used in this experiment. Soybean meal contains approximately 44 per cent crude protein, whereas, urea (45 per cent nitrogen) furnishes approximately 281.25 per cent crude protein equivalent. The rumen microorganisms are able to convert this nitrogen into microbial protein containing both essential and non-essential amino acids, provided a suitable carbon-chain source is available (34). In recent work, as reviewed by Coppock and Stone (12), it has been reported that even though all amino acids are produced, some are at such low levels that a deficiency may exist. This situation exists despite the fact that microbial activity and capacity for protein synthesis are reported to be higher with urea diets (53). Work in this area is further complicated by the fact that essential amino acid requirements of ruminants are not known except that amino acids which may be limiting for the dairy cow are those considered essential to simple stomach animals.

SUMMARY

The effects of chemical additives on the fermentation and subsequent feeding value of corn silage was investigated over a two-year period. Corn plants harvested in August 1967 (Experiment I) were ensiled with no additive, 0.50 per cent urea, or urea-mineral mix. Those harvested in August 1968 (Experiment II) were ensiled with no additive, 0.50 per cent urea, or 0.75 per cent urea. The nutritive value of these silages was evaluated chemically and by lactation trials.

The fermentation pattern of the Experiment II silages was investigated by determining the pH and concentrations of organic acids, ammonia-nitrogen, and urea-nitrogen of samples taken at 5-day intervals during the first 25 days after ensilation. Subsequent determinations were made on samples collected during the feeding trial.

The final pH of the two control silages were 4.4 and 3.8 for Experiments I and II, respectively. The addition of urea alone, or in combination with minerals elevated the initial pH and buffered against reduction of pH during fermentation. Urea-mineral combination exhibited a stronger buffering action than urea alone.

Results of the fermentation study in Experiment II indicated that the production of propionic, butyric and lactic acids was significantly increased by increased amounts of urea ($P<.01$). Acetic acid production was significantly increased ($P<.01$) by the addition of 0.75 per cent urea but was slightly, although not significantly, depressed by the addition of 0.50 per cent urea.

In both experiments the treated silages tended to have less crude fiber, ether extract, and nitrogen-free extract but more ash and crude protein than the control silages. The crude protein content appeared to be elevated in an amount corresponding to the amount of urea added.

The effects of fermentation on urea were studied in Experiment II. Approximately 72.7, 65.3, and 66.6 per cent of the initial nitrogen as urea in the control, 0.50 per cent urea, and 0.75 per cent urea silages, respectively, was converted to other forms. The increase in NH_3-N accounted for 22.8, 44.4, and 24.8 per cent of this decrease in urea-N in the control, 0.50 per cent urea, and 0.75 per cent urea silages, respectively.

In the lactation trials, 24 Holstein cows were arranged in a 3 by 3 Latin Square design. Experimental silages were fed ad libitum. The diets were isonitrogenous and isocaloric. No significant differences were noted in milk production, silage consumption, and body-weight change between cows fed the control and 0.50 per cent urea silages in both

experiments. Cows fed the urea-mineral silage in Experiment I produced significantly less milk, consumed significantly less silage, and gained significantly less body weight than did cows fed the control and 0.50 per cent urea silages ($P<.01$, $P<.01$, $P<.05$, respectively). In Experiment II, cows fed the control and 0.50 per cent urea silages consumed significantly more silage dry matter than cows fed the 0.75 per cent urea silage ($P<.01$). Cows fed the control silage gained significantly more weight than did those fed 0.75 per cent urea silage ($P<.05$), but cows fed 0.50 per cent urea silage were not different from the control and 0.75 per cent urea groups in this respect. No significant difference in milk production was noted among treatment groups.

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