ANHYDROUS AMMONIA APPLICATION TO HIGH-MOISTURE CORN

by

BRADLEY HARLAN

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INTRODUCTION

For centuries, the main method of corn storage and feeding has been at a low moisture content (10-13%). This reduces the probability of mold growth within the corn kernel. In the past decade, however, certain aspects of farm technology have made low-moisture grain a goal that's difficult to achieve and not always desirable.

Maximum yields for corn are obtained, according to Sauer (1973), by harvesting when the grain is at about 30% moisture. Thereafter, yields may decrease because of such things as insects, birds and weather. Therefore, early harvesting of fall grains at high-moisture contents increases yields because of maximizing kernel weight and reducing field losses. Ross and Rea (1959) showed harvesting corn at 27% moisture increased yield 5 to 6 bushels/acre on a dry matter basis. Farmers often artificially dry high-moisture corn before storage. But this is not satisfactory for all corn handling procedures. Fuel shortages, high fuel costs plus the failure of many drying systems' ability to keep pace with modern harvesting equipment have producers looking for alternative methods of storing and handling high-moisture corn.

The ensiling process is a method of storing wet grain which lets producers harvest early and eliminate drying expense. Fermentation and spoilage losses are incurred when using this method; however, research has shown that these losses can be reduced by applying preservatives, mainly organic acids, to the wet corn prior to ensiling.

High-moisture corn is deficient in protein for growing and finishing beef cattle rations and must be supplemented with protein. There are two types of protein sources that are utilized by ruminant animals--natural protein and non-protein-nitrogen (NPN). Natural proteins, especially soybean meal, have been the major supplemental protein used in high-moisture corn rations. These protein sources are becoming expensive and in high demand for alternative uses. Non-protein-nitrogen sources, primarily urea, are effective as supplements to high-moisture corn in ruminant rations.

Ammonia is also a NPN source which can be utilized by the rumen microbes, but only if sufficient carbohydrates or energy is available. Fewer industrial processes and less energy are required to produce anhydrous ammonia than urea, resulting in lower cost per unit of nitrogen.

In 1978, the Food and Drug Administration (FDA) approved the use of "Cold-Flow" ammonia application to corn silage. This process was developed by engineers and nutritionists at Pennsylvania State University in cooperation with USS chemicals.[a] The heart of the system is a condensation chamber which converts anhydrous ammonia to liquid ammonia. The liquid is applied directly to corn silage much easier and safer than the gaseous or aqueous forms.

Since only limited data have been published with ammonia application to high-moisture corn, a series of trials was conducted to evaluate the effects of liquid (Cold-Flow) ammonia on (1) the fermentation

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[a]USS Chemicals, P. O. Box 1685, Atlanta, Georgia.

characteristics of reconstituted cracked corn and (2) the performance of ruminant animals.

LITERATURE REVIEW

High-Moisture Corn Compared to Dry Corn

High-moisture corn has been shown in numerous feeding trials to be equal or superior to dry corn in animal performance. Ross and Rea (1959) showed a 1.5% improvement in feed efficiency with no difference in average daily gain. Daily gains were slightly greater (2.56 lb. vs. 2.33 lb.) for high-moisture corn compared to dry corn in a study by Beeson and Perry in 1958. However, feed efficiency was improved 10-15% with high-moisture corn. Riley and Corah (1978) summarized 15 trials comparing high-moisture corn to dry corn. High-moisture corn, ground and ensiled, reduced gain an average of 5.6% and efficiency by 0.7%. A wide variation existed between trials, ranging from an 11.5% improvement in gain to a reduction of 25.4%. They concluded source and level of roughage to be important variables. Variation could also be due to loss of volatile fatty acids during drying, leading to underestimation of dry matter intake and better feed efficiency values than normal.

Storage of High-Moisture Corn

To take full advantage of early harvest and high-moisture corn feeding, farmers have been storing the wet grain by ensiling. It can be ensiled in oxygen-limiting, conventional upright, or horizontal silos. Ensiling causes a loss of total dry matter with losses estimated in the range of 2-4% in oxygen-limiting silos, 5-10% in conventional

upright and trench silos, to above 10% in dirt-sided trenches without an adequate seal on the top (Sauer, 1973).

High-moisture storage is also conducive to spoilage losses because of mold contamination. Warden (1969) suggested that at least 1% of the world's grain supply was lost because of molding in the late 1940's. Grain losses in the late 1960's in the United States exceeded 50 million dollars, with corn and wheat especially susceptible to mold damage. The critical moisture levels for these two grains are 14.5-14.7% for whole grain and 12.3-13.0% when ground (32°C, 70% relative humidity) (Jones et al., 1974).

Major effects of fungal invasion on stored grain include: (1) decreased germinability, (2) discoloration of either the germ, embryo, or entire seed, (3) heating and mustiness, (4) potential production of harmful toxins, (5) biochemical changes within the grain, and (6) loss in weight (Christensen and Kaufman, 1969). These changes may occur before the mold becomes visible to the naked eye.

Organic Acid Preservation of High-Moisture Corn

In the past decade, organic acids such as propionic, acetic, and formic have been used for preservation and storage of high-moisture grain to decrease fermentation and spoilage losses. The amount of organic acids required depends primarily on the chemical used, the grain moisture content, and the length of storage. As the moisture content increases, the application rate must increase. For propionic acid addition, Sauer (1973) recommends 0.3-0.6% at 18% moisture and for 26% moisture, 0.6-1.0%. The higher rates are considered safe for

storage up to a year, while the lower rates are safe for shorter storage in cool weather.

Sauer and Burroughs (1974) conducted a trial to compare the efficacy of various chemicals as grain preservatives. Corn and grain sorghum were reconstituted to various moisture contents and treated with several chemicals at application rates from 0.2 to 1.0%. Adding the free acid forms was much more effective in eliminating initial mold growth than the same acids added as calcium or sodium salts, especially at lower moisture contents. The salts may be activated by contact with water; therefore, a low moisture content grain would not be preserved. Britt and Huber (1975) treated corn harvested at 27% moisture with 1.2% propionic acid. Total fungal colonies were reduced, but not eliminated. Clark et al. (1973) treated corn harvested at 24-26% moisture with 1.3% propionic acid. Viable counts of fungi were significantly ($P<.01$) reduced during storage. After 270 days of storage, the control contained greater than 5×10^6 molds/g while the acid treated corn had 4.5×10^2 molds/g.

Little or no fermentation occurs in properly handled chemically preserved corn grain (Sauer, 1973). This agrees with a study by Jones et al. (1970) where high-moisture (32%) corn was treated with 1.5% (w/w) propionic acid. Lactic acid analysis suggested that there was little fermentation in the treated grain. Since fermentation is reduced, dry matter losses should also be reduced. Brethour and Duitsman (1974) treated high-moisture milo, 25.7% and 22.8% moisture, with 1.39% and .97% propionic acid, respectively. Dry matter loss was essentially

zero with acid treatment but the control high-moisture milo lost 4.0% at 25.7% moisture and 6.9% at the 22.8% moisture level.

Effect of Acid Treatment on Beef Cattle Performance

In the last two years, several studies have been reported on the feeding value of acid-treated high-moisture grains for beef cattle, especially during the finishing phase. These experiments vary with regard to grain, species, moisture level, level of acid, processing method and amount and/or type of roughage fed. Consequently, results vary.

In a 120-day trial with 28% moisture milo treated with a mixture of 57% acetic and 40% propionic acids, Harris (1973) indicated dry milo had poorer feed efficiency by 15.9%. Bolsen et al. (1972) observed a significant ($P<.05$) increase in average daily gain for steers fed reconstituted, acid-treated whole milo compared to steam-flaked and reconstituted, rolled and ensiled milo. Feed efficiency was significantly improved with reconstituted, acid-treated whole milo compared to reconstituted, rolled and ensiled and was equal to the steam-flaked treatment. Bolsen et al. (1974) in a similar trial found feed efficiency was higher for reconstituted (29.5% moisture) and early-harvested (24% moisture) acid-treated milo than those fed reconstituted and early-harvested milo ensiled in an oxygen-limiting silo. Body weight gains of cattle fed high-moisture acid-treated milo were equal to that of cattle fed high-moisture milo ensiled in an oxygen-limiting silo. Brethour and Duitsman (1975) showed a significantly improved rate of gain and feed efficiency for propionic acid-treated

high-moisture (24%) milo stored in the whole form compared to dry, untreated ground high-moisture and propionic acid high-moisture ground milo. In another trial, Brethour and Duitsman (1974) showed a significant increase in body weight gain and efficiency from propionic acid-treated high-moisture (22.8% and 25.7%) milo over ground, ensiled milo.

Most of the acid-treated high-moisture grain studies with beef cattle in North America have involved corn. Macleod et al. (1976) concluded that dry corn and acetic-propionic acid-treated high-moisture corn are of equal feeding value for growing and finishing cattle fed with or without limited roughage. This agrees with work done by Forsyth et al. (1970), Tolman and Guyer (1972), and Tonroy et al. (1974). Acid treating high-moisture corn increased body weight gains according to W. M. D. Wilson et al. (1972), L. L. Wilson et al. (1972), and Fontenot et al. (1976).

Tonroy et al. (1974) observed a 7% improvement in feed efficiency for acid treated corn which is slightly less than the 10% improvement noted for Forsyth et al. (1970) and more than the 4.6% improvement shown by L. L. Wilson et al. (1972).

Jones et al. (1974) summarized 12 studies comparing the feeding value of acid-treated high-moisture shelled corn to dry shelled corn in beef cattle finishing rations. In general, the summary indicated acid-treated corn was equivalent to dry corn, on a dry matter basis for average daily gains, but slightly superior in feed efficiency (2.3%). Improvement in gain and feed efficiency varied from -6.2 to +6.8% and -2.4 to +9.0%, respectively.

Chemical and Physical Characteristics of High-Moisture Corn and Sorghum Grain

The trend of greater efficiency of nutrient utilization with acid-treated high-moisture and high-moisture grains compared to dry grain may be due to several factors. High moisture and dry grains differ in certain physical and chemical characteristics that may affect rumen fermentation patterns, extent of digestion in the rumen and (or) overall digestion. Florence et al. (1968) observed that reconstituted sorghum grain had a significant decrease in particle size, a less distinct cell wall and larger numbers of free starch granules than dry sorghum grain. These researchers suggested the increased numbers of starch granules are due to the disruption of the proteinaceous matrix surrounding the starch granules when reconstituted. Prigge et al. (1976b) indicated that starch availability is greatest when at least 24% of the total nitrogen is in the soluble form. Thus, the increase in soluble nitrogen during storage of ground high-moisture and acid-treated high-moisture corn observed by Jones et al. (1970), McKnight et al. (1973), and Prigge et al. (1976a) may have directly increased available energy. This may be an important factor in improving the energetic efficiency of high-moisture corn rations.

Studies by McKnight et al. (1973) showed high-moisture corn (acid-treated or ensiled) diets had higher dry matter, organic matter, and energy digestibilities than dry corn diets. Nitrogen retentions were similar as were rumen volatile fatty acid proportions. This agrees with work done by McLaren and Matushima (1968) with cattle where the

apparent dry matter digestibility of reconstituted, ensiled corn was significantly increased compared to dry corn. Tonroy et al. (1974) observed nonsignificant increases in the dry matter and energy digestibility with high-moisture corn compared to dry, reconstituted, and acid-treated high-moisture corn. This agrees with data generated by Polzin et al. (1972) with sheep and Macleod et al. (1976) with cattle.

Tonroy et al. (1974) suggested some of the benefits of feeding high-moisture corn may result from a significant increase in crude protein digestibility. McLaren and Matushima (1968) also showed a significant increase in crude protein digestibility with ensiled, reconstituted corn over that of dry corn. However, Macleod et al. (1976) and Polzin et al. (1972) indicated no significant differences in crude protein digestibility of high-moisture and acid-treated high-moisture corn compared to dry corn.

The high-moisture corn rations (ensiled and acid-treated) of McKnight et al. (1973) resulted in a significantly slower rate of passage from the rumen and increased ruminal digestion of dry matter, organic matter, and starch compared to dry corn. This explains the increased overall digestibility of the high-moisture corn observed in their study. Similar results were obtained by McNeill et al. (1971) with high-moisture sorghum. They observed that less soluble carbohydrate reached the abomasum and ruminal carbohydrate digestion was greater with reconstituted sorghum than dry sorghum.

These results indicate little difference in nutritional value between acid-treated high-moisture corn, ensiled high-moisture corn and dry shelled corn.

Until recently, the usual alternative to conventional storage or ensiling was the use of organic acids. But recent experiments (Bothast et al., 1973; Bothast et al., 1975; Dalmacio, 1976) have shown that ammonia (NH_3) can be used as a preservative for high-moisture corn as well.

Preservation of High-Moisture Corn With Ammonia

Bothast et al. (1973) applied 2% ammonia on a dry matter basis (DMB) as NH_4OH to 26% moisture corn. One hour after treatment, molds and yeasts were completely eliminated and remained extinct for two weeks. Bacterial numbers were reduced from 1.4×10^7/gram to 1.8×10^4 and 9.7×10^3/gram at one hour and two weeks after treatment, respectively.

Another trial was conducted by Bothast et al. (1975) to compare ammonia applied as aqueous ammonia, to ammonium isobutyrate (AIB), isobutyric acid and acetic-propionic acid. Concentrations used were .5%, .75%, 1.5%, and 2.0%, respectively. The chemicals were applied to freshly harvested corn containing 27% moisture. All chemicals initially reduced bacterial counts and eliminated molds and yeasts. After 10 days, the bacterial population increased similar to control corn stored in an oxygen-limiting structure (10^3 to 10^8/gram). But ammonia treatment did reduce mold and yeast growth up to 180 days of storage. The acids controlled bacterial growth more than ammonia or AIB and therefore appeared to be bacteriostatic as well as fungicidal.

Britt and Huber (1975) demonstrated that treatment of high-moisture (27%) corn with 1% ammonia (w/w) inhibits heating and fungal growth for 280 days during winter and early spring. Lower amounts of ammonia were

less effective as a preservative but this may have been because of a 50% loss of ammonia observed at the time of feeding. This agrees with work done by Dalmacio (1976) where highest mold counts, after 6 months storage, were observed for the 0.5% ammonia level compared to 1.0, 1.5, and 2.0% ammonia. The low level reduced mold counts initially but did not eliminate them as with the other ammonia treatments.

Results of the Dalmacio (1976) study showed treatments of ammonia, propionic acid, and combinations of the two were not significantly different at all levels in influencing mold growth. However, the 0.5% level seemed ineffective when the initial mold population was high (about 10^6/gram). The use of propionic acid and (or) ammonia as preservatives of whole corn was found to be superior to drying.

Mycotoxins in High-Moisture Grains

The production of mycotoxins in high-moisture grains is of prime importance since they can be injurious to man and to domestic animals when consumed. Of these mycotoxins, the aflatoxin has been the most studied. It has been proven to be carcinogenic and lethal to a large number of animals (Kadis et al., 1972; Thiesen, 1977).

Before 1960, the possibility of finding mycotoxins in feeds was disregarded. Reduced animal growth or death were caused by unknown factors. In 1960, more than 100,000 turkeys in Great Britain died after being fed mycotoxin-contaminated groundnut meal (Kadis et al., 1972). The mycotoxin, subsequently named aflatoxin, is produced by various fungi, especially Aspergillus species, but also species within Penicillium. Laboratory studies have shown aflatoxin can occur in many agricultural commodities like peanuts, soybeans, cottonseed, corn,

rice, barley, oats, rye, and wheat. Because of this, the Food and Drug Administration (FDA) has set a maximum level of 20 parts per billion (ppb) of aflatoxins in agricultural commodities and their derivative products (Stoloff, 1972).

Aflatoxin contamination of corn as affected by moisture content and temperature was investigated by Trenk and Hartman (1970). At moisture levels above 17.5% and temperatures greater than 24°C, aflatoxins were formed by A. flavus.

Goldblatt (1966) studied the elimination of aflatoxin from oilseed protein concentrates. He found exposure to moist heat and gaseous ammonia during processing offered a practical means to detoxify aflatoxin.

Lee et al. (1974) also found ammoniation a practical means of inactivating aflatoxin. Pure aflatoxin was reacted with ammonium hydroxide at 100°C under 40-50 psig for 1 hour.

Aflatoxic groundnut meal was used by Thiesen (1977) to study detoxification with ammonia during pelleting. A concentration of 7.4% ammonia at a moisture content of 30.5% resulted in an 89% detoxification. Higher degrees of detoxification (> 99%) were obtained when the ammonia-treated meal was stored without pelleting. The pelleting process drove off almost all the ammonia. Treatment with 2.1% ammonia (without pelleting) at 15% moisture resulted in 90% detoxification of meal after 11 days of storage.

High-moisture (14-20%) corn containing 32 to 1300 ppb total aflatoxin was used in a study by Brekke et al. (1978). Aflatoxin B_1

comprised 83-94% of the total content. Treatment with 1% ammonia gas reduced aflatoxin B_1 average levels from 1000 to 4.6 ppb.

Dalmacio (1976) concluded from her study that small amounts of ammonia could enhance aflatoxin production by A. parasiticus. Potato dextrose broth was adjusted to pH levels of 4, 7, and 9, and treated with various ammonia levels from 0 to 2.0 percent. Addition of 0.01% ammonia enhanced aflatoxin production in media with an initial pH of 9. No aflatoxins were produced in pH 7 with 0.2% ammonia and at pH 9 with 0.1% ammonia and greater. Aflatoxin production was not influenced by initial pH, but by the presence of ammonia in the medium.

Sources of Supplemental Proteins

Feedstuffs used in growing and finishing beef cattle rations are usually deficient in protein. Common feedstuffs are corn silage and grains, such as corn and milo. These feeds are high in energy but deficient in protein. To ensure maximum growth and production, rations must be supplemented with protein to meet the animals' requirement.

Natural proteins are widely used in cattle supplements. These can be derived from plants (soybean meal, cottonseed meal, etc.) or animals (fishmeal, meatmeal, etc.). Plant sources are more commonly used due primarily to cost. But even plant proteins are becoming expensive and in high demand for alternative uses, such as for human consumption. This has led to greater use of urea and other non-protein nitrogen (NPN) compounds as protein supplements. NPN compounds are rapidly converted to ammonia in the rumen. The ammonia is then used as a nitrogen source by bacteria for microbial protein synthesis. The

microbial proteins then pass to the abomasum where they are broken down into amino acids for subsequent absorption.

The use of NPN sources, primarily urea, has proven effective as protein supplements in ruminant rations containing high energy or readily available carbohydrates. Of major importance to the producer is that NPN supplementation often results in lower costs of gain than natural protein supplementation.

Urea Additions to Corn Silage

Studies by Bentley et al. (1955), McClure et al. (1972), Meiske et al. (1968) and Owens et al. (1967) support the conclusion that corn silages treated with NPN result in similar daily gains as urea supplementation at feeding time. Feed efficiency data are variable, but cattle fed NPN-treated corn silage have been slightly more efficient than cattle offered urea at feeding time.

Urea treatment of corn silage results in an increase in pH due to ammonia formed during fermentation. Ammonia neutralizes fermentation acids and thereby extends fermentation. This accounts for the significantly greater concentrations of lactic acid and total volatile fatty acids observed with urea-treated silage compared to untreated silage (Austin et al., 1968; Beattie et al., 1971; Britt and Huber, 1975; Henderson et al., 1971a; Lopez et al., 1970; Owens et al., 1970a).

Urea is commercially manufactured from ammonia and therefore ammonia has a lower cost per unit of nitrogen. This, in conjunction with the fact ruminants utilize ammonia as a NPN source for bacterial protein synthesis has prompted numerous research projects evaluating

ammonia addition to corn silage but only limited research with high-moisture corn.

Gaseous Ammonia Addition to Corn Silage

Henderson and Bergen (1972) added ammonia gas at a rate of 7.2 lb./T of corn silage averaging 33.5% and 50.8% dry matter (DM). With the 33.5% DM silage, ammonia losses to the environment varied from 36.6 to 80.2%, with a mean of 62.7%. Ammonia losses in the 50.8% DM silage were 92.5% for one load and 80.1% for the other load. Therefore, an increase in dry matter results in greater ammonia losses when applied in the gaseous form.

Steers averaging 227 kg were fed all-silage rations of the ammonia-treated or control corn silage for 98 days. The control corn silage was supplemented with soybean meal. No supplemental protein was supplied with the ammonia-treated silage.

Performance was drastically reduced by ammonia treatment. Cattle consuming control silage compared to those fed ammonia-treated silage obtained average daily gains (ADG), dry matter intakes and feed efficiencies of 1.06, 7.41, 6.99 and .72, 5.73, 8.00 kg, respectively.

In the same study, other groups of steers (227 kg) were placed on 40% shelled corn and 60% control or ammonia-treated corn silage for 98 days. Performance followed the same general trend as the cattle fed all-silage rations. ADG and dry matter intakes were reduced 18.25 and 13.95%, respectively, with ammonia treatment as compared to the control. Feed efficiency was 5.35% poorer for cattle consuming the ammonia-treated ration.

These researchers concluded treating corn silage with gaseous ammonia is not recommended. High losses of ammonia to the environment occurs during the treating process. Crude protein content of the treated silage was consequently only raised 36% over the control. Since the treated silage was not supplemented with protein to meet the cattle's requirement, poor performance occurred.

Treatment of Corn Silage with Aqueous Ammonia

To overcome problems encountered when ammonia gas was added, research was conducted to investigate other means of applying ammonia. Henderson et al. (1971a) added ammonia as aqueous ammonia to corn silage. A solution of 16% anhydrous ammonia and 84% water was applied at the rate of 45 lb/T (7.2 lb. ammonia/T) of 35% DM silage. This increased the crude protein content, on a dry matter basis, 60% over the control silage (11.57 vs. 7.22%).

Steers averaging 234 kg were fed all-silage rations composed of control, no protein supplement (negative control), control plus soybean meal (positive control) and ammonia-treated corn silage. ADG for the ammonia treatment compared to positive control was slightly less (1.13 vs. 1.16 kg). However, ammonia treatment significantly increased ADG over negative control (.49 kg). Feed efficiencies for the negative control, positive control and ammonia treatment groups were 8.02, 5.80, and 5.55, respectively. Henderson et al. (1971) in another 100% silage trial did not see this slight improvement in feed efficiency with ammonia treatment over positive control. Cattle fed ammonia-treated silage had a feed efficiency of 6.73 compared to 6.62 for the positive

control. ADG was slightly higher for the ammonia-treated group, 1.15 kg as opposed to 1.10 kg for cattle on the positive control ration.

When the same silages were fed with 40% shelled corn in the two studies by Henderson et al. (1971a,b), aqueous ammonia treatment resulted in similar daily gains and feed efficiency as the positive controls. Compared to the negative control, which was fed in the first study, ammonia treatment significantly improved body weight gains and feed efficiency.

Huber and Santana (1972) compared nitrogen recovery rates of corn silage treated with 0.3% aqueous ammonia to urea-treated corn silage. The 89% nitrogen recovery for urea-treated silage was higher than the 79% observed for ammonia treatment. This agrees with later work by Britt and Huber (1975) where 94% of the nitrogen added to silage as urea was recovered compared to 68% for aqueous ammonia-treated silage. The reason for the lower recoveries obtained with urea-treated silages in these two studies compared to the 100% nitrogen recovery rate observed by Henderson and Bergen (1972) is not known, but may partially be due to sampling error.

Cold-Flo Application of Ammonia to Corn Silage

In 1973, a system for applying ammonia to corn silage was developed by Kjelgaard and Anderson at Pennsylvania State University under a grant from USS Chemicals (Aldrich, 1977). This system is called the Cold-Flo method. The heart of the system is the condensation (Cold-Flo) chamber located downstream of the ammonia nurse tank and regulator. Liquid ammonia from the nurse tank flows through the regulator under pressure and into the Cold-Flo chamber. Upon release in the chamber, ammonia

expands and evaporates. Heat of evaporation is utilized in self-cooling the remaining ammonia to a stable cold liquid. Because of the high heat of evaporation for ammonia, normally 15% evaporates to cool and stabilize the remaining 85% as a cold liquid. The liquid portion flows by gravity through a hose into the silage. Another hose is used to vent the vaporized ammonia onto the silage.

This method can be used to add ammonia to silage either at the chopper or the blower. If ammonia is added at the chopper, the nurse tank must be mounted on the chopper or pulled behind. If the method is used at the blower, the liquid ammonia is added to the silage at the feeding inlet of the blower. To prevent harmful ammonia vapors at the silo-filling site, the vapor ammonia must be fed directly into the blower housing.

The Cold-Flo system was originally developed for applying ammonia to soil for nitrogen fertilization. Fox and Cook (1976) were the first to experiment with Cold-Flo ammonia application to corn silage. In their first trial, 26 steers (230 kg) per treatment were fed 202 days, four rations: (1) corn silage plus soybean meal (control), (2) corn silage treated with an ammonia-mineral suspension (AMS), (3) aqueous ammonia-treated corn silage (AQ), and (4) Cold-Flo ammonia-treated corn silage (CFN). Crude protein level (% in ration DM), ADG (kg) and feed efficiency were 11.5, 1.15, 6.92; 11.1, 1.15, 6.73; 12.7, 1.09, 7.19; 10.8, 1.06, 7.45 for control, AMS, AQ and CFN, respectively.

A 40% loss of nitrogen for the CFN treatment resulted in its low crude protein content and may explain the lower performance for the CFN treatment compared to the AQ treatment.

Cook and Fox (1977) evaluated the feeding value of Cold-Flo ammonia-treated corn silage (CFN) compared to untreated corn silage (negative control) and untreated corn silage plus soybean meal (control soy). The decreasing soy ration was started at 12.5% crude protein and decreased 0.5% for each 100 lb. of gain until the final level of 10.5% crude protein was reached. The CFN silage was treated with 4.1 kg of ammonia/metric ton. Feeding results with steers (234 kg) showed ADG and feed efficiency were improved 5% when decreasing soy was compared to the CFN treatment; however, there were no significant differences in gain between CFN, decreasing soy and control soy treatments. All three treatments gained significantly ($P<.05$) faster than the negative control. Feed efficiency values for the negative control, CFN, control soy and decreasing soy treatments were 14.40, 6.64, 6.35 and 6.21, respectively.

These results agree with a trial by Lomas et al. (1978). Cattle receiving protein supplementation (soybean meal or ammonia-treated silage) had a 44.4% greater ADG ($P<.0005$) and a 29.2% lower ($P<.0005$) feed efficiency than the negative control. Cattle supplemented with soybean meal gained 7% faster and required 8% less feed dry matter per kg of gain than cattle consuming silage treated with 4.5 kg ammonia/ metric ton.

Lomas et al. (1978) prepared a summary comparing corn silage treated with 4.5 kg Cold-Flo ammonia/metric ton to silage supplemented with soybean meal at feeding. This summary combined results from studies by Cook and Fox (1977), Fox and Cook (1977) and Lomas et al.

(1978). Ammonia treatment of silage resulted in 6.0% lower ADG, 2.4% greater dry matter intake and 7.2% poorer feed efficiency.

Addition of Various Cold-Flo Ammonia Levels to Corn Silage

In the trial by Cook and Fox (1977), the addition of three levels of ammonia to corn silage by the Cold-Flo method was investigated. Ammonia additions of 2.3, 3.2, and 4.1 kg/metric ton produced crude protein levels (% of DM) of 10.3, 11.1 and 12.3 for the three treatments, respectively.

Steer performance during the first 90 days was improved as level of ammonia increased. ADG (kg), dry matter intake (kg/day) and feed efficiency for the 2.3, 3.2, and 4.1 kg ammonia treatments were .68, 5.36, 7.87; .99, 5.83, 5.89; 1.08, 6.08, 5.63, respectively.

Steer performance during the final 92 days showed some differences from the first 90 days. The 2.3 kg ammonia treatment had a nonsignificantly greater ADG than the 3.2 kg treatment and a slightly lower ADG than the 4.1 kg ammonia level. Feed efficiency was best for the low level with only 6.8 kg of DM required per kg of gain compared to 7.75 and 7.62 for the 3.2 kg and 4.1 kg treatments, respectively.

Lomas et al. (1978) also experimented with different ammonia levels. Corn silage was treated with Cold-Flo ammonia at 2.3 and 4.5 kg ammonia/metric ton. ADG was increased 13% and feed efficiency was improved 8% by feeding corn silage treated with the higher level.

In an attempt to compare cost of gains, Lomas et al. (1978) pooled performance from their trial with that obtained by Cook and Fox (1977) and Fox and Cook (1977). Feeding corn silage treated with 4.5 kg ammonia/metric ton resulted in the lowest total cost of gain. Their

results indicate: (1) corn silage must be supplemented with nitrogen, (2) decreasing the level of soybean meal as cattle get heavier is an efficient and economical practice, and (3) the Cold-Flo system of adding ammonia to corn silage is effective for providing supplemental nitrogen.

Effect of Soybean Meal Supplementation of Corn Silage Treated with Low Levels of Ammonia

Fox et al. (1977) and Bergen and Black (1978) noted it was unlikely that calves started on feed could generate sufficient microbial protein from the "full-treat" (4.5 kg ammonia/metric ton) silage to meet their initial protein requirement. Therefore, feeding a natural source of protein during the animals' initial growth period would seem warranted, since it would partially escape rumen degradation to ammonia.

Also, as cattle get heavier, the protein requirement, on a percentage basis, decreases. Therefore, it was anticipated cattle could be fed silage treated with low levels of ammonia and supplemented with soybean meal during the initial portion of the feeding period. When the cattle reached an approximate weight of 318 kg, the soybean meal could be withdrawn from the ration without any adverse effects.

Cook and Fox (1977) fed steers (233 kg) corn silage treated with 2.3 and 3.2 kg ammonia/metric ton supplemented with soybean meal until the steers reached approximately 272 kg. The crude protein content of these rations was 12.5% prior to withdrawal of soybean meal. After soybean meal withdrawal, the cattle consumed rations containing 10.1% and 11.1% crude protein for the 2.3 and 3.2 kg ammonia treatments, respectively.

ADG (kg) for the 2.3 kg ammonia plus soy, 3.2 kg ammonia plus soy, control soy and decreasing soy treatments were 1.18, 1.11, 1.11, and 1.15, respectively. Feed efficiency was 6.30, 6.64, 6.37, and 6.21 for the respective treatments.

Supplementing soybean meal to corn silage treated with low levels of ammonia resulted in higher performance than cattle fed unsupplemented ammonia-treated corn silage. ADG was increased with soybean meal supplementation by 32.6% and 6.7% for the 2.3 and 3.2 kg ammonia treatments, respectively. The soybean meal supplemented 2.3 and 3.2 kg ammonia treatments had feed efficiency improvements of 14.2 and 2.6%, respectively over the 4.1 kg ammonia treatment.

Lomas et al. (1978) investigated the feasibility of the half-treat system (2.3 kg ammonia plus soybean meal) for growing and finishing cattle. Soybean meal was added to the ration until the steers reached 318 kg. Supplementing with soybean meal produced an improvement of 1.70% for ADG and 4.02% for feed efficiency over the 2.3 kg ammonia unsupplemented treatment. Since differences in performance between the two treatments were not significant ($P>.05$), the results of this study were inconsistent with those of Cook and Fox (1977). Lomas et al. (1978) concluded the differing responses were related to use of monensin in their study, but not by Cook and Fox (1977). Future research is needed to explain a possible protein sparing effect of monensin in protein withdrawal from ammonia-treated silage rations.

Fermentation Characteristics of Ammonia-Treated Corn Silage

Fermentation patterns of ammonia-treated corn silage closely resemble those of urea-treated corn silage. This is expected since

microbes in ensiled material partially hydrolyze urea to ammonia during fermentation. Total organic acids are increased by ammonia treatment compared to untreated silage (Fox and Fenderson, 1978; Lomas et al., 1978). Lactic acid (% of DM) is increased by ammonia treatment and as level of ammonia increases (Cook and Fox, 1977; Fox and Fenderson, 1978; Henderson et al., 1971a,b; Henderson and Bergen, 1972; Henderson and Geasler, 1970; Huber and Santana, 1972; LaLonde et al., 1975; Lomas et al., 1978). Acetic acid levels were increased by ammoniation in studies by Fox and Fenderson (1978), Henderson and Geasler (1970), Huber and Santana (1972), Huber et al. (1976), and Lomas et al. (1978), but either decreased or was not altered in the studies of Cook and Fox (1977), Henderson et al. (1971a,b), and Henderson and Bergen (1972). Butyric acid production was eliminated by addition of 3.2 kg ammonia/metric ton (Henderson et al., 1971a,b) and by addition of 2.3 kg ammonia/metric ton (Lomas et al., 1978). However, in the study by Lomas et al. (1978), when the ammonia level was increased to 4.5 kg/metric ton, butyric acid was increased to .07% from less than 0.01% in the control and 2.3 kg ammonia treatments. Fox and Fenderson (1978) also observed an increase in butyric acid levels with a treatment of 3.6 kg aqueous ammonia, but when ammonia was added as anhydrous ammonia at the same level, no change in butyric acid was observed. These differences observed between researchers are difficult to explain but they may be due to errors in dry matter determination (Fox and Fenderson, 1978).

Crude protein and pH were increased in all studies by ammonia treatment and level. Recently there has been concern regarding the

loss of natural plant proteins (true protein) during fermentation. Ammonia treated corn silage has been shown by Core et al. (1974), Huber and Santana (1972) and Huber et al. (1973) to contain greater amounts of true protein than non-treated corn silage.

Forage digestibility decreased as acid detergent fiber (ADF) increased in studies by Combs et al. (1978) and Lomas et al. (1978). In both studies, ADF was decreased with ammonia treatment, thus increasing apparent forage digestibility.

General Discussion of Ammonia Treatment of Corn Silage

Adding ammonia to corn silage is an effective method for providing supplemental nitrogen for growing and finishing cattle. Treatment with 4.1-4.5 kg ammonia/metric ton will result in nonsignificantly lower performance than cattle supplemented with soybean meal. Performance of cattle fed silage treated with 2.3 kg ammonia/metric ton can be substantially increased by supplementing with soybean meal during the initial growing phase. The soybean meal can then be withdrawn when cattle reach an equivalent weight of 318 kg (272 kg for English cattle breeds and 318 kg for larger, exotic types of cattle). This is the system that has the most potential for feeding growing and finishing cattle ammonia-treated corn silage.

More uniform application of non-protein nitrogen (NPN) is obtained by ammonia treatment than with urea treatment. This eliminates the clumping problem associated with urea and therefore, possible ammonia toxicity problems.

Corn silage treated with ammonia may be stored in upright or trench silos. Since ammonia is extremely corrosive to zinc, copper,

and brass, storage in zinc-coated steel silos is not recommended. Lactic acid and pH are increased due to the buffering action of ammonia and may cause extended fermentation. Increased dry matter losses may result during ensiling which would reduce the value of ammonia treatment. Research is quite limited on the amount of dry matter losses incurred with ammonia-treated silage compared to untreated silage.

Ammonia losses are variable depending on silage moisture content, form of ammonia applied and the regulator setting. A moisture content of 65-70% is the most desirable. If corn is chopped too wet or too dry, losses may be as high as 50%. Ammonia losses when added as a gas are highest (40-60%) but well managed Cold-Flo application with a proper regulator setting has shown recoveries as high as 85-90%.

Feedlot rations require supplementation in addition to nitrogen, such as minerals and vitamins. The feeding of ammonia-treated corn silage may lead some to think the ration is complete. As with any ration, the proper balance of energy, nitrogen, minerals, and vitamins is extremely important for maximum performance.

Adding ammonia to corn silage increases labor requirements at harvesting time which is when labor may already be stressed. Another serious limitation is the hazards of handling ammonia. Ammonia can burn the skin, damage eyes, and irritate nasal passages. All hose connections and fittings should be checked for cracks and leaks. Safety glasses, rubber gloves, and an apron is advised for protective clothing. Avoid breathing fumes during treatment and avoid entering

freshly-treated silos. Fresh water should be available near the vicinity of treatment in case of skin contact.

It must be emphasized that adding ammonia to corn silage is no substitute for poor management. Management practices such as fineness of chop, proper moisture content, and rapid filling of the silo must be followed.

Feeding Value of Ammonia-Treated High-Moisture Corn

La Londe et al. (1975) used the Cold-Flo method to apply ammonia to corn silage and high-moisture (25-30%) corn at harvest time. Ammonia was applied at rates of 4.5 kg/metric ton of corn silage and 2% (w/w) to high-moisture corn. Treatments were evaluated in a 183-day, three period feeding trial with steers (259 kg). During each successive feeding period 60, 40 and 20% of the dietary energy was supplied by the corn silage, with the remainder supplied by the grain. Composition of the rations was: (1) corn silage, high-moisture corn and soybean meal (control); (2) ammonia corn silage and high-moisture corn (ACS-HMC); (3) ammonia corn silage and whole ammoniated high-moisture corn (ACS-WAC); and (4) ammonia corn silage and cracked ammoniated high-moisture corn (ACS-CAC). The rations varied in crude protein, depending on the treatment.

Cattle receiving soybean meal supplementation outperformed cattle consuming the ammonia treatments in the initial period of the growth study. However, over the 183-day feeding trial, there were no significant differences in performance between control, ACS-HMC and ACS-CAC treatments. Cattle on the whole ammonia corn ration had a significantly

lower ADG and were less efficient than cattle on all other rations. This may have been caused by the excessive heating and visible molding of the whole ammonia corn.

Davis (1979) evaluated the following storage and processing methods for dry and high-moisture (25%) corn (HMC): (1) dry rolled corn, (2) rolled, ammonia-treated HMC (0.5% ammonia applied in aqueous form), (3) HMC stored whole in an oxygen-limiting bin, rolled prior to feeding (oxygen-limiting), (4) HMC rolled and stored in a concrete bunker silo (rolled bunker), and (5) HMC ground and stored in a concrete bunker silo (ground bunker). A 145-day finishing trial with steers (300 kg) was conducted. All rations were isonitrogenous (11.5% crude protein) with urea used as the supplemental protein source except with the ammonia-treated rations. Rate of gain did not differ significantly among treatment groups. Cattle consuming aqueous ammonia-treated corn had a feed efficiency improvement of 1.7, .7 and 3.5% over the dry rolled, ground bunker and rolled bunker treatments, respectively. However, the oxygen-limiting treatment was 3.8% more efficient than the anhydrous ammonia treatment.

Fermentation Characteristics of Ammonia-Treated High-Moisture Corn

As is the case with corn silage, ammonia treatment of high-moisture corn increases pH and total nitrogen content (Davis, 1979; LaLonde et al., 1975; Srivastava and Mowat, 1978). Thornton et al. (1977) applied aqueous ammonia to ground high-moisture (27%) corn to supply 0.0, 0.1, 0.15, 0.2, 0.3, 0.4, 0.6, 0.8, and 1.2% ammonia. As ammonia level increased, pH also increased. Ammonia additions from 0.1 to 0.4%

increased lactate levels over the control, with peak lactate levels occurring at 0.3 or 0.4% ammonia. Lactate levels were almost eliminated with ammonia levels of 0.6 through 1.2%, therefore indicating inhibition of fermentation. Soluble nitrogen was slightly reduced with increasing ammonia levels. These workers concluded treatment of high-moisture corn with less than 0.4% is recommended so that fermentation is stimulated.

Since research conducted with ammonia application to high-moisture corn is extremely limited, this study was conducted to evaluate the effects of ammonia on (1) the fermentation patterns of reconstituted ensiled cracked corn and (2) the performance of ruminant animals.

MATERIALS AND METHODS

Since field harvested high-moisture corn was not available to use in these studies, cracked corn was reconstituted by adding water and then allowed to ensile. For brevity in this thesis, reconstituted-ensiled corn grain will be referred to as high-moisture corn (HMC).

Trial 1. Thirty Hampshire, Suffolk and Rambouillet-Dorset cross lambs were used in a 42-day trial to compare three treatments: (1) dry cracked corn (DC), (2) high-moisture corn (HMC), and (3) ammonia-treated HMC (AHMC).

Cracked corn was reconstituted to 27% moisture and allowed to soak overnight. For determining the flow rate, ammonia flowed for a specified time period from the Cold-Flo chamber[a] into a plastic tub placed on a scale. After calibration, the chamber was mounted on a portable feed mixer. Liquid ammonia flowed through a hose into the mixer as the HMC was being mixed until the desired amount had been added. After mixing approximately one more minute, AHMC was transferred into black plastic-lined 55-gallon barrels. Untreated HMC was also transferred into plastic-lined 55-gallon barrels. All barrels were packed and sealed for 60 days prior to initiation of the feeding trial. Daily temperatures of each barrel were monitored for the first two weeks of fermentation by one thermistor placed in each barrel approximately 60 cm. from the top.

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[a]USS Agri-Chemicals, P.O. Box 1685, Atlanta, Georgia.

Lambs were withdrawn from feed and water 12 hours, weighed and allotted by breed and weight to the three treatments with two replications per treatment. Table 1 shows the composition of the rations that were fed twice daily, ad libitum. All lambs consumed rations composed of 30% chopped prairie hay, 60% of the respective corn treatment, and 10% supplement (dry matter basis). Soybean meal was added to all supplements to make the rations isonitrogenous (11.0% crude protein) (Table 2). Refusals were weighed each day and discarded. On day 42, lambs were held off feed and water for 12 hours and final weights were recorded.

Table 1. Composition of Rations - Trial 1.[a]

Ingredient	Ration 1	Ration 2	Ration 3
	---------- % ----------		
Chopped Prairie Hay	30	30	30
Dry Cracked Corn	60	--	--
High-Moisture Corn (HMC)	--	60	--
Ammoniated HMC	--	--	60
Supplement	10	10	10

[a]Percentages are on a dry matter basis.

Table 2. Composition of Supplements - Trial 1.

Ingredient	Ration 1	Ration 2	Ration 3
	%		
Ground Corn	20.36	.93	43.16
Ground Soybean Meal[a]	69.67	89.10	46.87
Ground Limestone	5.80	5.80	5.80
Salt	3.00	3.00	3.00
Trace Minerals	.50	.50	.50
Aurofac	.555	.555	.555
	g/cwt		
Vitamin A	27.70	27.70	27.70
Vitamin D	5.55	5.55	5.55
Vitamin E	19.00	19.00	19.00

[a]46% crude protein.

Weekly samples of DC, HMC, and AHMC were composited for analysis of dry matter, crude protein, pH, lactic acid, and volatile fatty acids (VFA). Crude protein was determined on the fresh HMC and AHMC samples prior to drying and on the DC samples after drying. Protein analyses were conducted by the Kjeldahl procedure with the boric acid modification (AOAC, 1975). For dry matter analysis, HMC and AHMC samples were dried at 54°C for three days, weighed, ground and then vacuum dried at 102°C for 16 hours. DC samples were dried at 102°C for 16 hours. All samples were extracted by placing 25 gm of fresh material in 100 ml 0.2N H_2SO_4 for VFA and lactic acid analyses. Lactic acid was determined

by the method of Barker and Summerson (1941). VFA were determined in a gas chromatograph equipped with a flame ionization detector. The 4M glass column was packed with Chromasorb 101[a] (100-120 mesh). Nitrogen was the carrier gas.

Trial 2. Two silos measuring 8' x 8' x 4' were constructed with plywood sides lined with black plastic. A roof was mounted over the top of both silos to keep rain and snow out of the grain.

Cracked corn was reconstituted to 27% moisture in a mobile feed mixer and allowed to mix for 30 minutes. Untreated HMC was elevated into one silo and packed during filling. The ammonia treatment was prepared by adding a precise amount of ammonia to approximately 27 kg water in a plastic tub. Water was used as a carrier for greater dispersion within the grain and to increase safety when the ammonia was added to the grain in the mixer. The application rate was .63% ammonia (dry matter basis). Each load of treated corn was mixed approximately five minutes and then transferred to the silo in the same manner as the untreated corn.

Six thermocouples were placed in each silo to monitor temperature during fermentation. Three thermocouples were placed 39 cm. from the top and 39 cm. from the bottom in the front, middle, and back portions of each silo. Temperatures were recorded each day for 19 days.

Twelve steers and six heifers were weighed after a 24-hour withdrawal from feed and water. All cattle were blocked by breed and sex into partially-sheltered, open-fronted pens with three animals per pen. Treatments for this trial were: (1) HMC plus soybean meal, (2) HMC

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[a]Johns - Manville, Denver, Colorado.

plus urea, and (3) ammoniated HMC (AHMC). The treatments were randomly allotted to the pens with two replications per treatment.

Nine Hereford steers (412 kg), uniform in weight, were randomly allotted to individual pens for more reliable measurement of daily feed intake and individual feed efficiency. The same three treatments of the group-fed cattle were randomly allotted to the individual pens with three replications per treatment.

All cattle were initially fed 60% corn silage, 5% supplement, and 35% of the respective corn treatments (dry matter basis) twice daily, ad libitum. The silage level was decreased in 10% increments every two to three days of the initial period, with the appropriate corn grain increased in 10% increments. All cattle were on the final rations (Table 3) of 15% corn silage, 80% corn, and 5% supplement (dry matter basis) before the first weigh period (14 days). Table 4 lists the supplements' composition.

Table 3. Composition of Rations - Trial 2.[a]

Ingredient	Ration 1	Ration 2	Ration 3
	---------- % ----------		
Corn Silage	15	15	15
HMC	80	80	—
AHMC	—	—	80
Supplement	5	5	5

[a]Percentages are on a dry matter basis.

Table 4. Composition of Supplements - Trial 2.

	Ration 1	Ration 2	Ration 3
	%		
Corn	19.5	73.5	81.0
Soybean Meal[a]	62.0	—	—
Urea[b]	—	7.5	—
Limestone	14.0	14.5	14.5
Salt	1.0	1.0	1.0
Trace Minerals	2.5	2.5	2.5
Vitamin A[c]	1.0	1.0	1.0

[a]44% crude protein.

[b]46% N, 287% crude protein equivalent.

[c]To furnish 30,000 IU/hd/day.

All cattle were weighed on day 14 and day 31 of the trial. The individually fed cattle were interval fed on weigh days to facilitate rumen and blood collection four hours post-feeding. Rumen samples were collected via a stomach tube and were therefore subject to saliva contamination. pH of the rumen samples was immediately recorded and each sample was then acidified with 10% of 6.0N HCl for ammonia analysis. Blood samples were taken via the jugular vein and 1 ml of 6.66% mercuric chloride was added per tube (15 ml) to inhibit enzymatic action (Davidovich et al., 1977).

A 4% shrink was subtracted from each 14 and 31-day weight. This was done to give more representative gains and feed efficiency values

without taking cattle off feed and therefore risking lactic acidosis when feeding was reinstated. This trial was ended on day 31 when the supply of HMC was depleted.

Weekly samples of HMC and AHMC were composited for laboratory analysis of dry matter, wet protein, wet ammonia, pH, lactic acid and VFA. Dry matter, wet protein, lactic acid and VFA were analyzed by the same procedures as in trial 1. Ammonia was determined by extracting each fresh sample at a rate of 25 gm/100 ml of 0.2N H_2SO_4 and then run by the Conway microdiffusion technique (AOAC, 1975). Whole blood and rumen ammonia were also determined by the Conway microdiffusion technique.

Upon depletion of the supply of untreated HMC, a third trial was immediately initiated to compare dry cracked corn to ammonia-treated high-moisture corn.

Table 3. Cattle that were fed untreated high-moisture corn were fed diets containing 15% sorghum silage, 80% dried corn and 5% supplement (soybean meal or urea-based), on a dry matter basis. The ammonia-treated HMC was fed in comparable amounts to the ration in trial 2, except sorghum silage was used as the roughage source. The supplements were the same as those fed in trial 2.

Final weights of trial 2, adjusted with a 4% shrink, were used as initial weights. Weights, blood and rumen samples were taken on days 14 and 25 in the same manner as in trial 2. Feed samples were collected weekly and composited for the same analyses as in trial 2 and as described in trials 1 and 2. Blood and rumen samples were analyzed for ammonia as described in trial 2. The trial was terminated when

excessive moldiness was observed in the treated HMC 138 days after ammonia treatment.

Trial 4. No research has been reported on the aerobic stability (bunklife) of high-moisture corn treated with ammonia. Therefore, six non-oxygen exposed samples were taken from the HMC and AHMC storage bins used in trial 2. Insulated minnow tubs lined with plastic bags were filled with samples of HMC and AHMC and weighed. A thermocouple was inserted in the center of each sample and temperatures recorded twice daily. Every two days, the tub with the highest temperature from each treatment was weighed off test. Samples of each tub were frozen for laboratory analysis of dry matter, wet protein, wet ammonia, pH, VFA and lactic acid. This trial was concluded on day 12 when the last two tubs were weighed.

Statistical Analysis of Data

Fermentation temperatures, ADG, dry matter intake (DMI), rumen pH and rumen ammonia were analyzed through analysis of variance. The means were separated by the Duncan's Multiple Range Test (Barr et al., 1976).

RESULTS AND DISCUSSION

Trial 1. In general, more high-moisture corn (HMC) than ammoniated HMC (AHMC) visibly spoiled. About 15.5 cm. were discarded from the top of the HMC barrels compared to about 8 cm. from AHMC barrels. The AHMC had a musty, dusty appearance but the HMC did not, indicating some internal spoilage occurred in the treated corn. This may have been due to the low moisture content (22%) of the HMC when it was treated with ammonia. By allowing the grain to soak overnight before treatment, some moisture was lost. The resulting moisture content may have been too low to retain ammonia, therefore as AHMC was transferred to the barrels, some ammonia loss may have occurred. The ammonia level retained in the grain may have been too low for adequate preservation during the storage and feeding period (102 days post-treatment).

Figure 1 shows a comparison of fermentation temperatures of HMC and AHMC. Temperature differences due to treatment were significant ($P<.05$) and fermentation time had a highly significant ($P<.0001$) effect on temperature. Temperatures of both treatments rapidly increased from day 4 to day 7, peaked and then rapidly decreased to day 12.

Performance of lambs fed the DC, HMC, and AHMC treatments is summarized in Table 5. Average daily gain (ADG), dry matter intake (DMI) and feed efficiency (F/G) did not differ significantly ($P<.05$) and were essentially equal for all three treatments.

FIGURE 1. BARREL TEMPERATURES

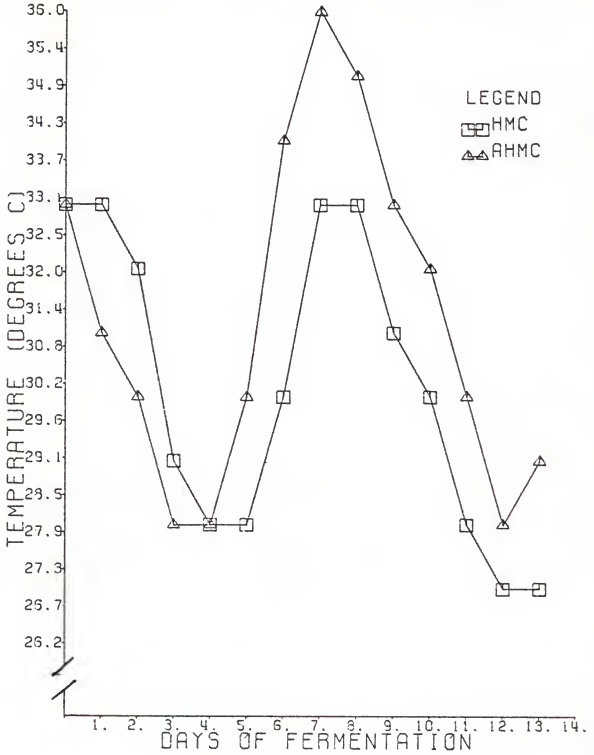


Table 5. Performance of Lambs Fed Dry Cracked Corn (DC), High-Moisture Corn (HMC) and Ammoniated HMC (AHMC).[a]

Item	DC	HMC	AHMC
Initial Wt., kg	30.5	30.6	30.5
ADG, kg[a]	.25	.24	.25
DMI, kg[a]	1.26	1.22	1.24
F/G, kg DM/kg Gain	5.04	5.08	4.96

[a]No significant (P<.05) differences were detected.

Laboratory analyses of the composite samples of DC, HMC, and AHMC for VFA (% weight basis), lactic acid, pH, and crude protein are presented in Table 6. Acetic and lactic acid levels of AHMC were 52 and 41% lower than in HMC, respectively. The lower level of lactic acid in AHMC indicates fermentation was reduced by ammonia treatment. Propionic and butyric acid levels were equal for both HMC and AHMC. Crude protein and pH of AHMC were higher than HMC, as expected with ammonia addition.

Table 6. Crude Protein, VFA, Lactic Acid and pH Levels in Dry Corn, HMC, and AHMC (Trial 1).[a]

	%					
	CP	Acetic	Propionic	Butyric	Lactic	pH
DC	9.80	.05	---	---	.01	----
HMC	9.84	.37	.03	.01	.56	4.13
AHMC	11.86	.20	.03	.01	.23	7.28

[a]All percentages are on a dry matter basis.

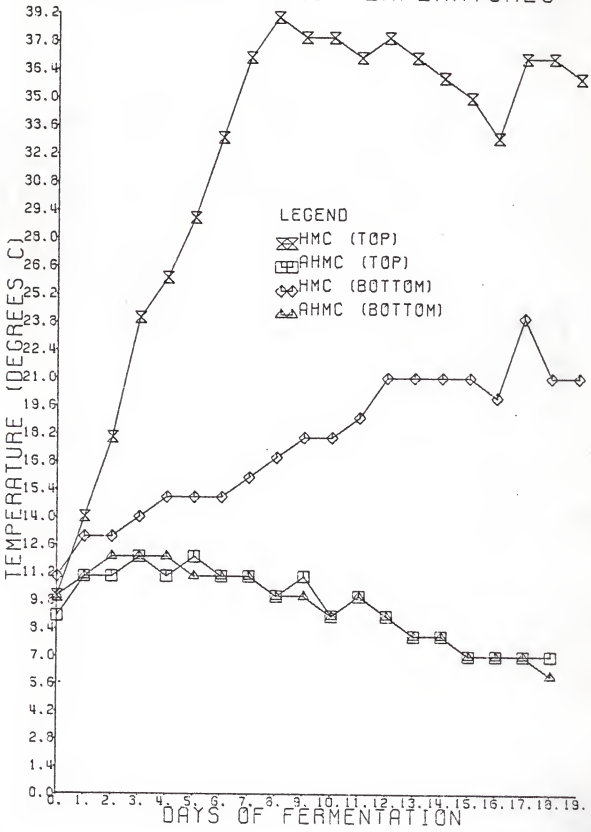
Since lamb performance was not adversely affected by ammonia treatment, the two trials with cattle were initiated to study the effects of ammoniation on cattle performance. Fermentation was reduced in trial 1 with ammoniation; therefore, dry matter loss during storage may also be reduced. Trials 2 and 3 were conducted to quantitate the comparative dry matter losses of HMC and AHMC.

Trial 2. Visible molding occurred in the top 21 cm. of HMC, after fermentation, and had to be discarded. No spoilage was visible in the AHMC for the duration of this trial.

Temperatures during fermentation of the two treatments in both top and bottom locations are shown in Figure 2. Differences due to both treatment and time were highly significant ($P<.0001$). The temperature of the top layer of HMC rapidly increased to 39°C by day 6 and then leveled off. The bottom layer of HMC, in contrast, gradually increased over time with the highest temperature of 24°C recorded on day 17. The bottom layer is considered more representative of the total mass in the silo since excessive molding was visible in close proximity to the thermocouples of the top layer. Temperature of AHMC, however, was essentially the same for both top and bottom layers, slightly decreased over time and averaged 22°C lower than HMC temperatures.

Table 7 exhibits the chemical analyses of HMC and AHMC before ensiling and 41 days after the corn was placed in the silos. The 41-day, post-ensiling samples of both samples were taken via a core sampler. Acetic and propionic acid (% weight basis of DM) increased after fermentation in HMC but the acetic acid level in AHMC remained the same. Butyric acid was not detected in either treatment before or

FIGURE 2. SILØ TEMPERATURES



after fermentation. Lactic acid production did not occur during fermentation of AHMC, whereas in HMC the lactic acid level increased from .03% to .7%.

Table 7. Comparison of VFA, Lactic Acid and Ammonia Levels of Pre-Ensiled and Post-Ensiled HMC and AHMC.[a]

	%				
	Acetic	Propionic	Isovaleric	Lactic	NH_3
HMC (Pre)	.05	.01	.02	.03	.02
HMC (Post)	.51	.06	.01	.70	.06
AHMC (Pre)	.17	.01	.01	.04	.34
AHMC (Post)	.18	---	.01	.02	.32

[a]All values are on a dry matter basis.

The performance of finishing cattle fed the three treatments is summarized in Table 8. ADG, DMI, and F/G were not significantly ($P<.05$) different during the initial 14 days and the entire trial (31 days). However, in both periods, ADG was higher, DMI lower and F/G more efficient for AHMC than both HMC treatments. ADG and F/G were favored during the initial 14-day period by urea compared to soybean meal supplementation of HMC. However, considerable animal variability existed during the initial period and performance for the entire trial showed soybean meal supplementation resulted in slightly higher ADG and improved feed efficiency.

Table 8. Effect of Feeding AHMC Compared to HMC Supplemented with Soybean Meal or Urea for Finishing Beef Cattle.

Item	HMC + SBM	HMC + Urea	AHMC
Day 0 - 14:			
Initial wt., kg	409	413	407
ADG, kg[a]	.58	.94	1.21
DMI, kg[a]	7.72	7.80	7.46
F/G, kg DM/kg gain	13.31	8.30	6.17
Day 0 - 31:			
ADG, kg[a]	1.15	1.08	1.31
DMI, kg[a]	7.59	7.84	7.81
F/G, kg DM/kg gain	6.60	7.26	5.96

[a]No significant ($P<.05$) differences were detected.

Analyses of blood and rumen samples taken from the individually-fed cattle, four hours post-feeding are shown in Table 9. No significant differences existed between treatments for rumen pH and rumen ammonia (NH_3). Therefore, the level of ammonia (.34%) in the AHMC did not exceed the microbes' capacity for assimilation of ammonia for protein synthesis. Blood ammonia analyses were performed but results were highly variable. Future trials should incorporate collections at hourly intervals for the first four hours after feeding in an attempt to monitor changes in blood ammonia levels.

Table 9. Effect of Treating HMC with Ammonia Compared to Soybean Meal or Urea Supplementation on Rumen pH and Ammonia of Finishing Beef Cattle.

Parameter	HMC + SBM	HMC + Urea	AHMC
Day 14:			
Rumen pH[a]	6.00	6.59	6.00
Rumen NH_3, mg/100 ml[a]	1.63	1.84	1.90
Day 31:			
Rumen pH[a]	6.35	6.20	6.28
Rumen NH_3, mg/100 ml[a]	2.90	3.20	3.38

[a]No significant ($P<.05$) differences were detected.

Table 10 presents the laboratory analyses of the composite samples of HMC and AHMC. As with 41-day post-ensiling (Table 7), the pH and ammonia were higher for AHMC than HMC. Lactic acid was higher in HMC than in AHMC (.52 vs. .07%). The depressed lactic acid level and storage temperatures indicate fermentation was inhibited by ammonia treatment.

Trial 3. The performance of cattle fed dry cracked corn (DC) supplemented with soybean meal or urea compared to AHMC is presented in Table 11. No significant treatment differences in ADG existed during the initial 14 days. The AHMC tended to have a lower ADG, and DMI was significantly ($P<.05$) lower than both DC treatments. Corresponding to the lower ADG, more feed DM tended to be required for body weight gains in the AHMC treatment than for the dry corn treatments.

Table 10. Dry Matter, Crude Protein, Ammonia, pH, VFA and Lactic Acid Analyses of HMC and AHMC Composite Samples.[a]

	%			%				
Treatment	DM	CP	pH	NH_3	Acetic	Propionic	Isovaleric	Lactic
HMC	64.76	9.70	4.53	.11	.30	.10	---	.52
AHMC	70.31	11.32	5.13	.37	.29	.03	.01	.07

[a]All percentages are on a dry matter basis.

Table 11. Performance of Finishing Cattle Fed AHMC Compared to Dry Cracked Corn Supplemented with Soybean Meal or Urea.

Item	DC + SBM	DC + Urea	AHMC
Day 0 - 14:			
Initial wt., kg	444	446	447
ADG, kg	2.66[a]	2.32[a]	1.42[a]
DMI, kg	11.38[a]	11.40[a]	8.35[b]
F/G, kg DM/kg gain	4.28	4.91	5.88
Day 0 - 25:			
ADG, kg	1.84[a]	1.63[a]	1.01[b]
DMI, kg	11.37[a]	11.42[a]	8.45[b]
F/G, kg DM/kg gain	6.18	7.01	8.37

[a,b]Means with different superscripts differ significantly (P<.05).

For the entire trial, ADG and DMI were significantly (P<.05) lower for AHMC compared to both dry corn treatments. The decreased performance of cattle fed AHMC was probably due to spoilage occurring in this grain that did not become serious until late in the trial. The length of this trial was restricted because of a very limited quantity of AHMC.

Table 12 gives the average values of rumen pH and rumen ammonia of the individually-fed cattle. As in trial 2, no significant differences in these parameters were observed. Blood ammonia values were highly variable as in trial 2.

Table 12. Comparison of Rumen pH and Ammonia of Cattle Fed AHMC and Dry Cracked Corn (DC) Supplemented with Soybean Meal or Urea.

Parameter	DC + SBM	DC + Urea	AHMC
Day 14:			
Rumen pH[a]	6.08	5.92	6.17
Rumen NH_3, mg/100 ml[a]	1.07	.45	.89
Day 25:			
Rumen pH[a]	6.53	6.30	6.68
Rumen NH_3, mg/100 ml[a]	4.64	1.50	2.35

[a]No significant ($P<.05$) differences were detected.

Since all AHMC was used after this trial, dry matter loss (%) in the HMC and AHMC silos was determined. A 6.81% dry matter loss for HMC occurred compared to a .94% loss for AHMC.

Trial 4. Excessive visible mold was observed in the HMC tubs by day 4; however, none occurred in AHMC during the entire trial. The change in temperature as shown in Figure 3 corresponds with increased moldiness seen in HMC. Within one day after exposure to oxygen, the temperature of HMC increased 18°C, leveled off for 36 hours and then peaked at 46°C on day 4. This represents an increase of 25°C within 4 days. In contrast, AHMC peaked in temperature at day 6. The total change of temperature from day 0 to day 6 was only 18°C. Differences of temperature due to time of exposure and treatment were highly significant ($P<.0001$) with AHMC averaging 23.4°C lower than HMC.

FIGURE 3. TEMPERATURES OF HMC AND AHMC AFTER EXPOSURE TO OXYGEN

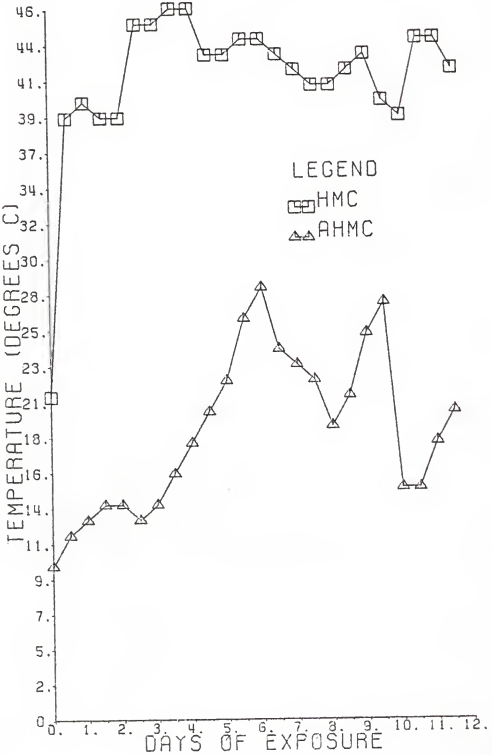


Figure 4 graphically exhibits the comparative dry matter loss (%) of HMC and AHMC. After day 2, AHMC had experienced an average loss of 3.37%. HMC by contrast had dry matter losses of 9.8 and 19.3% by day 4 and day 6, respectively. The average dry matter loss for HMC after day 2 was 16.06%.

Table 13 shows the laboratory analyses of HMC and AHMC at the different times after exposure. Crude protein remained relatively unchanged for HMC and AHMC. The relatively stable level of ammonia and crude protein for AHMC indicate that ammonia is not lost after exposure to oxygen. The acetic acid level of HMC appeared unstable over time of exposure but AHMC slightly declined to .36% on day 6 then rapidly declined to .05 after 8 days and leveled off. Butyric acid production in AHMC remained zero for the length of the trial but occurred in the HMC after day 4, averaging .18%. Lactic acid decreased over time for both treatments but averaged .83% for HMC compared to .08% in AHMC.

FIGURE 4. DRY MATTER LOSS OF HMC AND AHMC EXPOSED TO OXYGEN

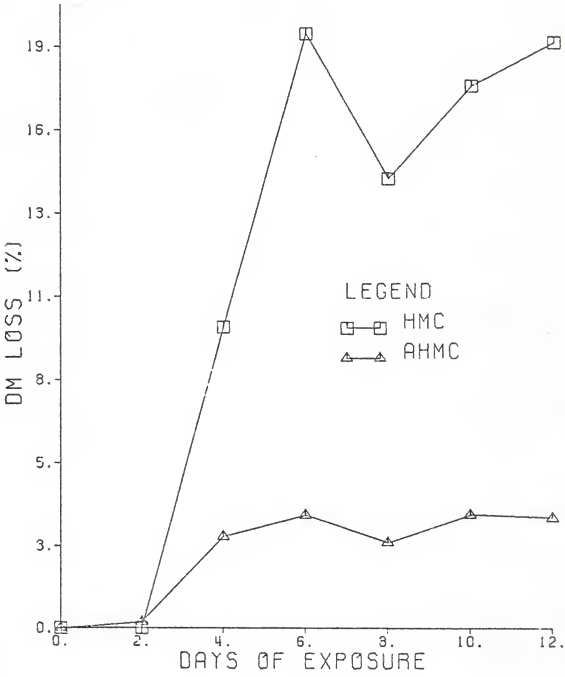


Table 13. Dry Matter, Crude Protein, pH, Ammonia, VFA, and Lactic Acid Analyses of HMC and AHMC After Exposure to Oxygen.[a]

Days[b]	Trt.	DM (%)	CP (%)	pH	NH_3 (%)	Acetic (%)	Propionic (%)	Butyric (%)	Isovaleric (%)	Lactic (%)
0	HMC	59.21	10.64	4.08	.10	.49	.02	---	---	1.16
	AHMC	67.23	12.09	6.91	.52	.45	.01	---	.01	.19
2	HMC	63.21	10.55	4.50	.09	.23	.02	---	---	1.01
	AHMC	67.67	12.00	5.90	.10	.40	.04	---	.01	.10
4	HMC	59.76	10.31	4.63	.10	.40	.03	---	---	.82
	AHMC	68.09	11.25	6.35	.40	.34	.03	---	---	.08
6	HMC	56.70	9.38	4.12	.14	.57	.08	.12	.01	.65
	AHMC	66.32	12.62	7.18	.32	.36	.01	---	---	.08
8	HMC	60.88	11.04	4.83	.08	.36	.10	.22	.03	.70
	AHMC	69.23	11.80	8.15	.38	.05	---	---	---	.04
10	HMC	60.58	10.37	5.32	.07	.46	.07	.10	.01	.31
	AHMC	67.89	11.99	6.30	.32	.08	---	---	---	.04
12	HMC	62.02	10.64	5.15	.25	.68	.15	.26	---	1.19
	AHMC	68.54	12.33	6.55	.26	.08	---	---	---	.04

[a]All values are reported on a dry matter basis.

[b]Days after exposure to oxygen.

SUMMARY

Treating high-moisture corn with "Cold-Flo" ammonia appears to inhibit fermentation. Temperature during fermentation was reduced by ammoniation in trial 2; however, temperatures of AHMC were higher than HMC in trial 1. This may have been due to the low moisture content (22%) of AHMC in trial 1. It should be stressed that a proper moisture level is needed to prevent ammonia loss and to enhance preservation. Since fermentation is inhibited, dry matter loss is inhibited. Visual molding is reduced by ammoniation and occurs much later than in HMC.

The aerobic stability (bunk life) is much greater with ammonia-treated HMC than untreated HMC. Temperatures and dry matter losses are dramatically reduced by ammonia treatment. A mold-free state is retained longer in AHMC than HMC after exposure to oxygen.

The length of the feeding trials was restricted because of a very limited quantity of HMC and AHMC. This makes estimation of the relative feeding value difficult. Dry matter intake was not significantly decreased when compared to HMC but intake of the dry corn was significantly higher than with AHMC. Body weight gains and feed efficiency results of AHMC were similar to HMC, but a high degree of animal variability existed. Therefore, more feeding trials with greater numbers of cattle, lighter in weight and conducted for longer lengths of time should be conducted to obtain a more accurate comparison of AHMC to HMC supplemented with protein at feeding time. A considerable

economic advantage exists for AHMC by lowering feed costs through reduced fermentation and spoilage losses and through a lower cost of protein compared to soybean meal or urea.

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ANHYDROUS AMMONIA APPLICATION TO HIGH-MOISTURE CORN

by

BRADLEY HARLAN

B.S., California Polytechnic State University
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ABSTRACT

Four trials were conducted to ascertain the effects of "Cold-Flo" ammonia treatment of high-moisture corn on fermentation, feeding value, and aerobic stability.

In the first trial, 30 Hampshire, Suffolk, and Rambouillet-Dorset cross lambs (30.5 kg) were assigned to three treatments: (1) dry cracked corn (DC), (2) high-moisture (22%) corn (HMC), (3) ammonia-treated HMC (AHMC). HMC and AHMC were stored in 55-gallon barrels for 60 days prior to the 42-day feeding trial. Daily temperatures were significantly (P<.05) higher in AHMC compared to HMC. ADG (kg), DMI (kg), and F/G for DC, HMC and AHMC were: .25, 1.26, 5.04; .24, 1.22, 5.08; .25, 1.24, 4.96, respectively, which were not significantly different. Acetic, propionic, butyric, lactic, crude protein (% of DM) and pH for HMC were: .37, .03, .01, .56, 9.84, and 4.13 compared to .20, .03, .01, .23, 11.86, and 7.28 for AHMC, respectively.

A second trial was conducted with 21 Hereford and Hereford-Angus steers and six Hereford and Simmental heifers (410 kg). Nine of the Hereford steers were individually fed. All cattle were randomly allotted by breed and sex to three treatments: (1) HMC + SBM, (2) HMC + Urea, and (3) AHMC. HMC and AHMC were stored in plywood-lined 8' x 8' x 4' silos. Daily temperatures were significantly (P<.0001) greater in HMC compared to AHMC, averaging 22°C higher.

ADG (kg), DMI (kg), and F/G for HMC + SBM, HMC + Urea, and AHMC for the 31-day feeding trial were: 1.15, 7.59, 6.60; 1.08, 7.84, 7.26; 1.31, 7.81, 5.96, respectively and were not significantly (P<.05) different. Rumen pH and rumen ammonia (mg %) were: 6.35, 2.90; 6.20,

3.20; 6.28, 3.38 for the HMC + SBM, HMC + Urea, and AHMC treatments, respectively.

Dry matter, crude protein (%), pH, ammonia, acetic, propionic, and lactic acid levels (%) for HMC were: 64.76, 9.70, 4.53, .11, .30, .10, and .52 compared to 70.31, 11.32, 5.13, .37, .29, .03, and .07 for AHMC, respectively.

A third trial was conducted comparing dry cracked corn (DC) supplemented with SBM or urea to AHMC. The same cattle fed in trial 2 were used in this 25-day feeding trial. ADG (kg), DMI (kg), and F/G for DC + SBM, DC + Urea, and AHMC were: 1.84, 11.37, 6.18; 1.63, 11.42, 7.01; 1.01, 8.45, 8.37, respectively. The performance of AHMC cattle was significantly lower than both DC treatments. No significant differences in rumen pH and rumen ammonia were observed.

A 6.81% loss of dry matter occurred in the HMC silo compared to only 0.94% loss in AHMC.

A fourth trial investigated the aerobic stability of non-exposed samples of HMC and AHMC placed in minnow buckets at room temperature for 12 days. AHMC temperatures were significantly ($P<.0001$) lower than HMC, averaging 23.4°C lower. After day 2, HMC lost 16.1% dry matter compared to only 3.4% in AHMC. Crude protein (% of DM) remained unchanged for the 12 days with HMC, averaging 10.42% and AHMC averaging 12.01%. The pH of HMC slightly increased over time (4.08 to 5.15) but AHMC remained relatively unchanged (averaging 6.76). Ammonia, propionic, and lactic acid levels remained unchanged, averaging .12, .05, and .83% for HMC and .33, .02, and .08% for AHMC, respectively. Acetic acid remained constant for HMC but decreased 82% from day 0-12 in AHMC. Butyric acid was produced after day 4 in HMC, averaging .18% but did not occur in AHMC.