PROPIONIC ACID TREATMENT OF CORN SILAGE HARVESTED AT MEDIUM AND HIGH DRY MATTER STAGES OF MATURITY

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ABSTRACT

PROPIONIC ACID TREATMENT OF CORN SILAGE
HARVESTED AT MEDIUM AND HIGH DRY
MATTER STAGES OF MATURITY

By

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The present experiment (Exp. 4) was conducted with corn silage harvested at 35 and 45% dry matter to evaluate the effectiveness of propionic acid in improving the preservation and feeding value for lactating dairy cows when fed as the sole forage. This experiment was combined with three previous studies conducted at Michigan State University with corn silages (ranging in dry matter from 35 to 45%) which were treated with organic acids at 0.3 and 0.6%.

After ensiling, whole chopped corn (35 and 45% DM) with or without 0.6% propionic acid, thermocouples were placed in centers of each silo at heights of 2.5, 5.0 and 7.5 m and temperatures were monitored daily during the first five weeks of fermentation. Propionic acid resulted cooler silage at all heights, both at 35 and 45% DM.

Silage and total dry matter intakes were not significantly different at either dry matter level, but cows receiving propionic treated silage consumed slightly more

than the corresponding controls. Milk yields again favored groups fed propionic treated silage, even though differences were not significant. Milk composition was not significantly different among groups, even though all milk constituents were slightly higher during treatment than standardization. No difference of the pH values due to the treatment were noted at 35 or 45% DM. Lactic acid production was significantly different ($P < 0.05$) between dry matter levels, but the propionic effect was not significant ($P < 0.1$). During the feeding trial, temperatures were also monitored. For all depths control silages were higher than the propionic silages ($P < 0.05$) at both levels of dry matter.

Upon exposure to air, lactic acid concentrations were decreased in all silages and no difference between treatments were detected for the rates of decrease. The pH values of all silages increased during refermentation, differences between controls and treatment were not significant, but there was a trend toward higher pHs for untreated silages. The number of fungal colonies during refermentation was significantly decreased ($P < 0.01$) by propionic treatment of 45% DM silage. Initial fungi of untreated silages were also higher for 45% than 35% DM. Visual fungal growth were present on days 6 and 10 for 35% DM control and treated silages, respectively, and on days 7 and 14 for the respective high dry matter silages.

Propionic treatment also resulted in slightly cooler silage during refermentation, but differences were not significant.

Pooling of animal data from experiments 2, 3 and 4 showed that propionic acid treatment increased silage dry matter intakes 12% ($P < 0.01$), total intakes 6% ($P < 0.05$) and milk persistency 5% ($P < 0.05$).

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INTRODUCTION

Silage is a basic roughage constituent of cattle feeding systems in the United States. Over the past 15 years, in areas of the United States and Canada suited for corn production, there has been almost a doubling in the use of corn silage for dairy and beef cattle (Huber, 1974). This increase in corn silage production can be attributed to (1) greater energy yields per acre when harvested as corn silage over shelled corn or any other grain, (2) consistently high digestibilities of corn silage, (3) increased feed efficiency over other type of feedstuffs and (4) mechanically handling of harvesting, storage and feeding, thus minimizing labor requirements (Geasler and Henderson, 1969; Hemken and Vandersall, 1967; Huber, 1974).

Due to the high proportion of total forage on dairy farms that is corn silage, attention should be given to the stage of maturity or time of harvest which will result in the most efficient use of land, labor, storage facilities and equipments. Gordon et al. (1968) comparing normal and late harvested of corn for silage found that high quality silage could be produced with late harvesting but it would be impractical due to high field losses. Similar results were obtained by Marx (1969).

However, corn silage, as known today is not the ultimate material to be fed. The chopped corn plant is a more desirable feedstuff than the ensiled material, due to fermentation changes (Wilkinson et al., 1976) and losses. Much of the materials involved in these losses could be utilized by the beef animal (Geasler and Henderson, 1969), but at present there is no method by which these losses can be totally prevented. Therefore, we have turned to investigation of methods which will minimize these losses and still produce the most desirable fermentation.

Many problems of efficient feed storage are directly or indirectly related to growth of aerobic microorganisms (especially fungi) when forages are stored between 25 and 50% moisture and grain between 14 and 40% moisture (Goering and Gordon, 1973). Traditionally, these problems have been minimized by either reducing moisture content below critical amounts or keeping the moisture content high enough to more easily obtain an anaerobic condition. It would be a great convenience, and in many cases an economy, if storage systems could be developed for grains and forage that would allow aerobic storage within a medium moisture range without fear of losses from fungal growth. Several chemicals have been identified as having fungistatic or fungicidal properties (Britt et al., 1975;

Candlish et al., 1973; Fellows, 1971; Forsyth et al., 1970; Goering and Gordon, 1974; Huber et al., 1972; Sleiman et al., 1972). Storing and feeding high moisture corn treated with organic acids have been reported by several research workers (Christensen, 1973; Goering and Gordon, 1974; Sleiman et al., 1972; Lessard et al., 1970). Also storing and feeding organic acid treated corn silage have been done by research workers (Huber et al., 1972; Sleiman, 1972; Waldo et al., 1975).

A large part of the corn silage crop is harvested late in the season when dry matter is too high for good preservation. Consequently, much of the silage fed from such silos has gone through excessive fermentation or has molded, carmelized and is of poor nutrient value (Huber, 1974). Also, inhibition of normal fermentation with propionic or other acids might improve the nutritive value of silage harvested at optimum dry matter by inhibiting proteolysis and acid production to depress silage intakes and efficiency of nutrient utilization.

The objectives of this thesis were to determine the effectiveness of organic acids in improving the preservation of corn silage harvested at varying dry matter levels (35 to 45%). Also to assess the feeding value of organic acids treated corn silage for lactating dairy cows when harvested at two stages of maturity.

LITERATURE REVIEW

Effect of Corn Plant Maturity on Silage Quality

Harvesting at the proper stage of maturity assures the maximum content of protein, minerals and vitamins, and the highest digestibility and the best preservation. Several research workers have studied the effect of stage of maturity of the corn plant at time of harvest for silage on its yields, acceptability and digestibility.

Dry Matter Yields Per Acre (hectare)

Henderson (1969) showed that the dry matter yield per acre increases until it reaches approximately 35% or until the first killing frost. It will then level off for 5-10 days (depending upon the extent of frost, wind and rain) and then begin declining at a rapid rate. Huber (1974) found that total dry matter in the corn plant increases until accumulation of starch in the kernels is complete. At this maturity the greatest nutrient yields per acre are obtained and total plant dry matter content ranges between 34 and 38%. If the harvest is delayed after this optimum stage, there is a decrease in yield of nutrients primarily due to falling of ears from the plants.

Caldwell and Perry (1971) stated that for both years of their experiments, the maximum yield of dry matter per hectare occurred at the time when the whole plant contained 33% dry matter.

Various criteria have been used to determine the proper time of harvesting corn silage. Maximum yield of dry matter (Johnson et al., 1966) and of digestible energy (Johnson and McClure, 1967) have been reported between the dent and glaze stages. Gay (1966) and Keeney et al. (1967) found that the late dent-hard, dough state gave maximum dry matter yields. However, Pratt et al. (1964) measured no differences in dry matter yield between the late milk, early dough and the well-dented stage. In addition, Geasler et al. (1967) reported a decrease in dry matter yield with increasing maturity when 28, 45 and 60% dry matter silages were compared. Obviously, highest yields would have occurred between 33 and 37%.

Feed Intake

Huber et al. (1965) reported the effect of maturity of corn silage on intakes of lactating cows. The corn was harvested at soft, medium and hard dough and the silage was fed ad libitum to 18 lactating cows as the only forage in two trials. Each trial consisted of two periods. During one period cows received soybean meal as the only supplemental feed. A concentrate mixture (containing 16% crude protein) was fed a 1 kg per 3.5 kg milk during the other period. Dry matter content of the respective maturities averaged 25.4, 30.3 and 33.3%. Dry matter intakes of silage were significantly increased with advancing maturity and were probably responsible for higher milk production. Differences due maturity were greater when cows were supplemented with only soybean meal. Gay (1966) also found that the maximum dry matter intake was in the hard dough stage. In contrast, Noller et al. (1963) harvested two different stages of maturity of corn plant for silage fed to Holstein steers. They found the maximum dry matter consumption occurred with very early dent stage compared to late dent.

Bryant et al. (1965) compared corn plant harvested at milk (21.7% DM) and medium hard dough (31.8% DM) stages of maturity for silage and found that dry matter consumption was higher at medium hard dough than milk, so it could be concluded that dry matter consumption increased with increasing maturity. The same result was stated by Geasler et al. (1967).

Another study was conducted by Marx (1969) who harvested corn plant material for silage at two different stages of maturity. The first harvest was called early cut with 31% dry matter and the second harvest was late cut with 51.9% dry matter. The difference between two stages of maturity was six weeks and he found that dry matter intake of early cut silage was significantly lower than late cut silage. With gas-tight silos Gordon et al. (1966) observed slightly higher intakes of silage containing 27% dry matter compared to 55%, but the difference was not significant. The above studies support the summary of Boman (1975) which showed that intake of corn silage increased linearly up to about 35-37% dry matter, plateaued to 43-45% and then gradually declined.

Production and Composition of Milk

Montgomery et al. (1974) harvested corn plants in three successive years at the early dough, late dough and mealy endosperm stages. Differences among years in date of harvest and dry matter content of the silage were due to the time at which the corn was planted in the spring and to variability in growing seasons and moisture conditions at harvest time. The silages, cut at three stages of maturity were fed to Jersey cows, with concentrate at 1 kg/3 kg of fat corrected milk. No significant differences in milk production were detected between treatments.

Byers and Ormiston (1964) harvested corn for silage at 31.5% DM (control) and 54.9% DM (mature) and fed these ad libitum to lactating dairy cows. Also, limited alfalfa hay, and about 1 kg of grain to 2.5 kg of milk were fed. Milk production on a two silages was not significantly different. It was suggested that mature corn silage can be used as a forage extender but that extra care in making the silage is needed to insure a fine chop and air tight storage by packing well in the conventional tower silos.

Huber et al. (1965) found that when corn plant was harvested at soft, medium and hard dough and fed ad libitum to three groups of lactating Holstein cows as the only forage, milk yields increased significantly with dry matter content of the silages. No significant effect due maturity of silage was noted in milk composition and efficiency of milk production. Virginia studies (Bryant et al., 1965) revealed an advantage in daily milk yields from cows fed a particular corn variety harvested for silage in the hard dough compared to the milk stage. A 5 to 10% improvement in milk yields was associated with an increase in dry matter intake of 10-20%. Similarly, Owens et al. (1967) harvested corn for silage at three different stages of maturity (low--25-29% DM, medium--36-39% DM and high--54-73% DM) and reported that milk production was highest for cows fed high dry matter silage with no difference in milk fat or solids--not fat percentages. In this experiment (Owens et al., 1967) high dry matter silages were ground with a hammer mill using a 3.8 cm screen before ensiling and silages were stored in gas-tight units. In 1969, Marx noted that milk fat and solids--not fat percentages were not significantly different between groups of lactating cows fed early cut silage (31% DM) or late cut silage (51.9% DM).

Gain

In studies with fattening beef cattle (Geasler, 1970), cattle gains were higher from silage harvested at 28% DM compared to 48% or 60%. Silage dry matter intakes were slightly higher for the two drier silages, but efficiency of gain was greater at 28% DM.

Chamberlain et al. (1971) harvested corn plants for silage at four stages of maturity: (1) late milk (approximately 90% of the kernels were in the late-milk stage), (2) early dough (approximately 90% of the kernels were dented), (3) late dough (when all kernels were dented) and (4) mealy endosperm (approximately 35% moisture in the grain). These silages were fed ad libitum to growing heifers together with 0.9 kg hay and 0.7 kg cottonseed meal per head per day. Result indicated that corn plant maturity between late milk and late dough did not affect the average daily gain. There was a significant reduction in average daily gain at the mealy endosperm stage. No significant effect due to maturity of silage was noted in body weight gains by Byers and Ormiston (1964) or Huber et al. (1965).

Controlling Silage Fermentation

The feeding value of corn silage is determined almost entirely by the degree and type of fermentation it undergoes and many factors that regulate fermentation can be controlled.

Lactic Acid Production

Products of silage fermentation are the metabolic end products of bacterial life and the bacteria per se. The most important points in bacterial control of silage fermentation are associated with production of lactic acid. The production of lactic acid occurs in the rumen from the fermentation of ingested food and in the silo from the fermentation of ensiled materials. Silage is an important source of lactic acid for domestic ruminants (Mackenzie, 1967). Sugar, hemicellulose and organic acids in the ensiled materials are fermented anaerobically to lactic acid by bacteria. The main species involved are *Lactobacillus*, *Peddicoccus*, and *Streptococcus* (Langston et al., 1962). Smaller quantities of the other acids (formic, acetic, propionic, butyric, and succinic) are also produced (Archibald, 1953; Ekern and Reid, 1963; Gordon et al., 1963; Miller et al., 1962). The lactic acid content of silage varies due to differences in composition of ensiled material and to variations in the ensiling process (Klosterman et al., 1961; Shearer and Cordukes, 1962). Generally, lactic acid comprises from 2 to 10% of dry matter content of good quality silage (Archibald, 1953; Elliot et al., 1957; Geasler and Henderson, 1969; Klosterman et al., 1961; Shearer and Cordukes, 1962), but it can range from less than 1% to more than 16% (Mackenzie, 1967). According to Barnett and Duncan (1954), poor quality silages are high in VFA content and low in lactic acid. To prevent the formation of butyric acid, they recommended compressing the materials to make the silo more air tight.

Temperature

Silage temperature affects the bacterial activity and the resulting level of lactic acid produced during fermentation, as well as preservation of the protein and energy in the silage. Lactic acid producing bacteria are most active at temperatures of approximately 43°C. Bacterial activity is slowed down in direct relationship to the reduction in temperature below 43°C and fermentation virtually ceases at temperatures below 15°C. With increasing temperatures, bacterial activity is again slowed down and virtually ceases above 54°C (Henderson, 1973; Man, 1953; Wieringa, 1959). With good packing and oxygen free storage, silo temperatures will not normally exceed 43°C.

Langston et al. (1960) observed that aerated silages showed higher temperatures and were of poorer quality than the sealed silages. The sealed silages which were tramped and weighed gave little temperature increase. They also found that aerated silages had high pH values with increased butyric acid and NH_3-N.

Ohyama et al. (1973) studied the effects of temperature and glucose addition on grass silage fermentation. They found that when no glucose was applied, silages held at 30°C were without exception of very poor quality, while those kept at 15°C were generally of fairly good quality. The addition of 2% glucose at ensiling resulted in excellent quality silage at both 15°C and 30°C. At 30°C, lactic acid was produced rapidly, pH decreased and silage reached a stable state in a short time. On the other hand, at 15°C, though the lactic acid formation was not so rapid in the early stages, the final products contained large amount of lactic acid and little acetic with a low pH value. Thus, the effects of glucose addition are related to the silage temperature, and its addition can overcome the deteriorating effect of the higher temperature.

Organic Acids for Preserving Grains and Forages

Organic acids recently have become available for preserving grains and forages. Various acids are used, such as: sulfuric, hydrochloric, phosphoric, formic, acetic, propionic, butyric, or mixtures of these.

Organic-Acid-Treated High Moisture Grains

Since the late 1960s when British Petroleum Ltd. announced the usefulness of propionic acid for the long term preservation of high moisture grain under practical conditions, the use of volatile fatty acids (VFA) for improving the storage life and enhancing the nutrient value of high moisture grains has been widely accepted (Anonymous, 1968).

Animal Performance

There has been an increasing interest in the use of corn, sorghum grain, barley, wheat and oats as high moisture grains for various classes of livestock. The storage of high moisture grains in sealed silos or bins has been relatively successful, but mold spoilage occurs when these structures are opened and grains are exposed to air (Ingalls et al., 1974). Recently, interest has developed in the application of several kinds of organic acids or their mixtures to high moisture grains. These decrease microbial activity (mainly fungi) and allow grain storage under conditions similar to those required for dry grain.

In 1970, Jones et al. fed high moisture shelled corn (66.7% DM) preserved with 1.5% propionic acid as part of the ration for 12 lactating dairy cows and seven growing dairy heifers. Ensiled high moisture shelled corn was fed to control groups. Fat-corrected milk yield, persistency of milk production, milk fat and protein percentage in lactating cows, and rate of gain in dairy heifers were not significantly different between rations. Mold counts were 1 and 1200 colonies/g, respectively, for the propionic treated and ensiled, untreated corns. There were no adverse effects of propionic acid treatment upon animal health or performance.

In another experiment, Forsyth et al. (1972) harvested shelled corn at approximately 70% CM, sprayed with propionic acid at a rate of 1.5% by weight and stored on a barn floor. Crossbred steers and lactating dairy cows were utilized in a feeding trial to compare high moisture corn preserved with propionic acid to dry corn. Acid-treated, high moisture corn was more efficient for weight gains than dry corn. There was no significant difference in milk production or milk composition, but a slight drop in milk fat percent with the treated corn ration was noted.

Jones (1973) preserved 34% moisture shelled corn with 1.5% propionic acid, stored on a concrete barn floor, and subsequently mixed into a concentrate ration. He found no adverse effect of treatment on animal health. Feeding value of high moisture shelled corn treated with propionic acid at harvest equalled that of dry shelled or ear corn.

McLeod et al. (1974) compared for dairy cows dry shelled corn, high moisture shelled corn (24% moisture) treated with 0.95% propionic acid or a 40-60 mixture of acetic-propionic acid (1.15%). Actual and solids corrected milk, milk fat, protein and forage dry matter intakes were not significantly different between groups fed the three types of corn. Moreover, rations had no apparent effect on body weight changes or animal health. They concluded that corn preserved by either acid treatment was equal in feeding value to dried shelled corn for lactating dairy cows. Similar results were reported by Chandler et al. (1975) and Clark et al. (1975). McCaffree (1968) and Larsen (1972) found no significant difference in milk yields, dry matter intakes or milk fat percent between cows fed propionic treated or untreated high moisture ear corn. In apparent contrast, Rook et al. (1965) observed a depression in milk yields and milk fat percent after intraruminal infusion of propionic acid.

Several studies have been conducted on the effect of corn preserved with propionic acid when fed to pigs. Young et al. (1970) treated high moisture corn containing approximately 76% DM with 1.5% propionic acid and stored the material in bins open to air. Pigs fed treated corn gained at a similar rate and had equal or better feed efficiencies than pigs fed dry corn (90% DM). Witting (1974) found that pigs tolerated a high concentration of propionic acid in their feed. Moreover, he reported high digestibilities for treated maize and that pigs fattened better on moist maize preserved with propionic acid than on dried maize. Jones et al. (1970) reported that propionic acid treated shelled corn (66.7% DM) resulted in greater gains by pigs than untreated corn.

Preservative Effects

Although the antifungal properties of organic acids have been known for many years (Byrde, 1969) and a number of recent articles have alluded to their preservation of moist grain, published reports verifying such activity are few (Hertig and Drury, 1974). Cameron reported in 1945 that the addition of butyric acid to water used to condition grain samples effectively supressed mold growth. Jones (1971) reported preservation of high moisture corn (72.1% DM) with a mixture of acetic, propionic and butyric acids. The preservative containing a high proportion of acetic acid appeared equal to one high in propionic acid. Seven days after treatment with VFA, there was no detectable heating of the treated corn samples but heat, mold formation and an off-smell were detected in the untreated corns. However, the presence of butyric acid in the preservative may not be desirable due to its objectionable odor.

Marion et al. (1972) observed that moist grain (70% DM) treated with 2% propionic acid, and stored in open barrels did not heat or show visible mold growth after it was ground and mixed with the ration. The ration containing untreated moist grain heated within eight hours and was moldy and fermented in four days.

Sauer (1972) conducted an experiment with yellow corn harvested at 22% moisture content (78% DM) and treated with 0.4% propionic acid or 0.8% acetic acid. He found that there was no detectable mold growth by six months at 25°C. Lower levels of acid prevented molds growth for shorter periods. Types of fungi which grew in grain treated with insufficient amounts of acids were similar to those in untreated grain, but the species diversity was not as great as in treated grains. Jones (1973) noted that there was no visible deterioration of high moisture shelled corn (66.5% DM) treated with 1.5% propionic acid, stored for 19 months on a concrete barn floor.

Propionic acid was added to moist cereals to inhibit microbial and enzymic breakdown (Furner, 1974). The mold content of corn containing initially 32% moisture (68% DM) and stored for five months was progressively reduced by adding 0.5 or 1.1% propionic acid. The amount of preservative needed depended on the initial moisture content of the cereals (ranging from 16 to 45%) and the intended length of storage. For long term preservation (more than six months) the maximum amount of propionic acid used was about 2.45% of the corn grain.

Bothast et al. (1975) harvested yellow dent corn at 27% moisture content and added ammonia, ammonium isobutyrate, isobutyric acid or propionic-acetic acids at 0.5, 1.75, 1.5 and 1.2%, respectively. Treated corn was stored in partially open wooden bins. Harvestore and barrel storage of untreated corn were included as controls. Temperature and microbiological changes were evaluated throughout six months of storage. All of the chemicals showed preservative properties for certain lengths of time. All reduced or eliminated molds, yeasts, bacteria and actinomycetes at the time of application. However, the acids controlled bacterial growth and temperature, and reduced actinomycetes better than ammonia or ammonium isobutyrate. Harvestore storage of control corn resulted in growth of bacteria and yeasts, while barrel storage enhanced proliferation of all classes of microorganisms.

Miller (1971) reported the amount of propionic acid needed for preservation was directly proportional to the moisture content of the grain. For high moisture corn at 25% moisture, 1% propionic acid was sufficient; while at 30% moisture 1.25% was necessary.

Britt and Huber (1974) compared the following preservatives for shelled corn harvested at 27% moisture: propionic acid (1.2%), 80% propionic and 20% acetic acid

(1.2%), aqua ammonia (0.54% NH_3), a commercial ammonia solution (0.63% NH_3) or no additive. Compared to the control, all additives reduced fungal counts 30 minutes after treatment, counts after 28 days for the aqua ammonia were significantly higher than for other treatments. During late storage both ammonia treatments increased in fungal colonies, but they occurred earlier and were of greater magnitude for aqua ammonia, which was added at a lower concentration than the ammonia solution. After 60 days of storage, corn treated with aqua ammonia heated to 50°C, while ammonia solution and propionic treated corn remained at ambient temperature. Mrvic and Zdravkovic (1974) confirmed that propionic acid was an effective preservative for moist maize grain. Preserved maize was stable during storage and no chemical or biological changes were observed.

Propionic acid has been studied as a preservative of high moisture soybeans by Alexander (1972). Soybeans of 18 and 22% moisture were treated and stored by adding 0.75% propionic acid. No heating was observed in the acid treated beans during the 10-week storage period. Mold counts of the treated samples were much lower than the controls. The lack of fungal activity suggests that mycotoxin production during storage was very low. Propionic acid treatment almost eliminated germination of the boybeans. Oil quality did not deteriorate after treatment with propionic acid. They concluded that propionic acid can be successfully used to preserve high moisture soybeans. Also Singh-Verma (1974) reported that propionic acid or a propionic-acetic acid mixture successfully preserved soybeans.

Anti-fungal activity of various volatile fatty acids on different grains was studied by Herting and Drury (1974). Grains used were corn, grain sorghum, wheat, oats, barley and soybeans. Acids tested were formic, acetic, propionic, butyric, isobutyric and mixture of these. Treated or untreated grains with various moisture contents were stored for four weeks or more at 30°C. All acids showed fungicidal properties, with isobutyric acid the highest. Most binary and tertiary mixtures of the acids were synergistic in action. The level of a formulation required for protection increased as the moisture content of the grain increased. Protection often lasted for periods of a year or more.

Herting et al. (1974) also investigated the effect of water dilution on the antifungal activity on grains of volatile fatty acids. The VFA's considered were acetic, propionic, butyric and isobutyric acids. All aqueus dilutions were effective fungicides. Activity of blends corresponded to the degree of dilution. Blends of acids with 50% or more water were synergistic in their activity and aqueous formulations were effective antifungal agents on barley, corn, grain sorghum, oats and wheat. Their data also indicated that the amount of acid required for protection again increased as the moisture content of the grain increased.

Christensen (1973) showed that sorghum at 19% moisture which was treated with 0.1 and 0.2% propionic acid became heavily molded in 16 days after storing at 27°C. Treatment of sorghum (16-17% moisture) with 0.2, 0.4 or 0.8% propionic acid kept it free of molds for 483 days when held at 12°C. Corn (19-20% moisture) treated with 0.5% propionic acid and stored at 25°C was free of fungi after 54 days, while a 30% moisture sample treated with 1.0% propionic acid and acetic acid (60:40) was free of molds after 140 days when held at 20°C. Samples treated with enough acid to prevent molding had zero germination.

In 1972, Arends et al. treated 27% high moisture corn (HMC) with 1.5% acetic and propionic acid (60:40). Control corn was dried to 12% moisture. Mold-spore counts of the untreated dried corn were 4.6×10^5/g, while counts of the treated dried and treated HMC were 6.0×10^2 and 23, respectively.

Goering and Gordon (1973) treated ground shelled corn (30% moisture) with sodium chloride or propionic acid at 0.2, 0.4, 0.6, 0.8 and 1.0% and sodium propionate in amounts equimolar to proprionic acid. Also formalin

(37% w/w formaldehyde) was added at 0.1, 0.2, 0.3, 0.4 and 0.5%. The results showed that sodium chloride had little value in delaying the onset of mold which developed within three to six days after storage on all NaCl treatments. Both propionic acid and formalin were effective and 0.6% of either additive was required to eliminate mold growth for the 62-day observation. Sodium propionate was 50% as effective as propionic acid or formalin.

Organic Acid-Treated Forages

Acid treatment of high moisture silage (< 20% DM) has been a widespread practice in Europe for several years, aiding in production of high quality silage without wilting. In Norway during 1968 to 1970, about 70% of all silage was treated with formic acid (Drysdale, 1968; Castle and Watson, 1970).

Excessive heating and carmelization often decrease the nutritive value and depress cattle intake of corn silage harvested at too high dry matter levels. Studies conducted at Michigan State showed that formic acid addition at ensiling increased intakes and resulted in higher milk yields of cows consuming 44% DM silage as the only forage treatment had little effect on untreated silage (Huber, 1970).

It was theorized that propionic acid might be better than formic acid in protecting high dry matter silage, because of stronger properties as a mold inhibitor and spoilage retardant (Huber, 1974).

Animal Performance

In 1970, Castle and Watson conducted an experiment with grass silages harvested in June and in September, from the same field. The silages were fed ad libitum with barley and groundnut cake to 12 Ayshire cows in a 16-week winter feeding experiment. One of the silages harvested in June and one in September had been treated with a half gallon of formic acid per ton of herbage when cut; whereas, the other two silages were untreated. Digestible organic matter in the silage DM made with and without acid was 67.4 and 63.8%, respectively, for the June silages, and 66.1 and 62.7% for the September silages. The intakes of silage and total DM were higher for the acid-treated than untreated silages. The mean daily milk yields from cows fed on the silages made with and without additive were 36.3 and 33.8 lb., respectively, for silages made in June; and 35.4 and 34.1 lb. for those made in September. The solid-not-fat contents of the milk averaged 8.60 and 8.50% respectively, from the silages with and without the additive. It was concluded that silages treated with the formic acid were superior to the untreated as feed for dairy cows.

Waldo et al. (1969) reported studies where forage (orchard grass) was harvested and preserved as hay or stored in a tower silo as unwilted silage with 0.5% formic acid added at the blower. The two forages were fed to Holstein heifers. Mean daily grains for heifers fed formic silage were 692 g versus 620 g for those fed hay. The digestibility of energy from the formic acid silage was 67.1, while that for the hay was 59.4. They observed that dairy heifers consumed a similar quality of digestible energy but made greater weight gains when fed formic acid silages than when fed hay. This implies that conservation method influences the efficiency of utilization of digestible energy.

Fisher et al. (1971) found that milk yields were significantly higher on silages made from direct cut sorghum-sudan grass treated with 0.5% formic acid compared to wilted silages stored without formic acid. The acid-treated silage had lower fiber and energy digestibilities but efficiency of energy utilization for milk production and body weight gains were greater.

Lessard et al. (1970) found DM intakes, DM digestibility and milk fat test were reduced by treating direct cut sudan-sorghum silage with formic acid, but milk yields were maintained slightly better with the treated than untreated silage. Wilted, untreated silage resulted in performance similar to the direct cut, formic acid-treated silage.

Candlish et al. (1973) studied the effects of acid treatment of chopped barley when ensiled at 35-40% DM. Barley was harvested, chopped and treated with the following at time of ensiling: no acids, 0.41% formic acid, 0.43% formic acid-formaldehyde mixture, 0.43% formic acid-acetic acid mixture, 0.34% of an 80% propionic, 20% acetic acid mixture. The silages were fed to sixty growing beef calves during 154 days to study intakes and weight gains and to eight sheep during 16 weeks to determine digestibility. Acid treatment of barley tended to reduce soluble nitrogen of the silages. Neither feed intake nor digestibilities of dry matter, energy and organic matter were different among treatments. Treatment of silage with formic acid-formaldehyde resulted in reduced protein digestibility compared to control and the propionic-acetic treated silages. All silages were readily eaten by beef and sheep and no advantage to adding acids was noted.

Bolsen et al. (1973) added aureomycin, sodium hydroxide, ammonium isobutyrate and a mixture of acetic and propionic acids to forage sorghum. They concluded that the feeding value of forage sorghum silage was not significantly improved by any of the additives.

Waldo et al. (1969) fed either unwilted alfalfa silage preserved with 0.5% formic acid or untreated silage as the sole ration for 63 days to twenty Holstein heifers. Results showed that mean daily weight gains were increased by formic treatment (817 vs. 429 g). Mean daily intakes (kcal DE/kg$^{3/4}$) were also higher (300 vs. 228). In 1970, Waldo et al. fed thirty Holstein heifers either direct cut (25% DM) alfalfa silage preserved with 0.5% formic acid or an untreated, wilted (35% DM) silage as the sole ration for 74 days. The results again showed an improvement in mean daily gains (763 vs. 653 g) and intakes (2.58 vs. 2.66% of bodyweight) from acid addition.

Formaldehyde (Waldo et al., 1973) and paraformaldehyde (Waldo and Keys, 1974; Waldo et al., 1975) were equal to formic acid in improving feed intakes, gain and feed conversion of in heifers fed direct-cut grass silages. In fact, treated silages produced over twice as much as gain as control silage.

Derbyshire and Gordon (1969) studied the utilization of formic acid silages by milk cows. First cutting orchardgrass forage was wilted (35% DM) and treated with 0.8% or no formic acid. A third treatment was direct cut material (18% DM) treated with 0.5% formic acid, silages were fed ad libitum to 18 milking cows. Fat corrected milk was not different between treatments, but silage dry matter consumption, as percent body weight, was significantly greater for wilted silage treated with acid than for direct cut or untreated, wilted silage.

In an additional study by Derbyshire and Gordon (1970), first cutting orchard grass was wilted (47% DM) and treated with or without 0.5% formic acid, or unwilted (20% DM) and treated with 0.4% formic. Silages were fed ad libitum to 18 milking cows. Addition of formic acid to wilted or unwilted forages resulted in increased dry matter and energy intakes and higher milk production. Similar results were also found by Derbyshire et al. (1971) by treating wilted (36% DM) orchard grass with or without 1.1% formic acid.

Norwegian experiments demonstrated that formic acid treated silage was equal to artificially dried grass and better than untreated silage or hay when fed in mixed rations for milk production and growth (Saue and Breirem, 1969).

Huber (1970) studied formic acid treatment of urea corn silage harvested at different maturities. Corn plants were treated at ensiling with 1.75% kg urea per 100 kg DM. The two factors studied were maturity at harvest (28 vs. 44% DM) and formic acid addition (0 vs. 1.6 kg/100 kg DM). Silages were fed ad libitum and a 13% crude protein concentrate was fed at 1 kg/3 kg milk. The formic acid treatment resulted in an 8% improvement ($P < 0.05$) in milk yields of cows fed 44% DM silage. Dry matter intakes of mature corn silage increased 11% due to acid treatment and accounted for the higher milk yields. It was demonstrated that through acidification with formic acid, high dry matter corn silage can be treated with urea without depressing animal performance.

Barker et al. (1973) treated wilted or unwilted alfalfa-bromegrass with formic acid or a formic acid-formalin mixture. The silages were fed to dairy cows and crossbred beef bulls. Silage DM intakes, solids corrected milk yields, body weight gains and carcass composition were not significantly affected by treatment.

Sleiman (1972) treated rye with 0.4% formic acid and ensiled in conventional, upright silos. Milk production and persistency and milk composition were not different for cows fed formic rye, control rye or alfalfa haylage. Although forage intakes were not significantly different, slightly higher consumption was observed on the formic treated rye compared to control.

Preservative Effects

Poor quality silages, characterized by low amount lactic acid, high butyric and acetic acids, high ammoniacal nitrogen and a pH of 4.8 or above result in high dry matter losses and unsatisfactory nutrient preservation (Barnet and Duncan, 1954; Langston et al., 1958). Better packing and sealing to exclude air improves silage quality, but inhibiting or slowing down secondary fermentation with organic acids has also been studied.

Organic acids, especially propionic, has the ability to inhibit mold growth in forages. Daniel et al.

(1970) demonstrated a reduction in temperature rise in ensiled forage treated with propionic acid. These German workers ensiled grass with and without propionic acid and observed decreased dry matter losses with the propionic silage. Carbon dioxide production was lower and temperature rise was reduced with the propionic compared to control silage. Gross (1969) also observed a reduction in ensiling losses when organic acids were added as preservatives to silage.

In 1969, Carpintero et al. treated lucerne with 0.85% formic acid and found this level was sufficient to achieve an immediate pH fall to 4.2. Acetic acid production and chlostridial activities were inhibited by formic acid.

Lopez et al. (1970) showed a greater pH value for corn silage harvested at low (25%) and high (52%) compared to medium (30%) dry matter. Lactic acid declined significantly with advancing maturity, and total organic acids decreased from 11.94% at 25% DM to 3.14% at 52% DM.

Waldo et al. (1969) reported that silages treated with formic acid were lower in pH, butyric acid, acetic acid and ammoniacal nitrogen and higher in lactic acid than untreated silages. Wilkins and Wilson (1960) treated grass with formic silage acid at the rate of one half gallon/ton and found an immediate drop in pH. Lactic acid in the treated silage was also low.

Huber et al. (1972) treated 25% DM corn silage with formic, acetic, propionic and lactic acids at 0.13 to 0.85% and ensiled in 220 l experimental silos. Acetic acid levels in resulting silages were higher than control when 0.17, 0.34 and 0.57% formic acid was added, but 50% of the control at 0.85%. Acetic acid treatment increased silage acetate when 0.68 and 0.85% was added; whereas propionic and lactic acid additions decreased acetate to about 50% of the controls. Lactic acid production was depressed by formic acid, unchanged by acetic and increased at higher levels of propionic and lactic acid.

Wilson and Wilkins (1973) studied the effect of formic acid as a silage additive. They ensiled cockfoot and perennial ryegrass in test tube silos after three treatments; unwilted without additive, unwilted after addition of 0.23% formic acid and wilted (30% DM) without additive. The addition of formic acid resulted in reduction in pH of the ensiled material.

Barker et al. (1973) compared the effect of formic acid or formic acid-formalin mixture as silage additives. They ensiled alfalfa-bromegrass mixture and treated with: wilted--nothing, direct cut--85% formic acid at 0.5%, and direct cut--formic-formalin mixture at 0.5%. The results showed that wilted silage was significantly higher in pH and soluble N than the direct cut silages which had been treated with either additive. The formic-formalin treatment produced significantly more total acids, butyric acid and propionic acid than the wilted or direct cut silage treated with formic acid.

Candlish and McKirdy (1973) treated chopped corn plants prior to ensiling with formic acid, propionic acid, propionic:acetic acid, or Hay Savor at 0.75% or 1.5% of the fresh weight. They observed that formic acid addition lowered the pH to a greater extent than the other acids. Treatments did not severely alter lactic acid production.

Goering and Gordon (1973) evaluated the effectiveness of several chemicals as mold inhibitors for forages. They treated a wilted grass-clover mixture (35-50% moisture) ensiled in small snow-fence stacks with propionic acid, propionic:acetic acid, and ammonium isobutyrate. Ammonium isobutyrate and propionic:acetic acid produced less temperature rise than propionic acid which showed lower heat production than the control stacks. Ammonium isobutyrate was the most effective in preventing mold growth and forage shrinkage.

Sleiman (1972) treated chopped rye with nothing, 1% formic acid or a mixture of 60 acetic:40 propionic and placed the uncompacted forage in open experimental silos (220 l). Silage temperatures, recorded daily for four weeks, averaged: 47.8, 34.8 and 35.7 C for the respective treatments. Spoilage of silage and pH were also higher for control than acetic-propionic and formic. At 3, 4 and 9 days after storage, mold was detected in the respective treatments.

In another study, Sleiman (1972) treated whole chopped corn with various mixtures of formic, acetic and propionic acids. All acids reduced temperature increases in silos with propionic most effective. Days until molding were lowest for control and highest for propionic. Dry matter discarded because of spoilage was lowest for the acetic plus propionic and highest for acetic treatments. In a comparison trial, it was shown that propionic addition resulted in less top spoilage of upright and bunker silos than the other acids, but all acid treatments were superior to controls. It was concluded that of those treatments compared, the most effective retardant of spoilage for unprotected forage was propionic acid added at a minimum of 1% of the fresh weight.

Britt (1973) treated whole chopped corn (35% DM) with either propionic, formic, propionic plus formic or propionic plus acetic acids at 0, 0.5, 1.0 or 2.0% of the fresh weight. All acid treatments reduced the average temperatures with propionic more effective than formic. Lactic production was totally inhibited by all acids at the 2% addition but at 1.0 and 0.5%, formic silages were lower in lactic acid than those treated with propionic. Days until complete spoilage was increased by acid treatments with propionic more effective than formic. All acids significantly decreased fungal colonies within two days after addition. During refermentation all treatments at the 1% level or lower exhibited a rapid increase in number of colonies, however, propionic-treated silages showed a slower increase in fungi than those treated with formic. The proportion of yeast was greatest at initiation of fermentation and decreased at day 40. During refermentation, yeast growth again started. *Geotrichum* were maximized at day 40 of fermentation but plateaued thereafter. *Aspergillus* was significantly higher at days 40 of fermentation and 36 of refermentation than at other times. No significant amounts of *Penicillium* were detected at any date.

Significance of Fungal Contamination of Feeds

Fungi are common throughout nature; however, the important factors that influence mold development are: (1) degree of aeration, (2) moisture content, (3) temperature, and (4) length of storage. Christensen and Kaufman (1969) indicated that molds will develop in stored grain when the grain moisture content exceeds 18-20% and ambient temperatures are sufficiently high. The most rapid growth of molds will occur at 30 to 32 C. It has been suggested that at least 1% of the world's grain supply was lost due to molding in the late 1940s (Warden, 1969). The value of grain losses due to fungal contamination in the late 1960s in the United States alone exceeded 50 million dollars, with corn and wheat being particularly susceptible. 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).

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

Fungi of greatest concern include *Aspergillus flavus*, *Fusarium* and *Penicillium* (Christensen and Kaufman, 1969). Jones et al. (1974) stated that a 3-5% invasion of grain by *Aspergillus flavus* could result in a potentially toxic feed. The organism can be found in corn when moisture content exceeds 18-20% and the temperature is sufficiently high for the growth. If fed to milking cows, some of the toxins can be secreted in milk. *Fusarium* is a common cause of corn blight and decay and is not uncommon in cribbed corn in the Midwestern United States. *Penicillium* has been observed in moist corn (Jones et al., 1974).

Tuite and Christensen (1955) found *Fusarium* was common in seeds prior to harvest while *Aspergillus* and *Penicillium* appeared after harvest. Christensen (1949) found that *Fusarium* was the common field fungi, while *Aspergillus* and *Penicillium* were the predominating storage fungi growing best at about 30 C. Christensen and Gordon (1948) observed that mold caused the temperature of grains to rise within a few degrees of the maximum that the molds could endure.

In 1963, Gregory et al. harvested wet hay (60% DM) and found that actinomycetes and bacteria grew during the first heating with increases in acidity. The pH rose to 7.0 or above when fungi grew.

Summary of Literature Review

After reviewing the literature it becomes apparent that addition of organic acids, such as formic, acetic, propionic, butyric or a mixture of these can aid in better preservation of grains and forages. There has been much interest in their use for high moisture grains for retarding spoilage during storage, but information on forages (particularly corn silage) is limited.

When dry silages undergo excessive heating, molding or carmelization, there is often a decrease in their nutrient value and a depression in animal performance. It was theorized that organic acid addition might protect high dry matter corn silage from these detrimental effects.

Even though formic acid has been shown beneficial for treating direct cut, high moisture silage, propionic acid should be more effective in retarding spoilage of high dry matter silage. Therefore, further research on preservation of high dry matter corn silage treated with propionic and formic acids is needed.

MATERIAL AND METHODS

This study covers four experiments with hybrid corn harvested as silage from 35 to 45% dry matter treated with various organic acids on Michigan State University dairy farms. The silages were fed lactating dairy cows as the principal forage and concentrate was fed according to milk production.

1970-1971 Experiment (Experiment 1)

This was a study of organic acid treatment of urea-silages for lactating cows. The objectives of this study were to determine which acid (formic, acetic or propionic) added to corn silage at ensiling time is most effective in its nutritive value for lactating cows and to compare two levels of formic and propionic acids.

Silage Treatments

Silage containing 35-40% dry matter was treated at ensiling with the following additives:

(1) control plus urea,

(2) formic acid (0.6%),

(3) formic acid (0.6%) plus urea,

(4) formic acid)0.3%) plus urea,

(5) propionic acid (0.3%) plus urea,

(6) propionic acid (0.3%) plus urea,

(7) acetic acid (0.6%) plus urea,

(8) formic acid (0.3%) plus propionic acid (0.3%) plus urea.

Urea was added at 0.6% (5.4 kg/ton). During emptying the silages were sampled three times weekly. Weekly composite samples were frozen for subsequent analyses. Dry matter, lactic and pH were determined as described in Experiment 4.

Animal Trials

Cows averaging about 25 kg milk daily were alloted to the treatments in a randomized block design. Groups were alloted according to milk yields during a 3-week preliminary period and were balanced for stage of lactation, age and breeding groups. There were seven cows per group and duration of treatment was six weeks. During standardization the cows were fed corn silage ad libitum, haylage at 4.5 kg/day and concentrate (containing urea) at 1 kg/3 kg of milk. During treatment cows were fed the treated corn silages ad libitum, haylage at 4.5 kg/day and concentrate formulated to provide isonitrogenous rations at 1 kg/3 kg milk. Body weights of cows were taken twice for two consecutive days one week after the cows were on treatment and twice during the final week of treatment. Milk was sampled twice during standardization and at biweekly intervals during treatment. Milk was analyzed for fat, protein and for total solids as described for Experiment 4.

1971-1972 Experiment (Experiment 2)

Formic and propionic acid additions to high dry matter corn silage treated with and without urea were studied. The objectives of this study were to determine the effect of organic acids on preservation and the nutritive value of mature corn silage (in excess of 45% dry matter) fed high producing dairy cows, to compare propionic and formic acids as preservatives agents and also to determine the effect of organic acids on the nutritive value of mature corn silage treated with urea.

Silage Treatments

Mature corn silage was ensiled in six (3 x 13 m) silos at 44-46% and treated at the time of ensiling with the following:

Silo 3 - A - nothing

Silo 4 - B - 0.5% formic acid

Silo 5 - C - 0.5% propionic acid

Silo 6 - D - 0.6% urea

Silo 7 - E - 0.6% urea plus 0.5% formic acid

Silo 8 - D - 0.6% urea plus 0.5% propionic acid.

During emptying silages were sampled three times weekly.

Weekly composite samples were frozen and subsequently analyzed for dry matter and lactic acid as described for Experiment 4.

Animal Trials

Forty two high producing dairy cows, averaging not less than 22 kg milk daily were alloted to six treatment groups (balanced for milk production during a 21-day standardization period, during which all cows were fed 22 kg/day of control corn silage, 4.5 kg haylage and a urea-containing concentrate at 1 kg/3 kg of milk). Then the cows were fed one of the silages as the only forage for ten weeks. Concentrate was fed according to milk production (1 kg/3 kg milk). Daily milk yields and feed intake were taken during standardization and treatment periods. Body weights were determined and milk was sampled similarly to the Experiment 1.

1972-1973 Experiment (Experiment 3)

The addition of water and two levels of propionic acid were compared in high dry matter corn silage. The objectives of this study were to confirm the beneficial effect of propionic acid as a preservative of high dry matter corn silage, to ascertain the minimum effective level of propionic acid under field conditions and to compare water and propionic acid effects on preservation and animal performance.

<u>Silage Treatments</u>

Four upright silos at the MSU Dairy Research Center were filled with mature corn silage (44% DM) and treated at the time of ensiling with the following:

Silo 9 - water (10%)

Silo 10 - 0.3% propionic acid

Silo 11 - 0.6% propionic acid

Silo 12 - Nothing.

During emptying the silages were sampled three times weekly. Weekly composite samples were frozen for dry matter analyses as described Experiment 4. Temperatures were monitored in the silos during the five-week feeding period at depths of 15 and 45 cm. Also, 40 kg lots of the different silages were removed from the silos and placed in open 220 l barrels. Temperatures of silages in the open barrels were monitored daily for seven days after removal.

<u>Animal Trials</u>

Thirty two lactating cows, averaging not less than 22.5 kg milk/day, were fed the normal herd ration for three weeks which consisted of 18 kg/day of control corn silage, haylage ad libitum and herd concentrate at 1 kg/ 3 kg of milk. Cows were alloted to treatment groups on the basis of standardization production and experimental rations were fed for five weeks. Milk yields, feed intakes, and body weights were determined and milk was sampled as in the two previous experiments.

Present Experiment (Experiment 4)

Ensiling Techniques and Temperature Measurements

Whole corn plant was field chopped on September 25 or October 11, 1974, transported to the Michigan State University Dairy Cattle Research Center in self unloading wagons and weighed prior to ensiling in four vertical, concrete stave silos (3 x 13 m). The fresh material, containing 35% or 45% dry matter, was ensiled with and without the addition of 1.7% propionic acid (on a dry matter basis). On each date, two silos were filled simultaneously from alternate wagon loads until each silo contained approximately 15,000 kg of dry matter.

At the time of ensiling, samples of the green chopped corn were taken from each load prior to entering the blower. Composites for every load were placed in a plastic bag and frozen at -20 C for future analysis.

A plastic container (30 l) equipped with faucet connected to a plastic tube was used for application of propionic acid.[1] For each load a weighed amount of propionic acid was dribbled onto the plant material as it

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[1]Furnished through courtesy of Union Carbide Corporation, 270 Park Avenue, New York, N.Y.

entered the blower from the unloading wagon. The flow of propionic acid was controlled by a clamp on the plastic tube which was adjusted during the emptying of each load depending on the flow rate of plant material and level of acid in the container.

Three thermocouples were placed in the centers of each silo at heights of 2.5, 5.0 and 7.5 m (after the leveling and tramping). Exteriorized leads from the thermocouples were connected to a portable potentiometer[1] for monitoring temperature during fermentation. This equipment was also used to measure silage temperatures (at 10, 20 and 30 cm depth) three times per week during the ten week feeding period.

Animal Trials

Eight lactating dairy cows producing over 22.5 kg milk/day were assigned to each of the four corn silage treatments in a randomized block design. Blocks were based on milk production during a 14 day standardization period, in which control silage was fed ad libitum and an 18% crude protein concentrate was fed at 1 kg/3 kg milk. Milk weights and total feed intakes were recorded during standardization. Composite (AM and PM) milk samples were taken from each cow at biweekly intervals. Samples of

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[1]Brown Portable Potentiometer Model 126 W2, Minneapolis, Honeywell Regulatory Co., Philadelphia, PA.

silages were taken on Mondays, Wednesdays and Fridays of each week, composited weekly and frozen at -20 C for future analysis. Bodyweights of the cows were taken for two consecutive days 7 days after the beginning and at the end of the experimental period.

Refermentation Trial

During the feeding trial, 68 kg portions of corn silage were removed in duplicate from each silo and placed in unsealed 200 l steel barrels (lined with polyethylene sheeting) to test the effectiveness of the acid in preventing spoilage when silages were exposed to air. Temperatures in barrels were monitored by using the portable potentiometer three times per week for 30 days. Also, samples were taken on days 1, 7, 14, 21 and 28, and determined for dry matter and number of fungi.

Chemical Analyses

Dry matter of corn silage samples was determined in duplicate by placing approximately 40 g of material in a forced-air oven at 90 C for 24 hours. Total nitrogen as determined by macro Kjeldahl. Silages were prepared for pH, lactic acid, volatile fatty acids (VFAs) and number of fungi by homogenizing 20 g of silage and 180 l of distilled water in a Sorvall Omni-Mixer[1] for three minutes with the cup immersed in ice. The homogenized

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[1]Ivann Sorvall, Inc., Newton, Conn.

material was used for measuring the pH with a Sargent pH meter[1] and for plating to estimate fungal population. Extracts from the material were strained through two layers of cheesecloth, deproteinized with sulfosalicylic acid (15 ml of the filtrate was added to 1.5 ml of sulfosalicylic acid), and centrifuged[2] at 15,000 rpm for ten minutes. The supernatant was removed and frozen at -20 C until analyzed for lactic acid and VFAs.

Colorimetric procedures of Barker and Summerson (1941) were used to determine lactic acid. Volatile fatty acids were determined by injecting 3 ul of the deproteinized samples into a Hewlett-Packard F and M gas chromatograph[3] using a glass column packed with chromosorb 101 (80/100 mesh).[4] The injection port temperature was set at 340 C, the column temperature at 285 C, and the flame detector at 320 C. Nitrogen was used as the carrier gas and flow rate was 30-40 ml per minute. Sample VFA concentrations were calculated by comparing peak heights with a standard solution made with known weights of analytical grade acids in a stock solution and diluted until a concentration comparable to the samples was reached.

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[1]E. H. Sargent and Co., Chicago, Ill.

[2]Sorvall-Superspeed, RC_2-B.

[3]Hewlett-Packard, F and M Scientific Co., Model 402.

[4]Johns-Manville, Celite Div., Denver, Colorado.

Concentrates were determined for dry matter and nitrogen as described for silages.

Fungal population was determined by transferring (with a sterile pipette) 1 ml aliquots of the freshly homogenized silage sample into a dilution bottle filled with 99 ml of sterile, distilled water. The sample was thoroughly mixed and serially diluted until the proper concentrations of fungal spores and mycelia were reached. Either 1 or 0.1 ml of the diluted sample was then dispensed into sterile plastic petri dishes. Enough potato dextrose agar[1] (with 100 mg per liter of novobiocin[2] which had been melted and cooled to 45 C) was then added to cover the bottom of the petri dish and swirled to insure complete mixing of the agar and silage homogenate. After cooling, the plates were sealed and placed in the dark at 20 C for 5-7 days at which time the plates were removed and colonies were counted using a colony counter.[3]

Milk Analysis

Total solids were determined by drying 2 ml of milk for two hours in a forced-air oven at 90-100 C. Butter fat was determined by the Babcock method. A portion of each sample was placed in plastic vial and frozen at -20 C,

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[1]BBL, Cockeysville, Maryland.

[2]Upjohn Co., Kalamazoo, Michigan.

[3]Fisher Scientific Co., New York, N.Y.

and at the end of the trial it was analyzed for nitrogen by micro Kjeldahl.

RESULTS

Animal Performance

Experiment 1

None of the acid additions had a significant effect on animal responses. Daily intakes of cows fed medium dry matter (35-39%) corn silages treated with different organic acids are shown in Table 1. There were no significant differences in silages and total dry matter intakes due to treatment by any of the acids. Highest silage consumptions were noted for the high propionic treatment and lowest for low propionic, but these differences were probably due to chance.

As shown in Table 2, milk persistencies were high for all groups (> 90%), but were lowest for the group fed silage treated with only formic acid.

This agrees with fattening cattle (Henderson et al., 1971) who also showed a slight depression in body weight gains when formic acid (0.6%) was added to medium dry matter corn silage. Some improvement in both milk yields and fat cattle gains (Henderson et al., 1971) were noted by urea addition to formic acid silages. The increase in body weight for all groups receiving acid-treated silages

Table 1.--Influence of organic acids and urea addition to medium dry matter corn silage (35-39%) on dry matter intakes of lactating cows (Experiment 1).[a]

Silage Treatment	Corn Silage DM Intake kg/day	Corn Silage DM Intake % BW[b]	Total DM Intake % BW[b]
Control + U[c]	8.13	1.23	2.82
Formic (0.6%)	8.35	1.25	2.63
Formic (0.6%) + U	7.72	1.21	2.81
Formic (0.3%) + U	8.31	1.26	2.74
Propionic 0.6%) + U	9.35	1.40	2.83
Propionic (0.3%) + U	7.31	1.20	2.81
Acetic (0.6%) + U	7.35	1.27	2.89
Formic (0.3%) + Prop. (0.3%) + U	8.76	1.30	2.79

[a]Seven cows/treatment for six weeks.

[b]None of the differences are significant ($P < 0.05$).

[c]Urea addition: 0.6%.

Table 2.--Influence of organic acids and urea additions to medium dry matter corn silage (35-39%) on milk yields and body weight gains of lactating cows (Experiment 1).[a]

Silage Treatments	Milk Yields Stand. kg/day	Milk Yields Treat. kg/day	Milk Yields Change kg/day[b]	Milk Yields Persist.[b]	Body Weight Gains kg/day[c]
Control + U[d]	26.20	25.29	-0.91	96.53	-0.03
Formic (0.6%)	25.02	22.38	-2.64	89.45	+0.27
Formic (0.6%) + U	26.20	25.06	-0.14	95.65	+0.25
Formic (0.3%) + U	25.70	23.47	-2.23	91.32	+0.28
Propionic (0.6%) + U	24.79	22.83	-1.96	92.09	+0.18
Propionic (0.3%) + U	25.47	24.74	-0.73	97.13	+0.58
Acetic (0.6%) + U	25.15	23.84	-1.31	94.79	+0.36
Formic (0.3%) + Prop. (0.3%) + U	25.79	23.93	-1.86	92.79	+0.33
Std. error			2.03		0.33

[a]Seven cows/treatment for six weeks. [b]None of the differences are significant ($P < 0.05$).

[c]Control significant lower than all acids ($P < 0.05$). [d]Urea addition: 0.6%.

Persistency: (treatment/stand.) x 100.

averaged 0.32 kg/day while a slight decrease in weight was noted for the group on the control silage. The overall effect of the acid on weight gains of the lactating cows was significant ($P < 0.05$), as shown in Table 2.

Similar to data for feed intakes and milk yields, acid treatment of silages had no effect on changes in milk composition, as shown in Table 3.

<u>Experiment 2</u>

Daily intakes and body weight gains of cows fed high dry matter corn silage (44%) treated with different organic acids and .rea are shown in Table 4. Silage intakes were higher ($P < 0.1$) for cows fed the propionic treated silages than for other groups. However, due to the large variation between individuals, differences only approached significance ($P < 0.1$). A similar trend was noted for total intake. Average daily gains did not differ between treatments and all groups gained weight during treatment.

The control groups produced less ($P < 0.05$) milk than those fed propionic treated silage with formic groups intermediate (Table 5).

Urea had no significant effect on production but tended to increase yields on control silage and decrease them when propionic was added.

Table 3.--Influence of organic acids and urea addition to medium dry matter corn silage (35-39%) on milk composition of lactating cows (Experiment 1).[a]

Silage Treatment	Fat		Protein		Total Solids	
	%	% change[b]	%	% change[b]	%	% change[b]
Control + U[c]	3.20	-0.09	3.14	+0.11	11.99	-0.06
Formic (0.6%)	3.45	-0.15	3.25	+0.09	12.49	-0.09
Formic (0.6%) + U	3.06	-0.11	3.18	+0.05	12.17	-0.14
Formic (0.3%) + U	3.30	-0.10	3.15	+0.09	12.34	+0.09
Propionic (0.6%) + U	3.35	-0.23	3.15	+0.02	12.41	-0.14
Propionic (0.3%) + U	3.54	-0.07	3.23	+0.05	12.68	-0.09
Acetic (0.6%) + U	3.33	-0.08	3.05	-0.05	12.34	+0.13
Formic (0.3%) + Prop. (0.3%) + U	3.37	-0.28	3.18	+0.02	12.28	-0.16

[a]Seven cows/treatment for six weeks.

[b]None of the treatment differences are significant ($P < 0.05$).

[c]Urea addition: 0.6%.

Table 4.--Influence of organic acids and urea addition to high dry matter corn silage (44-46%) on dry matter intakes and body weight gains of lactating cows (Experiment 2).[2]

Silage DM	Silage Treatment[b]					
	Contr.	Contr. + U	Formic	Form. + U	Prop.	Prop. + U
	44.1	46.0	43.7	41.0	45.6	45.1
Corn silage DM intake[c]						
(kg/day)	8.49	10.97	10.58	10.90	11.76	11.12
(% BW)	1.56	1.71	1.74	1.68	1.87	1.74
(g/kg $BW^{3/4}$)	77.70	85.90	86.40	84.30	93.50	87.10
Total DM intake[c]						
(kg/day)	16.30	17.84	17.16	17.89	18.93	18.21
(% BW)	2.63	2.79	2.84	2.79	3.01	2.83
(g/kg $BW^{3/4}$)	131.00	140.30	141.10	140.10	150.70	142.20
Body weight gains						
(kg/day)[d]	0.59	0.35	0.40	0.44	0.43	0.49

[a]Seven cows/treatment for ten weeks.

[b]Acid added at 0.5% and urea at 0.6%.

[c]Differences in all intake measures between the control and propionic silages approached significance ($P < 0.10$).

[d]None of the differences were significant ($P < 0.1$).

Table 5.--Influence of organic acids and urea addition to high dry matter corn silage (44-46%) on milk yields of lactating cows (Experiment 2).[a]

	Silage Treatment[b]					
	Control	Contr. + U	Formic	Form. + U	Propionic	Prop. + U
Silage DM	44.1	46.0	43.7	41.0	45.6	45.1
Standard (kg/day)	24.56	26.20	24.88	26.06	26.06	25.74
Treatment (kg/day)	21.57	23.84	22.70	24.15	25.70	23.84
Change (kg/day)	-2.99	-2.36	-2.18	-1.91	-0.36	-1.91
Persistency[c]	87.83[d]	90.99[d]	91.24[d]	92.67[de]	98.62[e]	92.62[de]

[a]Seven cows/treatment for ten weeks.

[b]Acid added at 0.5% and urea at 0.6%.

[c]Statistical comparisons based on this value. Acid effect, significant at $P < 0.05$.

[d]Urea effect was not significant.

[de]Individual values not sharing a common superscript are significantly different ($P < 0.05$).

Persistency: (treatment/stand) x 100.

Experiment 3

As shown in Table 6, silage dry matter intakes were again stimulated by propionic acid addition. Cows fed corn silage (44% DM) treated with 0.6% propionic acid consumed slightly more than those fed 0.3%. Cows fed control silages (with and without added water) were lower in dry matter intakes than those fed silages treated with 0.3 and 0.6% propionic acid ($P < 0.05$). The superiority of propionic acid treatment to water addition is obvious.

Total dry matter intakes were not significantly different between treatments. However, total intakes of cows fed silages treated with 0.3 and 0.6% propionic acid were slightly higher than controls.

Body weight gains did not differ between treatments, and averaged 0.81, 1.06, 0.85 and 0.74 kg/day, respectively, for control, control + water, 0.3% propionic and 0.6% propionic.

Cows fed the 0.6% propionic acid silage were most persistent in maintaining milk yields, but they were only slightly higher than controls, as shown in Table 7.

Experiment 4

Average daily intake of silage and total dry matter, and average daily gains are shown in Table 8. Silage dry matter intake were not significantly different among groups. However, cows receiving propionic treated

Table 6.--Influence of propionic acid and water additions to high dry matter corn silage (44%) on dry matter intakes and body weight gains of lactating cows (Experiment 3).[a]

	Silage Treatment			
	Control	Control + water	0.3% prop.	0.6% prop.
Corn silage DM intake[b]				
(kg/day)	9.29	8.99	10.61	11.10
(% BW)	1.55	1.43	1.65	1.71
(g/kg $BW^{3/4}$)	76.50	71.70	83.00	85.90
Total DM intake				
(kg/day)	16.77	16.33	17.88	18.61
(% BW)	2.80	2.61	2.81	2.84
(g/kg $BW^{3/4}$)	138.50	130.40	141.00	143.30
Body weight gain				
(kg/day)	0.81	1.06	0.85	0.74

[a]Eight cows/treatment for five weeks.

[b]Control and water lower than 0.3 and 0.6% propionic acid ($P < 0.05$).

Table 7.--Influence of propionic acid and water additions to high dry matter corn silage (44%) on milk yields of lactating cows (Experiment 3).[a]

	Silage Treatment			
	Control	Control + water	0.3% prop.	0.6% prop.
Standardization (kg/day)	25.11	24.47	26.38	24.11
Treatment (kg/day)	21.52	20.16	21.84	20.93
Change (kg/day)	-3.59	-4.31	-4.54	-3.18
Persistency[b]	85.70	82.38	82.79	86.81

[a]Eight cows/treatment for five weeks.

[b]Persistency: (treatment/stand) x 100. None of the differences were significant ($P < 0.1$).

Table 8.--Influence of propionic acid addition to medium and high dry matter corn silage (35 and 45%) on dry matter intake and body weight gains of lactating cows (Experiment 4).[a]

Silage DM	Silage Treatment[b]				S.E.
	Control HDM	Propionic HDM	Control MDM	Propionic MDM	
	44.81	43.63	35.54	36.12	
Corn silage DM intake[c]					
(kg/day)	11.08	11.89	10.71	11.40	1.74
(% BW)	1.73	1.86	1.74	1.87	0.10
(g/kg $BW^{3/4}$)	86.80	93.30	86.60	89.30	4.51
Total DM intake[c]					
(kg/day)	17.48	18.34	16.98	17.43	2.10
(% BW)	2.74	2.87	2.78	2.90	0.13
(g/kg $BW^{3/4}$)	137.80	144.20	137.80	138.50	4.79
Body weight gain (kg/day)[c]	0.59	0.59	0.69	0.68	

[a]Eight cows/treatment for ten weeks.

[b]Propionic addition: 0.6%.

[c]None of the differences were significant ($P < 0.1$).

HDM = high dry matter; MDM = medium dry matter.

silage (both at medium and high dry matter) consumed slightly more than corresponding controls.

Intakes of silage dry matter (kg/day) were slightly greater for high than medium dry matter groups (11.08 vs. 10.71), but the same when based on % of BW (1.73 vs. 1.74). A similar trend was observed for total dry matter intakes.

All groups gained weight during the experiment and weight changes were not significantly affected by treatment. However, gains of cows fed 35% dry matter silage were slightly higher than those fed the 45%.

As shown in Table 9, milk yields again favored groups fed propionic treated silages, even though the differences were not significant.

Milk composition was not significantly different among the groups, as shown in Table 10. Percent of almost all milk constituents were slightly higher during treatment than during standardization. Because

Pooled Data

Because intakes and milk persistencies were consistently higher for the three experiments (Experiment 2, 3 and 4) where propionic acid was added to high dry matter corn silage (43-46%) and no year x treatment interaction was detectable, pooling of the data for statistical analyses was possible. For the three experiments, propionic acid treatment increased silage dry matter intakes 12%, total intakes 6% and milk persistency 5% (Table 11).

Table 9.--Influence of propionic acid addition to medium and high dry matter corn silage (35 and 45%) on milk yields of lactating cows (Experiment 4).[a]

Silage DM	Silage Treatment[b]				S.E.
	Control HDM 44.81	Propionic HDM 43.63	Control MDM 35.54	Propionic MDM 36.12	
Standardization (kg/day)	21.81	21.96	21.31	21.12	
Treatment (kg/day)	19.95	20.75	20.27	20.27	
Change (kg/day)	-1.86	-1.21	-1.04	-0.85	
Persistency[c]	91.50	94.50	95.10	96.00	3.07

[a]Eight cows/treatment for ten weeks.

[b]Propionic addition: 0.6%.

[c]None of the differences was significant ($P < 0.1$).

Persistency: (treatment/stand) x 100.

Table 10.--Influence of propionic acid addition to medium and high dry matter corn silage (35 and 45%) on milk composition of lactating cows (Experiment 4).[a]

Silage DM	Silage Treatment[b]			
	Control HDM 44.81	Propionic HDM 43.63	Control MDM 35.54	Propionic MDM 36.12
Fat (%)	4.16	3.80	3.62	3.93
(% change)[c]	+0.38	+0.08	-0.08	+0.17
Protein (%)	3.44	3.33	3.40	3.43
(% change)[c]	+0.12	+0.09	+0.41	+0.32
Total solids (%)	13.29	12.74	12.81	13.03
(% change)[c]	+0.71	0.21	+0.17	+0.20

[a]Eight cows/treatment for ten weeks.

[b]Propionic addition: 0.6%.

[c]None of the differences were significant ($P < 0.1$).

Table 11.--Influence of propionic acid addition to high dry matter corn silage (44-46%) performance of lactating cows for the three experiments.[a]

Silage Treatment	Dry Matter Intake (% BW)		Milk Yield Persistency
	Silage	Total	%
Control	1.62	2.73	88.5
0.6% prop. acid[b]	1.81**	2.90*	92.9*
Difference (%)	12	6	5

[a]Means for 23 cows.

[b]Significantly higher: $^{**}P < 0.01$; $^{*}P < 0.05$.

Differences between cows fed control and propionic treated silages were all significant.

Preservative Effects

Experiment 1

As shown in Table 12, the lowest pH values were shown for treatment with formic acid alone, but urea addition to the formic treated silage resulted in the highest and most variable pH values. Formic acid greatly depressed lactic acid production during ensiling. Propionic and acetic had a less depressing effect than formic on silage lactic acid. Addition of 0.6 and 0.3% propionic acid to 35-39% DM corn silage resulted in slightly lower lactic acid than in control silage, but the depression was not as great as for formic acid. Differences in lactate

Table 12.--Influence of organic acids and urea additions to medium dry matter corn silage (35-39%) on pH and lactic acid production (Experiment 1).

Silage Treatment	Silage DM %	pH	Lactic acid % of DM
Control + U[a]	37.6	4.38	5.37
Formic (0.6%)	34.8	4.03	1.63
Formic (0.6%) + U	36.7	5.25	1.23
Formic (0.3%) + U	38.1	4.85	2.70
Propionic (0.3%) + U	38.5	4.62	3.51
Acetic (0.6%) + U	39.8	4.38	4.49
Formic (0.3%) + Prop. (0.3%) + U	37.7	4.50	2.09

[a]Urea addition: 0.6%.

production between propionic treated silages and the control were not significant.

Experiment 2

Addition of 0.6% propionic acid to high dry matter (44-46%) corn silage did not diminish the normal preservative power as indicated by lactic acid content (% of DM) of 3.6 for control and 5.3 for the propionic treatments (Table 13).

Experiment 3

As shown in Table 14, both propionic and water treatments resulted in cooler silage during the feeding trial (after fermentation was complete) and also when silages exposed to air (during Moreover, the 0.6% propionic acid treatment was more effective than 0.3% or water.

Experiment 4

The average pH and lactic acid (% DM) of silages are shown in Table 15. There was no significant difference between groups. The pH of control 35% DM was slightly higher than that of treated silages (4.17 vs. 4.02), but no difference due to treatment was noted at 45% DM (4.18 vs. 4.20). Also, pH values for control silages were not as affected by dry matter (4.17 vs. 4.18), as they were for treated silages (4.02 vs. 4.20).

Table 13.--Influence of organic acids and urea addition to high dry matter corn silage (44%) on lactic acid production (Experiment 2).

	Silage Treatment					
	Control	Cont. + U	Formic	Form. + U	Propionic	Prop. + U
Silage DM	44.1	46.0	43.7	41.0	45.6	45.1
Lactic acid (% of DM)	3.61	4.14	3.54	5.61	5.31	4.46

Table 14.--Influence of propionic acid and water additions to high dry matter corn silage (44%) on temperature (Experiment 3).

Silage DM	Silage Treatment			
	Control	Control + water	0.3% propionic	0.6% propionic
	42.5	35.9	43.5	44.5
	mean temperature °C			
Within silos (15 cm)	38.7	36.3	36.0	33.0
(45 cm)	37.8	34.0	35.0	33.2
In open barrels	40.8	37.6	39.1	32.8

Ambient day-time temperature ranged: 19 to 23°C.

Table 15.--Influence of propionic acid addition to medium and high dry matter corn silage (35 and 45%) on pH and lactic acid production (Experiment 4).

Silage DM	Silage Treatment[a]			
	Control HDM	Propionic HDM	Control LDM	Propionic LDM
	44.81	43.63	35.54	36.12
pH	4.18	4.20	4.17	4.02
Lactic acid (% DM)[b]	4.81	3.66	6.17	5.28

[a]Propionic addition: 0.6%.

[b]HDM < LDM ($P < 0.05$); propionic effect was not significant ($P < 0.1$).

Lactic acid production was significantly different ($P < 0.05$) between control medium dry matter and control high dry matter (6.17 vs. 4.81% DM); also between treated medium dry matter and treated medium dry matter and treated high dry matter (5.28 vs. 3.66% DM). Propionic treatments caused a slight decrease in lactate content at both dry matter levels, but difference was not significant.

Average temperatures of control and propionic treated silage (35% DM) during first five weeks of fermentation are shown in Table 16. Propionic treatment resulted in cooler silage at all heights during fermentation. There were no significant differences among heights in control, but mean temperatures of the top silage were higher than middle and bottom silages, averaging 34.3,

Table 16.--Influence of propionic acid addition on mean temperature of 35% corn silages during first five weeks of fermentation (Experiment 4).

	Silage Treatment[a]	
	Control LDM	Propionic LDM
Silage DM	35.54	36.12
	mean temperature °C	
Height 2.5 m[b]	32.1	26.7
5.0 m[b]	31.5	24.7
7.5 m	34.3	33.3

[a]Propionic addition: 0.6%.

[b]Significantly different ($P < 0.05$).

Ambient day-time temperature ranged: -3 to 22°C.

31.5 and 32.5°C, respectively. In treated silages, there was a significant difference ($P < 0.05$ between depths with the temperature of top silage again higher than the middle or bottom (33.3 vs. 24.7 and 26.7°C, respectively). There was no significant difference between top control and treated silages (34.3 vs. 33.3°C), but the overall effect of treatment on temperatures of silages was significant ($P < 0.05$).

Figures 1, 2 and 3 show how temperatures changed with time of ensiling. Greatest heating was noted during week 1 and temperatures plateaued thereafter. Differences due to propionic treatment (at 2.5 and 5.0 m) were maintained for the entire measuring period.

Table 17 shows the average temperatures of 45% DM control and propionic treated silages during first five weeks of fermentation. Propionic treatment again resulted in cooler silage ($P < 0.05$). Unlike the 35% DM comparisons, all locations (2.5, 5.0 and 7.5 m) showed decreased heat production due to propionic treatment.

Unlike 35% DM silage, depth had no significant effect on mean temperatures. Figures 4, 5 and 6 show changes in mean temperatures of 45% silages with time of fermentation. Patterns were somewhat different than for 35% DM silage with maxima occurring at about two weeks. Lower initial temperatures may have reflected a slower fermentation in the drier silages. Even though the 45%

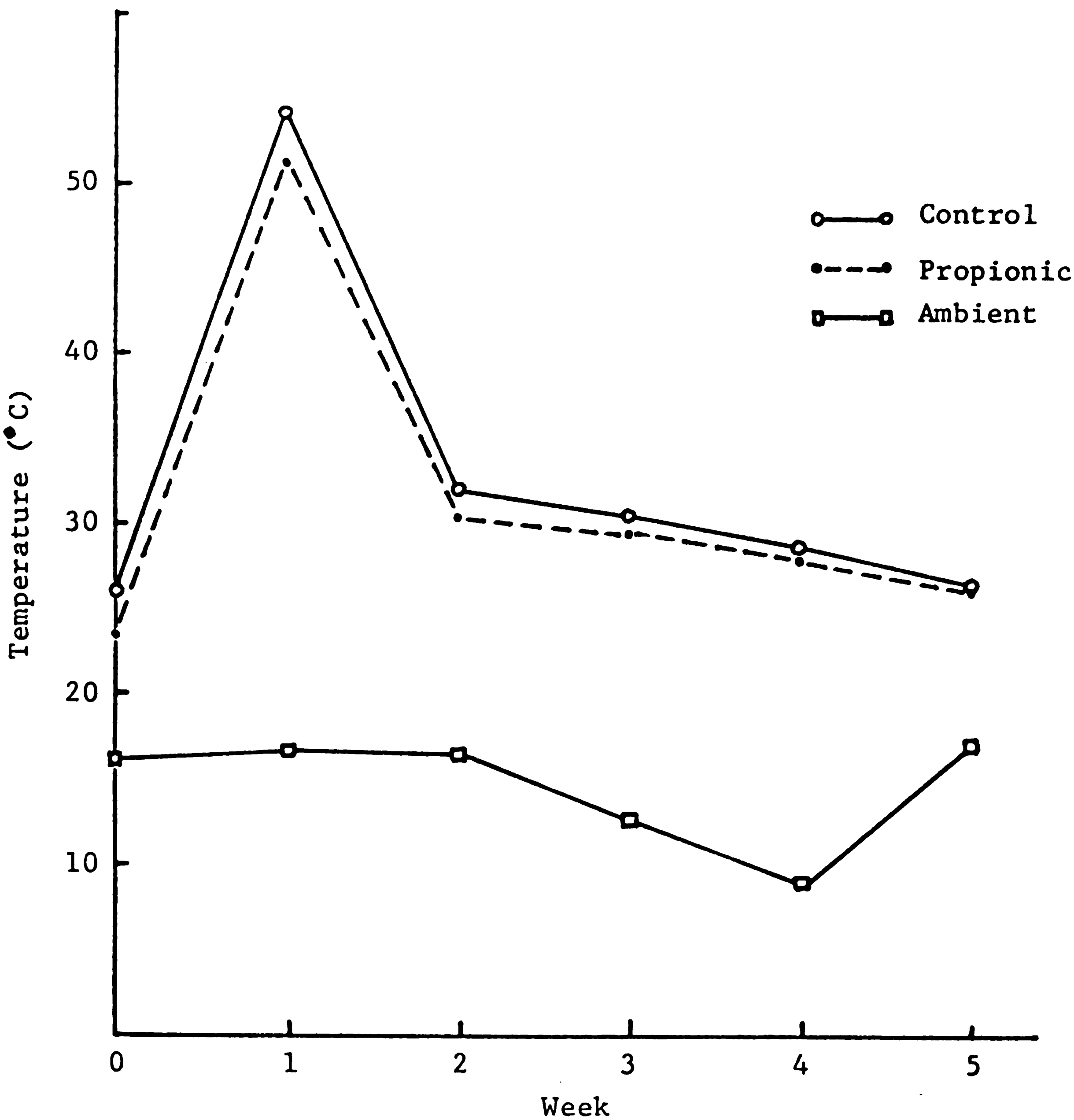

Fig. 1.--Temperature development of control and propionic corn silage (35% DM) during fermentation at a height of 7.5 m (top) (Experiment 4).

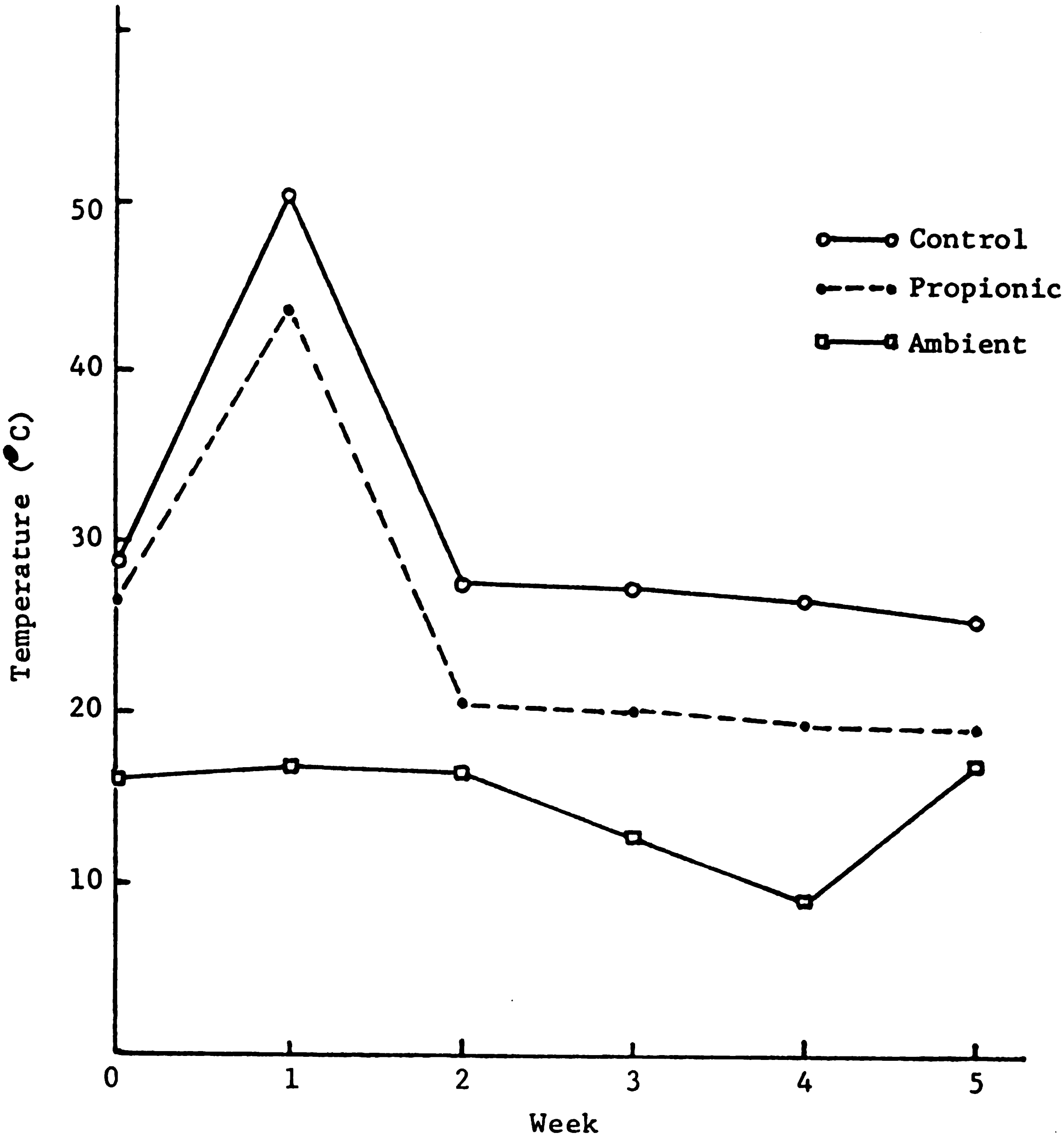

Fig. 2.--Temperature development of control and propionic corn silage (35% DM) during fermentation at a height of 5.0 m (middle) (Experiment 4).

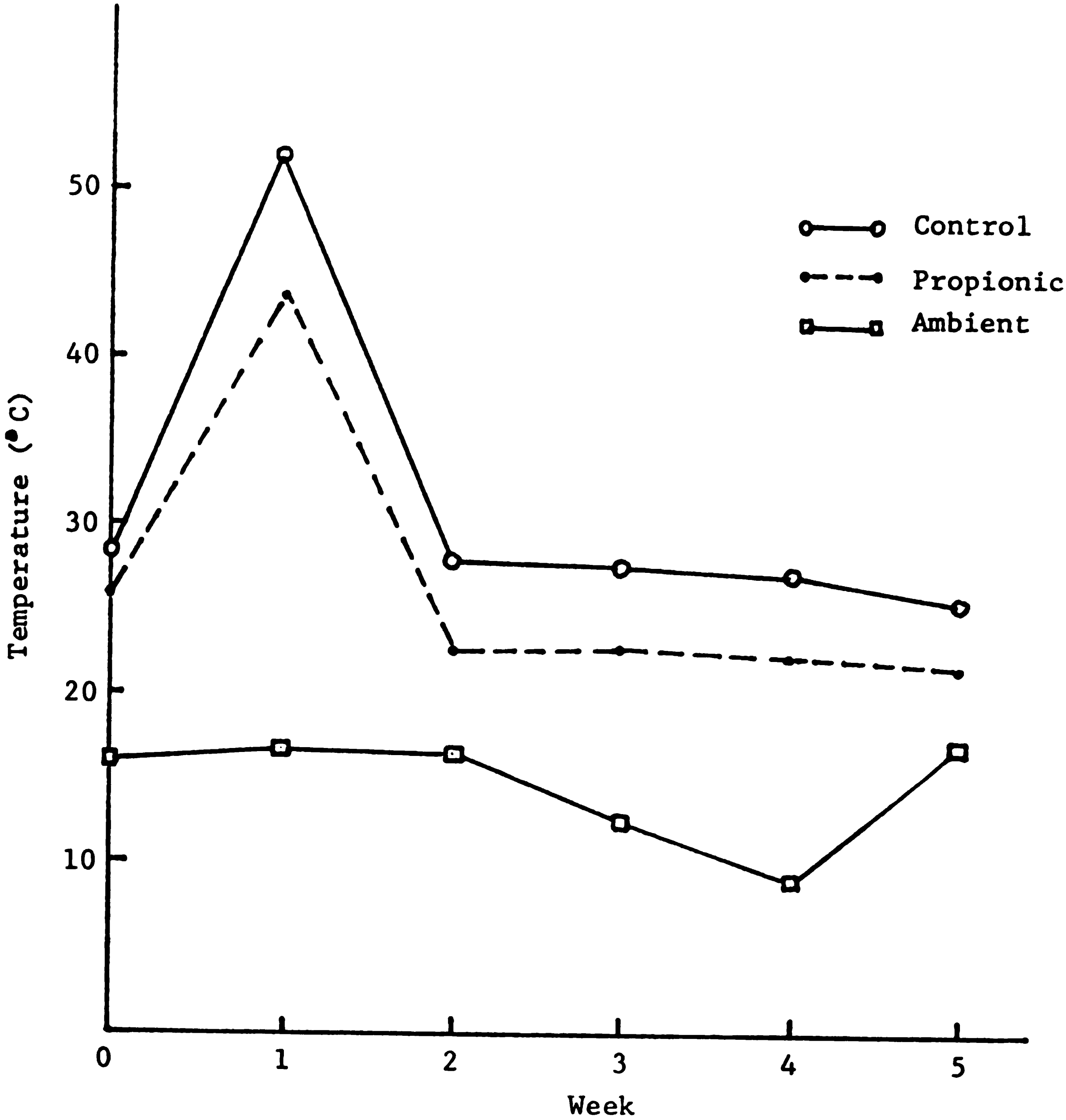

Fig. 3.--Temperature development of control and propionic corn silage (35% DM) during fermentation at a height of 2.5 m (bottom) (Experiment 4).

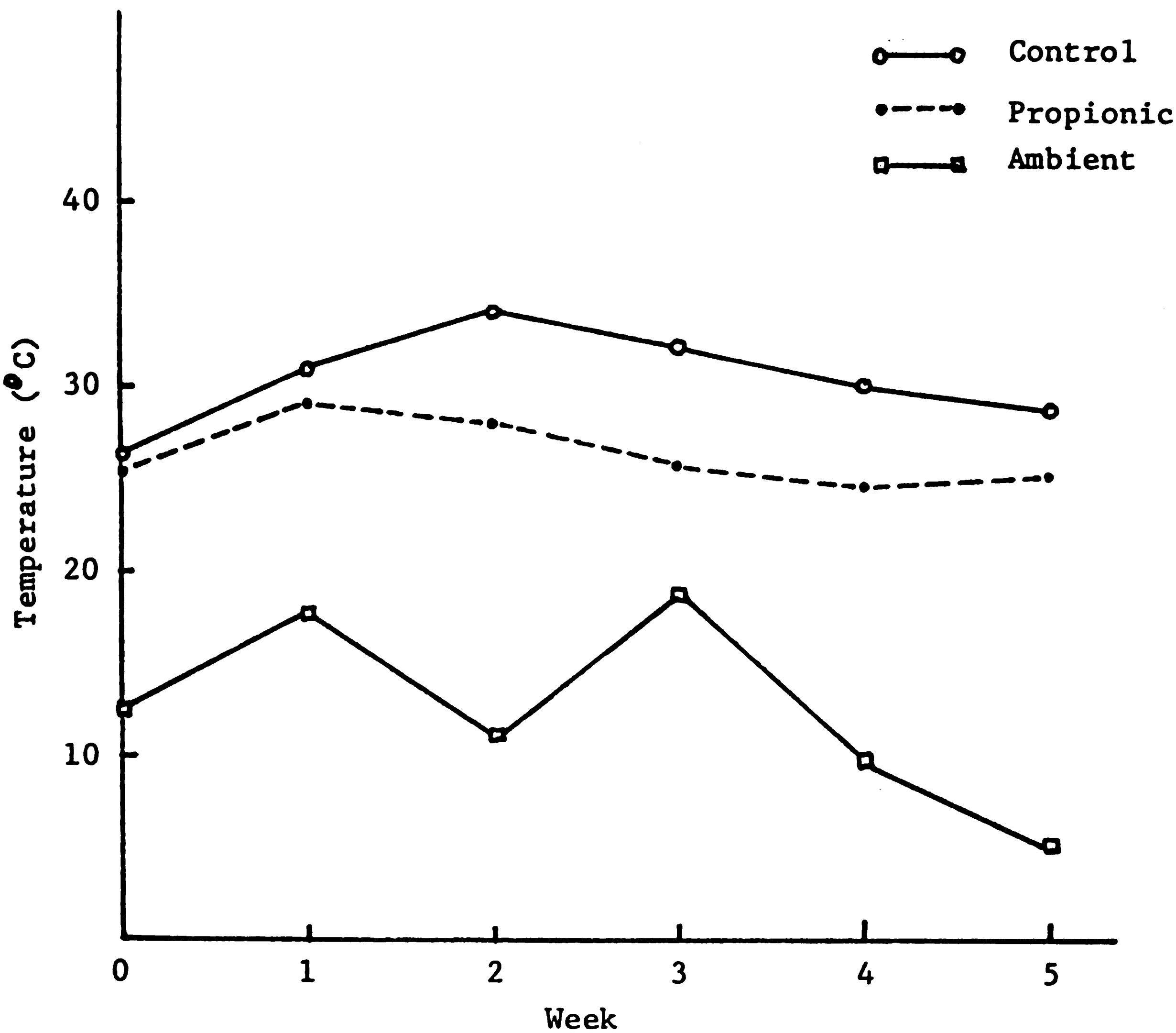

Fig. 4.--Temperature development of control and propionic acid corn silage (45% DM) during fermentation at a height of 7.5 m (top) (Experiment 4).

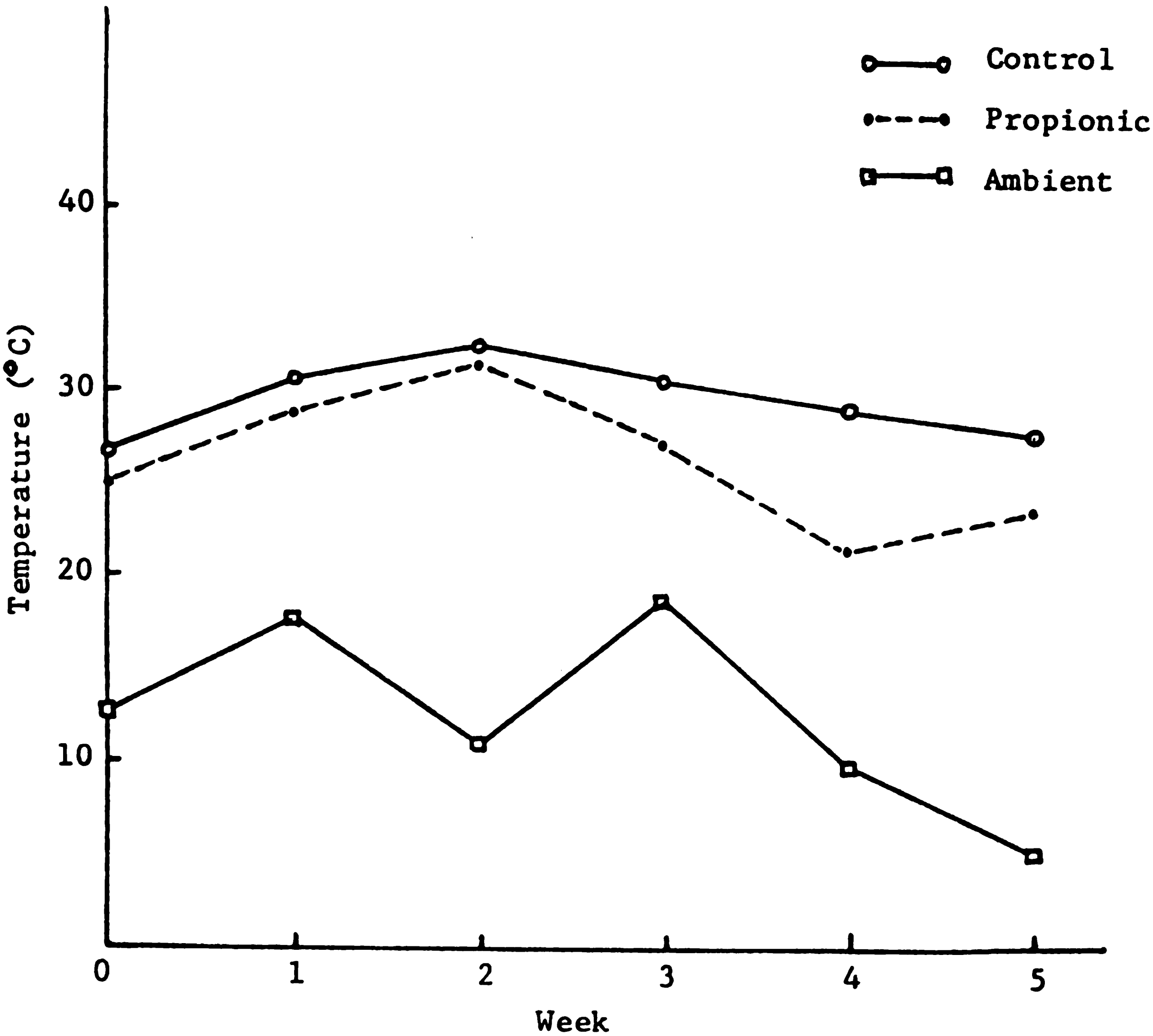

Fig. 5.--Temperature development of control and propionic acid corn silage (45% DM) during fermentation at a height of 5.0 m (middle) (Experiment 4).

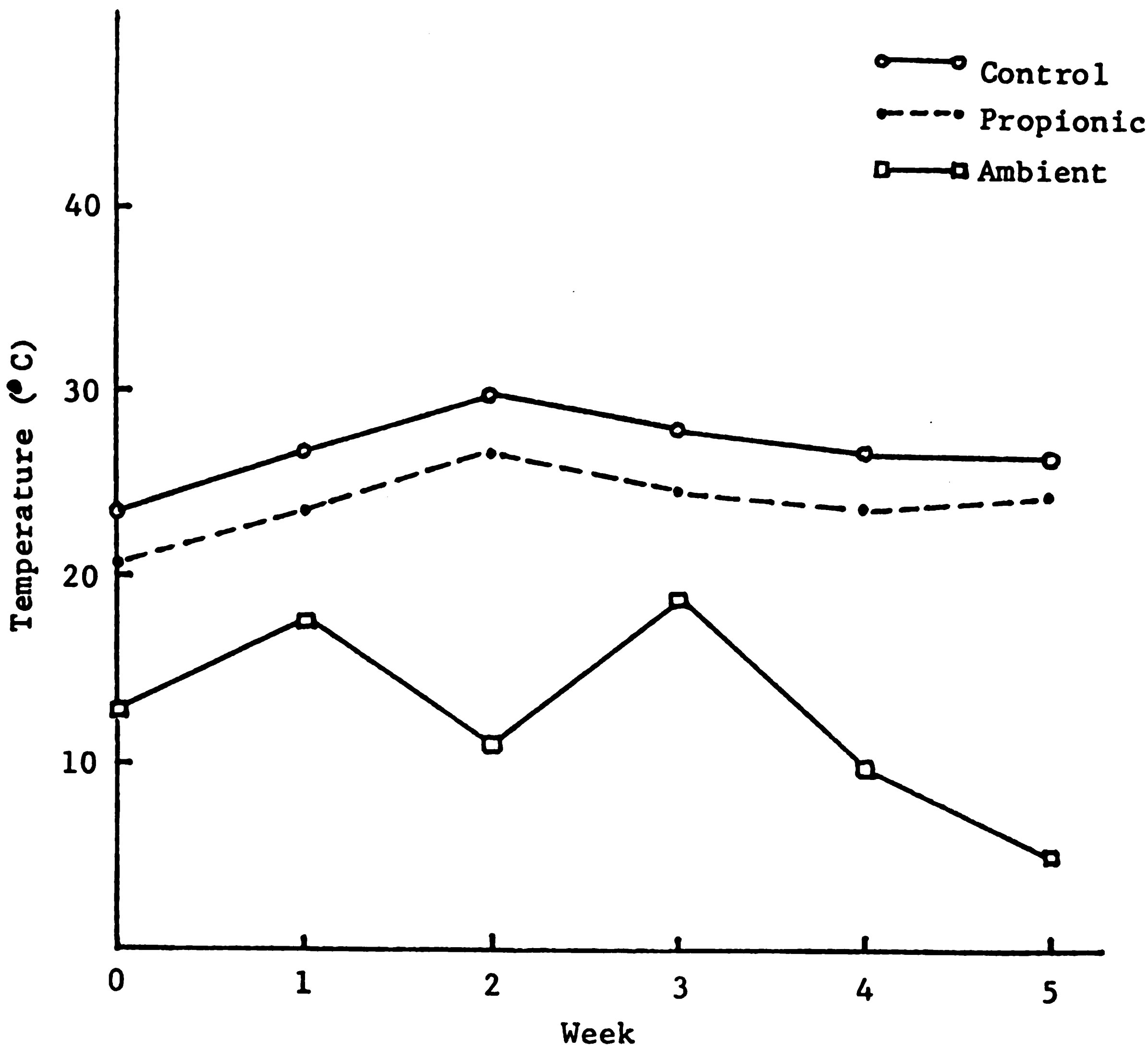

Fig. 6.--Temperature development of control and propionic acid corn silage (45% DM) during fermentation at a height of 2.5 m (bottom) (Experiment 4).

Table 17.--Influence of propionic acid addition on mean temperature of 45% corn silages during first five weeks of fermentation (Experiment 4).

	Silage Treatment[a]	
	Control HDM	Propionic HDM
Silage DM	44.81	43.63
	mean temperature °C	
Height: 2.5 m[b]	27.4	24.6
5.0 m[b]	30.1	26.5
7.5 m[b]	31.1	26.6

[a]Propionic addition: 0.6%.

[b]Significantly different ($P < 0.05$).

Ambient day-time temperature ranged from -4 to +22°C.

silage was harvested later in the season than 35% DM, ambient temperatures were similar and were not the cause of the different patterns. Table 18 shows the average temperatures of corn silages during feeding trial. All of the temperatures at all depths (10, 20 and 30 cm) for control silages were higher than for the propionic treatment ($P < 0.05$). This was true for both the low and high dry matter comparisons.

During the first weeks of feeding, temperatures were significantly different ($P < 0.05$) between treatments (Fig. 7, 8 and 9) with control-HDM the highest and propionic-LDM the lowest. Thereafter, differences between treatments were negligible.

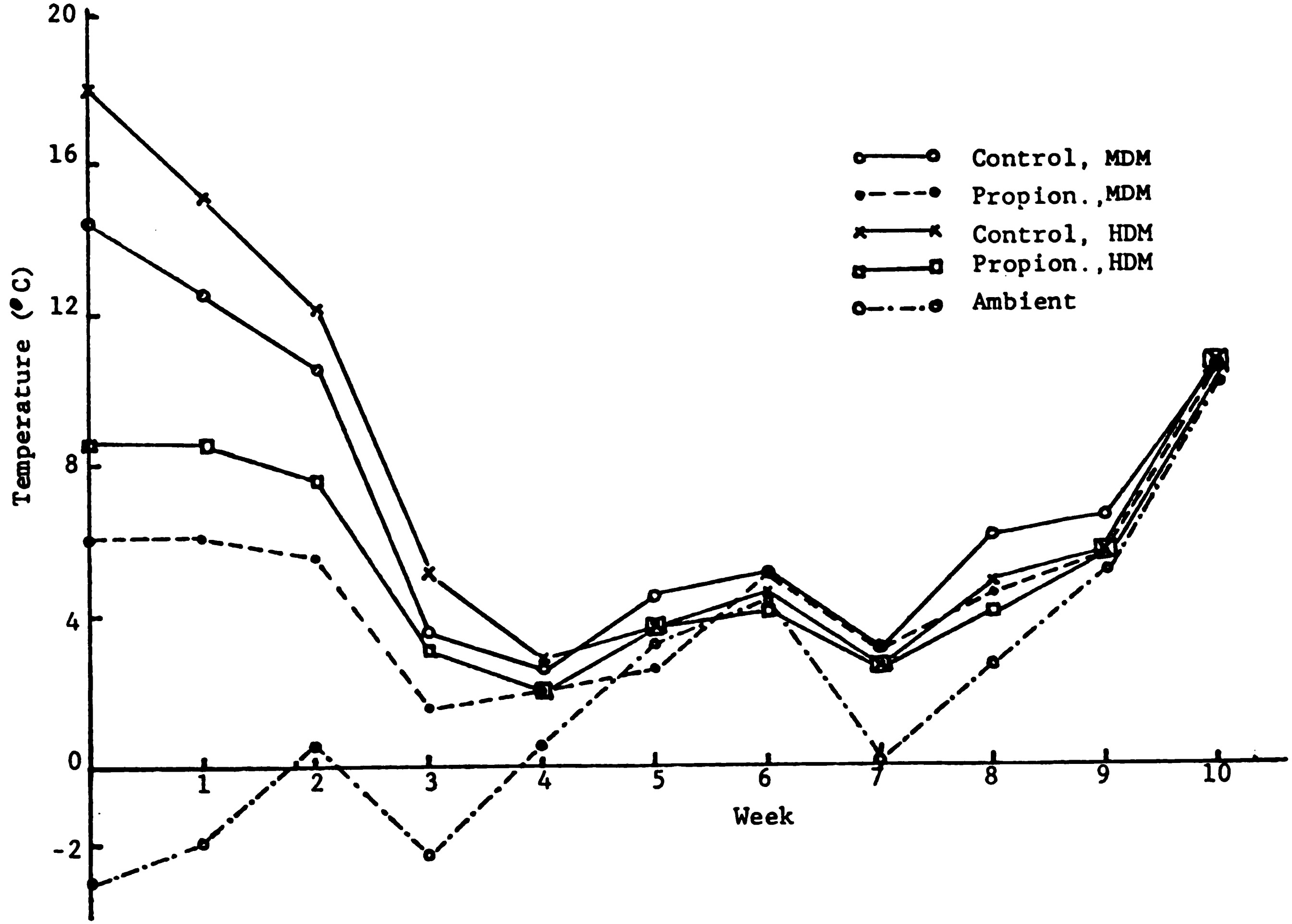

Fig. 7.--Temperature development during the feeding trial of control and propionic acid treated corn silage (35 and 45% DM) at a depth of 10 cm (Experiment 4).

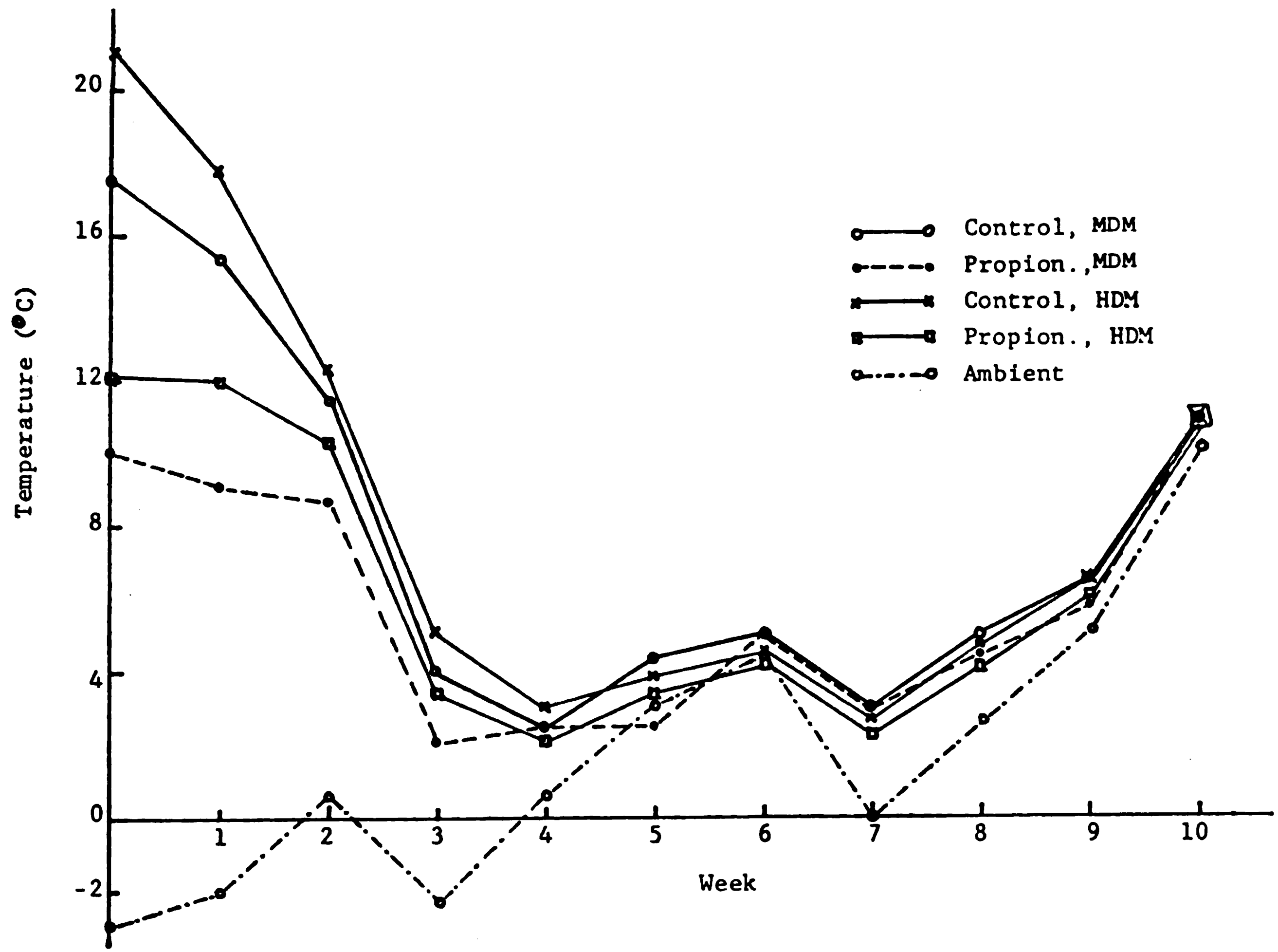

Fig. 8.--Temperature development during the feeding trial of control and propionic acid treated corn silage (35 and 45% DM) at a depth of 20 cm (Experiment 4).

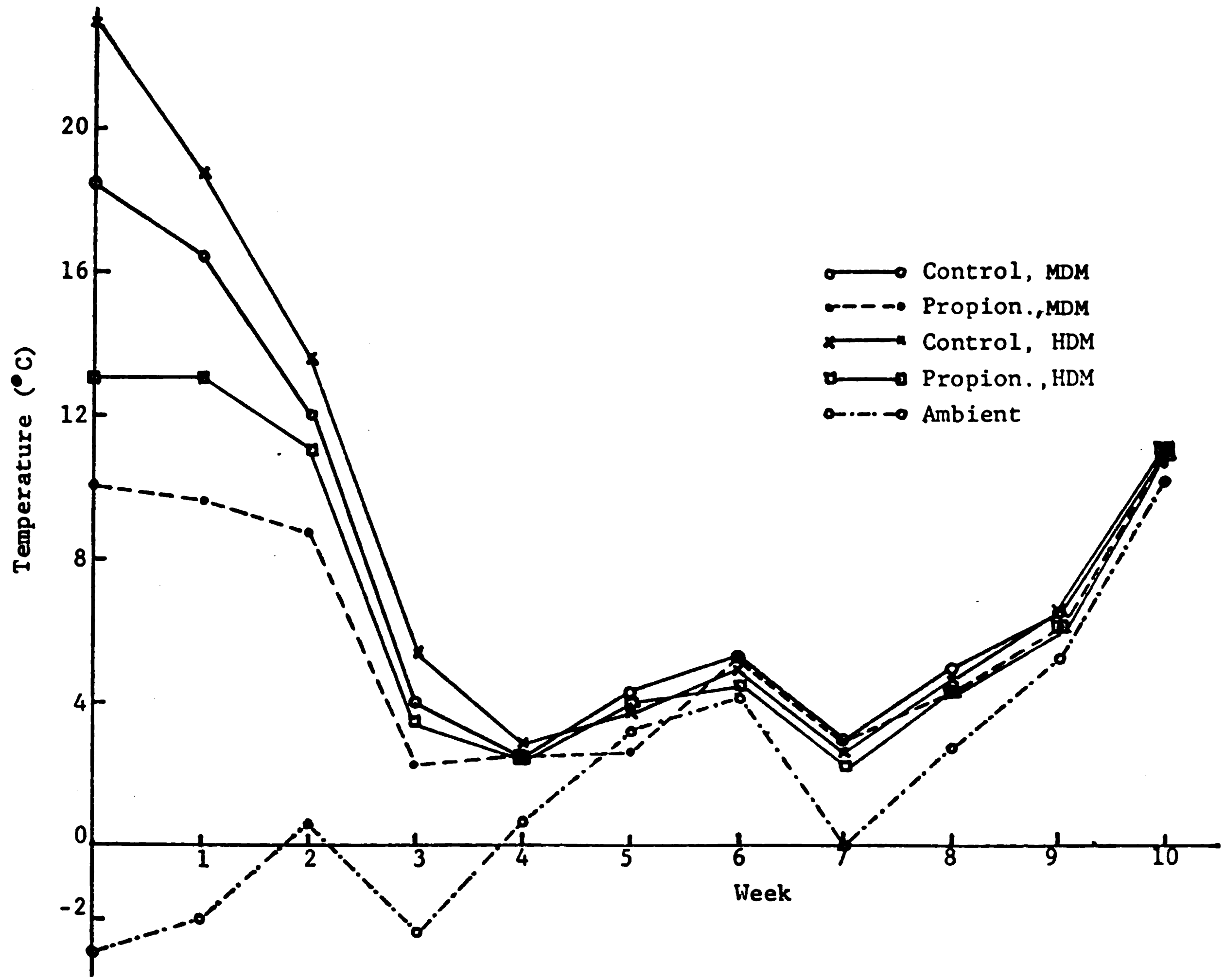

Fig. 9.--Temperature development during the feeding trial of control and propionic acid treated corn silage (35 and 45% DM) at a depth of 30 cm (Experiment 4).

Table 18.--Influence of propionic acid addition on mean temperatures of medium and high dry mattern corn silage (35 and 45%) during the feeding-out period (Experiment 4).

		Silage Treatment[a]			
		Control HDM	Propionic HDM	Control MDM	Propionic MDM
Silage DM		44.81	43.63	35.54	36.12
		mean temperatures °C			
Depths[b]	10 cm	6.8	5.2	6.4	4.6
	20 cm	7.1	5.9	6.8	5.4
	30 cm	7.4	6.2	7.0	5.5

[a]Propionic addition at 0.6%.

[b]Propionic effect was significant ($P < 0.1$).

Ambient day-time temperature ranged from -5 to +12°C.

Upon exposure to air lactic acid concentrations were decreased in all silages. As shown in Table 19, no meaningful difference between treatments were detected for the rates of decrease.

By 14 days after exposure most silages were devoid of lactate. This decrease corresponds with an increase in pH and susceptibility to fungal contamination.

The pH values (as shown in Table 20) of all silages increased during refermentation. As mentioned, these increases are related to the decrease in lactic acid content. Differences between controls and treatment were not significant, but there was a trend towards high pHs of

Table 19.--Influence of propionic acid addition[a] on lactic acid concentration (% of DM)[b] of medium and high dry matter corn silage (35 and 45%) during refermentation (Experiment 4).

Silage Treatment	Days of Refermentation				
	1	7	14	21	28
Control (45% DM)	3.24	1.72	0	0	0
Propionic (45% DM)	1.90	0.65	0.50	0.20	0
Control (35% DM)	5.60	0.43	0	0.70	0
Propionic (35% DM)	5.40	3.35	0	0.80	0

[a]Propionic addition: 0.6%.

[b]Each value is the average of two duplicates.

Table 20.--Influence of propionic acid addition[a] on pHs[b] of medium and high dry matter corn silage (35 and 45%) during refermentation (Experiment 4).

Silage Treatment	Days of Refermentation				
	1	7	14	21	28
Control (45% DM)	3.94	4.03	6.42	6.78	[c]
Propionic (45% DM)	3.95	4.32	5.12	5.15	4.96
Control (35% DM)	4.28	4.85	5.30	5.05	4.40
Propionic (35% DM)	4.14	4.69	4.59	5.03	5.12

[a]Propionic addition: 0.6%.

[b]Each value is the average of two duplicates.

[c]Missing value indicates spoilage of silage.

control silages during the latter stages of refermentation (before complete spoilage).

The number of fungal colonies in silages is shown in Table 21. Significant differences between 45% DM control and treated silages were noted ($P < 0.01$). Also it was found that there was a significant difference between 45 and 35% DM controls ($P < 0.05$), where the 45% DM control was higher initially than in the 35% DM control. Visual fungal growth was present on days 6 and 10 for 35% DM control and treated silages, respectively; and on days 7 and 14 for the respective high dry matter silages. Complete spoilage was seen on days 15 and 17 for 35% DM control and treated silages; and on 14 and 21 for 45% control and treated silages (Table 22).

Again, as shown in Table 23, propionic treatment resulted cooler silage during refermentation; but differences were not significant. Ambient temperatures during refermentation changed from 15 to 23°C.

A complete identification of fungal species was not made, but several slides that were made showed that *Penicillium* and *Aspergillus* were predominant. These species were also found in corn silages by Britt (1973) and Christensen and Kaufman (1969).

Table 21.--Number of fungal colonies[a] (per g/10^5) during refermentation of medium and high dry matter corn silage (35 and 45%) treated with and without propionic acid (Experiment 4).[b]

Silage Treatment	Days of Refermentation				
	1	7	14	21	28
Control (45% DM)	40	96	152	178	190
Propionic (45% DM)	20	30	30	16	21
Control (35% DM)	14	36	80	132	[c]
Propionic (35% DM)	10	34	60	35	26

[a]Each value is the average of two duplicates.

[b]Propionic addition: 0.6%.

[c]Missing value.

Table 22.--Number of days until fungi were noted and complete spoilage on medium and high dry matter corn silage (35 and 45%) treated with and without propionic acid[a] during refermentation (Experiment 4).

Silage Treatment	Days until visual fungal growth	Days until complete spoilage
Control (45% DM)	7	14
Propionic (45% DM)	14	21
Control (35% DM)	6	15
Propionic (35% DM)	10	17

[a]Propionic addition: 0.6%.

Table 25.--Influence of propionic acid addition on mean temperatures of medium and high dry matter corn silage (35 and 45%) during refermentation.

	Silage Treatment[a]			
	Control HDM	Propionic HDM	Control MDM	Propionic MDM
Silage DM	44.84	43.63	35.54	36.12
At depth[b] 30 cm	24.4	22.0	23.6	23.1

[a]Propionic addition: 0.6%.

[b]None of the differences were significant ($P < 0.1$).

DISCUSSION

The emphasis of these studies was to evaluate the effects of feeding corn silage treated with propionic acid on performance of lactating cows and its effects as a preservative. Dry matter levels of corn silage ranged between 35 and 45% and added propionic acid between 0.3 and 0.6%.

Experiment 1 showed no significant difference in silage and total DM intakes due to addition of 0.3 and 0.6% propionic, formic or acetic acids to medium dry matter (35-39%) corn silage; however, intakes were slightly higher for the 0.6% propionic treatment. Experiment 4, which also compared 35% dry matter silages (with and without propionic acids) again showed slightly higher intakes of cows consuming the treated silage.

In experiment 2, 3 and 4 treatment of 45% DM silage with propionic resulted in increased silage and total DM intakes. Only in experiment 2 did intake differences approach significance ($P < 0.1$). However, pooled data from the three studies comparing the control and 0.6% propionic acid treatment showed significantly higher ($P < 0.05$) dry matter intakes. Even though no previous studies were found where propionic acid was added to corn silage for dairy cows, results on addition of formic acid have been reported. For example, higher intakes (11%) of dairy cows fed corn silage treated with formic acid than untreated silage were reported by Huber (1970). Derbyshire and Gordon (1969 and 1970) also found increased intakes when they treated grass silage with formic acid. Also, Candlish (1973) reported benefit from adding formic acid to barley silage (35-45% DM). No effect on intakes of silage was reported by Barker et al. (1973) when they fed alfalfa silage treated with formic acid to dairy cows.

In all four experiments, milk yields on treated silages were higher than on control silages (both at 35 and 45% DM) but only differences in experiment 2 were significant. However, pooling of the 45% DM treatments from experiments 2, 3 and 4 (as was done for intakes) showed that application of 0.6% propionic acid to high dry matter corn silage increased ($P < 0.05$) milk yields about 5%. The relatively short duration of feeding was probably insufficient for the differences in energy intake between treatments to be fully reflected in milk production. The reason of the higher milk production appeared due to higher dry matter intakes of silages treated with propionic acid. The relatively greater effects on intake and milk production of propionic treatment at 45 than 35% dry matter might be related to more difficulty in packing and excluding oxygen in the drier silage. Higher milk yields were reported by Fisher et al. (1971) when they fed grass silage treated with formic acid to dairy cows which was attributed to a higher efficiency of energy utilization for milk production. Derbyshire and Gordon (1970) and Waldo (1971) showed higher milk yields in cows fed grass silage treated with formic acid than in cows fed controls silages. Huber (1970) reported that milk yields increased 8% when cows were fed corn silage treated with formic acid.

Inferior nutrient preservation has been associated with poor quality silage (Barnet and Duncan, 1954; Langston et al., 1958). Poor quality silages were characterized by low lactic acid, high acetic and butyric acids and a pH of 4.8 or above. In these studies, lactic acid production was usually lower for propionic treated silages than controls, but the depression was not as great as for silages treated formic acid. Data in experiments 1 and 2 suggest a greater effect on intake and milk yields from adding propionic acid to medium and high dry matter silages than results from addition of formic acid. This superiority might be explained by the work of Britt et al. (1975) who showed that propionic acid was a more effective fungicide than formic acid when applied to corn silage. However, differences in lactic production between propionic treated and control silages were not significant. Hence, it can be concluded that the addition of 0.6% propionic

acid to medium or high dry matter silage did not diminish its normal preservation potential. On the contrary, the refermentation data from experiment 4 show that propionic acid markedly improved preservation of corn silage as indicated by lower heat production and fungal counts of treated compared to control silages after exposure to air.

Huber et al. (1972) reported that lactic acid production was less in formic treated silage than control. Similar results were found by Lopez et al. (1970) and Wilkins and Wilson (1969), when they treated grass silages with formic acid. Lopez et al. (1970) noted that lactic acid production declined with the maturity. This effect was also shown in experiment 4, with 35% DM higher than 45%. The pH of silages was related to the production of acids. Experiment 4 showed that pH was slightly less in treated silage than the control at 35% DM, but slightly higher than the control at 45% DM. In experiment 1, the pH was higher in propionic treated than control silage. Waldo (1969) found that pH was lower when grass silage was treated with formic acid. Similar results were found by Wilson and Wilkins (1969 and 1973), and Candlish and McKirdy (1973). In experiment 1, the lowest pH value was shown for treatment with formic acid alone. The reason for a greater decrease in pH from formic than propionic treatment was because formic is a stronger acid.

In all experiments propionic treatments resulted in cooler silage than controls. This applied to all heights and at both 35 and 45% DM. The decreased heating was due to inhibition of growth of both bacteria and fungi as reported by Daniel et al. (1970) for grass silage treated with propionic. Also, Goering and Gordon (1973) found that treatment of 35-50% DM grass silage with propionic or ammonium isobutyrate resulted in lower temperatures than control silages.

Propionic treatment also resulted in cooler silage while feeding out which was again due to inhibiting growth of organisms. The higher intakes of silages treated with propionic acid may have been partially due to its effect on silage stability during feeding.

When silages were exposed to air in experiments 3 and 4 (refermentation), propionic treatment again retarded heating, fungal development and days until complete spoilage, which was related to the antimicrobial activity of the additive.

From these data it can be concluded that treatment of high dry matter (45-50%) corn silage with 0.6% propionic acid results in a cooler fermentation and more stable silage, which stimulates dry matter intakes and increases milk production, but the critical question is its profitability. At present prices the cost of added propionic acid would be about 11¢ per cow daily and higher intakes

(12% of silage DM) would increase feed cost about 8¢/ day. If an increase of 5% milk production were realized (as observed from pooled data), then a cow producing 25 kg of milk daily would yield 1.25 kg more milk if consuming treated silage. The value of this milk (at $10.00/cwt) would be 28¢. Hence, the profit from the practice might be calculated at 9¢/cow daily.

SUMMARY

Lactating Holstein cows were used to evaluate the nutritive value of corn silages treated with organic acids.

Initially (experiment 1), propionic, formic and acetic acids were applied to medium dry matter silage with little effect on intakes or milk yields. In experiment 2 propionic treatment of high dry matter silages increased animal performance and was more effective than formic acid. Experiments 3 and 4 also showed trend toward higher intakes and milk yields on propionic than control silages. Decreasing dry matter from 45% silage to 35% with added water had no effect on intakes or milk yields when compared to 45% DM control silage. Pooled data for experiments 2, 3 and 4 showed significantly ($P < 0.05$) higher intakes and milk yields from propionic treatment. Superior preservation was suggested by decreased temperatures and fungal counts. Normal concentration of lactic acid and normal pH values result from propionic treatment. The higher milk yields resulting from propionic treatment to high dry matter silage was calculated as a profitable practice at present prices.

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