A REVIEW ON SILAGE ADDITIVES AND ENZYMES

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INTRODUCTION

Fermentation in the silo can be a very uncontrolled process leading to less than optimal preservation of nutrients. Silage additives have been used to improve the ensiling process (better energy and DM recovery) with subsequent improvements in animal performance.

In order to understand how silage additives can help, one must first understand the ensiling process. Silage fermentation can be divided into 4 phases. The first phase is characterized by the presence of oxygen after forage is chopped and packed in the silo. Plant respiration continues for several hours (and perhaps days if silage is poorly packed) and plant enzymes (e.g., proteases) are active until oxygen is used up. During this phase, excess oxygen can lead to unwanted protein breakdown and excessive heating and growth of yeasts and molds that are undesirable. Oxygen can be eliminated by quick packing, even distribution of forage in the storage structure, chopping to a correct length and ensiling at recommended dry matters (DM) for specific storage structures. Oxygen must be eliminated before optimal fermentation can take place.

Under anaerobic conditions (lack of oxygen) the second phase of silage fermentation is dominated by microbial activity. Fermentation is controlled primarily by: a) type of micro- organisms that dominate the fermentation, b) available substrate (waster soluble carbohydrates) for microbial growth, and c) moisture content of the crop. During this phase, lactic acid producing bacteria (LAB) should utilize water soluble carbohydrates to produce lactic acid; the primary acid responsible for decreasing the pH in silage. Undesirable fermentations from microorganisms such as Enterobacteria and Clostridia can dominate if the pH does not drop rapidly. Where weather permits, wilting forage above 30-35% DM prior to ensiling can eliminate clostridia.

Lack of oxygen prevents the growth of yeast and molds and low pH prevents the growth of most bacteria during the third phase of fermentation. Silage can be kept for prolonged periods of time if these conditions prevail. The last, and fourth, stage of silage fermentation is during feed out and exposure to air. Good silage will remain stable and not change in composition or heat during the third and fourth stages of fermentation. Airtight silos and removal of sufficient silage during feed-out can prevent aerobic spoilage. Some good silage management practices are listed in Table 1.

The end products of silage fermentation are often monitored to assess silage quality and the composition of “normal silages” is presented in Table 2. Many commercial laboratories now offer analytical services for silage end products. Readers should be aware that numerous factors may affect silage composition.

Table 1. Some good silage management practices.

Silage Practice	Reasoning
Harvest crop at correct maturity and DM ¨ Corn silage: 1/2 to 2/3 milk line; 35% DM ¨ Alfalfa: < 1/10 bloom; bunk or bag silo - 35 to 45% DM, conventional upright 35 to 50% DM, oxygen limiting silo - 45 to 60% DM ¨ Grasses: boot; bunk or bag silo - 35 to 45% DM ¨ Small grains: boot to dough; 30 to 40% DM	· Optimizes nutritive value (protein, fiber, energy, etc.) · In some cases optimizes DM content · Ensures good packing, elimination of excess oxygen · Minimizes seepage losses · Prevents clostridial (butyric acid) fermentation
Chop material to correct length: about 3/8 to 1/2 inch	· Promotes good packing and elimination of oxygen · Promotes cud chewing by cow
Harvest, fill, and seal quickly	· Quick elimination of oxygen reduces DM losses from respiration and prevents growth of undesirable aerobic organisms · Sealing minimizes exposure to air · Pack to proper density to eliminate air
Wilt and chop during dry weather	· Prevents extensive DM losses from rained on forage · Promotes rapid drying
Check that all equipment is in good working order	· Sharpen knives · Be sure that silos are free from leaks · In upright silos, a good distributor helps to distribute and pack silage

Allow silage to ferment for at least 14 to 21 days	Properly ensiled silage will minimize production losses during silage changeover

Table 2. Amounts of common fermentation end products in various silages.

Item	Alfalfa Silage, 30 - 35% DM	Alfalfa Silage, 45 - 55% DM	Grass Silage, 25 - 35% DM	Corn Silage, 35 - 40% DM	HM Corn,* 75% DM
PH	4.3 - 4.5	4.7 - 5.0	4.3 - 4.7	3.7 - 4.2	4.0 - 4.5
Lactic acid, %	7 - 8	2 - 4	6 - 10	4 - 7	0.5 - 2.0
Acetic acid, %	2 - 3	0.5 - 2.0	1 - 3	1 - 3	< 0.5
Propionic acid, %	< 0.5	< 0.1	< 0.1	< 0.1	< 0.1
Butyric acid, %	< 0.5	0	<0.5	0	0
Ethanol, %	0.5 - 1.0	0.5	0.5 - 1.0	1 - 3	0.2 - 2.0
Ammonia-N, % of CP	10 - 15	< 12	8 - 12	5 - 7	< 10

*High moisture.

SILAGE ADDITIVES

Silage fermentation is a dynamic process that is affected by variety of factors. Research on silage and silage additives has been conducted for many years.

This review will focus on silage additives commonly used in North America. Readers are encouraged to further their knowledge on silage additives by reviewing the extensive body of journal articles on this subject. In addition, several excellent in-depth reviews are available on this subject (Bolsen, 1995; Muck and Kung, 1997; Kung and Muck, 1997).

Silage additives have been classified into various categories that generally include 1) stimulants of fermentation (microbial inoculants, enzymes, fermentable substrates), 2) inhibitors of fermentation (acids, other preservatives), and 3) nutrient additives (ammonia and urea).

In order for a silage additive to be useful it must increase DM (nutrient) recovery, improve animal performance (milk [quantity and/or composition], gain, body condition, reproduction), or 3) decrease heating and molding during storage and feed out. Changes in fermentation end products without quantifiable improvements in one or more of these categories is questionable.

STIMULANTS OF FERMENTATION

MICROBIAL INOCULATION. Organisms. Silage fermentation is highly dependent on the type of microorganisms that can dominate the process. Natural populations of lactic acid bacteria (LAB) on plant material are often low in number and heterofermentative (produce end products other than lactic acid). As shown in Table 3 homolactic fermentation is more desirable than other types of fermentations because it results in a theoretical recovery of 100% for DM and 99% for energy in contrast to lower recoveries of DM and energy from other fermentations (note that certain types of heterolactic fermentation are also efficient). Thus, the concept of adding a microbial inoculant to silage was to add fast growing homofermentative lactic acid bacteria (^{ho}LAB) in order dominate the fermentation resulting in a higher quality silage.

Table 3. Predominant fermentation pathways in silage.

Type of fermentation	End-products	Theoretical DM recovery, %	Theoretical Energy recovery, %
homolactic (glucose)	lactic acid	100	99
heterolactic (glucose)	lactic acid, ethanol, CO_2	76	98
heterolactic (fructose)	lactic acid, acetate, mannitol, CO_2	95	99
yeast (glucose)	ethanol, CO_2	51	99

clostridia (glucose and lactate)	Butyric acid, CO_2	49	82

Some of the more common ^{ho}LAB used in silage inoculants include: *Lactobacillus plantarum, L. acidophilus, Pediococcus acidilactici, P. pentacaceus, and Enterococcus faecium.* Microbial inoculants contain one or more of these bacteria which have been selected for their ability to dominate the fermentation. The rationale for multiple organisms comes from potential synergistic actions. For example, growth rate is faster in *Streptococcus* > *Pediococcus* > *Lactobacillus*. Some *Pediococcus* strains are more tolerant of high DM conditions than are *Lactobacillus* and have a wider range of optimal temperature and pH for growth (they grow better in cool conditions found in late Fall and early Spring).

MICROBIAL INOCULATION. Fermentation and animal responses. Alfalfa, grass and small cereal grain crops have responded well to microbial inoculation. The fermentation of high moisture corn has also been improved with microbial inoculation. However, microbial inoculation has been less effective on corn silage. For example, I found 14 published (peer reviewed) studies in North America where corn silage was treated with a microbial inoculant, improvements in animal performance where found in only 3 instances and only minor changes in fermentation where found. However, Bolsen et al. (1992) reported that in 19 studies conducted at Kansas State University, with corn silage, inoculated silages had 1.3 percentage unit higher DM recovery, supported 1.8% more efficient gains, and produced 3.6 lb more gain per ton of crop ensiled with beef cattle. Similar results were found with treated sorghum silages. In certain instances, significant animal responses have been observed with inoculation although there was little effect on traditional end-products of fermentation (Gordon, 1989; Kung et al., 1993). These data would suggest that there may be unidentified components in inoculated silages that are responsible for improved animal performance.

When compared to untreated silages, silages treated with adequate numbers of a viable ^{ho}LAB should be lower in pH, acetic acid, butyric acid and ammonia-N but higher in lactic acid content. In a review of the literature between 1990-95, Muck and Kung (1997) reported that microbial inoculation lowered pH, improved the lactic:acetic ratio, and lowered ammonia nitrogen content in more than 60% of studies. Dry matter recovery was improved by more than 35% and bunk life improved in about 30% of the studies. Dry matter digestibility was also improved in about one third of the cases. Microbial inoculation usually has little or no effect on the fiber content of silages because most lactic acid bacteria contain little or no ability to degrade plant cell walls. Decreases in fiber content may be due to partial acid hydrolysis of hemicellulose. Some data suggests that certain microbial inoculants can increase fiber digestion (Rice et al., 1990). Bunk life or aerobic stability has not been consistently improved by inoculation and in some instance inoculation has made aerobic stability worse. This is probably due to a lower acetic acid content.

Relative to animal responses Kung and Muck (1997) reported positive responses to microbial inoculants on intake, gain, and milk production (Table 4). The average response in milk production was a +3.1 lb per day in studies where milk production was statistically improved.

Table 4. A summary of animal responses to microbial inoculants between 1990 and 1995.

Type of Study	Intake	Gain	Milk Production
Number of Studies	67	15	36
Studies with Positive Responses	28%	53%	47%

(Kung and Muck[26])

Although literature summaries are encouraging, caution should be used when interpreting such data because all inoculants are not equal and the conditions (e.g. rate of application, inoculant viability, species of bacteria, crop, moisture levels) varied markedly among the studies. As many have pointed out in the past, products with organisms with the same name are not necessarily the same organism and may not have the same effectiveness (Dennis, 1992). For example, Rooke and Kafilzadeh (1994) reported that various strains of ^{ho}LAB improved silage fermentation but animal performance was improved by only 1 strain of organism. An impressive number of animal experiments has been conducted using a single silage inoculant containing *Lactobacillus plantarum* MTD1. A summary of 14 lactation studies (Moran and Owen, 1994) conducted in University and government research institutes in North America and Europe using MTD1 is shown in Table 5. Statistical analyses revealed that DM intake was numerically increased by 4.8% and that milk production was significantly increased by 4.6%. Improvements in milk yield were obtained with a variety of crops (grass, corn, alfalfa) across a wide spectrum of DM contents (15 to 46% DM). Body weight gain also tended to be better in cows fed silage treated with MTD1. Similarly, 19 comparisons among untreated silages and silages treated with MTD1 were summarized by Moran and Owen (1995) for beef cattle. Across all studies and types of forage, cattle fed inoculated silage ate 7.5% more DM and gained 11.1% more weight.

Table 5. The effect of feeding silage inoculated with MTD1 from 14 studies on silage DM intake and milk yield from lactating cows.

	Silage DM intake (lb/d) CONTROL	Silage DM intake (lb/d) MTD1	Milk yield (lb/d) CONTROL	Milk yield (lb/d) MTD1
Average	23.1	24.2	57.2	59.8
Difference		+ 4.8%		+ 4.6%

(Moran and Owen, 1995)

Unfortunately, there is no good way to predict the effectiveness of microbial inoculants. A model developed by Pitt (1990) suggested that inoculants would be most effective on alfalfa during cool conditions of first, third and fourth cuttings. However, there are numerous products that have little or no research to support claims of improved fermentation or animal performance. Another factor which complicates the evaluating process is that the majority of bacterial inoculants are repackaged for distribution under private label and numbers of bacteria may be low and/or other additives (e.g., enzymes, fermentation extracts, minerals) are included in the formulations.

MICROBIAL INOCULATION. Inoculation rate, use, and storage. The organism(s) from microbial inoculants must be present in sufficient numbers to effectively dominate the fermentation. Thus the most commonly recommended inoculation rate supplies 100,000 (or 1 x 105) organisms per gm of wet forage. There is little evidence that suggests that doubling or tripling this amount (e.g. 200-300,000 cfu) is beneficial. Additions of 1,000,000 cfu per gm of wet forage are probably not cost effective in North America.

Most microbial inoculants are available in powder or granular form. Inoculants applied in the dry form are often mixed with calcium carbonate (limestone), dried skim milk, sucrose or other carriers. These products can be applied by hand or by solid metering devices as per manufacturer's recommendations. Inoculants to be applied in the liquid form come as dried powders and are mixed with water just prior to use. (Use of chlorinated water may be detrimental to the inoculant.) Application can be with a simple watering can by weighing the incoming forage load and adjusting application based on the average unloading time. A better method is to use a metered liquid sprayer to evenly disperse the inoculant on the forage. Unused liquids should be discarded after a period of 24 to 48 h because bacterial numbers begin to decline.

Microbial inoculants can be applied to the forage at a variety of locations. However, application to forage at the chopper is highly recommended in order to maximize the time that microorganisms have in contact with fermentable substrates. Inoculants can also be applied at the blower of an upright silo or sprinkled over the forage mass between loads in a bunk silo. Proper distribution cannot be overlooked and is important for the inoculant to be effective. Throwing a can of dry inoculant in a wagon load of forage and hoping for even distribution is not an acceptable practice!

Theoretically, when inoculants are applied in the dry or liquid form to forage wilted to about 30 to 50% DM, efficacy of the same product should be equal, but there is little published data to support this contention. However, when moisture limits microbial activity (> 50% DM), inoculants applied in a liquid may be more advantageous since bacteria are added with their own moisture to help speed up fermentation.

Storage is an important aspect of a high quality inoculant that contains live microorganisms. Inoculants should be kept in cool dry areas away from direct sunlight. Moisture, oxygen and sunlight will decrease stability of inoculants. Opened bags of inoculants should be used as soon as possible.

MICROBIAL INOCULATION. Miscellaneous organisms. Several microorganisms that are not ^{ho}LAB have been used as silage inoculants specifically for the purpose of improving aerobic stability. For example, the *Propionibacteria* are able to convert lactic acid and glucose to acetic and propionic acids that are more

antifungal than lactic acid. Florez-Galaraza et al. (1985) reported that addition of *P. shermanii* prevented the growth of molds and markedly reduced the initial population of yeast in high moisture corn where the final pH was greater than 4.5. Dawson (1994) reported similar findings in high moisture corn. Weinberg et al. (1995) reported little benefit from adding *Propionibacteria* to pearl millet and corn silage (final pH < 4.0) but reported improvements in the aerobic stability of wheat silage when the decline in pH was slow. Similarly, in 3 studies using laboratory silos, we (Kung et al., unpublished data) did not observed beneficial effects of *Propionibacteria* in corn silage (final pH 3.6 to 3.8). However, Bolsen et al. (1996) reported more propionic acid, lower yeasts and molds, and greater aerobic stability in corn silage (pH of 3.6) treated with *Propionibacteria*. Some concerns relative to the use of *Propionibacteria* that have not been adequately addressed are the loss of DM (from CO_2 production) and the fact that *Propionibacteria* have proteolytic activity. In general *Propionibacteria* have been effective in situations where the decline in pH is slow and (or) when the final pH of silage has been relatively high (> 4.2 to 4.5).

Recently, *Lactobacillus buchneri,* a heterolactic bacteria capable of producing lactic and acetic acid, has been included as an inoculant for improving the aerobic stability of silages. Muck (1996) reported that corn silage treated with *L. buchneri* TY16 had greater acetic acid content and was more stable when exposed to air than untreated corn silage. In Europe, Driehuis et al. (1996) reported that increasing doses of *L. buchneri* from 10^3 to 10^6 cfu/g in laboratory silos decreased the lactic acid content but increase the acetic acid content in corn silage**.** Aerobic stability was markedly enhanced and improved with increasing inoculation rate. More positive data on non-homolactic acid fermenting is needed before their use becomes widespread.

ENZYME ADDITIVES. General description. Enzymes are proteins that assist in metabolic processes. A variety of enzymes, particularly those that digest plant fiber and starch have used as silages additives (Table 6). To date, we can find no evidence that would promote the use of protease enzymes as silage additives since they would most likely increase the concentration of rumen degradable protein in silage (an undesirable result). Silage additives may contain single enzyme complexes, combinations of enzyme complexes and combinations of enzyme complexes and LAB. Plant fiber-digesting enzymes (cellulases and hemicellulases) are the most widely used enzyme additives and will be the focus of the remainder of this discussion.

There are two primary reasons for adding fiber-digesting enzymes to silage. First these enzymes could partially digest the plant cell walls (cellulose and hemicellulose) yielding soluble sugars which could be fermented by LAB to lower the silage pH. This would stimulate silage fermentation and improve fermentation quality by increasing the rate and extent of decline in pH, increasing the concentration of lactic acid, improving the lactic acid**:**acetic acid ratio (which is indicative of greater efficiency of fermentation), and hence reduce DM losses. A faster decline in pH would also limit degradation and deamination of forage proteins and reduce ammonia production. Second, partial digestion of the plant cell wall may improve the rate and/or extent of digestibility. In order for the first event to take place the rate of cellulose hydrolysis must coincide with early growth of lactic acid bacteria. For an improvement in digestibility, a change in the association of cell wall components must occur. (Amylase enzymes may provide substrates for LAB by partially digesting starch but would not degrade fiber.)

Table 6. Enzymes used as silage additives.

Enzyme complex	Target substrate	End-products
Cellulase	Cellulose	Glucose, maltose, limit dextrins
Hemicellulase (xylanase)	Hemicellulose	Xylose, xylans, arabinose
Amylase	Starch	Glucose, maltose

ENZYME ADDITIVES. Effects on silage fermentation and animal production. Fiber-digesting enzymes have been most effective in reducing the fiber content of grass and alfalfa crops ensiled in the 60 to 70% moisture range (Muck and Kung, 1997) the effect being greatest in grasses. Improvements in silage fermentation and decreases in fiber content appear more pronounced in immature grasses than mature grasses where hydrolysis of the cell wall would be more difficult due to increased lignification. Enzymes have improved fermentation by stimulating acid production, lowering pH, and lowering ammonia N. Results of enzymes on DM or fiber digestion have been more negative than positive. A possible reason for this is that fiber-degrading enzymes predigest the readily digestible fiber leaving a slower and less degradable fraction.

In a summary of animal responses between 1990-95, Kung and Muck (1997) found that positive responses in intake, gain and milk production were less for silages treated with enzymes (Table 7) than with microbial inoculants.

Table 7. A summary of animal responses to enzyme-treatment between 1990 and 1995.

Type of Study	Intake	Gain	Milk Production
Number of studies	29	10	12
Studies with positive responses	28%	40%	33%

(Kung and Muck[26])

There are many variables that may affect the efficacy of fiber-degrading enzymes. Just as bacterial inoculants require certain conditions for growth, enzymes require certain conditions for maximum activity. Most cellulase enzymes require a pH of 4.5 and temperature of 50oC for optimal activity. Surface area, binding sites, moisture level and plant proteases may also inhibit enzyme activity. We also do not know the optimum mixture of enzymes that will improve silage fermentation. For example, 'cellulase' enzymes are a complex of various endo- and exo-beta-glucanases, cellobiohydrolase, and cellobiase. Complete breakdown of insoluble cellulose to glucose requires synergistic action between the enzymes. Furthermore, there is no universally accepted method for measuring enzyme activity. In the case of cellulases, activity is often expressed as the ability of the enzyme preparation to degrade filter paper cellulose under defined conditions that are not equivalent to conditions that are present in the silo. In many silage additives the quantity of enzymes is so small that one must question whether these enzymes have any positive effect on fermentation and animal performance and there is little published evidence that support additive effects from many of these products.

ENZYME ADDITIVES. Enzymes as feed additives. Recently, there has been increased research into treating diets for ruminants with plant cell-wall degrading enzymes just prior to feeding and an excellent review on this topic was recently published by Treacher and Hunt (1996). Silage fermentation is not affected but this method of treatment can improve the nutritive value of silage and thus a brief discussion is warranted. This approach offers exciting possibilities for using enzymes to improve nutrient digestion, utilization, and animal productivity and at the same time reduce animal fecal material and pollution. Spraying enzymes onto forages just before feeding provides increased management flexibility for feeding and also bypasses any negative interactions that the ensiling process may have on silage enzyme performance. When enzymes are sprayed onto silage before feeding, binding with substrates may help to protect these exogenous enzymes from ruminal degradation. Treating forages with enzymes in this manner may improve digestibility via a number of different mechanisms that including, direct hydrolysis, improvements in palatability, changes in gut viscosity, and changes in the site of digestion.

Spraying enzymes on the silage has increased the release of residual sugars and rate of NDF digestion. A mixture of fiber degrading enzymes sprayed onto the forage portion of a total mixed ration resulted in cows consuming 4 lb more DM per day and producing 2.8 lb more milk per day (stokes and Zheng, 1995). Maine researchers reported that dry matter intake increased by 10.7% and milk yield by 14.7% in one study (Stokes, 1992). However, Zheng and Stokes (1997) reported that the growth of Holstein heifers was not improved by application of fiber-degrading enzymes to the silage of a total mixed ration immediately before feeding. Sanchez et al. (1996) reported marked improvements in milk production when an alfalfa hay, alfalfa silage, and cottonseed mix was sprayed with a moderate but not with a lower or higher amount of fiber degrading enzymes. Positive responses to treating the forage portion (primarily corn silage) of a TMR with enzymes in 3 consecutive years have also been observed (Kung et al. 1997, unpublished data).

MOLASSES. Molasses has been used as a fermentation stimulant for many years and recently there has been a renewed interest in its use. Molasses is a by-product of the sugar-cane and sugar-beet industries and contains 79% soluble

carbohydrates; 45 to 50%, of which sucrose is the main component. Molasses provides a relatively cheap source of fermentable carbohydrate for lactic acid bacteria and has been applied at a rate of 40-80 lb per ton of fresh forage.

Molasses in numerous silage experiments has been proven to be an effective silage additive in terms of promoting lactic fermentation, reducing silage pH, discouraging a clostridial fermentation and proteolysis, and generally decreasing organic matter losses. It is of particular benefit when applied to forage crops low in fermentable carbohydrates for lactobacilli. Recently, Keady (1996) reviewed the published literature on molasses as silage additives and concluded that molasses treatment improved silage preservation, but did not significantly alter the silage digestibility or animal performance although silage DM intake was improved.

INHIBITORS OF FERMENTATION

PROPIONIC ACID. Of the short-chain fatty acids, propionic acid has the greatest antimycotic activity. It is effective in reducing yeast and molds which are responsible for aerobic deterioration in silages. The antimycotic effect of propionic acid is enhanced as pH declines, making it an ideal candidate for improving the aerobic stability of corn silage where pH is low. In the past, aerobic stability was improved when large amounts of propionic acid (1 to 2% of the DM) were added to silage, but the high percentage of acid often restricted fermentation in these cases. The application rate of propionic acid additives has varied depending on moisture content of the forage, length of storage[13] and formulation with other preservatives. For example, for high moisture corn with a moisture content of 20% the application rate should be 0.1 and 0.5% for storage of 1 and 6 months, respectively, while it should be increased to 0.8 and 1.1% for 30% moisture of silage for the corresponding lengths of storage. Application rates of 1.5 to 2.0% for haylage and 2.0 to 2.5% for haylage with less than 30% of DM have been suggested. For corn silage, propionic acid at usage rates of 0.2 to 0.5% have been shown to be effective (Beck, 1975). Many current products that are added to forages at ensiling for the purpose of improving aerobic stability contain several ingredients including benzoic acid, sorbic acid, and citric acid; however, propionic acid usually constitutes the greatest percentage of the active ingredients. Recommended application rates of these products are relatively low (2-4 lb/ton of fresh forage). Such low application rates usually do not affect silage fermentation but reduce the numbers of spoilage yeasts and improve aerobic stability (Table 8). In addition, several products have been designed to be added to silages or TMR just prior to feeding to prevent heating and spoiling in the feed bunk. However, research from our lab and others suggests that controlling yeasts at the time of ensiling is more efficient than trying to control their numbers and metabolism in the feed bunk.

Table 8. Effect of a propionic acid-based additive on the number of yeasts and hours of aerobic stability of corn silage.

Treatment*, application rate	Yeast in silage, Number per gram	Aerobic stability, ** hours
Control	257,000	65

Product A, 2 lb/ton	27,000	120
Product A, 4 lb/ton	2,800	>160

*Product A contained buffered propionic acid (primary active ingredient) and other active ingredients.

**Hours before the temperature of the silage rose more than 2^0C.

Kung et al. 1998. (University of Delaware).

Propionic acid is difficult to handle because it is corrosive. Thus, the acid salts, e.g., calcium, sodium and ammonium propionate have been used in some commercial products. The efficacy of propionic acid and its salts is closely related to their solubility in water. The stronger the bond is between the acid-base, the less soluble the product is and thereby less effective in inhibiting fungi. Among these salts, ammonium propionate is most soluble in water (90%), followed by sodium propionate (25%) and calcium propionate (5%).

NUTRIENT ADDITIVES

AMMONIA and UREA. General description and effects. Anhydrous ammonia or water- or molasses-ammonia mixes have been used as silage additives. Ammonia additions have resulted in a) addition of an economical source of crude protein (Huber et al., 1979); b) prolonged bunk life during feeding (aerobic stability, Britt and Huber, 1975); c) less molding and heating during ensiling; and d) decreased protein degradation in the silo (Johnson et al., 1982). Urea has been added to corn silage as an economical source of crude protein. However, a beneficial effect of urea on improved bunk life and decrease in proteolysis has not been totally substantiated. Whenever ammonia or urea is added to the diet, special attention should be made to ensure that degradable and undegradable protein requirements are balance for the target ruminant animal.

Ammonia has been used to treat corn silage, small cereal grain silage and high moisture corn with varying degrees of success. Although some have used ammonia on alfalfa silage, this practice is not recommended (Kung et al., 1989). Addition of anhydrous ammonia or water-ammonia mixes initially buffers the plant material. For example, corn forage may have a pH of 5.9 but treated corn forage will have a pH of about 8.5 to 9.0. When fermentation in the silo is complete, corn silage treated with anhydrous ammonia usually is .1-.2 units higher in pH, contains .5-1.5% (DMB) more lactic acid, .5-1.5% more acetic acid, and less residual water soluble carbohydrates. Forages treated with ammonia have also been shown to be higher in insoluble N and true protein (Buchanan-Smith, 1982) primarily because ammonia reduces plant proteolysis. Although fermentation is generally stimulated by ammonia, the ensiling processes is prolonged because of ammonia buffering effect resulting in greater total acid production and inconsistent effects on DM recovery. Bolsen et al. (1992) reported that use of anhydrous ammonia had adverse effects on DM recovery, particularly in high moisture sorghum silage.

AMMONIA and UREA. Application to forage. Ammonia can be added at the chopper, blower, bagger or bunk. Mixed ammonia solutions are bulkier than anhydrous ammonia but retention of ammonia is usually greater. In addition, molasses (to improve palatability and fermentation) and minerals can be added in these solutions. Some ammonia will be lost (between 10 and 30%) and losses will be greater if ammonia is not applied properly and if forage becomes too dry. Ammonia should be applied to the forage before it contacts the blower to minimize

losses. Ammonia should be added at the end nearest the cutter in a chopper with an auger system. If no auger is used, ammonia can be added behind the cutter prior to entering the blower. Ammonia can also be spiked into bunks between loads and it will disperse into the mass. Application of anhydrous ammonia should be at approximately 6 to 7 lb of N per 700 lb of forage DM (Table 9). This will increase crude protein from about 8 to 12.5% on a dry matter basis. Excess ammonia (12-15 lb per ton) may result in poor fermentation (because of a prolonged buffering effect) and animal performance. Using the Cold-flo method is the simplest way to add ammonia to silage. Gaseous ammonia is super cooled in a converter box and about 80-85% becomes liquid.

Table 9. Addition of ammonia and urea to corn silage.

	Anhydrous Ammonia	Ammonia-molasses mixes	Urea
Nitrogen, %	82	20-23a	46
CP equivalent, %	515	125a	282
Application, lb/ton of 35% DM foragec	7	± 25a	10-12b

aVaries based on specific product.

bDo not add urea to forage over 45% DM.

cApplication rate should vary depending on forage DM. Higher amounts should be applied to drier forage. In all cases, the desired application rate is 5-6 lb of N per 700 lb of forage DM. i.e. 5-6 lb/ton at 35% DM; 4.3 to 5.1 lb/ton at 30% DM; 5.7-6.9 lb/ton at 40% DM.

Anhydrous ammonia should not be added to corn forage if the DM content is above 40-42% because fermentation is restricted in drier material and binding of ammonia will be less; thus normal fermentation may be disrupted. In instances where forage DM is above 40-42%, water-ammonia mixes or molasses-ammonia mixes should be used. Application for molasses-ammonia mixes should be as recommended by the manufacturer.

Ammonia is a hazardous gas and should be handled with care. Eye protection should be worn when making connections to pressurized tanks. Water should be available at all times. Ammonia is also corrosive to zinc, copper and brass. Therefore storage of ammonia-treated forage in zinc coated steel silos is not recommended.

Problems with hyper-irritability (bovine bonkers syndrome) in cattle fed ammoniated forages has not been observed in cattle fed ammoniated corn forages. Addition of ammonia to corn silage has no effect on nitrate levels in corn silage (Li

et al., 1992)

CONCLUSIONS

Silage additives can be useful tools to improve silage quality and animal performance, however, they are not replacements for good management practices. Care should be taken when choosing a silage additive. Users should ask for proof of claims that are usually in the form of published scientific articles that have undergone peer review.

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