Silage Inoculation

Inoculation of Silage and its Effects on Silage Quality

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Introduction

Ensiling is a principal means of storing forages for consumption by livestock. There were over 85 million tons of alfalfa and alfalfa mixtures and 65 million tons of other forages produced in the United States in 1990 (USDA, 1991). Assuming that a third was stored as silage, approximately 50 million tons of legumes and grasses were ensiled. In addition, approximately 95 million tons of whole plant corn silage were made. As a result, a small reduction in losses or improvement in feed value could easily be worth $100 million annually to farmers.

A wide variety of silage additives are marketed to improve silage quality. In the US, the principal additive is the bacterial inoculant. This type of additive supplements the natural lactic acid bacteria on the crop to help guarantee a fast and efficient silage fermentation.

At the Dairy Forage Research Center, considerable effort has been devoted to understanding how and when inoculants will be beneficial in making silage, particularly alfalfa silage. This paper will talk in general about what inoculants should do and when should farmers use them, highlighting contributions made by the Center.

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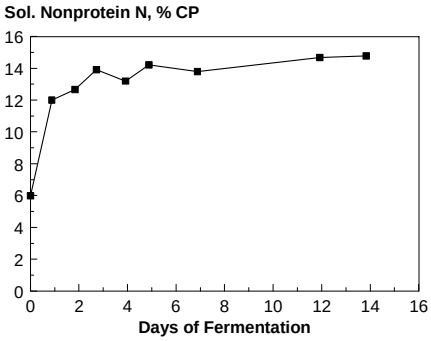

Figure 1. Typical change in soluble nonprotein nitrogen in alfalfa silage at 35% DM (Muck 1987).

"Plant respiration is useful in that it removes oxygen from the silo, creating an anaerobic environment."

What Changes in Quality Occur During Normal Ensiling?

Before talking about inoculants, it is important to know something about the typical changes that occur to a crop during ensiling. This will help us understand in what ways an inoculant might be able to improve silage quality.

In general, the crop is preserved in the silo by two factors: an anaerobic (oxygen-free) environment and a low pH. The former prevents the growth of spoilage microorganisms which need oxygen, and the latter primarily inhibits detrimental anaerobic microorganisms and plant enzyme activity. After the silo is sealed, an anaerobic environment is normally created by plant respiration, which consumes oxygen, whereas the low pH occurs because lactic acid bacteria on the crop ferment sugars to lactic acid. These two processes alone do not provide an adequate picture of the changes occurring in the crop. When the crop is placed in the silo, three general classes of processes are active: plant, microbial and chemical.

Plant Processes

Normally, the plant material is still biologically active at ensiling, and many plant enzymes may be affecting forage quality. There are three categories of plant activity that are particularly important relative to silage quality: respiration, protein breakdown (proteolysis), and hemicellulose breakdown (hemicellulase activity).

Respiration is the process by which plants obtain energy for growth and maintenance. Sugars are the principal compounds which are respired. The process also requires oxygen and produces carbon dioxide, water and heat. Plant respiration is useful in that it removes oxygen from the silo, creating an anaerobic environment. However, excessive respiration is undesirable because it reduces the energy content of the silage, may lead to excess heating and may not leave enough sugar for fermentation by the lactic acid bacteria. Such problems arise from poor management practices such as slow filling of the silo and/or inadequate sealing of the silo.

Once the silo is anaerobic, many of the plant cells will rupture or lyse within a few hours. The lysing releases many enzymes including proteases (which break down proteins to soluble nonprotein fractions) and hemicellulases (which break hemicellulose into its component sugars). Inhibiting the action of the proteases is important in legumes and many grasses with high crude protein contents. Nagel and Broderick (1992) at the Center found that dairy cows fed alfalfa silage with a higher true protein content produced more milk than cows fed alfalfa silage with lower protein content even though total nitrogen (or crude protein) contents of the diets were similar. Protease activity is reduced by low pH (~ 4.0). However, because most protease activity occurs in the first 48 h in the silo (Fig. 1), control of proteolysis is difficult except by use of acid or chemical silage additives.

Hemicellulase activity appears to be important only in grasses (Jones et al. 1992a). It can reduce neutral detergent fiber (NDF) content 1-2 percentage units in grass silage. Similar to proteases, their activity declines rapidly over the first week of storage. However, their activity is less sensitive to pH (Dewar et al. 1963).

Microbial Processes

There is a great diversity in the microorganisms active on a crop in a silo. The principal anaerobic microorganisms in silage are the lactic acid bacteria (LAB). These bacteria include the four genera: *Lactobacillus, Pediococcus, Enterococcus* and *Leuconostoc*. Their common characteristics are that they primarily ferment sugars to lactic acid and that they grow best under anaerobic conditions. Their fermentation is the main mechanism by which crop pH is lowered and subsequently detrimental anaerobic bacteria are inhibited. Species and strains vary in 1) the amount of other products such as acetic acid and ethanol (alcohol) that they produce when growing on various sugars, 2) their tolerance for growing when oxygen is present, and 3) the types of compounds

that they will ferment. Some LAB will ferment amino acids to ammonia and/or amines. Traditionally, LAB that grow solely on sugars producing just lactic acid (homofermenters) have been favored because lactic acid is a stronger acid than acetic and because dry matter (DM) losses and energy losses are greater with many of the pathways producing acetic acid and ethanol.

The most detrimental anaerobic bacteria in the silo are clostridia. Some of the clostridia ferment lactic acid and sugars to butyric acid. Others ferment amino acids to ammonia and amines. Many of these fermentation pathways lead to significant DM and energy losses. In addition, poor animal intake is associated with silages with clostridial fermentation. Clostridia are inhibited by low pH. For typical silages in the US with moisture contents less than 70%, a pH below 5.0 normally will inhibit clostridial growth.

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The other major anaerobic bacterial group are the enterobacteria. These bacteria ferment sugars producing mainly acetic acid and creating higher DM and energy losses from the crop than the LAB. While lowering the pH some, acetic acid will buffer silage pH in the high 4's, resisting a further decline in pH. These bacteria are generally inhibited at pHs below 5.0.

When oxygen is present, spoilage microorganisms including yeasts, molds and various aerobic bacteria (bacilli, acetic acid bacteria, and listeria) may thrive on plant sugars, fermentation products and other compounds released by plant cells cut or ruptured during harvest and storage. These microorganisms will use up much of the highly digestible portion of the crop if allowed to grow unchecked. Reducing pH below 5 will slow many bacilli and stop listeria. However, many of the yeasts, molds and acetic acid bacteria thrive at typical silage pHs (4 to 5) so that the only practical means of preventing their growth is maintaining an anaerobic environment. Fermentation products such as acetic, propionic and butyric acids are inhibitory to the yeasts and molds. The acetic acid bacteria are more inhibited by lactic acid. Unfortunately, levels of these fermentation products usually are insufficient to prevent yeast, molds and acetic acid bacteria from growing. Yeasts and acetic acid bacteria growing on lactic and acetic acids will cause silage pH to increase. Once silage pH is raised, the other aerobic microorganisms can grow rapidly on the other remaining substrates. Further complicating the picture, some yeasts and bacilli can grow anaerobically, fermenting sugars to ethanol and other products. This may create high levels of these organisms, even with good silo management, that may be ready to spoil the silage when oxygen enters the silo during emptying.

Chemical Processes

Finally, two chemical processes (Maillard reactions and acid hydrolysis of hemicellulose) can affect silage quality. Maillard reactions are commonly referred to as browning reactions. Sugars react with amino acids, releasing heat and forming large molecules that are slowly digestible. The rate of this chemical reaction is slow and does not substantially affect silage quality when temperatures are below 100 °F. However, the rate increases with higher temperatures, and under such circumstances Maillard reactions can substantially reduce silage digestibility. Under extreme conditions, the heat given off by the process can raise silage temperatures to the point of starting silo fires in dry silages (< 40% moisture).

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Acid hydrolysis of hemicellulose is a slow chemical breakdown of hemicellulose in the plant cell wall caused by interaction with the hydrogen ions in the silage. The lower the pH the higher the hydrogen ion concentration and the faster the rate of hydrolysis. However, under normal silage pHs, rates are slow and would reduce NDF content less than 0.5 percentage units.

What are Inoculants and How Would We Expect Them to Affect Ensiling?

Inoculant Strains

As mentioned earlier, inoculants are silage additives that supply lactic acid bacteria to the crop to guarantee a fast

and efficient silage fermentation. The most common lactic acid bacterial species in inoculants is *Lactobacillus plantarum*. However, many inoculants contain more than one species or may contain several strains of the same species. Other common species are *Enterococcus faecium*, various *Pediococcus* species and other *Lactobacillus* species. Multiple strains are not necessary in an inoculant but may be beneficial in several ways. Often several strains that grow better at different pHs are contained in a product so that a rapid fermentation is ensured over the range of pHs in silage (~ 6.0 to 4.0). Multiple strains also may be used to improve inoculant performance over a range of crops, moisture contents and/or temperatures. The strains of LAB used in silage inoculants generally have been isolated from crops and silages. They have been selected from the natural population primarily because they grow rapidly and are homofermentative. Based on the nature of homofermentative LAB, we can speculate how inoculants should affect fermentation and silage quality. The expected effects are as follows.

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Effects on Fermentation

The principal effects of inoculants on silage should be an increase in the rate of fermentation and a shift in the products of fermentation. If the inoculant LAB dominate the fermentation, their fast growth rate should cause pH to begin to decline sooner. Lactic acid concentrations relative to acetic acid and ethanol should be increased. Because lactic acid is a stronger acid than acetic, pH should drop more rapidly, and successful inoculation should produce a lower final pH. This should occur for two possible reasons. Inoculants typically contain LAB that can thrive at low pHs so that fermentation can continue to a lower pH before the LAB are unable to grow. However, even in fermentations which are limited by sugar, the shift from acetic acid to lactic should drive pH lower.

Effects on Silage Quality

The shift in fermentation products should also produce improvements in dry matter recovery, as shown in Table 1. Homofermentative fermentation of sugars should result in no dry matter loss whereas losses from heterofermentation can be significant. Overall, one might expect an inoculant to produce a 1 to 3% improvement in dry matter recovery. On the other hand, Table 1 indicates that an inoculant should not significantly affect gross energy loss from the silage. In fact, uninoculated silage may be somewhat more energy dense because of the higher dry matter losses.

Other areas of silage quality would be expected to be less affected. A more rapid decline in pH should have some small effects in terms of protecting true protein. Inoculant LAB should not grow on amino acids plus they should overwhelm microorganisms that do, resulting in lower ammonia concentrations. Fiber content is unlikely to be affected. A faster drop in pH may reduce enzymatic breakdown in hemicellulose whereas a lower pH would increase acid hydrolysis of hemicellulose. So net effects should be small.

Inoculants based on homofermentative LAB should have variable effects on aerobic stability (time until a silage heats in the feed bunk or bunk life) of silages. This initial heating or spoiling of silage is most often initiated by yeasts and sometimes by acetic acid bacteria. As mentioned earlier, yeasts are inhibited by volatile fatty acids such as acetic, propionic and butyric acids, and the degree of inhibition increases as pH is lowered. Consequently, if the inoculant decreases acetic acid levels, aerobic stability may be reduced. However, this may be counteracted by a sufficient decrease in pH. Acetic acid bacteria are more affected by high lactic acid concentrations so that an inoculant may help to inhibit these microorganisms.

Table 1.
Dry matter and gross energy losses for typical lactic acid bacterial fermentation pathways (McDonald 1981).

Pathway	DM Loss, %	Energy Loss, %
Homofermentative		
glucose + 2 ADP ® 2 lactate + 2 ATP	0.0	0.7
fructose + 2 ADP ® 2 lactate + 2 ATP	0.0	0.7
Heterofermentative		
glucose + ADP ® lactate + ethanol + CO_2 + ATP	24.0	1.7
3 fructose + 2 ADP ® lactate + acetate + 2 mannitol + CO_2 + ATP	4.8	1.0

An additional factor is that most spoilage microorganisms grow faster and prefer to grow on sugar rather than fermentation products. So if an inoculant increases the residual sugar content, aerobic stability may be reduced. Consequently, aerobic stability could be improved or worsened by inoculant use, depending on the relative shifts in final pH, lactic acid, acetic acid and sugar contents.

Effects on Animal Performance

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Finally, inoculants would be expected to have small, positive effects on animal performance. Of the main fermentation products (lactic acid, acetic acid and ethanol), lactic acid is best utilized by rumen microorganisms whereas acetic acid is not fermented and is absorbed directly across the rumen wall. Thus there should be a small improvement in rumen microbial growth and subsequent capture of microbial protein in the gut. There is also some evidence that acetic acid and ethanol may have a negative effect on palatability and intake. Small changes in nitrogen form (less ammonia, more protein and peptides) by inoculation could help nitrogen retention by the animal. Lastly, by overwhelming or inhibiting other microorganisms in the silage, the inoculant may inhibit the production of toxins and thus have a positive effect on the rumen environment. All together, inoculants should improve animal performance 1% or less.

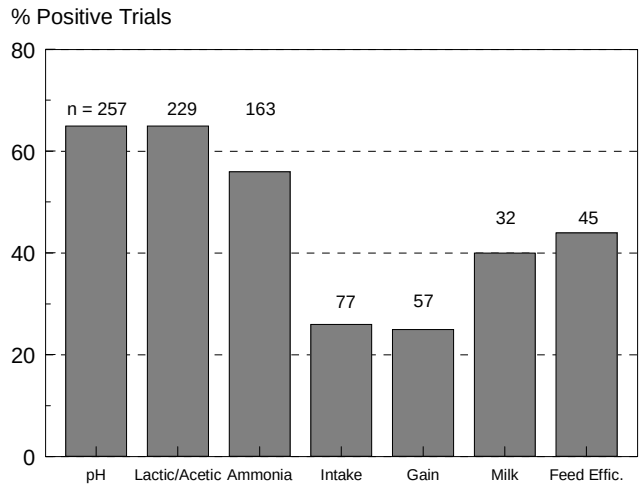

Figure 2. Percentage of trials in published research (1985-1992) where silage inoculants signficantly improved fermentation or animal performance. Number of trials per characteristic is above each bar (Muck 1993).

How Have They Performed?

In 1993, we reviewed published reports of inoculant studies between 1985 and 1992. These studies were primarily performed in North America and Europe on legume, grass and corn silages. Figure 2 shows the summary of inoculant effectiveness in all trials reviewed. Not surprisingly, inoculants were most successful in altering fermentation. The lactic:acetic acid ratio was increased and pH decreased in approximately two-thirds of the cases. Inoculants were less effective in improving fermentation in corn silage (40% of cases) than in alfalfa (75%) or grass silages (71%). Ammonia nitrogen was reduced in more than half of reported cases. Overall, the inoculants were reasonably successful in improving fermentation, particularly in legume and grass silages.

Inoculants did not improve other areas of silage quality or performance as consistently with the exception of dry matter recovery. Dry matter recovery improved in approximately 60% of the cases, and where improvement occurred, recovery increased by 2 to 3 percentage points. As expected, inoculation improved aerobic stability in less than half the cases and reduced it in some.

Animal performance significantly improved in 25 to more than 40% of the cases depending on the parameter measured (Fig. 2). Feed efficiency improved most often whereas intake and liveweight gain improved the least. When statistically significant improvements were observed, the levels of improvements were substantial: 11, 11, 5 and 9%, respectively, for dry matter intake, average daily gain, milk production and feed efficiency. Over all trials, the average improvement in animal performance is on the order of 2 to 4%, clearly greater than would be anticipated from shifts in fermentation products.

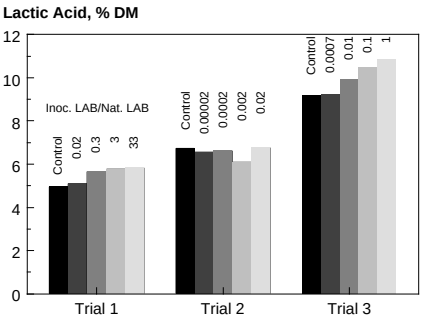

Figure 3. Lactic acid concentration in alfalfa silages from 3 trials as related to the ratio of inoculant LAB to the natural, acid-tolerant LAB population (Muck 1989).

When Will Inoculants be Successful?

We will consider two areas: effects on fermentation and effects on animal performance. Work at the Center has contributed to both areas, particularly regarding use of inoculants on alfalfa.

Improving Fermentation

As indicated earlier, inoculants are not always successful in improving fermentation. It appears that there are five possible causes for failure: high natural LAB population, a natural population that does an equally good job of fermentation, low sugar content, activity of the inoculant bacteria and phage activity.

The most likely cause for an inoculant failing to improve fermentation is a high natural LAB population relative to the level being applied by the inoculant. We performed three trials in alfalfa silage where we varied the level of LAB inoculant. When the LAB supplied by the inoculant was at least 10% of the natural, acid-tolerant LAB population, lactic acid concentration increased (Fig. 3) and the rate of pH decline was more rapid. At inoculation rates below 10%, there were minimal or no improvements in fermentation. These results indicate that a good inoculant can overwhelm a much larger natural population; however, there is a limit to how much lower the inoculant LAB popoulation can be and still have an effect. Obviously the actual value in a particular situation will depend on the prevalent natural strains and the characteristics of the inoculant strains. Generally, inoculants have been less successful on corn than grasses and legumes (Muck 1993). This may be due to the higher natural LAB populations on corn compared to those on grasses or legumes.

Another, but less likely, cause for the inoculant failing to improve fermentation is that the natural LAB performed an equally good job of fermentation as the inoculant LAB. This is certainly possible because inoculant LAB have come from the natural environment. However, it is almost impossible to prove that this has occurred.

A third possible cause is a low sugar content. Because sugar is the principal food for LAB, low sugar levels may prevent the inoculant LAB from substantially changing final silage quality even though the initial rate of pH decline may have improved. In other words, the opportunity to enhance fermentation is limited by the lack of food for the LAB. We have observed this particularly in alfalfa (Table 2), which tends to be relatively low in sugar content compared with other silage crops.

Another factor is the interaction of the inoculant LAB strains with the crop. Hill (1989) found that when three strains of *L. plantarum*, one isolated from alfalfa, corn and sorghum, were co-inoculated on these three crops, the dominant strain in each silage was the one isolated from the same crop. This suggests, for example, that an inoculant developed for alfalfa may or may not be as competitive on grass or corn. This factor has been most clearly seen in the failure of silage inoculants developed for forages when used on whole-crop wheat silage even though inoculation rates were more than 10 times the natural LAB populations (Weinberg et al. 1988).

A final factor is bacteriophages. Phages have been a concern for a long time in the production and use of LAB inoculants for the food processing industry. However, only recently has anyone looked for potential problems in silage. Tanaka et al. (1995) in Japan found that 25% of the ryegrass silages analyzed contained bacteriophages and that *L. plantarum* strains were often affected by the phages. This suggests that phages could be a factor in inoculant failures when other conditions would indicate that the inoculant should have been successful.

Table 2.
Effect of inoculant and sugar treatments on alfalfa silage at 33% DM (Jones et al. 1992b).

Parameter	Control	Sugar	Inoculant	Inoc + Sugar
pH	4.38	4.17	4.22	4.05
Lactic Acid, % DM	8.97	10.44	9.95	10.95
Acetic Acid, % DM	2.14	1.78	1.16	0.81

Improving Animal Performance

All of the factors which influence inoculant performance in terms of fermentation also would be expected to affect

Table 3.
Milk yield response to inoculated silage relative to the control (Satter et al. 1988).

Ratio of LAB (Treated/Control)	Milk Yield (% of Control)
151	101.5
140	106.2
110	103.0
46	100.0
36	100.4
18	102.2
11	108.0
8	97.8
7	100.7
6	99.6
4	98.5
1	100.0
1	98.5

"These results strongly suggest that a silage inoculant's effects on animal performance cannot be ascertained or surmised by the inoculant's effectiveness on fermentation."

animal performance. However, of these, there is only reasonable evidence to suggest that the natural LAB population is related to an inoculant's improvement of animal performance. Work at the Center (Satter et al. 1988) has studied the animal response to inoculated silage. As shown in Table 3, milk yield responses were observed only when the inoculation rate was at least 10 times the natural, acid-tolerant LAB population. At rates above a 10-fold increase, milk yield was improved 3% on average. These results indicate that a higher level of inoculation is needed to obtain an animal performance effect than is needed for improving fermentation.

In reviewing inoculant studies, it is apparent that effects on animal performance are not consistently linked with effects on fermentation. First, as indicated earlier, animal response to inoculated silage often appears to be much greater than would be expected from shifting fermentation products and lowering pH. Second, Muck (1993) found that in the review of 1985-1992 studies that dry matter and fiber digestibilities were improved in 55 and 30% of the cases measured. The improvement in fiber digestibility was particularly puzzling because inoculant LAB cannot degrade polysaccharides. That review also noted that when DM digestibility improved, animal performance improved in 9 of 16 cases, whereas animal performance improved in only 2 of 15 cases when DM digestibility was unaffected by the inoculant. A final piece of evidence is a summary of grass silage studies using an inoculant containing a single strain, *L. plantarum* MTD1 (Weinberg and Muck 1996). As shown in Table 4, animal performance effects with this inoculant appear to be independent of effects on fermentation and on digestibility. In fact, in one study, three LAB strains were tested. All three improved fermentation in a similar manner, but only MTD1 improved DM intake with respect to the control.

These results strongly suggest that a silage inoculant's effects on animal performance cannot be ascertained or surmised by the inoculant's effectiveness on fermentation. How is it possible for fiber digestibility to be improved by an inoculant? Is the lower pH causing more acid hydrolysis of hemicellulose and opening up the fiber for rumen microbial attack? Are certain inoculant LAB strains causing a beneficial effect on the animal or rumen microorganisms? Are the inoculant strains producing bacteriocins that are inhibiting some microorganisms and shifting rumen microbial ecology? These important questions need to be answered in order to really know how inoculants affect animal performance and how these products could be made even more effective.

How Can We Maximize the Benefits from Inoculant Use?

Profitability in using inoculants could be enhanced if farmers knew when the natural LAB population was higher than the level applied by the inoculant they were going to use. Then application could be limited to those circumstances when an inoculant is most likely to benefit the farmer. Unfortunately, the standard method for determining LAB numbers takes approximately 2 days, far too late to help a farmer make a decision.

In the mid-1980s, we began to study the numbers of acid-tolerant LAB on alfalfa prior to ensiling. We found low levels of LAB on standing alfalfa and immediately after mowing. After chopping, numbers varied widely [100 to 10,000,000 colony-forming units (CFU)/g crop]. However, trends were apparent in the data. When alfalfa was wilted one to three days prior to chopping, LAB counts were higher under slow drying conditions and/or high temperatures. We developed equations to predict natural

Table 4.
Studies with *L. plantarum* MTD1 inoculant applied to grass silages: interaction of effects on animal performance with effects on fermentation and digestibility (Weinberg and Muck 1996).

		Fermentation Improvement		Digestibility Improvement	
		No	Yes	No	Yes
Animal Performance	No	1	1	0	1
Improvement	Yes	3	5	3	2

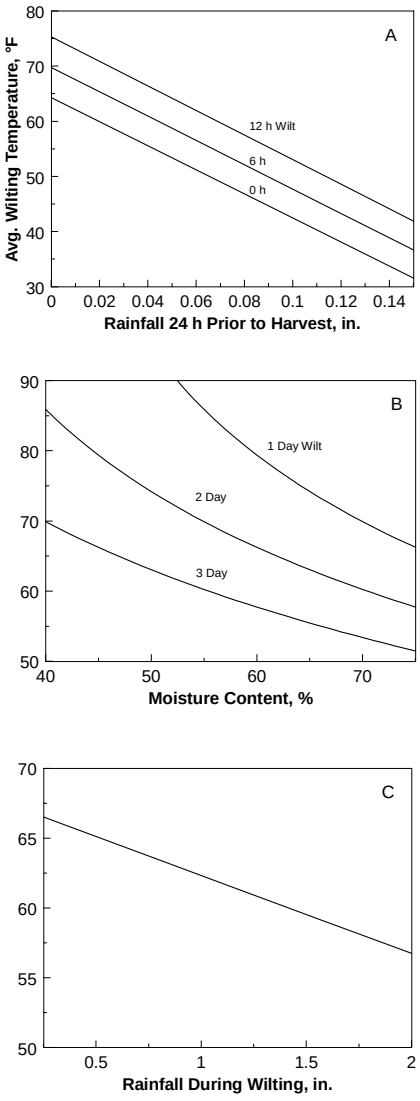

Figure 4. Conditions (area beneath lines) in which an inoculant applied at 10^5 CFU/g to alfalfa at ensiling is cost effective. a) wilting < 24 h, b) wilting 1 to 3 days, c) wilting ≥ 3 days (Muck 1991, Pitt and Muck 1995).

LAB populations on alfalfa at ensiling after 1 to 3 days of wilting based on two years of data at our research farm (Prairie du Sac, WI). These equations proved successful in predicting LAB counts in subsequent field measurements over 3 years at our research farm and over 2 years at 5 other farms in Wisconsin.

More recently we collaborated with Dr. Ronald Pitt of Cornell University to test these equations under New York conditions. The equations were successful, but the majority of the field results could not be predicted because wilting times and environmental conditions were outside those used to develop the original equations. This led to the development of equations to predict LAB numbers on alfalfa mown and harvested the same day as well as alfalfa wilted more than 3 days. As a result, we now can reasonably predict LAB counts on alfalfa entering a silo over the wide range of conditions that might occur in the northern midwest and northeastern areas of the US.

In collaboration with Dr. Pitt, we have used these equations to develop graphs that farmers can use to determine when inoculants will be profitable on alfalfa. Graphs based on an inoculant providing 10^5 CFU/g crop, costing $1/ton and improving animal performance 3% when successful are shown in Fig. 4. Average air temperature and rainfall for the 24 h prior to harvest is needed for less than 24 h of wilting. For the other wilting times, average air temperature during wilting is needed plus either moisture content at harvest or wilting rainfall. Average air temperatures can be obtained by averaging daily highs and lows.

As an example, assume that the alfalfa was chopped at 60% moisture, that the average wilting temperature was 70°F, and that the crop was not rained on during wilting. Whether an inoculant is profitable will depend then on the length of wilting. For 6 or 12 hour of wilting (Fig. 4a), one would be at or below the line, respectively, and an inoculant would be profitable. Similarly for a 1 day wilt (Fig. 4b), an inoculant would be beneficial. However, at 2 or 3 days of wilting, conditions are above their respective lines, and using an inoculant would not be profitable.

These graphs provide farmers with the first practical tool for determining when inoculants will be the most profitable on alfalfa. Once the farmer uses this method for a while, he or she will recognize times when inoculant use is warranted without calculating average air temperatures and/or moisture contents. Consequently, the process will not be as laborious as may seem at the outset.

Similar graphs should be possible for other forage crops although no one is doing such work at this time. Work on corn would be particularly valuable but will most likely take 10 years or more of effort because of the short harvest time relative to that for legumes and grasses.

Is There Room for Improvement?

Inoculants are not a panacea for improving silage quality. One area that inoculants have not consistently provided benefits is in improving bunk life. Particularly in small grain and corn silages, inoculants have sometimes caused the silages to be more susceptible to heating in the silo and feed bunk. Considerable work is ongoing by inoculant manufacturers and the public sector to develop inoculants that improve silage stability during emptying. A variety of bacteria are being investigated including propionic acid bacteria and lactic acid bacteria.

The propionic acid bacteria have been some of the first bacteria explored because propionic acid is a good inhibitor of yeasts and molds. However, so far, these bacteria have not been particularly effective in forage silages because the lactic acid bacteria generally cause the pH to drop too rapidly for the propionic bacteria to become established.

Currently, work is ongoing at the Center relative to finding lactic acid bacteria with unique properties to enhance bunk life. We have established two Cooperative Research and Development Agreements with industry: one to test an organism that we isolated which has promise in improving bunk life and another to

look for lactic acid bacteria with specific anti-microbial activity. We are hopeful that these collaborative research projects will result in improved strains for the inoculant industry.

Another area of importance for the US market is that of understanding the mechanisms by which inoculants improve animal performance. As stated earlier, improvements in fermentation should provide some benefit in terms of animal performance but do not appear to explain the whole effect observed with some inoculants. Research to uncover potential mechanisms influencing fiber digestibility and animal performance are important in developing inoculants that further enhance animal productivity. This could perhaps lead to specific products that could target enhanced milk production or increased rates of liveweight gain.

Summary

Silage inoculants have been and will continue to be additives that are useful in improving silage quality. These additives have been successful in improving the rate and products of fermentation so that dry matter recovery and often animal performance are enhanced. The Center has been instrumental in determining when these products will be efficacious both in improving fermentation and animal performance. We have also helped develop techniques that will allow farmers to know when these products will be profitable on alfalfa. Finally, efforts to develop inoculants that will improve bunk life and animal performance are needed. Current efforts at the Center are focusing on finding strains that will improve the bunk life of silages.

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