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### **Strategies for Improving the Aerobic Stability of Silages**

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#### **INTRODUCTION**

Many factors affect the silage fermentation process. For example, the DM content and buffering capacity of the crop to be ensiled, the amount of fermentable sugar available at ensiling and the type and numbers of microorganisms that dominate the fermentation process can markedly affect fermentation. However, Woolford (1990) stated that "the single most important factor which influences the efficiency with which forage crops are conserved as silage is the degree of anaerobiosis achieved in the completed silo". Rapid removal of air from the forage mass and the ability to prevent air from infiltrating the silage mass during storage and feedout can have profound effects on feed quality. Excessive exposure to air at the start of fermentation prolongs the metabolism of unwanted microbes that thrive in air and delays the growth of beneficial bacteria that produce lactic acid. This can lead to undesirable fermentations and a loss in nutritive value. Prolonged infiltration of air during storage or feedout into the silage mass can lead to aerobic spoilage. Silage that is unstable when exposed to air heats rapidly and spoils leading to a loss of DM and nutrients with the potential for production of undesirable compounds. Aerobic spoilage during storage often is responsible for the majority of total DM lost in forage conserved as silage and may be as high as 30-40%. Even short term exposure to air results in losses. For example, DM losses from corn silage exposed to air for just 1 to 2 d was measured to be as high as 6% (Ranjit and Kung, 2000). In addition, much of the readily spoiled DM is of high quality. Besides an economic loss of nutrients, feeding spoiled silage to ruminants depresses nutrient intake and decreases production (Hoffman and Ocker, 1997; Whitlock et al., 2000). Preventing silage from spoiling when it is exposed to air can improve the efficiency of a farm by preserving forage as high quality silage that is palatable to cows.

## AEROBIC STABILITY

Aerobic stability is a term that nutritionists have used to define the length of time that silage remains cool and does not spoil after it is exposed to air. When fermentation is completed, and silage is exposed to air during feedout or during storage (e.g., leaky silos, holes in bag silos, poorly packed silage), heating in the silo and feed bunk is usually initiated by yeasts (and to a lesser extent sometimes by some bacteria). Exposure to air is the first domino to fall that causes a chain reaction ultimately resulting in spoiled feed (Figure 1). Specifically, yeasts that degrade lactic acid in the presence of air are the primary microbes that cause spoilage in silages. The major species of these yeasts include those of *Candida*, *Hansenula*, *Pichia*, *Issatchenkia* and *Saccharomyces* (Woolford, 1990, Inglis et al., 1999). Degradation of lactic acid also increases the pH of the silage to a level that allows opportunistic bacteria (e.g. *Bacilli*) and molds (e.g. *Aspergillus*, *Fusarium*, and *Pencillium*) to grow and further reduce silage quality (McDonald et al., 1991). In some cases bacteria from the genus *Acetobacter* may initiate aerobic spoilage in corn silages but their role is less understood (Muck and Pitt, 1994). An important point to remember is that silages may be exposed to air days, weeks, or months prior to actual feeding.

### **Silages**

When animals consume spoiled silages, the exact causes of reduced intake and/or performance are not fully understood. Nevertheless, feedback from the field suggests that producers often have problems when the numbers of yeasts are more than  $10^6$  (1,000,000)/g of silage. Under optimum conditions, yeasts can double in number in about 2 h. Let's take a scenario where a sample of corn silage starts with 100,000 yeasts per gm, which is quite normal. That sample could contain 1,600,000 yeasts per gm in 8 hours! Thus it is evident that silage can spoil rapidly when exposed to air under warm conditions. Detrimental yeasts may produce end products that might alter rumen fermentation, the direct consumption of spoiled nutrients may reduce performance, and the production of undesirable end products (e.g. mycotoxins) from further spoilage by molds and other organisms may also be a problem. Effects on immune function may occur.

Some general relationships between variables that make a crop more or less prone to aerobic instability are shown in Table 1. For example, crops with a high concentration of starch and sugar will have a tendency to have more yeasts. Thus, high moisture corn followed by corn silage can be very prone to spoilage when conditions are right. Some fermentation end products are more antifungal (inhibit the growth of yeasts and molds) than others. Although high concentrations of lactic acid are highly desirable because it drops the pH of silage quickly, it has poor antifungal attributes. Acetic and propionic acids are good antifungal acids (Woolford, 1975) whose concentrations can be increased via chemical addition or via specific microbial inoculants (to be discussed later). It should be noted however, that high concentrations of acetic acid produced via "wild-type" pathways may be less desirable than if it were produced via "controlled" pathways (e.g. from controlled inoculation with *Propionibacteria* or *Lactobacillus buchneri*). Ironically, one of the most antifungal acids produced is butyric acid! This end product of clostridial fermentation is very

active in inhibiting the growth of yeasts but is certainly not something we should strive for in our silages because of the other detrimental factors that are associated with this type of fermentation (i.e. large dry matter loss and protein degradation). Ammonia also has good antifungal activity but it is doubtful that natural concentrations of this compound affects populations of yeasts in silages (see later discussion on ammonia additives). Because many silages undergo more extensive fermentations that tend to result in higher concentrations of acetic, propionic, and butyric acids when they are high in moisture (Ward, 2000), these silages tend to be more stable when exposed to air than their drier counterparts. Conversely, because drier silages undergo a restricted fermentation and have lower acid end products, they often are more prone to aerobic spoilage. When there is a lack of adequate water activity in a harvested crop, even yeasts are unable to grow and the dry forage is stable (this is why dry hay does not spoil). Any condition (e.g., tears in silo bags, insufficient weight to keep the plastic down on silos, etc.) or practice (e.g., poor pack density, poor bunker face management, etc.) that allows for more penetration of air into the silo mass may also result in the proliferation of yeasts and increase aerobic instability. For example, Dickerson et al. (1990) reported that in the top 20 inches of silage, DM losses were 27 and 41% in a survey of uncovered and covered bunker silos, respectively. Ruppel (1990) reported that tighter packing densities of bunker silos were related to less total DM loss in these silos. Harvesting forages at optimum moisture levels (not too dry), correct particle size (not too long), filling and sealing quickly and feeding out adequate amounts of silage from the silo each day will help to minimize silage's exposure to air. Clean and efficient removal of silage from the face of bunkers and bag silos will also help to minimize spoilage because this minimizes infiltration of air into the silage mass. Warm weather is also stimulatory to microbial growth so aerobic spoilage is usually a larger problem during the summer months.

#### **Total mixed rations (TMR)**

Because silages are often incorporated into TMR, the stability of the TMR may also be an issue on many farms. In a small survey of TMR sampled in DE, PA and MD over two years, more than 50% of 30 TMR that were sampled within 1 hour of being made spoiled in less than 12 h when incubated at a controlled laboratory temperature of about 72°F (Kung, Mulrooney and Morges, unpublished data Univ. of Delaware). On these farms, TMR had the potential to spoil in the feed bunk even if these farms were feeding twice daily. Additionally, the sampled TMR would have spoiled even quicker if they were incubated at the ambient temperatures encountered during an average summer day (high 80 to 90 °F). The numbers of yeasts were generally greater and the aerobic stabilities of the TMR were generally shorter than that usually observed in laboratory silages alone. The reason for this was probably because silages used to make the TMR had more than likely already gone through some degree of aerobic exposure and spoilage before being mixed into the TMR. The relationship between numbers of yeasts in the TMR and aerobic stability in that study is shown in Figure 2. By products, e.g. wet distiller's grains, may be a source of spoilage yeasts and molds when incorporated into a TMR and reduce aerobic stability.

## IMPROVING AEROBIC STABILITY VIA SILO MANAGEMENT

The keys to making quality silage are to 1) rapidly exclude air from the forage mass, which will result in 2) a rapid production of lactic acid and reduction in silage pH, and 3) to prevent the penetration of air into the silage mass during storage. Excessive air, due to slow silo filling or poor packing (overly dry forage or forage chopped too coarsely) allows the plant to respire for prolonged periods of time. This results in utilization of sugars and excessive degradation of plant protein. Air also encourages the growth of undesirable microbes such as yeasts and molds.

Air can be eliminated by fast filling (but not too fast), even distribution of forage in the storage structure, chopping to a correct length and ensiling at recommended dry matters (DM) for specific storage structures. Bunk and pile silos should be filled as a progressive wedge to minimize exposure to air and packed in 6 to 8 inch layers. The recommended optimal packing density for bunk silos is 14 - 16 lbs. of dry matter per cubic foot (Ruppel et al., 1995). Silage corers can be obtained from several commercial sources. An Excel spreadsheet can be downloaded from the University of Wisconsin Extension web site that helps with bunker silo filling ([www.uwex.edu/ces/crops/uwforage/storage.htm](http://www.uwex.edu/ces/crops/uwforage/storage.htm)). Users can input silo dimensions, tractor weight, forage delivery rate, forage dry matter, and packing time to estimate packing density. In several recent surveys of bag silos, packing densities are more commonly between 9 to 12 lb of DM/cu ft. Silage in bags should be packed tightly by monitoring the stretch marks on the bags. Tunnel extensions on older units can be added to increase pack density. Silo bags should be vented for about 3 days to rid the bags of excess gas.

After filling silage should be covered with plastic as soon as possible and weighted down with tires (tires should be touching) or gravel bags to exclude air. Split tires are good alternative because they are easier to handle, do not accumulate water (thus less breeding grounds for mosquitoes that could carry the West Nile Virus), and are undesirable for animals to nest in. The return on investment (labor and plastic) is extremely high for covering bunk and pile silos (Bolsen et al., 1993). Oxygen barrier plastics are also now available for use (Borreani et al., 2007).

Proper management for removal of silage from silos and management at the feed bunk can help producers to maximize profits and production. Enough silage should be removed between facing to minimize aerobic spoilage. Lesser amounts may be removed in areas of the country where ambient temperatures remain cool during the winter months. Removal of silage should be such to minimize loose silage on the ground between feedings. Hot, moldy feeds should not be fed because they are low in nutritive value and digestibility and depress intakes. Feed bunks should be kept full but clean of decaying feed. Face shavers are becoming popular but more research is needed to prove their benefit. Extreme care should be taken to prevent air from penetrating between the plastic and reaching the silage mass during feedout and this can be accomplished by stacking tires or lining gravel bags on the plastic at the leading edge of the feeding face (Figure 4).

## IMPROVING AEROBIC STABILITY WITH ADDITIVES

### **Chemical additives**

Various chemical additives with antifungal properties have been used to enhance the aerobic stability of silages. Buffered propionic acid-based products are generally non-corrosive and safe to handle. Undissociated propionic acid has strong antifungal properties, and the fraction of propionic acid that is undissociated is dependent on pH. At the pH of a standing crop, about 6, only about 1% of the acid is in the undissociated form whereas, at a pH of 4.8, about 50% of the acid is undissociated. The undissociated acid functions both by staying active on the surface of microorganisms and competing with amino acids for space on active sites of enzymes and by altering the cell permeability of microbes. Application of buffered propionic acid-based products ranges from about 1 to 6 lb/ton of forage. The efficacy of low application rates is questionable. For example, if we added 2 lb of a product that contained 65% propionic acid to 35% DM corn silage, this would increase the propionic acid content in that silage by 0.18% on a DM basis. In previous studies, we have found that, as expected, the effectiveness of propionic acid based additives increases with higher application rates (Kung et al., 1998; Kung et al., 2000). Sorbate, benzoate and acetic acid are commonly found as components of many antifungal formulations but are too expensive to be used alone in high concentrations. A less commonly used additive to control yeasts and molds is anhydrous ammonia (5-7 lbs/ton). The major drawback with ammonia is operator safety during application. Ammonia is quite dangerous to work with and safety precautions should always be taken when it is used (protective eye-ware and respirator if needed). Rations with ammonia treated silage must also be carefully balanced for proper amounts of rumen-degradable and -undegradable protein. Urea is generally less effective at improving the aerobic stability of silages than is ammonia. A study comparing the effects of ammonia versus a buffered propionic acid-based product on the aerobic stability of corn silage is shown in Figure 3.

### **Microbial inoculants**

Bacterial inoculants, based on homofermentative lactic acid bacteria are commonly added to silages to improve fermentation and increase DM and energy recovery. However, most of these inoculants do little to inhibit growth of yeasts because they tend to maximize the production of lactic acid (poor antifungal activity) and decrease the accumulation of volatile acids that have good antifungal activity. At the last NRAES silage symposium in 1997, Muck and Kung (1997) reported that a summary of the literature showed that treatment with classical homolactic acid-based inoculants improved aerobic stability about one third of the time, had no effect about one third of the time but made aerobic stability worse about one third of the time.

Recently, *Lactobacillus buchneri*, an obligate heterolactic acid bacterium, has been used as a silage inoculant to enhance the aerobic stability in a variety of silages (e.g. corn silage, sorghum silage, barley silage, alfalfa silage, ryegrass silage, orchard grass silage,

etc.) (Muck, 1996, Dreihuis et al., 1999a, Kung and Ranjit, 2001, Kleinschmit et al., 2005). A moderate increase in the concentration of acetic acid has been the hallmark of this effect. In studies summarized via meta-analysis in citable studies, inoculation with *L. buchneri* decreased the concentration of lactic acid and increased the concentrations of acetic acid in corn silages (Kleinschmit and Kung, 2006). In that analysis, the effects of *L. buchneri* were divided into a low level of addition ( $\leq 100,000$  cfu/g addition, LB1) or a high level of addition ( $>100,000$  cfu/g addition, LB2). The increase in acetic acid due to inoculation with *L. buchneri* was greater as the application rate increased in both types of crops. However, the increase was of a moderate nature as the concentration of acetic acid was only 3.89% even with the highest level of application in corn silages. (Note that this increase was the equivalent of adding about 12 lb of acetic acid/ton of forage.) In corn silage, the changes in lactic and acetic acids resulted in a decrease in the ratios of lactic to acetic acid in untreated corn silage from approximately 3.0:1 to 2.3:1 and 1.3:1, for the low and high dose of *L. buchneri*, respectively. Practical recommendations in the field have suggested a desirable lactic:acetic ratio of more than 3:1 (Kung and Stokes, 2001), which would be an indication of a more dominant homolactic fermentation. However, it is now evident that silages treated with *L. buchneri* should not be held to this standard. In the summarized experiments (Kleinschmit and Kung), treatment of corn silage with the lower application rates of *L. buchneri* resulted in a 10-fold decrease in numbers of yeasts (3.10 log cfu/g of silage) compared to the untreated silage (4.18 log cfu/g of silage) and treatment with LB2 decreased the numbers of yeasts by more than 100-fold (1.88 log cfu/g of silage). Associated with these lower numbers of yeasts was an improvement in aerobic stability but the effect was markedly greater in silage treated with the higher application rate (25, 35, and 503 h of aerobic stability for untreated, LB1, and LB2, respectively). Preliminary concerns relative to the potential of large losses of DM from silages treated with *L. buchneri* because of its heterolactic nature do not appear to be substantiated by the results of the meta-analyses. The loss of DM in corn silage by the higher application of *L. buchneri* was 1 percentage point more than for untreated silage. Relative to the potential beneficial effects of improved aerobic stability during storage and feeding, this loss is small. Although some have suggested that high levels of acetic acid in silages may depress intake, research studies have shown that ruminants fed silages treated with *L. buchneri* consume the same amount of DM when compared to counterparts fed untreated silages (Dreihuis et al., 1999b, Kung et al., 2003, Ranjit et al., 2002, Taylor et al., 2002). Most research on improving the aerobic stability of silages has dealt with the stability of the silages alone. However, there is good evidence that if silages are stable, their resulting TMR will also be stable. In two studies TMR that were made with silages treated with *L. buchneri* were more stable than TMR made from untreated silages (Kung et al., 2003, Taylor et al., 2002).

#### **When Should Additives Be Used**

A question that is often asked is when should products that specifically provide enhanced aerobic stability to silage be used? Here are some scenarios. Such additives may be called for to treat historic problems of silages heating in the silos (over sizing, slow feedout rate, poor packing and filling). Corn silages or high moisture

corn that will be stored for prolonged periods of time (more than 6-9 months) or be fed during hot weather are other good candidates for treatment. Consider treating specific silos or parts of a silo relative to summer feeding. Treating an entire silo or all of your silage may not be justifiable if the problem occurs for only a few weeks out of the year. However, it is extremely difficult to predict in advance whether silage will remain cool. Silage moved from one silo structure to another and purchased silage that is moved and exposed to air for several days before feeding should be considered for treatment. Spraying the face of a bunk with a propionic acid-based preservative is probably not useful because only silage on the immediate face is protected as air can penetrate deeply into the silage mass.

### ***Improving Aerobic Stability in Moved Silage***

Silages are sometimes moved between storage structures that introduces air into the mass. When moving silages, do so as quickly as possible and do it in the coolest weather possible. Packing density and plastic management will be critical to keep this moved silage stable. On many large dairies it is now quite common to find several days worth of silage to be fed in temporary piles (brought in from other farms or silos and dumped at a staging area). During hot weather this can be a worse case scenario because the moved silage is usually not repacked to exclude air. For moved silage and feeding piles, addition of chemical preservatives that contain antifungal compounds (e.g., buffered propionic acid, sorbates, benzoates, acetic acid, etc.) can be added at the time of moving to enhance stability (perhaps 2 to 6 lb/ton). A better idea would be to consider treating these silages at the time of ensiling with an additive to enhance aerobic stability (e.g. chemical additives or *L. buchneri*). (Microbial based additives and ammonia are ineffective on forages that have already fermented.)

### ***Improving Aerobic Stability in TMR***

When dealing with heating (spoilage) TMR issues try to first determine the primary cause(s) of the problem and try to fix that. If nothing can be done to alleviate the primary causes(s) then preservatives (commonly referred to as "TMR-savers") based on buffered propionic acid are available that can be added directly to the TMR to improve aerobic stability. The degree to which silages have spoiled in the silo and ambient temperatures will determine the doses required to stop further spoilage in the feed bunk. Thus, if poor bunk management has allowed silage to spoil considerably in the silo before mixing into the TMR, high levels of additives (perhaps 4 to 8 lb of additive per ton of TMR) may be required to prevent further spoilage in the feed bunk. To stop heating in the feed bunk with such preservatives, start with a high dose for several days. This should temporarily fix the problem right away and also "clean out" the equipment and feed bunks. If stability in the bunk has been achieved producers can slowly back off to a lower level that keeps the TMR from heating in the bunk. TMR-savers can be helpful but they are not economical for long term use because the rates of addition are very high. For example, even added only at 4 lb/ton of TMR, the equivalent would be adding 8 lb of the product per ton of forage. In addition, stopping further heating and spoilage in the feed bunk does nothing to stop the initial heating and loss of nutrients that can occurred in the silo.

Use caution when adding any feed to a TMR that has begun to spoil prior to mixing. For example, wet distiller's grains spoils rapidly in warm weather and incorporating even a small amount of this into a TMR can make it extremely prone to aerobic spoilage even if the silages were moderately stable. If given a choice, data from our lab suggests that it is better to control yeasts at that time of ensiling rather than after the fact in a TMR. Remember that the more yeasts that are present in the silage and TMR, the higher the dose of a TMR-saver will be needed to keep the feed from spoiling.

### ***Diagnosing Problems with Aerobic Stability***

On farm, silage or TMR that are spoiling due to exposure to air often have a distinct moldy smell and heats rapidly. Heat itself is not an absolute indicator of spoilage in silage because large silos often retain relatively high core temperatures even in the winter. Thus, steam coming from the silage mass during silo removal is not necessarily a sign of aerobic spoilage. In a recent survey, we have noted core silage temperatures as high as +90 °F in some silage for as long as 90 d. In contrast, aerobically spoiled silage can often reach temperatures as high as 120-130°F for short periods of time. Signs that silage is aerobically spoiling include measuring temperatures in excess of 115-120 °F four to eight inches in back of the silo face at feed out, reheating in the bunk, visible mold, lack of a sharp or sweet smell to the silage and/or a flat or moldy/musty smell. If a pH meter is available, a moldy smell coupled with a high pH may also be a good indicator that a feed has undergone aerobic deterioration. Aerobic deterioration is of course more commonly found during warmer weather. Relatively inexpensive temperature probes can be used to monitor temperatures in silage piles. Purchase one that has at least a 2 -3 foot probe.

Silages can also be sent to a laboratory for analyses of determination of fermentation end products and yeasts and molds. Care should be taken to ensure that the sample is representative of that being fed. In addition, samples for microbial analyses should be kept refrigerated (not frozen) and sent to the laboratory as quickly as possible (preferably stored with ice packs). This will minimize the growth of yeasts and molds that could grow during transit and thus give a false reading.

### **CONCLUSIONS**

Heating and spoiling silage is undesirable because of losses in nutrients and lowered animal performance. Producers should work with their nutritionists and feed consultants to evaluate their specific problems in this area. Proper sizing and maintenance of silos and proper harvesting, filling and sealing of silos should be emphasized. Bacterial inoculation can help with silage fermentation quality. In instances where spoilage is still a major factor, preservatives such as buffered propionic acid and newer inoculants designed to improve aerobic stability (e.g. *L. buchneri*) can be used. Research suggests that treating silage at the time of ensiling with these preservatives is more efficacious than trying to treat a TMR.

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Figure 1. The “domino effect” of air causing aerobic spoilage in silages.

**Silage is exposed to air**



**Dormant yeast that degrade lactic acid are revived**



**Yeast degrade lactic acid to CO<sub>2</sub> and water, producing heat**



**Numbers of yeasts increase in the silage mass**



**pH of silage increases**



**Molds and aerobic bacteria are revived and further degrade the silage**



**Massive spoilage**

Figure 2. The aerobic stability of TMR sampled during the summers of 2003–2004 in from farms in DE, MD and PA. (Kung, Mulrooney and Morges. Univ. of Delaware)

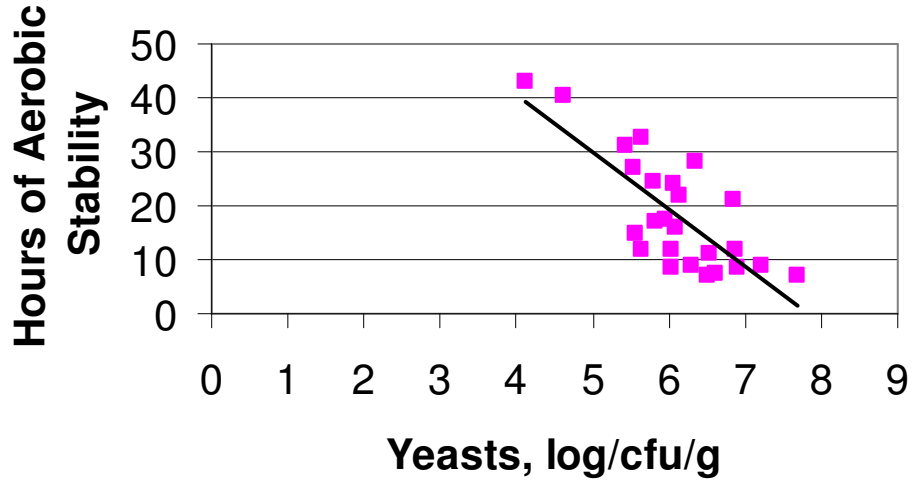


Figure 3. The effect of ammonia (NH<sub>3</sub>-N) or a buffered propionic acid based preservative (BP) on the aerobic stability of corn silage. Bars with unlike letters are different, *P* < 0.05 (Kung et al., 2000).

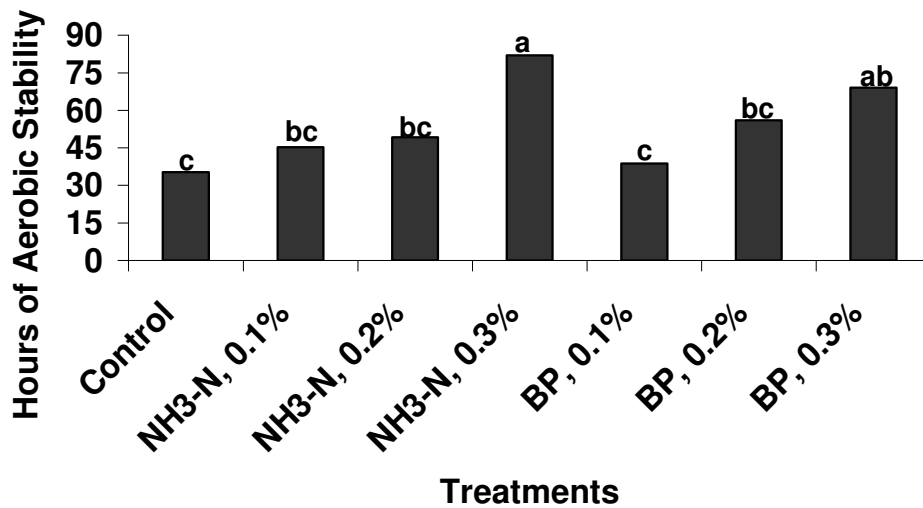


Figure 4. Examples of tires and gravel bags on plastic at the feeding face of the silo to prevent air from contaminating the silage mass.



Table 1. Some factors that may make silages more prone to aerobic spoilage.

Item	Effects	Examples
High starch or sugar content	Yeast use sugar and starch as energy sources during fermentation	High moisture corn and corn silage tend to be most prone to aerobic spoilage
High DM content	a) High DM restricts fermentation and reduces acids that could prevent growth of yeasts b) High DM crops are more difficult to pack and allow infiltration of air into the mass	a) Haylage ensiled > 50% DM b) Corn silage ensiled > 40% DM
Poor pack density	Allows penetration of air into the silage mass	a) Fill rate too fast b) Insufficient tractor weight
Poor silage management	Allows penetration of air into the silage mass	a) Slow silage removal b) Knocked down silage c) Uneven silage face d) Intermediate feeding piles e) Moved silage
Poor management of plastic and weights	Allows penetration of air into the silage mass	a) torn bag silos b) torn silo covers c) insufficient weight on plastic d) plastic pulled back too far in advance
High ambient temperatures	Spoilage organisms grow faster in warmer weather	More spoilage in the summer than winter months
Addition of spoiled feeds to a TMR	Spoiled feeds bring spoilage organisms to the TMR	Spoiled wet distillers grains
Overly dominant homolactic acid fermentation	High concentrations of lactic and very low concentrations of other organic acids (that have antifungal properties)	An extremely dominant homolactic acid fermentation caused by microbial inoculation

Table 2. A meta-analysis of the effects of *L. buchneri* on the fermentation, numbers of yeasts, DM recovery and aerobic stability of corn silage (Kleinschmit and Kung, 2006).

Item	Control	LB-low	LB-high	Contrast	
				1	2
Lactic acid, %	6.59	5.87	4.79	< 0.01	< 0.01
Acetic acid, %	2.18	2.63	3.89	< 0.01	< 0.01
Yeasts, log cfu/g	4.18	3.10	1.80	< 0.01	0.02
DM recovery, %	95.5	95.5	94.5	0.05	0.01
Aerobic Stability, hr	25	35	503	< 0.01	< 0.01

<sup>1</sup>Corn silage treated with *Lactobacillus buchneri* at application rates  $\leq$  100,000 cfu/g of fresh forage.

<sup>2</sup>Corn silage treated with *L. buchneri* at application rates  $>$  100,000 cfu/g.

<sup>3</sup>1 = U vs. LB1 and LB2; 2 = LB1 vs. LB2.

<sup>4</sup>Aerobic stability = the numbers of h before a 1-2 °C rise in temperature after exposure to air.