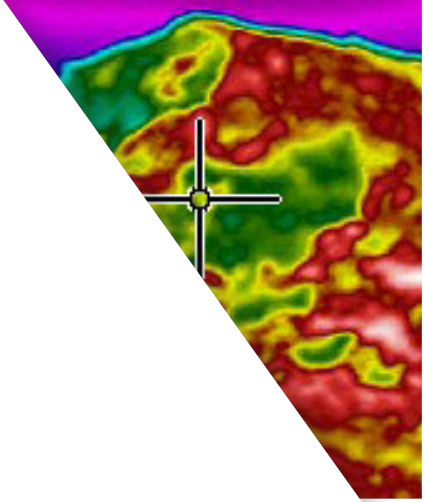

SILAGE MANAGEMENT

TECHNICAL GUIDE

LALLEMAND FORWARD

Technical advice on creating and maintaining high-quality silage

LALLEMAND ANIMAL NUTRITION
Tel: 1 (800) 541-5598 Email: LAN_NA@lallemand.com

www.lallemandanimalnutrition.com

LALLEMAND

LALLEMAND FORWARD

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INTRODUCTION

Robert Charley, Lallemand Animal Nutrition

Continually evolving industry and market dynamics puts constant pressure for milk and beef producers to become more efficient and stay profitable.

One way that efficiencies can be improved is by producing high-quality forages and increasing their proportion in the ration. This converts perishable forage into stable silage so that it can be stored and fed throughout the year. Ensiling involves acidifying, or pickling, the crop, either by direct addition of acid or by fermentation. The ensiling fermentation is an anaerobic process involving the conversion of sugars into organic acids such as lactic, acetic and propionic (Figure 1). These organic acids are produced by bacteria, either present naturally on the crop or added by the use of an inoculant.

The ensiling process can be divided into four phases (Figure 2):

Figure 1: Chemical changes during fermentation

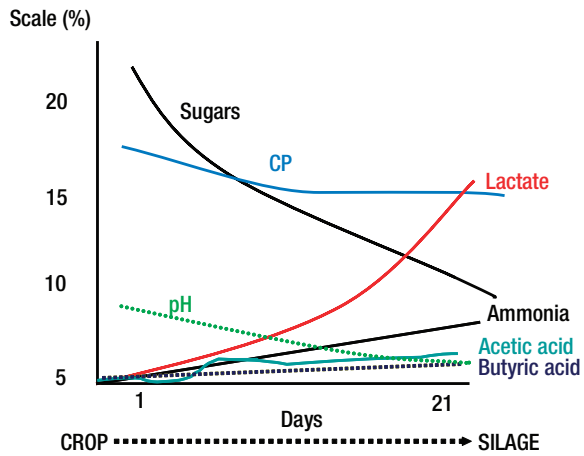
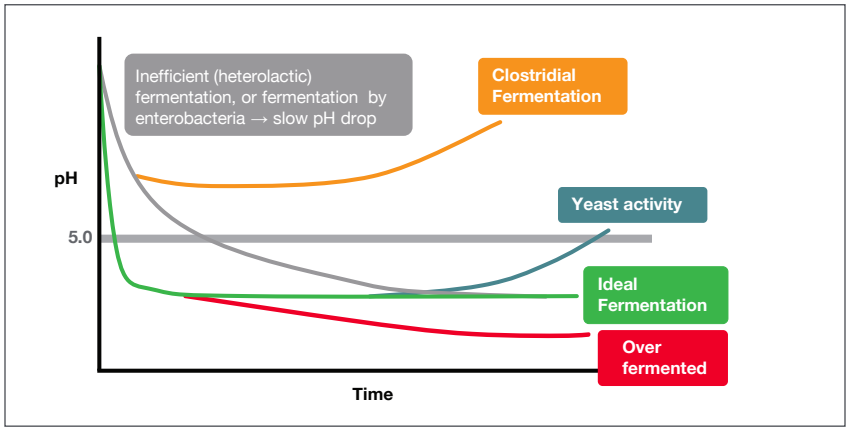


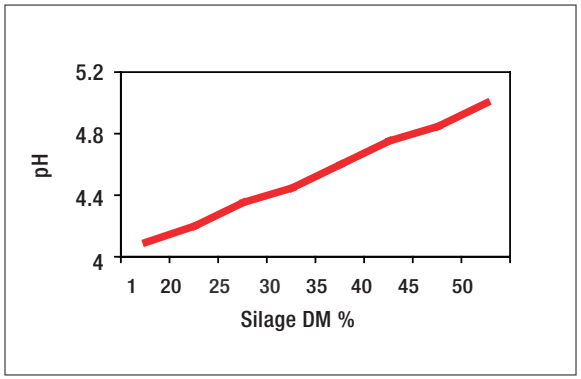
Figure 2: Phases of silage fermentation



PHASE 1: AEROBIC GROWTH. During filling, and after the silo has been filled and sealed, the forage still contains some entrapped oxygen. This is reduced (converted to carbon dioxide) by respiration of the plant material itself and by growth of aerobic and aerotolerant anaerobic microbes such as yeasts, molds, enterobacteria and lactic acid bacteria. Since lactic bacteria can grow and produce lactic acid in aerobic conditions, during this stage, the pH of the silage will start to fall, provided the population of lactic bacteria present is sufficient. During the aerobic stage, plant enzymes including proteases and polysacharrases will also remain active, leading to increases in soluble nitrogen and sugars.

PHASE 2: FERMENTATION. Once the silage has become anaerobic, the ensiling fermentation and conversion of forage to silage begins. Lactic bacteria that have been growing aerobically shift to anaerobic fermentation pathways and obligate anaerobic microbes, e.g. clostridia, can start to grow. For a successful initial fermentation--with pH being rapidly reduced below 5 and culminating with a pH low enough to achieve a stabilized silage (Figure 3)--production of lactic acid as the predominant acid is essential. During the initial fermentation phase, the silage composition changes quite dramatically, as show in Figure 1. Thus, feeding new-season silage should be avoided until this phase is completed (at least 30 days) to avoid feeding and performance issues.

Figure 3: Relationship between pH for stabilization and silage DM



PHASE 3: STORAGE. In an ideal world, little in the silage would change during prolonged storage. However, in practice, there may be some air ingresses into the silage at the margins, resulting in some patches where aerobic microbes can grow and spoil the silage (typically, the tops of bunkers and pits, the sides of poorly packed bunkers, pits of piles, tops of bags and outer layers of bales). Also, in some instances, the silage may contain elevated levels of yeasts that can ferment the lactic acid produced during the fermentation phases, causing the pH to rise and increase the level of ethanol in the silage. ***Lactobacillus buchneri*** is a lactic acid bacterium that has been shown to be capable of converting lactic acid to acetic acid in the anaerobic silage environment and can cause a shift in the fermentation acid profile, with an associated increase in the silage pH, during the storage phase. As discussed in the section "Managing Aerobic Stability," this acetic acid can help avoid problems caused by elevated initial yeast populations. During the storage phase, some acid tolerant enzymes, including protease and cellulases, can remain active and there may be increases in soluble nitrogen, e.g. ammonia, during the storage period. Other types of microbes can also form resistant spores--e.g. molds, clostridia, bacilli--which enable them to survive in a dormant state in the silage.

PHASE 4: FEEDOUT. As the silage is opened and fed, it is once again exposed to air and aerobic organisms that survived the ensiling process, e.g. bacilli, yeasts and molds, can grow. In most situations, this aerobic growth at feedout will be initially dominated by yeasts. As these aerobic organisms grow, nutrients are lost from the silage, and the material can become badly spoiled, rendering it unfeedable. The rate and extent of this spoilage is dependent on the extent of air ingress into the silage and, the levels of the spoilage organisms present in the stored

silage. The extent of air ingress is governed in part by the density of the silage and also by the management of feedout, as addressed in later sections. The levels of spoilage organisms in the stored silage is partly governed by the levels on the plant material going into the silage but also by management factors that affect the speed at which the aerobic phase is completed (filling speed, packing density, speed and effiency of silo sealing, etc.) and the use of forage additives, e.g. inoculants, that have been proven to reduce their numbers in the silage.

The purpose of this book is provide information to help producers obtain the best quality feeds from their own forages. There are specific sections on the management of crops for silage, inoculants, different storage structures, aerobic stability and mycotoxins, written by experts in the respective fields. The appendices provide troubleshooting advice for some common silage problems, information tables on silo capacities, etc. and contain a glossary to explain many of the terms used in the field.

Some factors that can affect forage quality cannot be controlled, for example, weather and equipment breakdowns. Key areas that can be controlled, and require your management focus, include:

- Harvesting at optimum maturity and dry matter (DM)
- Optimizing chop length
- Using inoculants relevant to the challenges presented
- Packing the silage effectively to get air out
- Covering and sealing to keep air out
- Managing feedout properly

Further information on factors affecting silage quality is available at www.qualitysilage.com.

CROPS FOR SILAGE

Everett D. Thomas, Oak Point Agronomics, Ltd.

As livestock farms have increased in size, an increasing proportion of forage crops are being preserved as silage. Even on smaller farms, the need for high quality forages is causing farmers to make the shift from dry hay to silage. Harvesting hay crops as silage decreases dry matter (DM) losses, reduces the risk of weather damage and results in forage ideally suited to mechanical feeding systems. The trend to more ensiled forages is expected to continue as new harvest technologies improve corn silage quality and better windrow management of hay crops makes “stem to silo in a day” an achievable goal.

COMMONLY ENSILED FORAGE CROPS

Corn: More tons of whole-plant corn silage are made in the U.S. than of any other ensiled crop. Corn is a high-yielding, high-energy crop, and both harvest and feeding are easily mechanized. In most parts of the U.S., higher silage yields are possible with corn than with any other forage crop. Genetic improvements have resulted in corn hybrids with higher forage quality. Corn is a sugar-rich crop and, therefore, one of the easiest to ensile. However, all those sugars can pose challenges when the silage is fed out, making management of the exposed surface critical. Fortunately, recent years have seen the development of inoculants containing ***Lactobacillus buchneri*** that greatly reduce heating on the silage face and in the feedbunk.

Alfalfa, alfalfa-grass, grass-alfalfa and grass (as well as other forage legumes) can be considered together since harvest management of these forages is quite similar. In the Northeastern U.S., most alfalfa is seeded with a cool-season forage grass, while in other areas alfalfa is more commonly seeded alone. These types of forage crops begin to lose sugars soon after they are mowed, and sugars are the food of fermentation bacteria. The key to high quality hay crop silage is to dry the crop to the proper DM level (Table 1) for ensiling in the respective storage structure as quickly as possible. Leaving the mowed forage in wide swaths will result in much faster drying and better conservation of plant sugars. Butyric acid formation in low DM forages is a greater problem when forages are left in the field overnight. Hay crops normally have a lower sugar concentration than corn, so conserving plant sugars is important. Cutting haylage in the afternoon following a sunny morning results in higher forage sugar levels, but

Table 1: Optimum harvest stage and moisture

CROP	HARVEST STAGE	DM LEVEL %
Corn Silage	1/2 - 2/3 milkline	32-38%
HMC/Cereals		65-75%
Grasses and small grain silages (grown as a protein crop)	boot	35-45%
Alfalfa:		
Bunker or Bag	bud - 1/10 bloom	35-45%
Stave	bud - 1/10 bloom	40-55%
Harvestore	bud - 1/10 bloom	50-65%

much of these sugars are lost if the forage remains in the windrow overnight. Because of the lower sugar levels, face and bunk life of hay crop silage is usually less of a problem than with corn silage.

Summer annuals: Millet, sudangrass, sorghum-sudangrass and forage sorghum are all summer annuals that can be ensiled. These are lush crops, with fresh forage DM contents of 12% to 15%, so good windrow management is absolutely essential for proper ensiling. Brown midrib (BMR) sorghum-sudangrass hybrids are more digestible than are non-BMR hybrids. They are lower yielding but should result in improved animal performance. Spreading swaths to at least 2/3 of mower width as they are mowed greatly decreases drying time, sometimes to the extent that the crop can be mowed in the morning and ensiled in the afternoon. This is more likely, however, with second and subsequent harvests than with the first harvest because of the heavier yield typical with the first cut. Because of the high sugar content of these forages, face and bunk management (and therefore the choice of silage inoculants) is more similar to corn silage than to hay crop silage. In fact, fresh BMR sorghum-sudangrass is often higher in sugar concentration than is whole-plant corn.

Small grains: Although there are regional differences in popularity, all of the common small grain (cereal) crops including oats, barley, wheat, rye and triticale are commonly ensiled. Small grain-Canadian field pea mixtures are popular on dairy farms in some parts of the U.S.; the quality of forage from this mixed crop is usually intermediate between a small grain and alfalfa.

Table 2: Typical silage quality

CROP	% CRUDE PROTEIN	% ADF	% NDF	% 30-HR NDF DIGESTIBILITY
Corn	7-9	22-30	38-50	38-50
Alfalfa	18-24	30-40	40-50	40-50
Grass	12-18	30-40	50-65	50-65
Summer annuals	10-16	34-44	55-67	55-67
Small grains	12-17	33-43	50-65	50-65

The steps necessary for ensiling small grains are similar to ensiling grasses. It's especially important to wilt them to a least 30% DM following mowing since small grains are notorious for producing smelly, high butyric acid silage if ensiled at low DM. Adding field peas to a cereal often makes the forage slower to dry, so spreading the windrow to at least 2/3 mowed width is critical. In some areas, cereal silages are grown as an energy crop, as an alternative to corn silage. In this case, the crop is harvested at a more advanced stage with more grain fill and, hence, higher starch levels, and direct cut at a higher DM. Typically, this has been done with wheat, oats or barley, harvested around the soft cheddar stage at a DM level around 40%.

FRESH FORAGE VS. SILAGE

During the ensiling fermentation, bacteria use plant sugars, but they have much less effect on cell walls. Nutrients are lost during harvest and ensiling, even under ideal conditions. Alfalfa and other forage legume leaf loss can be minimized by careful management, but it cannot be eliminated. The best combination of alfalfa yield, quality and stand persistence is when it is mowed at 38% NDF. With good management, this should result in fully fermented alfalfa silage that is about 45% NDF. Silage fermentation also results in a small decrease in DM percentage, usually one or two units. For instance, alfalfa that is 35% DM when first ensiled will result in 33% to 34% DM silage. Table 2 shows the typical range in silage quality for the most commonly ensiled crops. Note that, in most cases, there is a wide range in "typical" silage quality. For instance, grass silage at 50% NDF is very high in quality, while grass silage at 65% NDF, although unfortunately all too common, is not. Good harvest management should produce silages that are at the "high quality" end of the range: higher in protein and fiber digestibility, lower in ADF and NDF.

MANAGING MATURITY

Corn should be harvested at 32% to 38% DM with 30% DM the absolute minimum, not the goal. While examination of the kernel milk-line is a good start (Figure 4), because of differences among hybrids, including the "staygreen" characteristic, this is only approximate and should always be confirmed by drying a representative sample of the crop. To get a representative sample, randomly harvest about 10 plants from a field, hand-feed the plants through a chipper shredder or chopper. Determine the sample DM content, and then subtract about 2 percentage

Figure 4: Development of milkline in corn kernels (left); Milkline in corn ready for harvest for silage (right)

points from the result. For instance, if the sample tests 32% DM, it is likely that the field actually is about 30% DM. This is because most samples are not truly representative and are almost always slightly on the dry side. Although there are slight differences between hybrids, the best combination of yield and digestibility is usually at 32% to 38% DM. Also, silage effluent in bunker silos is greatly reduced at DMs of 30% and above. Alfalfa and most other legumes should be harvested at the late bud stage. A reasonable goal for top quality alfalfa is to never allow it to bloom. This often results in a harvest interval of 35 days or less, especially between first and second crops. Grasses should normally be harvested at the late boot (pre-heading) stage. Most forage grasses lose quality very quickly after heading, which gives us the adage "when you see the head, the quality is dead." If there is a large acreage of grass to harvest, all at about the same maturity, it may be necessary to start harvest several days prior to the late boot stage. This will sacrifice some yield but should result in higher forage quality. Also, grass mowed prior to heading often grows better following harvest than if it is allowed to head out. With alfalfa-grass stands, the field should be managed according to the maturity of the alfalfa. When the alfalfa is in late bud stage it should be mowed, regardless of the stage of maturity

of the grass. Only when grass represents more than 50% of the stand should an alfalfa-grass crop be harvested according to the maturity of the grass. Small grains, other than cereal silage crops grown as an alternative to corn as discussed above, should be harvested prior to heading. Triticale is often harvested in the flag leaf stage, resulting in very high forage quality.

Harvest management of summer annuals can be influenced both by species and intended use (pasture vs. silage). First harvest BMR sorghum-sudangrass hybrids should be mowed for silage at 36-48 inches stand height, slightly less height for second and succeeding harvests and under dry conditions. The crop will grow much taller than 48 inches, but forage quality will quickly decline.

MOWING AND CHOP HEIGHT

Mowing and chop height decisions often involve a trade-off between yield and quality. Increased chop height of corn has a more pronounced effect on quality than does the mowing height of alfalfa and grass. Grass quality doesn't change much from top to bottom of the plant, but mowing height should be about 4 inches. That's because unlike alfalfa, the nutrients for the following crop of grass is in the bottom several inches of the above-ground portion of the plant. Alfalfa regrows from crown buds and can be mowed at 2 inches with no impact on regrowth or plant health. However, mowing should be high enough to avoid scalping the field, which can contaminate the silage with soil, manure residues and crop debris. Increasing the chop height of corn from the normal 4 to 8 inches to 12 to 18 inches decreases yield but increases energy concentration, with lesser effects on fiber digestibility. For instance chop height of 18 inches vs. 6 inches, increases whole plant DM concentration by about two percentage points, which can be either a plus or minus depending on crop maturity. If the crop is already higher in DM percentage than is desirable, chopping higher will only make the situation worse. Immature corn, as well as BMR and other high fiber digestibility corn hybrids, should not be chopped higher than about 8 inches. Summer annual crops that experience drought conditions can contain high levels of nitrates which can have detrimental effects on feeding. Nitrates accumulate in the bottom portion of the plant so raising the cutter bar to leave about 12 to 18 inches (or more) of stalk in the field can be effective in reducing nitrate levels in the resulting silage.

CHOP LENGTH AND PROCESSING CORN SILAGE

The correct chop length for corn depends on whether the crop is harvested conventionally, with a kernel processor (KP), or with a shredding processor. Processing silage crops can be expected to be of more benefit when the crop is at the recommended level of maturity. Much of the advantage of kernel processed and shredded corn silage is due to better kernel breakage and, therefore, higher kernel processing scores (KPS). Kernel processed corn should be chopped at ¾ inches (19 mm) theoretical length of cut (TLC), while a TLC of 1 inch (30 mm) is recommended for shredding processors. Corn that isn't processed or shredded should be chopped at a TLC of ¼ inch to ½ inch (6 to 13 mm). The particle size of KP silage at ¾ inch TLC will usually be about the same as unprocessed 3/8 inch TLC silage. For KP silage, the roll clearance should usually be set at 1 to 3 mm, the specific clearance depending on both the equipment and the maturity and variety of the crop. Increasingly, some farmers and custom operators are setting roll clearance to 1 to 2 mm (instead of 3 mm) in an effort to improve the KPS, especially with hard kernel varieties. Processor maintenance is critical since worn rolls can result in many unbroken kernels. If the corn is properly processed, all the kernels should be broken, nicked or damaged, and there should be no cob fragments larger than 1/4 inch. One suggested rule of thumb is that in a quart of KP corn silage, there should be no more than one whole or two half kernels.

In recent years, the use of shredding processors has become more common, particularly on dairy farms using high levels of corn silage in rations. The processor tears the corn stalk into longer pieces than with KP, providing longer pieces of fiber, while the chop length is greater (26 to 30 mm at 30% to 35% DM) and the processing rolls are set a bit closer (1.75 to 2.25 mm) to better crush the corn kernels. As with KP corn silage, as the standing crop gets drier, the rolls are adjusted to a slightly tighter clearance. To date, research on shredded corn silage has been limited, but current results suggest that compared with KP corn silage, it may increase milk production by about 2 pounds per cow. However, in these trials, the kernel processing score was somewhat higher for shredlage than for KP corn silage. Results may have been different if both crops were at the same KPS.

For most other forage crops, chop length can vary from 1/4 inch to 3/8 inch (6 to 10 mm) depending on how much of the ration consists of silage. To maintain good rumen function with all-silage rations, 3/8 inch TLC is generally preferred to shorter chop lengths.

Measuring forage particle size using the NASCO Penn State Particle Separator (Figures 5 and 6) continues to be a popular way to objectively evaluate if forages and TMRs have optimal particle size on the farm. The weight retained on each screen is compared with guideline levels (Table 3). Field observations indicate if the top screen retention from screening a TMR is more than 15 %, cows may sort the ration. Feed particles in the middle box may be more important than the top box only. Compared with conventional KP, considerably more particles remain on the top screen with shredded silage, though the extent depends on the length of cut.

If the four-box system is used, the third screen (1,100) micron screen) should have about 2/3 of the material contained in the bottom box in the three screen system (for example, a TMR in the three box system is <50% in the bottom box or <35% in the third screen and <15% on the box using the four box unit) (Table 4).

Figure 5: Particle size distribution obtained from chopping silages using NASCO Penn State forage particle separator

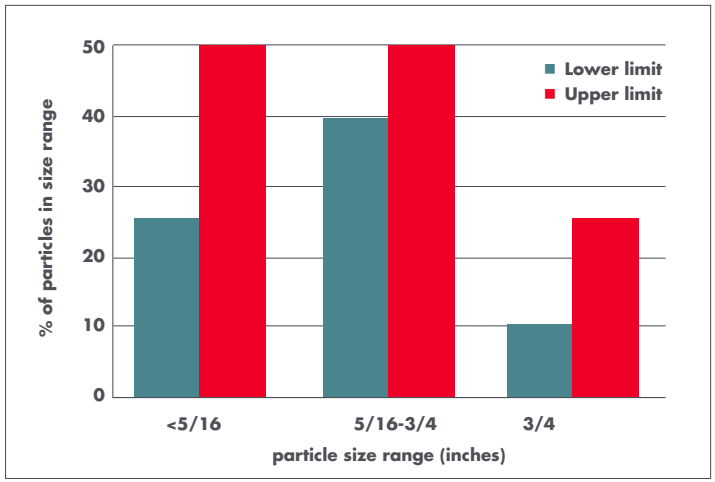


Figure 6: The NASCO Penn State forage particle separator - 4 screen model

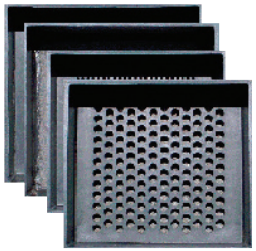


Table 3: Penn State particle size box guidelines expressed as a percent on an as-fed basis (three box separator)

	% OF TOTAL		
FEED TESTED	TOP	MIDDLE	BOTTOM
TMR	8-15	35-45	<50
Haylage	>20	>40	<25
Corn Silage (3/4" TLC, processed)	10-20	40-60	<35
Corn Silage (3/8" TLC, processed)	<5	<50	<50

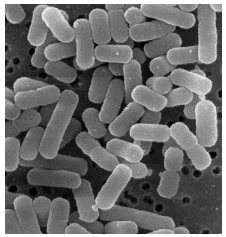
Table 4: Penn State particle size box guidelines expressed as a percent on an as-fed basis (four box separator)

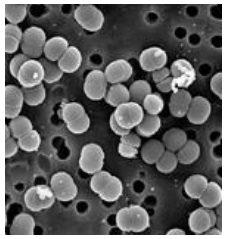
	% OF TOTAL			
FEED TESTED	TOP	SECOND	THIRD	BOTTOM
TMR	10-15	>40	>35	<20
Haylage	>20	>40	>20	<5
Corn Silage (3/4" TLC, processed)	5-15	>50	>30	<5

FORAGE INOCULANTS

Limin Kung, Jr., University of Delaware
Robert Charley, Lallemand Animal Nutrition

Forage inoculants are biological products that contain a source of live, viable bacteria, sometimes combined with enzymes. The bacteria are applied to inoculate freshly harvested forage, much the same as live yeasts are used to inoculate alcohol fermentations or bread. Enzymes, when present, are there to generate sugars for the inoculant bacteria to use for growth and fermentation. The bacteria grow in the forage, producing acids to drive the ensiling fermentation (see Introduction), converting the fresh forage from near neutral pH into an acidic end product (silage). The lower pH created by acid production helps to preserve the crop by inhibiting the metabolism of acid intolerant microbes.





The photographs left show the two main cell morphologies of lactic bacteria. The rod-shaped bacteria are called bacilli after the Greek word "bacillus," which means rod. Shown left are *Lactobacillus buchneri* 40788 cells. The spherical bacteria are called cocci after the Greek word "coccus," which means sphere. Shown to the right are *Pedioccus pentosaceus* 12422 cells.

Inoculants are used for two primary reasons:

1. To stimulate or ensure a rapid, more efficent fermentation (by producing fermentation aids, which for a rapid pH drop means predominantly lactic acid), which helps avoid bad (e.g. clostridial, enterobacterial) fermentations.
2. To inhibit aerobic spoilage (spoilage inhibitors).

Fermentation aids generally contain efficient (homofermentative) lactic acid-producing bacteria (LAB) and are mainly used on low dry matter (DM) forage crops that can have low concentrations of fermentable carbohydrates and high inherent buffering capacities (e.g. grass, alfalfa, clover).

Inoculants that are designed to inhibit spoilage may contain specific LAB, e.g. ***Lactobacillus buchneri***, or propionic-acid-producing bacteria. These products are designed for use on materials more prone to aerobic spoilage such as drier haylages (>35% DM), corn, cereal silages, high moisture corn (HMC), cereal grains and baleage.

Things to consider when comparing silage inoculants include:

- Is there ample data for the specific product in the target crop from trials conducted at independent research facilities, such as universities, verifying their claims? Are these data statistically analyzed and published in reputable journals and research meetings? These trials should validate the efficacy of the product at the application rate it is being sold at and should validate any and all claims made for the product. Without data to validate specific product claims, let the buyer beware!

- Remember that not all bacteria are the same even if they have the same name. ***Pediococcus pentosaceus***, ***Lactobacillus plantarum*** or ***L. buchneri*** from one company cannot be expected to perform in exactly the same manner as a ***Pediococcus pentosaceus***, ***L. plantarum*** or ***L. buchneri*** from another company. Companies have unique strains that have been tested and developed under rigorous conditions. Be sure that there is published data supporting a product and the specific strains used in the product. Look for strain identification numbers and make sure they match up.

- Is the product manufactured to quality control standards and does the manufacturer have accreditation to show that manufacturing procedures are independently reviewed?

- Is the product packaged appropriately? Inoculants contain dried viable products and three enemies of these live products are heat, moisture and air. Prevention from exposure to heat comes down to following storage instructions (see p. 17), but packaging must be designed to prevent exposure of the contents to moisture and air. The use of high barrier foils is one common approach that achieves these goals, as is packaging in sealed tubs. Manufacturers should also use nitrogen flushing during packaging to minimize residual oxygen and include specific preservation agents, e.g. moisture scavengers, in the product formulation.

- Read and understand the label (Figure 7):

  - Number of bacteria, application rate and weight: Does data supplied by the company validate the recommended application rate? (Calculations may have to be done to determine the application rate of bacteria on forage [Table 5].) It is generally accepted that fermentation aids containing homolactic acid LAB should be applied at a minimum of 100,000 colony forming units count (CFU)/g forage. Rates for organisms in spoilage inhibitors vary, through the FDA has allowed that products

Figure 7: Example of a forage inoculant label

Table 5: Calculations for the number of bacteria per pack of inoculant and product application rate (CFU/g forage)

bacteria/gram x grams = bacteria in package *example:* 45.4 billion CFU/g x 100 g = 4.54 trillion CFU/package
bacteria in package/tons treated x 1 ton/908,000 g = Application Rate *example:* 4.54 trillion CFU/50 tons x 1/908,000 = 100,000 CFU/g forage

containing ***L. buchneri*** 40788 can claim improvement in aerobic stability in silages and HMC stored for 60 days, provided the product is applied at a minimum of 400,000 CFU/g for silage or 600,000 CFU/g for HMC. In the U.S., for microorganisms to be legally included in products, they must be on the direct-fed microorganisms list approved by the Association of American Feed Control Officials (AAFCO) (Table 6). Microorganisms that are not on this list are not approved for use in animal feeding in the United States.

Table 6: Organisms approved by AAFCO for use in animal feed products in the US

Aspergillus niger	*Lactobacillus farciminis (swine only)*
Aspergillus oryzae	*Lactobacillus fermentum*
Bacillus coagulans	*Lactobacillus helveticus*
Bacillus lentus	*Lactobacillus lactis*
Bacillus licheniformis	*Lactobacillus plantarum*
Bacillus pumilus	*Lactobacillus reuteri*
Bacillus subtilis	*Leuconostoc mesenteroides*
Bacteroides amylophilus	*Megasphaera elsdenii (cattle only)*
Bacteroides capillosus	*Pediococcus acidilactici*
Bacteroides ruminocola	*Pediococcus cerevisiae (damnosus)*
Bacteroides suis	*Pediococcus pentosaceus*
Bifidobacterium adolescentis	*Propionibacterium acidipropionici (cattle only)*
Bifidobacterium animalis	*Propionibacterium freudenreichii*
Bifidobacterium bifidum	*Propionibacterium shermanii*
Bifidobacterium infantis	*Rhodopseudomonas Palustris (broiler chickens only*
Biflidobacterium longum	*Saccharomyces cerevisiae*
Bifidobacterium thermophilum	**Enterococcus cremoris*
Lactobacillus acidolphilus	**Enterococcus diacetylactis*
Lactobacillus brevis	**Enterococcus faecium*
Lactobacillus buchneri (cattle only)	**Enterococcus intermedius*
Lactobacillus bulgaricus	**Enterococcus lactis*
Lactobacillus casei	**Enterococcus therniophilus*
Lactobacillus cellobiosus	*Yeast (as defined elsewhere)*
Lactobacillus curvatus	**Formerly classified as Streptococcus.*
Lactobacillus delbruekii	

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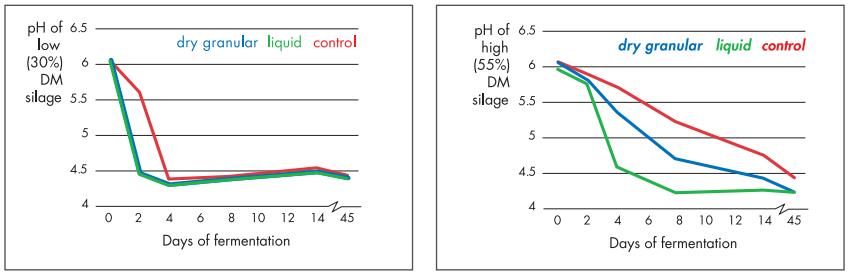
- Levels of enzymes: If the product claims to include enzymes, guaranteed levels should be declared, and they should be the same as those used in trials to validate product efficacy. If no guarantee levels are given for enzymes, it's best to consider that they are not present. Like microorganisms, there is a list of enzymes and sources approved by AAFCO. Again, anything not on this list is not approved for use in animal feeding in the United States.
- Shelf life and storage conditions should be listed clearly on the product label, read, understood and followed. The shelf life of the inoculant is linked to the recommended storage conditions. Improperly storing the product could significantly reduce its shelf life and efficacy.
- Do not use expired inoculant: Check the expiration date! If you have a stock of product that is beyond the expiration date, it may be worth a check to see if the manufacturer can get the product tested for you. This should be a test conducted by an independent laboratory.

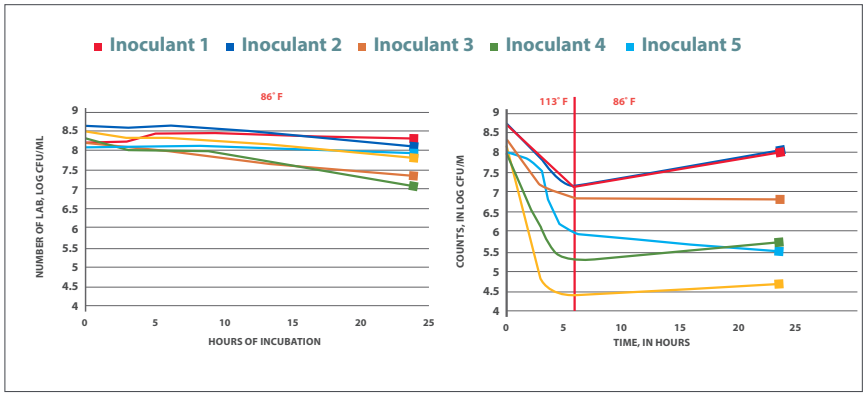
Suitability of product form. Dry granular application may be easier but is less effective than liquid application as crop DM increases (Figure 8). Granular inoculants should not be used in crops with DM levels above 40 (less than 60% moisture). Also, be aware that the stability of granular inoculants is subject to the same variables as noted above: heat, moisture and oxygen. Leaving granular product packs open for extended times will expose the product to both moisture and oxygen and the levels of viable bacteria in the product may decline rapidly. It is also more difficult to store granular products under optimal temperature conditions. Small pack liquid applied products can even be kept cool out in the field (e.g. in a cooler with ice packs), while granular products are more likely to be at ambient temperature during the harvest. Be sure at the very least to keep product out of direct sunlight.

Figure 8: Effect of inoculant form on rate of pH drop in alfalfa silage



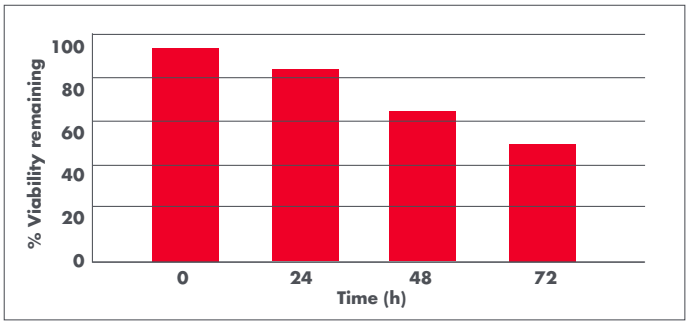
- Product stability in the application tank or hopper. The bacteria in liquid applied inoculants can die off quickly following rehydration if not kept cool (Figure 9). Do not allow water with bacterial inoculants to reach temperatures above 95 to 100 F during use. Ask to see the rehydration stability data for any product you are considering. If liquid applied product becomes slimy, it should be discarded (this indicates that bacteria have died, releasing their DNA and causing the sliminess). Granular, dry applied inoculants also die off in the hopper (Figure 10) due to exposure to air (oxygen), absorption of moisture from the atmosphere and the increasing ambient temperature. The product flow characteristics may also suffer due to the absorption of moisture. Discard granular inoculant left over in the hopper at the end of the day to ensure optimum product performance.

Figure 9: The effect of temperature on the stability of liquid applied inoculants after rehydration.



Mulrooney, C.N., and L. Kung Jr. 2008.

Figure 10: Stability of granular silage inoculant in the applicator hopper

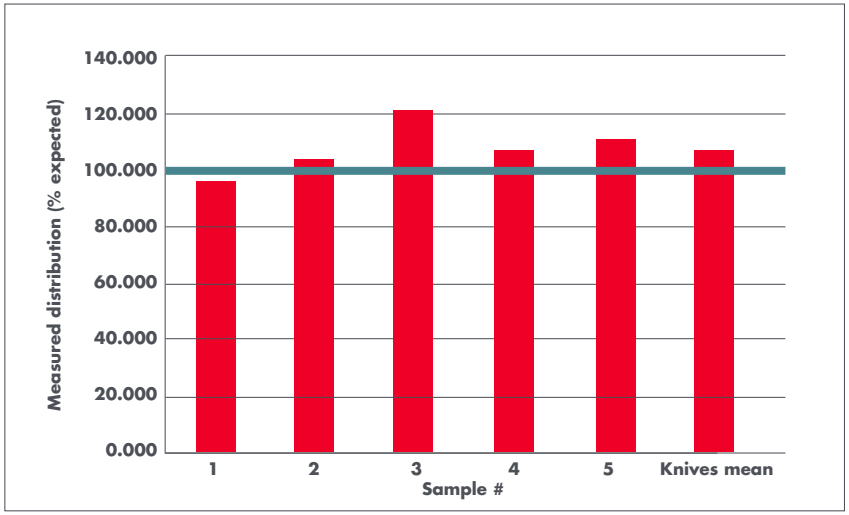


- Does the type of product match your expectations? Do you need a fermentation aid, a spoilage inhibitor or both? Is there independent data to show that the product can do what you are looking for? Some products require pre-incubation to achieve the correct numbers for product efficacy. Consider carefully whether you are prepared for, and capable of, taking on the burden of production and quality control required for this. Ready-to-use products from reputable companies are produced in food grade facilities using sterile media and GMP procedures to recognized QC/QA standards.

- Calibrate your application rates for liquid and dry-applied inoculants. Application rates should be checked several times a day. Even distribution of the inoculants is a key factor in their ability to help the fermentation process. Products are best applied at the chopper box or accelerator on the harvester. The DE-1008.5/ 1010 (Dohrmann Enterprises, Inc.) are low-volume liquid applicators (1.28 oz. per ton/ 40 ml/ ton), which have been validated as achieving even distribution (Figure 11). The product reservoir on this system is a 10-gallon insulated tank, which helps keep the product cool to maintain viability. Ice blocks can be added to the product in the tank to maintain viability, based on recommendations for the specific product from the manufacturer.

It is generally accepted that using a proven, validated inoculant as part of a good forage

Figure 11: Consistency of Product Application Rate Using Dohrmann Low Volume Liquid Applicator (red bar shows actual application rates; blue line shows theoretical perfect application)



management program will give a return on the required financial investment (Hutjens, 2010). The guidelines above should help you in the selection process and ensure that the product you select is applied as a live, viable product ready for the ensiling challenges that lie ahead. However, inoculants are not magic bullets that will make up for lax management practices; they are one tool to help as part of the overall management program.

Note:

1. In Canada, forage inoculant products have to be registered with the Canadian Food Inspection Agency (CFIA). This involves submitting production and QC data to the CFIA so that they can validate the production process, reproducibility of production and shelf life (by validating data from tests on three manufacturing lots) and submitting data from scientifically designed practical scale studies that are relevant to Canadian practice (e.g. crop type; ambient conditions; ration fed, if appropriate) and that provides a statistically significant response supporting claims that are made for the efficacy of the product. Products must validate at least one claim to be approved for registration. All approved claims must be printed on the product label, along with a purpose statement, registration number, declaration of ingredients, guaranteed activity levels and shelf life (as validated by the CFIA), pack weight, use instructions and contact details for the registrant. Labels are reviewed and approved by the CFIA. Only product carrying a CFIA-approved registration number and approved final label is allowed to be used. Non-conforming product is subject to impounding and further actions.

2. In Mexico, forage inoculant products have to be registered with the Secretary of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA or Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación). This involves submitting a complete technical dossier to SAGARPA. Production data, among others, is part of the technical dossier so that they can validate the production process, reproducibility of production and shelf life (by validating data from tests on three manufacturing lots). Scientific data from scientifically-designed practical scale studies that provide a statistically significant response supporting claim that are made for the efficacy of the product is also required. The Quality Control data to validate the CFU count needs to be sent to a third part laboratory, authorized by SAGARPA, in order to be validated and should match with the label guarantee. The final label should as well have the authorization number, a declaration of ingredients, guaranteed activity levels (as validated by the SAGARPA approved laboratory) and shelf life (as validated by SAGARPA), pack weight, use instructions and contact details for the manufacturer, registrant if different from manufacturer and distributor if the case. Lot number, manufacture date and expiration date are also required to be present on Mexican labels. Labels are reviewed and approved by SAGARPA. Only products carrying a SAGARPA authorization number and SAGARPA's approved final label is allowed to be used in Mexico. Non-conforming product is subject to impounding and further actions.

MANAGEMENT OF BUNKER SILOS

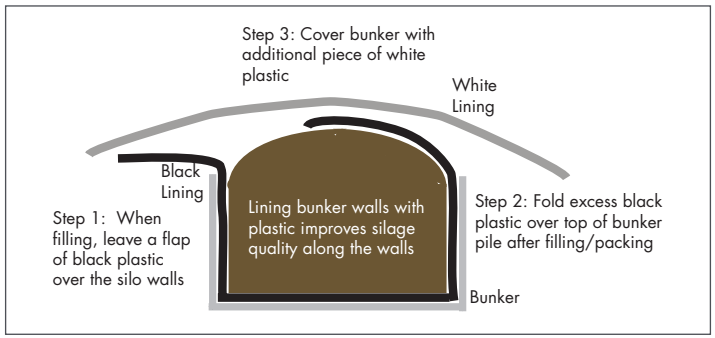
Bill Stone, Diamond V

PREPARING FOR FILLING

Before starting, all old silage should be removed and, ideally, the empty silo left open to be further sanitized by rain and sun. Silo floors and sides should be repaired if any structural damage has occurred. Asphalt has become a popular material to use for silo floors, as it is unaffected by silage acids. The lack of seams in an asphalt floor also eliminates the risk of water seeping through a seam and undermining the floor. The keys to success are to make an extremely well-packed base and to use at least 4 inches, or preferably 6 inches, of asphalt.

Lining the inside of bunker walls with plastic prior to filing prevents water from seeping in at the edges. The results of this additional effort is that silage quality and dry matter (DM) along the wall is the same as that throughout the silo. This procedure can be accomplished by placing a small amount of old silage on the bottom of the plastic at floor level. Stretch the plastic to the top of the wall and then extend it an additional 6 to 8 feet. The plastic can be damaged during filling when it is stretched across the jagged concrete edges at the top of the wall. To prevent this, cover the edges with either tape (it actually can be done!) or drain tile cut lengthwise. Sealing is completed after filling by extending the wall plastic back out onto the top of the pile prior to covering with the top plastic (Figure 12). An alternative approach is to extend the top plastic beyond the edge of the silo and seal at the wall with sand or gravel filled silage bags (or tubes). Tubes should be laid inside, as opposed to on top of, the silo wall to eliminate the risk of damaging the plastic as the silage settles. This approach is not as effective as lining the

Figure 12: Bunker Lining Diagram



walls with plastic, since there is still silage deterioration along the wall from oxygen infiltration through, and along, the edge of the wall. Additionally, water can accumulate in the plastic swale along the wall.

RECEIVING, FILLING AND PACKING

Forage DM should be checked throughout the filing process to ensure feed is being chopped at the appropriate DM. Collecting samples of silage throughout the day, composing and then submitting a sub-sample for laboratory analysis removes much of the mystery concerning the contents of the bunker silo.

ALFALFA HAYLAGE

Alfalfa haylage should be harvested at 35%-42% DM. Alfalfa haylage that is chopped below 34% DM may not have enough sugar present for bacteria to convert into acids, which decreases the silage pH to a stable level. Clostridia bacteria can then grow, converting the lactic acid to butyric acid, and the amino acids to biogenic amines. The biogenic amines, in particular, can be very disruptive to the normal ruminal bacteria, leading to indigestion and diarrhea. Wide-swathing of haylage, where the windrow is at least 75% of the cutterbar width, results in higher sugar levels, reduced drying times and less risk for rain damage. As alfalfa haylage starts to move above 40% DM, leaf shatter increases. This occurs even when a continuous merger is used to merge rows of haylage, although much less than with a conventional rake. The net result is a loss in crude protein (from one to several percentage points) and crop energy levels. Use the wide-swathing approach, but don't get too far ahead of the chopper especially when it is going to be hot and windy.

CORN SILAGE

The ear is filling out as the corn plant is maturing, and crop yield and energy levels are increasing. The goal is to let this occur as much as possible but to still have a crop with sufficient moisture to ferment and pack properly. This "sweet spot" for corn silage is 33%-36% DM, with an additional point either way to give producers some more flexibility during harvest.

The ruminal availability of starch in corn silage increases with ensiling time, processing level and with crop moisture level. Kernel processing scores assess one of these variables (processing level). It has been recommended that scores should exceed 70%, indicating a pulverized kernel. Silage processed in this manner will have starch that is more rapidly and completely available, and this guideline should be followed for silage fed within 6 months of harvest. However, it becomes less critical that processing scores are as high as ensiling time increases, especially if crop DM is near the lower end of the acceptable range.

Marshall McCullough wrote that silage is a feedstuff resulting from the anaerobic preservation of moist forage by the formation and/or addition of acids. The key words here are "anaerobic" and "acids." Oxygen needs to be forced out from the silage – and this is achieved by correct packing. Silage density is primarily the result of packing intensity and crop DM. It is directly related to DM losses from the silo, and to the amount of silage storage space required. The packing density achieved on commercial operations has been shown to vary considerably (Table 7).

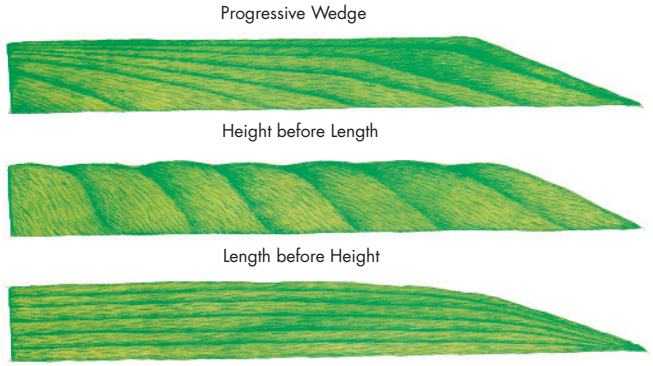
Inadequate packing causes problems both at ensiling and feedout, resulting in increased DM losses and reduced silage quality. At ensiling, plant respiration is extended and increases the growth of undesirable organisms and soluble protein levels while reducing the quantity of sugars available for the desirable acid-producing organisms. Poor packing increases silage porosity, which results in additional spoilage and DM loss at feedout due to greater oxygen infiltration.

Table 7: Summary of core samples collected from 168 bunker silos

	HAYLAGE (87 SILOS)		CORN SILAGE (81 SILOS)	
	AVERAGE	RANGE	AVERAGE	RANGE
DM %	42	24.67	34	25-46
Wet Density (lbs/ft^3)	37	13-61	43	23-60
Dry Density (lbs/ft^3)	14.8	6.6-27.1	14.5	7.8-23.6
Ave. Particle Size (in)	0.46	0.27-1.23	0.43	0.28-0.68

The progressive wedge (Figure 13), with a slope of about 30 degrees, is the recommended approach to filling bunker silos as it minimizes the amount of silage exposed to oxygen if the top surface is covered as filing progresses. Packing vehicle weight and the thickness of the layer of silage being packed are two of the main variables influencing silage density. The estimated amount of packing weight needed can be calculated by multiplying the estimated tons of crop delivered to the silo in an hour by 800 (Ruppel et al., 1995) (Table 8).

Figure 13: The Progressive Wedge



The progressive wedge method is the best way to fill a bunker silo. There is less silage respiration with the progressive method than when bunkers are filled length before height or height before length.

Table 8: Calculations for packing tractor weight/filling rate to achieve minimum target packing density (14 lb./cu ft.) in trench and bunker silos

Optimum packing vehicle weight (lbs) = filling rate (tons/hr) x 800
Optimum filling rate (tons/hr) = vehicle weight (lbs)/800

Better yet, refer to the bunker silo density calculator (www.uwex.edu/ces/crops/uwforage.htm) and estimate what will need to be done in your silo to achieve your density goals. Remember that average bunker silo densities are around 15 lbs. DM per ft^3, while elite bunker silo managers will have silo densities of around 20 lbs. DM per ft^3. Running these calculations prior to starting the ensiling process allows you to check if you have enough and large enough tractors. Can you get another tractor on the pile? Can you add additional tractor weights or put a concrete block on the 3-point hitch? The train wheel packing weights have increased silage densities, especially in the upper region of the silo. The calculator emphasizes the importance of keeping the tractors on the pile as much as possible. Obviously, bunker density isn't being increased when the operator is parked on the bunker floor. Packing with dual-wheeled, as compared to single-wheeled, tractors does not significantly reduce silage densities, provided packing time is sufficient. Make sure that either the width of the packing blade is narrower than the axle, or that there is a tractor without a blade, to allow for tires to become very close to the wall so that the edges are adequately packed.

In many situations, particularly with larger and custom chopping operations, the crop is coming in faster than there physically is room on the silo for the necessary number of tractors. In these situations the "wedge" should be flattened so that it becomes more of a platform increasing the available surface area for packing tractors. The increased surface area also makes it easier to spread thinner layers of silage.

The packing process should be viewed with as much importance as that associated with the chopping process. Packing equipment should be operated continuously throughout the chopping process, with forage distributed in layers ideally no more than 4 inches and certainly less than 6 inches thick prior to packing. Packing operators must also understand the importance of keeping on the pile as much as possible.

Drive-over piles can be used to successfully store silage. Many producers, however, make the sides so steep that they cannot be adequately packed. This results in a tremendous amount of DM loss and silage with reduced quality. Run-to-rise ratio should not be less than 4:1 (slope<25% or about 22%) along the sides to allow for continued effective and safe packing in all directions throughout silo filling (Figures 14 and 15).

All packing tractors should be equipped with operator safety belts and cabs or roll-over protection systems.

Figure 14: The proper run/rise ratio for a well-made drive-over pile

Figure 15: Drive-Over Piles

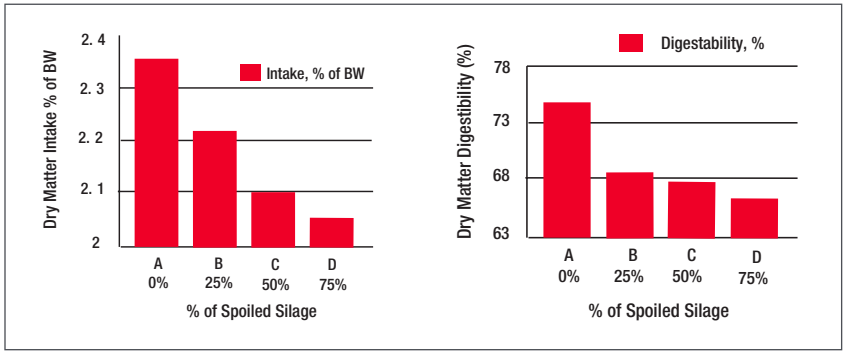
COVERING

If it starts to rain during silo filling, will you be shut down? How long will it last and how much rain will there be? Since these answers are unknown, the safest and best approach is to perform a quick cover job with plastic and a minimal number of tires (Figure 16) to minimize the spoilage layer that often occurs with these harvest interruptions.

Silo covering is one of the least favorite jobs on the dairy, but also a very profitable one. It improves silage DM recovery and will likely result in healthier cows. Sealing and covering a 40-foot by 100-foot bunker returns approximately $2,000-$4,000 in improved silage DM recovery when filled with corn or alfalfa silage, respectively. Additionally, feeding spoiled silage from an uncovered silo top has been shown to dramatically affect intake and digestibility (Figure 17). The silage should be covered as soon as possible after filling is completed in order to assist the desired anaerobic process, and to reduce spoilage. Don't skimp on plastic thickness or

Figure 16: Cover the silage surface temporarily if rain halts silage production

Figure 17: The effect of feeding spoiled silage on dry matter intake and total ration dry matter digestibility



Whitlock, et al. 2000.

quality – the cost of the plastic is trivial in comparison to the effort to properly put it on and its importance to silage quality and DM recovery. Use plastic that is at least 5 mm thick. Dual layer – black inner and white outer – thick (>5 mm) plastic resists deterioration well. Cover the entire slope in front of the bunker or around the drive-over pile with plastic when filling is complete to prevent excessive spoilage in these areas. Oxygen barrier films are much less permeable to oxygen than standard plastic and reduce top spoilage. Tire-to-tire placement is the most popular way to keep plastic in place. Concerns about mosquitoes harboring West Nile virus, rodents and the mess and effort associated with complete tires have led to the use of alternatives, including gravel filled bags, cut tires and truck tire sidewalls. All of these can work, but it is imperative that there is sufficient weight along all of the edges of the plastic to resist the wind, keep the plastic in place and to prevent air infiltration. The gravel filled bags are the most effective tool to easily accomplish this goal (Figure 18).

Plastic covers should be inspected by a manager on a regular, and at least monthly, basis. Silage workers should be reminded of the importance of observing the top cover for tears or bird damage, that all edges need to be properly weighted down, and that all spoiled feed should be discarded rather than fed. (Figure 18).

Figure 18: Use of gravel filled bags (left) and tires (right) to weigh down plastic covering

FEED OUT MANAGEMENT

The key steps are to:

- Remove all spoiled silage
- Keep the silage face vertical and tight
- Remove enough silage to avoid any heating and do not pile silage ahead of feeding, as this can result in composting
- Premix the silage that has been obtained from the entire face with the loader bucket or mixer wagon prior to feeding
- Strive to have as little loose silage at the end of feeding as possible
- Keep the leading edge of plastic sufficiently weighted down to prevent air infiltration beneath the plastic
- Remove plastic at least twice weekly, or as often as necessary, so that top spoilage does not occur prior to feeding

Spoiled silage from along the top and sides of the silo, also balls or chunks in the main body of the silo, should be discarded. As we have seen in Figure 17, reductions in intake and digestibility can occur if this feed is included in the diet. Silage with only slightly compromised quality (wetter or underwent a poorer fermentation) can still be fed to groups such as bred heifers or far-off dry cows.

Constantly observe the surface of the silo for top spoilage. Often this spoilage is occurring because too much plastic is being taken off and the surface is left open too long (Figure 19). It can also occur if the leading edge of plastic is not properly weighted and air is infiltrating beneath the plastic and causing spoilage prior to plastic removal.

Figure 19: Bunk defacer

The best approach for removing silage is to use a bunk defacer (Figure 19). Defacers have a lot of benefits: they do not cause fracture lines that allow air into the silo; they mix the silage from across the height of the silo, reducing ration variability; they break up haylage clumps, which can reduce mixing time; they leave a very straight face, which does not catch water; and they can cause less damage to the silo equipment used to remove silage from the bunker. When using loader buckets to remove silage, either shave across the width of the silo, or try to remove a chunk of silage from the bottom of the silo, and then chip downward as the bucket is progressively moved.

Silage should be removed at the rate of at least 4 inches during the summer and 3 inches during the winter to stay ahead of spoilage. The rate necessary will vary, due primarily to the packed density and resultant porosity. Feedout rate should be managed to avoid silage heating. As Table 9 indicates, variation in silage density is extreme. Thus, the necessary silage removal rate is variable as well. The fermentation acid profile will also influence the necessary face removal rate. Silage that has increased levels of acetate, propionate or butyrate will be more stable than those only high in lactate since these acids are much more potent inhibitors of molds and yeasts than lactic acids. Silage inoculated with ***L. buchneri*** 40788 will not have to be fed as quickly since the elevated levels of acetate and propionate in this silage impairs the growth of yeasts and molds and improves feed stability.

The objective when collecting a silage sample for DM or laboratory analysis is to obtain a sample representative of all silage that will be fed. This is important because silage varies considerably across the height of the silo (Table 9).

Table 9: Variation between regions (upper, middle and lower thirds) in DM and NDF in 9 haylage and 11 corn silage bunker silos

	HAYLAGE		CORN SILAGE	
	DM	NDF	DM	NDF
Average deviation, %	21.0	14.7	12.3	8.6
Median deviation, %	19.4	14.4	8.3	8.4
Smallest deviation, %	5.2	5.4	1.3	.5
Largest deviation, %	44.7	24.8	55.0	18.6

(Stone, 2003)

DM results can be very consistent when samples are properly taken and truly representative of the silage being fed. It is important to take your time and do a careful job. If silage along the top and sides of the silo is fed separately, then it should be sampled separately. It would be entirely inappropriate to collect samples as high as one could reach, and then not bother to sample the upper half of the silo.

In a survey of bunker silos, haylage DM varied between upper, middle and lower regions of the silo by 20% and core silage by 10%, (Table 9). Consider this variability when collecting a silage sample for analysis and when feeding cows.

The best way to collect a sample for DM or laboratory analysis is to subsample the pile of feed that has been defaced from the entire silo (including that at the bottom of the face), and pushed into a central pile and either mixed with the loader bucket or briefly mixed in the mixer wagon and discharged. Walk around the pile, collecting forage with a scoop, or using your hand in a scooping motion, to collect forage from at least 10 locations, and place the forage into a 5-gallon bucket. Dump the collected forage onto a clean, dry surface and mix it with a scoop shovel. Finally, divide the forage pile into four quadrants by drawing lines in the forage pile with your finger. Subsample with your scoop from each of the four quadrants and submit this sample for analysis. Care should be taken to use the scoop mentioned, or at least to grab all silage particles “scooped” by your hand, or fines can be left behind.

Be an alert, organized silo manager. Remember that details matter. Remove plastic and tires in a timely manner, ideally on a daily basis but certainly no more than three days ahead of feeding. Keep the leading edge of plastic completely weighted down. Always try to exclude tires from entering the mixer wagon since hardware damage could occur from mixer wagon knifes cutting into steel belted radial tires. Carefully observe and smell layers of silage within the bunker. Watch for layers of silage that went through clostridial or abnormal fermentations. Consider the selective removal of these layers and either discard or feed to nonlactating animals. Premix forages obtained from the entire bunker face prior to preparing loads of feed. Sample forages for DM or laboratory analysis in the manner described above. The additional care and attention paid to details like this will result in more consistent intakes, production and milk components.

MANAGEMENT OF TOWER SILOS

Mike Hutjens, University of Illinois, Urbana

Tower silos are popular systems for storing silage in the Midwest and Northeast regions of the United States. A Hoard's Dairyman Magazine survey in 2013 of selected readers summarizes the type and number of various silage storage units. Dairy managers may use several storage systems on their farms. As herd sizes increase, fewer tower units are built, but upright storage can be a logical and economical choice on dairy farms. How to store forages is an important decision for beef and dairy managers, with several systems available for evaluation based on the following factors:

- Initial and annual costs to store forage
- Herd size
- Feed delivery system
- Optimizing forage quality (harvest and stored)

STORE COSTS

University of Wisconsin agricultural engineers reported silage storage costs including capital investment and annual costs at various herd sizes. The analysis included hay silage stored in 8 different systems (Table 10).

Table 10: Total capital cost and annual cost (in parenthesis) per ton of DM for 384 and 768 tons of stored DM

STORAGE TYPE	384 TONS DM $/TON OF DM		768 TONS DM $/TON OF DM	
Steel-glass oxygen limiting (new)	427	(82)	301	(60)
Steel-glass oxygen limiting (used)	268	(55)	187	(41)
Cast-in-place oxygen limiting	285	(58)	186	(41)
Concrete stave	192	(46)	138	(36)
Above ground bunker	152	(45)	103	(37)
Packed silage pile	63	(37)	41	(32)
Bagger	88	(38)	53	(32)
Wrapped bales	64	(36)	38	(32)

(Holmes, 1998)

Capital costs included structures and equipment used in filling, storing and emptying the hay silage. Transportation, harvesting or moving feed to the animals were not included. Silos and gravel pads had a life expectancy of 20 years while equipment was assumed to have 10 years of life expectancy. Annual costs include capital costs, labor, plastic coverings, fuel and dry matter (DM) lost during storage. Forage (hay equivalent basis) was valued at $85 a ton. Tractors were assumed to have other uses besides forage management and allocated on a proportional basis to handle forage storage.

Capital cost per ton of silage DM was highest for new steel oxygen-limiting structures compared to other systems. If towers or vertical storage units are re-filled (1.5 to 2 times annually), costs will be reduced. Cast in place and used oxygen-limiting structures were similar. Silo bags, silage piles and wrapped bales had the lowest investment. No significant economies of scale occurred above 758 tons of DM (other storage amounts evaluated were 1,536 and 3,072 tons). Capital cost per ton can be important on farms where capital limited due to expansion and/or existing debt load.

Good management is needed to achieve the values in Table 10. For example, DM losses in storage were estimated to be 6% for oxygen-limiting units; 10% for concrete stave and bags; and 13% for piles, bunkers and wrapped bales.

HERD SIZE FACTORS

After cost, herd size is the next important factor. If herd size is less than 200 cows plus young stock, large permanent storage structures are not viable. Upright silos, bags and wrapped bales are good choices. If forages are fed in a conventional barn, upright silos minimize weather-related risks and use of tractors to feed cattle. In-line stationary mixers and belt feeders also favor tower structures. Bottom unloading structures can provide a consistent supply of fermented forage to cows, but a layer of low-quality forage can occur between each cutting or filling period. Removing 4 to 6 inches of silage per day from the surface in the summer will limit aerobic spoilage. During cool seasons, removing 2 to 4 inches should maintain silage quality: always keep feedout rates high enough to prevent silage heating. Sizing of tower silos is an important consideration when building vertical storage to maintain an adequate feeding rate to maintain palatability and quality (see Capacity Tables, Appendix V).

FORAGE QUALITY

Tower storage units (conventional and oxygen limiting) can be successful if matched to herd size to optimize feedout rates. Harvesting forages with higher moisture contents reduces field losses, but this must be balanced against seepage losses due to excessively wet silage. The guidelines given in Table 11 can be used for target DM levels for different crops in various vertical storage units.

Excessive moisture content can result in an undesirable fermentation and excessive losses of soluble nutrients due to seepage. Applying a research-proven inoculant will improve fermentation characteristics, lower DM loss, increase digestibility and optimize desirable VFA pattern in tower structures.

Table 11: Target crop DM levels for vertical storage systems

OXYGEN LIMITING STRUCTURE	
Legume-grass silage	50-65% DM
Small grain silage	50-65% DM
Corn silage	40-65% DM
CONVENTIONAL CONCRETE AND STAVE STRUCTURE	
Legume-grass silage	40-55% DM
Small grain silage	40-55% DM
Corn silage	
Under 60 feet	32-36% DM
Over 60 feet	Increase 2% DM per 10 feet vertical height

Factors that can improve forage fermentation profile and quality are:

- Rapid harvest and storage (ideally in one day if possible)
- Reduce air exposure by rapid filling and sealing (can be covered with plastic sheet if feeding will be delayed for several weeks) or the last loads treated with propionic acid or commercial mold inhibitor. Check the quality and appearance of the top 6 to 12 inches of the silage before adding more silage or feeding to dairy cattle: discard if it is moldy or low quality
- Increase compaction by adding wetter material on top and covering
- Adding 20 to 50 pounds of finely ground corn or barley per wet ton of silage can provide a source of fermentable carbohydrate in legume, grass and small grain silages
- Apply a research proven silage inoculant to direct, and increase, the rate of fermentation
- Fermented silage can be moved from bags to other storage units during cool times of the year to refill tower silos allowing additional use of the tower silos for automated feeding systems. Treating the forage with a proven inoculant containing ***L. Bucherni*** prior to bagging helps minimize spoilage issues in these situations.

FEED DELIVERY SYSTEM

With Total Mixed Rations (TMR), the silo or unit unloading equipment must allow for rapid forage removal to meet the manager's expectation on filling the TMR mixer and optimizing feeding time. Tower silos are a logical choice if herd size is less than 200 cows, or cows are housed inside an insulated or warm housing system and/or labor wants to work in a favorable environment. To increase feedout time or with larger herds, having a series of upright structures unloading at the same time can deliver large amounts of silages and also reduce silage variation during the feeding season as silages from several sources are blended. Another approach to speed up filling time is to run silage unloaders before silage is needed. A skid steer can quickly load larger quantities into a mobile TMR mixer.

If silage is fed in a bunk or in a confinement barn, blending alfalfa-grass silage with corn silage is recommended on a volume basis. Each silage type can complement the other forage source.

- Corn and sorghum silage is high in starch, contains more rumen fermentable carbohydrate than either silage on its own, is low in total protein and calcium content, and has enhanced TMR palatability.
- Legume-grass silage is higher in soluble, degradable and total protein to improve microbial growth, low in starch and rumen fermentable carbohydrate and can provide more functional (long) fiber.
- Small grain forage (such as wheat, triticale, oats and/or barley) can provide an early source of silage in spring that is modestly high in protein and intermediate in energy content. Stage of maturity of small grain forage is critical to match animal needs and balance yield (boot stage for high producing cows, milk stage for growing heifers, dry and lower producing cows).
- Sorghum/sudan warm season grasses can be an excellent emergency forage source. It is planted after soil temperatures have increased (typically in May or June) and can be harvested every 24 to 28 days depending on rain. It also provides location to spread manure in the summer. Quality can be optimal for milk cows cut at 20 to 30 inches in height and if a brown mid-rib (low lignin) hybrid is selected.

Tower storage also provides the opportunity for inventory control if more than one silo or unit is available on the farm. Lower quality forage can be placed in a dedicated structure for growing heifers, dry and lower producing cows.

Table 12: Storage sturctures

Storage structure	% farms	Number of units
Vertical sealed unit	26.7	2.2
Poured concrete vertical silo	11.6	1.9
Staved vertical silos	47.3	2.3
Bunker silos	26.4	2.6
Drive-over piles	15.5	2.4
Silage bags	31.4	5.3

Holmes, 1998

MANAGEMENT OF BAGGED SILOS

Joe Harrison, Washington State University, Puyallup Research and Extension Center

Bagged silage can be an effective storage system and can offer the following advantages over bunker or upright silos:

- Cost effective – evaluations have shown that bagged silage can be cost competitive when compared to silage stored in bunkers and can be a good option when expanding a livestock operation. Bagged silage offers a lower initial investment cost, low annual storage costs and lower loss of dry matter (DM) during storage.
- Flexibility – you can store different qualities, different forage types, and different cuttings and feed according to quality for different production classes of livestock.
- Safety – use of bags avoids the need for packing tractors to traverse the heights needed to pack silage into bunker silos and avoids dangerous silage overhangs experienced in high bunkers.

DISADVANTAGES TO BAGGED SILAGE

Storing forage in silage bags can result in significant losses of DM if bags are not routinely monitored for holes and tears caused by rodents, wildlife and farm machinery. DM losses have been measured as low as 4% but can exceed 20% if conditions for storage are not optimum. Occasionally bags split open, usually due to inadequate venting of fermentation gases during the first 7 to 10 days. The material is then exposed to oxygen and can spoil if not re-bagged as soon as possible. The plastic from silage bags needs to be disposed of properly, and recycling opportunities exist in some areas. Ensiling forage with large variations in DM from load to load can result in variability in silage DM at feedout. This needs to be monitored and TMRs should be adjusted accordingly.

EFFECT OF PACKING ON PARTICLE SIZE, BROKEN COBS AND WHOLE KERNELS OF CORN SILAGE

The process of packing forage in a bag, particularly corn silage, can result in significant additional mechanical treatment to the forage. This additional mechanical action of the packing fingers has been shown to reduce particle size, decrease the number of whole cobs and decrease the number of whole kernels of the final silage (Tables 13 and 14).

Table 13: Physical properties of processed and unprocessed whole plant corn silage stored in a bag

SILAGE	Mean particle size before bagging (mm)	Mean particle size after bagging (mm)	Coarse fiber action before bagging %	Coarse fiber action after bagging %
Unprocessed 9.5 mm TLC	11.3	7.3	17.4	4.6
Processed 9.5 mm TLC	8.9	5.6	5.1	1.2
Processed 14 mm TLC	10.5	7.4	24.7	6.5
Processed 19 mm TLC	14.1	7.6	44.5	13.5

Table 14: Fraction of total kernel mass damaged before bagging

SILAGE	Fraction of total kernel mass damaged before bagging %	Fraction of total kernel mass damaged after bagging %	Fraction of particle-size sample as whole cob before bagging %	Fraction of particle-size sample as whole cob after bagging %
Unprocessed 9.5 mm TLC	68	83	9.9	4.3
Processed 9.5 mm TLC	100	100	0	0
Processed 14 mm TLC	100	100	0	0
Processed 19 mm TLC	100	100	0.4	0.6

(Jirovec et al, 1999)

ESSENTIAL MANAGEMENT TIPS FOR SUCCESSFULLY USING BAGGED SILAGE

- Harvest the forage at desirable DM content (25% to 45%)
- Chop the forage to the desired chop length (see section “Crops for Silage”), keeping in mind that the forage will receive additional mechanical processing going into the bag.
- Use a proven inoculant.
- Use a quality bag for ensiling.
- Select a clean and hard surface for the bag.
- Leave about 4 feet of space between bags to facilitate feedout management. Silage will settle during storage, extending the lateral “footprint” of the bag.
- Locate bags away from heavily trafficked areas where other farm equipment may cause damage.
- Collect samples of forage periodically to determine the variability in DM content.
- Pack tightly to exclude oxygen (avoid ripples along the side of bag), target a packed density of 14 lbs. DM/ft^3
- Do not overfill bags (Table 15).

Table 15: Dimensions for properly filled silage bags

Bag Diameter	Ground-to-ground Measurement
8 ft	19.5 ft
9 ft	20.5 ft
10 ft	21.5 ft
12 ft	27 ft

- Use bag vents to release the gases produced during the fermentation to avoid the bag becoming pressurized and ripping or blowing open.
- Monitor for tears and holes created by machinery and rodents and patch holes or tears with an effective adhesive tape immediately.
- Feed the silage at a rate that prevents heating (about 2 ft. of silage bag length/day, possibly more in warmer weather). Feeding less than this in warm weather can result in silage that becomes hot and moldy.

SELECTING A CLEAN AND HARD SURFACE FOR BAGS AND MAINTAINING A SEALED BAG

It is critical that a clean, hard and dry surface be available to store the filled silage bags to facilitate both filling and emptying. Select an area that is convenient for feeding and one where you can avoid having to traffic through deep mud. Some points to consider are:

- Keep area free of grass and weeds, this will discourage rodents and wildlife.
- Develop a firm and well drained base, e.g. packed gravel, concrete or blacktop (asphalt).
- Make sure that you provide a firm "apron" area at the end of the bag for use when initially opening and feeding the silage.
- If wildlife are an issue, consider using a double strand electric fence to keep animals away.
- If birds are a common problem, bird netting is available. One effective tip is to place tires on top of the bag and under the netting at intervals to keep the net up off the bag.
- Mothballs can be used to keep away rodents, using them either whole or dissolved in water, around the base of the bag.

ONLINE RESOURCES AVAILABLE

The University of Wisconsin website (http://www.uwex.edu/ces/crops/uwforage/storage.htm) has some very useful information available, including additional information on bag capacities and forage storage cost calculators.

MANAGING AEROBIC STABILITY

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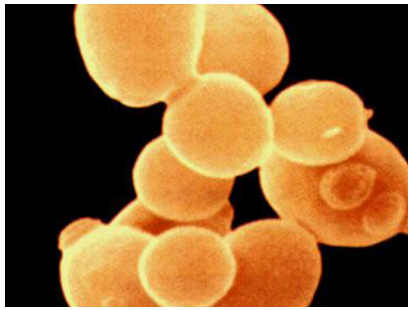
Aerobic instability of silage and high moisture corn (HMC) at feedout is a common problem. Typical symptoms are heating, mold growth or mustiness occurring on the face or surface. Feeding aerobically unstable materials can reduce feed intake and/or growth or milk production. Each 15 F increase in temperature in 1 ton of 30% dry matter (DM) silage requires more than 6.3 MCal of energy (Richard Much, personal communication: assumes core temperature readings in a silage bunker or pile with minimal heat loss), costing around 20 lbs. in lost milk production per ton of silage. Additionally, feed costs increase due to lost nutrients and DM, and increased refusals. Clearly, preventing aerobic instability is an important aspect of producing high-quality forages and ensiled grains for livestock and dairy production.

Even crops harvested at the optimal maturity, moisture content and chop length can be susceptible to secondary fermentation and heating. Aerobic spoilage can occur shortly after harvest, while there is still oxygen present in the plant mass, or the crop may ferment well and reach a low pH, only to heat rapidly and spoil at feedout. Lactate-assimilatutiliz yeasts that naturally occur in all forage and high moisture grain crops are the major cause of aerobic instability. Corn and cereal silages and HMC can have high indigenous yeast populations because yeasts grow best on feeds that contain starch and soluble sugars (Figure 20).

FACTORS RELATED TO AEROBIC INSTABILITY

Aerobic instability is usually due to rapid growth of yeasts over a short period of time. Yeasts can multiply during the first few days after harvest, before all of the oxygen in the ensiled feed is consumed, metabolizing sugars and starches, generating carbon dioxide, water, alcohol and heat. Management practices that reduce exposure to air, such as

Figure 20: Yeasts reproduce by budding, allowing for rapid growth when conditions are favorable



rapid silo filling, good packing and rapid covering and sealing, reduce yeast growth and their negative effects on silage quality. Ensiled crops with greater than 1,000,000 (10^6) CFU of yeast per gram typically have a 'yeasty' or alcohol smell and will heat and spoil (due to subsequent mold growth) quickly when exposed to air.

Aerobic instability can also be a bigger problem if feedout rates are not adequate or if ensiled feeds are not consumed within a few hours after removal, especially during warm weather. While some yeasts ferment only sugars, as mentioned some yeasts naturally present on forages and in silages can also metabolize lactic acid, the primary acid produced in silage fermentations. Traditional microbial silage inoculants contain homo-fermentative lactic acid-producing bacteria to increase the production of lactic acid, improve the ensiling fermentation efficiency and reduce the pH more rapidly. The production of lactic acid is very important to maximize DM and total digestible nutrient (TDN) recovery at the front end, but we now know that production of lactic acid alone can actually increase heating and spoilage at the back end during feedout. The progression of aerobic instability appears to be as follows:

1. Crops with high natural yeast populations are ensiled.
2. Yeasts grow until oxygen is fully consumed, then become dormant and silage fermentation may continue and produce lactic acid.
3. At feedout, feed is exposed to oxygen, infiltrating back from the face, up to 3 feet depending on packing density, etc.
4. Yeasts begin to grow, usually within a few hours of air exposure.
5. Lactic acid is metabolized by yeasts, resulting in loss of DM and TDN and generating heat.
6. Other silage acids are volatized along with other volatile components (e.g. ethanol).
7. Silage pH rises as the acids in the silage are lost.
8. Molds and other opportunistic microbes begin to grow.
9. Digestibility and palatability further decline. Toxins may also be produced.

Aerobic stability is measured by speed of heating after exposure to air. University of Delaware researchers (Kung et al., 1998) demonstrated that aerobic stability was negatively correlated to the number of yeasts present at the time the silo was opened (Figure 21). Corn silage with low yeast populations (10^3 CFU/g) remained cool for up to 3 times longer than silages with high initial yeast populations (10^6 CFU/g).

Aerobic instability increases nutrient losses in feed and reduces feed intake and production of dairy cattle (Hoffman and Ocker, 1997) and beef cattle (Whitlock et al., 2000). Cows fed high moisture corn (HMC) from a 14-day supply removed all at once from a silo, kept in a loose pile and fed daily showed a declining milk yield as the level of yeasts in the pile rose (Figure 22). Cows fed material removed fresh from the silo daily were unaffected. Intakes of all animals in the study were not affected. Over 14 days, lactic acid declined and pH and mold growth increased in the HMC that had been piled. This suggests that the energy content

Figure 21: The effect of yeast on the aerobic stability of corn silage

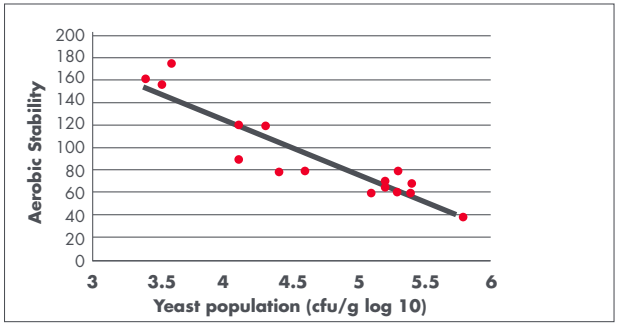
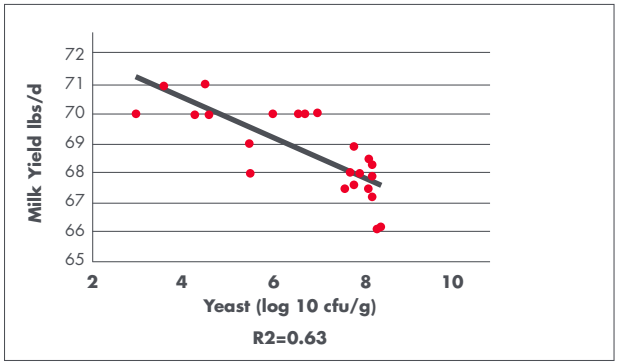


Figure 22: Milk production losses feeding aerobically unstable high moisture corn



of the HMC declined as it became progressively more unstable, which, in turn, reduced milk output. Intake may have been unaffected because the HMC was blended with fresh forages immediately before feeding. Furthermore, recent research has shown that spoilage yeasts have a detrimental effect on the in vitro ruminal fermentation (Santos et al., 2014). Adding a predominant species of spoilage yeast at 10^6 CFU or higher per mL of in vitro fluid reduced NDF digestion and altered other aspects of ruminal fermentation.

To produce silages, HMC and other preserved feeds that have good aerobic stability, good harvest and management practices that reduce exposure to air are critical. In addition, certain additives can also help to improve aerobic stability. Management practices generally do not eliminate yeasts but reduce their ability to grow:

1. PROPER SILAGE MANAGEMENT

Reducing economic and nutritional losses due to aerobic instability starts with good silage management. Harvesting at proper moisture levels and plant maturity, rapid harvest and filling, extensive packing and the use of plastic covers weighted down effectively, are all important and necessary to exclude oxygen.

Limiting exposure of the feed to oxygen promotes rapid acidogenic fermentation, reducing time in which yeast and mold populations can grow. In addition to regular polyethylene plastic covers, oxygen-limiting plastics (OB) provide more resistance to oxygen permeability. Just as with inoculants, you should look for independent evidence of the efficacy of any plastic film offered with claims of improved oxygen barrier properties. Using an OB plastic film will require either an extra sheet of regular plastic or tarp over the OB to protect its physical integrity during the storage period.

Practical aspects of employing all of the best silage management techniques are often challenging, and even when perfectly executed, aerobic instability can still sometimes occur due to the high indigenous yeast levels on the crop at harvest. Yeast levels increase with increasing plant maturity, and also when the plant is damaged (e.g. hail, insects, frost) or stressed (e.g. drought).

2. LACTOBACILLUS BUCHNERI

In numerous research trials ***L. buchneri*** 40788 has been shown to dramatically improve aerobic stability by inhibiting the growth of yeasts. Work at the University of Delaware (Kleinschmit et al., 2005) and USDA research (Table 16) indicate that inoculation of corn silage with the FDA recommended rate of 4×10^5 CFU ***L. buchneri*** 40788/g forage is one of the most consistent additives for improving aerobic stability. The review of the high dose level ***L. buchneri*** 40788 by the FDA to allow claims for improving aerobic stability in silages and HMC is unique among inoculant products.

Table 16: effect of *L. buchneri* 40788 on aerobic stability of corn silage

Treatment	Stability, hr*
Control	75
Inoculant 1	91
Inoculant 2	71
Inoculant 3	50
L. buchneri 40788	217
Inoculant + sodium benzoate	151
* Time required for corn silage temperature to rise 2° C. (Muck, 2004)	

Lactobacillus buchneri is a hetero-fermentative bacterium that converts moderate amounts of lactic acid to acetic acid and 1,2-propanediol during the storage period. While lactic acid can be used as a food source by some silage spoilage yeasts, acetic acid is a potent inhibitor of mold and yeast growth (Danner et al., 2003). When applied at the time of ensiling, the high dose level ***L. buchneri*** 40788 has been shown to increase aerobic stability of high moisture corn (Taylor and Kung, 2002, Kendall, et al., 2002), corn silage (Kleinschmit, et al. 2005), alfalfa silage (Kung et al., 2003), small grain silages (Taylor, et al. 2002), grass silage (Driehuis, et al., 1996) and sugar cane silage (Pedroso, et al., 2002) and to prevent spoilage in dry baled hay (Baah, et al., 2005).

Feeds inoculated with the high dose level ***L. buchneri*** 40788 have also been shown to improve aerobic stability of the rations they are mixed into. Combs and Hoffman (2003) found that a total mixed ration (TMR) containing corn silage and high moisture shelled corn inoculated with ***L. buchneri*** 40788 remained stable nearly 30 hours longer than a TMR containing untreated corn silage and high moisture corn.

Using ***L. buchneri*** in a silage management program is of most benefit where problems with aerobic instability are expected. Corn silage, small grain silages, and HMC are more susceptible to spoilage once exposed to air than legume silage. Other situations that favor the use of ***L. buchneri*** are feeding ensiled feeds during hot weather, low feed removal rate, when it is known that the silage will be moved (e.g. from bag to tower or when silage is sold or transported from a centralized production facility) or in situations where silages treated with lactic acid-producing bacteria have a history of heating before feedout.

Acetic acid in silage has often been associated with reduced feed intake in ruminants in the field. Research at the University of Wisconsin (Combs and Hoffman, 2003) and the University of Delaware (Ranjut et al., 2002) showed that, while feeds inoculated with ***L. buchneri*** 40788 had higher concentrations of acetic acid and were more stable than the untreated corn silage or high moisture corn, milk production and feed intake were not affected.

3. ORGANIC ACIDS

Organic acids, e.g. propionic, acetic and benzoic acids can be applied to control aerobic instability using one of the strategies. The first is to apply high rates of the acid to achieve complete preservation. To be effective, 10 to 20 lbs. active ingredient (AI) of organic acids are required per ton of feed ensiled.

The second strategy is to apply organic acids at low rates (2 to 5 lbs. AI per ton) at ensiling to control yeast populations at feed out.

These latter rates do not provide full preservation, and the material is still dependent on an ensiling fermentation. Therefore, it is advised to use an inoculant at ensiling to help ensure adequate fermentation. However, the organic acid and the inoculant cannot be mixed, leading to practical application issues, and using both an organic acid and inoculant significantly increases production costs. Research studies comparing corn silage or HMC normally fermented or treated with organic acids have shown no differences in palatability, intake or animal performance.

4. ANHYDROUS AMMONIA

Anhydrous ammonia can also be used to control aerobic stability in silages. Use on HMC is not recommended due to the low moisture content. Anhydrous ammonia is a very effective anti-fungal agent and can dramatically reduce yeast and mold populations in silages. It does, however, alter the fermentation: it is basic in nature and immediately after application elevates the pH. Thereafter the pH slowly declines via a stilted, slower and less extensive fermentation. Some research has shown associated elevated fermentation DM losses, though anhydrous ammonia treatment often improves aerobic stability and lowers DM losses at feedout. To be effective, it is applied at 6 to 8 lbs. per ton of silage, and its caustic nature requires specialized handling equipment. Application is dangerous and should only be done by skilled personnel with proper safety equipment.

MYCOTOXINS IN ENSILED FORAGES

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Mycotoxins are secondary metabolites produced by more than 100 different molds. Mycotoxins can cause reduced feed intake and milk production, reproductive problems and death in livestock. In addition, certain mycotoxins can be transmitted from livestock diets to animal products and therefore pose a food safety hazard. Mycotoxins may be carcinogenic, mutagenic (cause mutations), neurotoxic, immunotoxic, oestrogenic, teratogenic (embyrotoxic or fetotoxic agent) or neurotoxic (Yiannikourisa and Jouany, 2002).

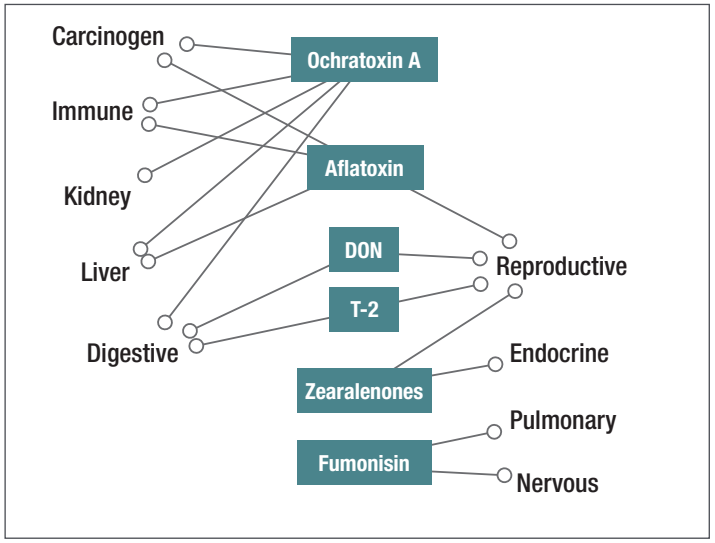
Mycotoxins can act by altering nutrient content, absorption and metabolism, modifying enzyme, endocrine and neuroendocrine function, and suppressing immunity (Fink-Gremmels, 2008) (Figure 23). Diseases caused directly by molds are called mycoses, while those caused by mycotoxins are mycotoxicoses. It is typically difficult to diagnose mycotoxicoses because of the difficulty of representatively sampling feedstuffs, limited knowledge about the role of mycotoxins in disease incidence, similarity between mycotoxin-induced symptoms and those from other pathogens, interaction between mycotoxins, and the cost and complexity of mycotoxin analysis (Whitlow, 1993). Mycotoxins should not be implicated in causing a disease unless the disease: 1) is feed related; 2) is not contagious, transferable or infectious; 3) cannot

Table 17: Rumen degradation and detoxification of mycotoxins

MYCOTOXIN	RUMEN DEGRADED	RUMEN DETOXIFIED	POTENTIAL TRANSFER INTO MILK	HEALTH RISK
Aflatoxin B1	No	No	High (1 – 6%)	Human/Animal
Ochratoxin A	Yes	Yes	Low (< 0.03%)	Animal
DON	Yes	Yes	Low (< 0.02%)	Animal
T2-toxin	Yes	Yes	Low (< 0.02%)	Animal
Zearalenone	Yes	No	Low (< 0.03%)	Animal
Fumonisin B1	Yes	No	Low (< 0.001%)	Animal
Claviceps alkaloids	Yes	No	Low (< 0.01%)	Animal
Roquefortin C	No	No	Low (< 0.005%)	Animal
Mycophenolic acid	No	No	Low (< 0.005%)	Animal

Adapted from Driehuis (2015)

Figure 23: Overview of the main health effects of the most frequently observed mycotoxins



Adapted from from Gabler, 2015

be associated with a pathogenic microorganism; 4) cannot be cured by therapeutic drugs and/or antibiotics; 5) symptoms disappear when the contaminated feed is withdrawn; and 6) feed analysis confirms the presence of mycotoxins that are known to cause the disease symptoms (Robb, 1990).

A high level of contamination by molds is often visible on silage and species differ by their variety of colors (Figure 24). The color or level of mold infestation does not reflect the type or level of mycotoxin contamination; mycotoxins can be present even when molds are not visible. However, visibly moldy forages should not be fed due to the possible presence of mycotoxins.

Figure 24: Appearance of spoilage caused by common silage molds.

In addition, by the time visible mold growth is present, much of the digestible nutrients in the crop have been used up, and so the nutritional value is compromised. Molds thrive in the presence of oxygen, therefore mycotoxin production can occur during plant growth in the field or during the stages of silage making or storage that allow air ingress into the ensiled material. Delayed harvesting, slow or delayed filing, inadequate packing and sealing, slow feedout rates, bridging in silage bags, and damaged plastic wrap, bags or silo covers can lead to pockets of mycotoxin production where the presence of oxygen and a conducive microclimate allow mold proliferation (Whitlow, 1993).

The most common mycotoxins in forages include aflatoxin, deoxynivalenol (DON), zearalenone (ZEN), T-2 toxin and fumonisin. These mycotoxins are mainly produced by ***Aspergillus***, which require warm, humid conditions, and ***Penicillium*** and ***Fusarium***, which require moist, humid, cooler conditions. ***Fusarium*** ear and stalk rot and head blight is also common in corn grown in warm, humid climates. Other factors that predispose to mold growth and mycotoxin production include insect, rodent, rain, hail and lodging damage, drought and floods. These factors can create entry points for fungal spores that germinate, grow and produce mycotoxins.

Ruminants are more tolerant to some mycotoxins due to detoxification in the rumen (Table 16), however, the increased rumen passage rates of today's high producing dairy cattle may reduce the detoxifying influence of the rumen (Fink-Gremmels, 2008). Generally, mycotoxins that have a cyclic lactone ring are quite susceptible to hydrolysis in the rumen. Animal feed, milk and other animal products may be contaminated with mycotoxins (Flores-Flores et al., 2015). Such secondary contamination sources are subject to regulation as are the animal feeds.

The following section classifies mycotoxins based on their mold source and outlines their debilitating effects on livestock, toxic levels in feed and, where known, their fate in silage and animals.

ASPERGILLUS TOXINS

Aflatoxins

Aflatoxins are some of the most common and potent forage mycotoxins. Their production is favored by high humidity (> 80%) and temperature (> 90 F; 32 C), insect damage and drought stress (DeWolf et al., 2005). These carcinogenic toxins are mainly produced by ***A. flavus***, ***A. parasiticus*** and ***A. fumigatus***, soil-borne molds that thrive in nutrient dense environments, particularly after a drought. Symptoms include inappetence due to reduced digestion, reduced rumen motility and fermentation, liver damage, ataxia, rough hair coat, delayed blood clotting and reduced immunity (Cavallarin et al., 2011). Aflatoxins are classified based on the blue and green fluorescence that develops when they are viewed under ultraviolet light into B1, B2, B2a, G1, G2 and Ga. The structure of aflatoxins is not based on a lactone ring, and they are thus generally poorly degraded in the rumen and low concentrations can inhibit ruminal bacterial growth (Yiannikourisa and Jouany, 2002). The most toxic and widespread is B1, which is excreted in milk as aflatoxin M1. Milk M1 concentrations are usually 1.7% of the aflatoxin B1 concentration in the total ration dry matter (DM) (Whitlow, 2005) though they can range from about 1% to 4%. Levels of B1 above 100 ppb can compromise the performance of dairy cattle and cause kidney damage in beef cattle (Whitlow, 2005). In fact, Queiroz et al. (2012) showed that feeding 75 ppb of B1 reduced milk production by dairy cows. Aflatoxin is the only mycotoxin with Food and Drug Administration (FDA) Action Levels in the United States. These levels are 20 ppb in feeds for dairy animals, 300 ppb for finishing beef cattle, and 0.5 ppb in milk (aflatoxin M1).

Other potent ***Aspergillus*** mycotoxins whose roles in the aetiology of mycotoxicoses in animals are not understood include:

- Fumitremoregens e.g. fumigaclavine A and B from ***A. fumigatus***, which are common in silages made in the southeast United States and can cause anorexia, diarrhea, unthrifitiness and irritability (Cole et al., 1977). These mycotoxins are called tremorgens because the toxins cause trembling due to neurotoxicity.
- Sterigmatocystin, produced by ***A. versicolor***, which has been associated with bloody diarrhea and death in cattle (Whitlow and Hagler, 2004).
- Gliotoxin, produced by ***A. fumigatus*** and some ***Penicillium*** species, which has been associated with gastroenteritis and Hemorrhagic Bowel Syndrome in dairy cows.

FUSARIUM TOXINS

Fusarium mycotoxins include several toxins that infest plants in the field and survive during ensiling. They include tricothecenes, which are about 150 structurally related compounds produced by several fungi including ***F. sporotrichiodes*** and ***F. graminearum***. Some of the most potent tricothecenes produced in conserved forages are deoxynivalenol and T-2 toxin. Others include diacetoxyscirpenol (DAS), nivalenol, neosolalaniols and hydroxyl-T-2 toxin.

Deoxynivalenol (DON) also, known as vomitoxin, is one of the most commonly found mycotoxins in conserved forages, and is often produced along with other mycotoxins. Consequently it is often used as a marker for the presence of mycotoxins in general. It is produced by ***F. roseum*** or ***F. graminearum*** (previously named Gibberella zeae) often when a cold, wet spell is followed by a short, dry period (Diekmann and Green, 1992). It is also prevalent when wet conditions coincide with warm days and cool nights. Symptoms include feed refusal, reduced milk production, emesis (vomiting), unthriftiness, immunosuppression or immunoexcitation, diarrhea, emaciation, reproductive failure and death (Whitlow, 1993; Rotter et al., 1996). DON inhibits protein syntheses and alters brain chemicals involved in serotonin production (Rotter et al., 1996).

DON is extensively degraded in the rumen (50% in 24 hours) into much less harmful products. It is excreted mainly through the urine and there is little transfer to milk (Côté et al., 1986 and Prelusky et al., 1984). The FDA stipulates advisory levels of 1 ppm for finished wheat products for human consumption, and 10 ppm DON on grains and grain by-products (on an 88% DM basis) and 30 ppm in distillers grains, brewers grains, and gluten feeds and meals derived from grains (on an 88% dry matter basis) destined for ruminating beef and feedlot cattle older than 4 months and ruminating dairy cattle older than 4 months. Additionally, it is recommended that the total ration for ruminating beef and feedlot cattle older than 4 months not exceed 10 ppm DON, and the total ration for ruminating dairy cattle older than 4 months not exceed 5 ppm DON (FDA, 2015). Beef cattle have tolerated feeds with up to 20 ppm DON, but research on effects of low levels (2-6 ppm) on milk production in dairy cows is not conclusive.

ZEARALENONE (ZEN)

Zearalenone is an estrogen-like compound that is mainly produced by ***F. graminearum*** and ***F. sporotrichiodes***. Moist conditions with alternating low (53-57 F; 12-14 C) and moderate (81 F; 27 C) temperatures favor its production (De Wolf et al., 2005). It is structural similarity to estrogen, and the ability to mimic the hormone leads to infertility, prolonged estrus, reduced conception rates, decreased litter size, rectal or vaginal prolapse and malformed offspring and abortions. Other symptoms include reduced feed intake and milk production, and diarrhea. Although ZEN is partly ruminally degradable, metabolites of ZEN can be more, or less, toxic than the parent toxin. Milk carryover rate of 0.06% of the dietary dose has been reported when 544 mg of ZEN was ingested daily for 21 days. However, ingestion of much higher, single doses produced negligible transfer to milk (Yiannikourisa and Jouany, 2002). Levels of 12 and 50 ppm can reduce conception in virgin heifers and dairy cows, respectively (DeWolf et al., 2005).

FUMONISINS

Fumonisin B1 (FB1) and B2 (FB2) are the most important of the 28 forms of the toxin in silage. Produced by ***F. moniliforme*** and ***F. proliferatum***, they are estrogenic and carcinogenic in humans and act by blocking biosynthesis of important membrane lipids, resulting in cell dysfunction and death (Yiannikourisa and Jouany, 2002). Hot, dry periods followed by humid conditions and insect damage favour production (DeWolf et al., 2005). Symptoms include leucoencephalomalica in horses, and inappetance and liver damage in ruminants (DeWolf et al., 2005). Excretion of fumonisin in milk is thought to be negligible (Whitlow, 2005), though a carryover rate of 0.05% was reported when the diet contained 3 ppm of FB1 toxin (Yiannikourisa and Jouany, 2002). The FDA stipulates guidance levels for total fumonisin concentration in contaminated corn and corn by-products of no more than 2-4 ppm in human food, 30 ppm in feed for breeding ruminants, and 60 ppm in feed for calves more than 3 months that are raised for slaughter. Levels of contaminated corn and corn by-product in ruminant rations should also not exceed 50% (DM basis of the ration).

T-2 TOXIN

T-2 is a common contaminant of feeds and is more prevalent in wet, warm (60-89 F; 15-30 C) conditions. Symptoms include feed refusal, perineal and pharyngeal irritation reduced immunity, gastroenteritis, hemorrhage of the gastrointestinal tract, diarrhea, infertility and death. It is potentially harmful to cattle at levels of 0.7-1.5 ppm in the ration (Li et al., 2011). T-2 is degraded in the rumen to metabolites that are less toxic, but still poisonous (Whitlow, 1993). Between 0.05 and 2% of dietary T-2 can be excreted in milk. The lethal dose in cattle is more than 13 mg kg-1 body weight (Yiannikourisa and Jouany, 2002).

FUSARIC ACID

Fusaric acid is produced by ***F. monoliforme*** and several other ***Fusarium*** species. It inhibits plant growth and blocks Dopamine ß-hydroxylase in the nervous system (Toshiharu et al., 1970), which is integral for the flight or fight response in animals. It is often found with trichothecenes like DON, and it increases the toxicity of such toxins.

PENICILLIUM TOXINS

Ochratoxin

This toxin is produced by ***A. ochraceus***, ***A. clavatus*** and ***Penicillium verrucosum,*** particularly when temperatures range between 32 to 99 F (0 to 37 C) for ***P. verrucosum*** and 59 to 99 F (15 to 37 C) for ***A. ochraceus*** (FAO, 2001), moisture content exceeds 16%, and oxygen is present. Ochratoxins A and B occur naturally but the former is more widespread. It is carcinogenic and immunotoxic, and it impairs enzyme and kidney function, inhibits cellular respiration and glucose metabolism, therefore, increases the incidence of fatty live syndrome and retards growth (Whitlow, 1993; Yiannikourisa and Jouany, 2002). The toxin can be ruminally degraded into a less toxic product (Hult, et al., 1976). When the detoxifying capacity of the rumen is exceeded, (> 1.7 mg/kg body weight), the toxin can be detected in milk. Symptoms have included diarrhea, kidney damage and reduced milk production (Whitlow, 1993; Yiannikourisa and Jouany, 2002).

Other potent ***Penicillium*** mycotoxins have poorly understood effects on animal performance and health:

- Secalonic acid, produced by ***P. expansum***, ***P. urticae***, ***A. clavatus*** and ***Byssochlamys nivea*** (Yiannikourisa and Jouany, 2002). It is commonly found in deteriorating silage and can reduce digestion of protein, fiber and organic matter, alter rumen volatile fatty acid profile and kill cows (Yiannikourisa and Jouany, 2002). It is carcinogenic and mutagenic, and also causes lack of coordination of motor organs, gastric paralysis and death (Yiannikourisa and Jouany, 2002).

- PR toxin and Roquefortin are tremorgens produced by ***P. roqueforti*** that cause rumen stasis, digestive upsets, abortion and retained placenta (Whitlow, 1993). They have relatively low stability in the silo (Yiannikourisa and Jouany, 2002).

PRE- AND POST-FERMENTATION MYCOTOXIN INCIDENCE

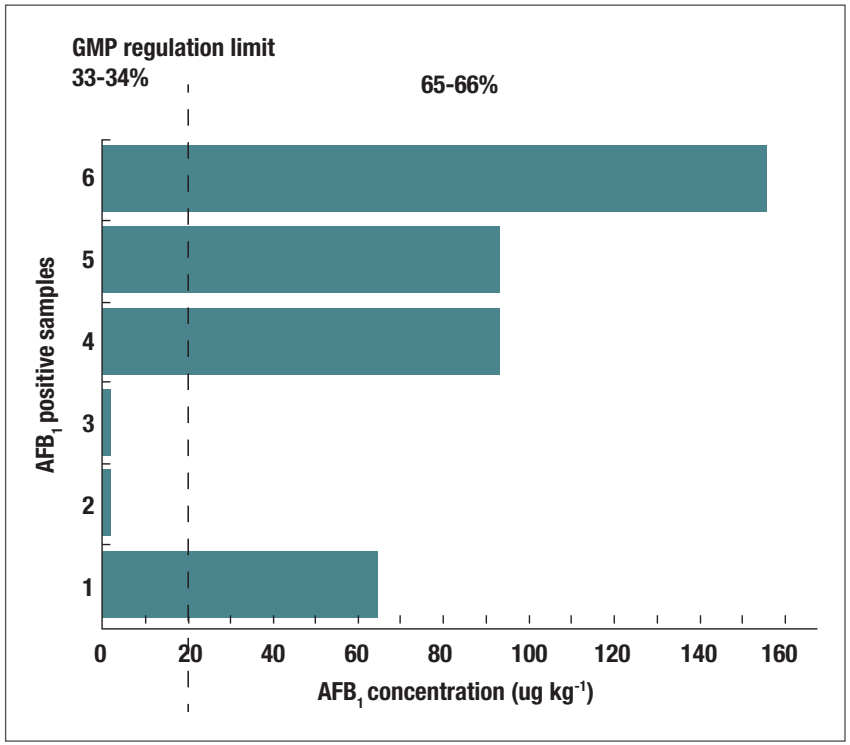
In silage, mycotoxins may originate in the field or be produced during storage (Miller et al., 2014). Production in the field is mainly due to plant pathogenic fungi, such as ***Fusarium*** species that cause ear rot and blight diseases and produce mycotoxins like DON, zearalenone, fumonisins, T2-toxin, enniatins, beauvericin and nivalenol in certain cereal grains and corn. Other field mycotoxins are produced by ***Claviceps*** and ***Neotyphodium*** species, which produce ergot alkaloids in fescue and certain cereals and grasses and ***Aspergillus*** species, which produce aflatoxins in peanut, corn, cotton, etc. Fungi that grow on senescent or stressed plants, including ***F. verticillioide***s (fumonisins), ***A. flavus*** (aflatoxins), ***A. fumigatus*** (gliotoxin) and ***P. verrucosum*** (ochratoxin), ***P. roquefortii*** and ***P. paneum*** (roquefortin C and mycophenolic acid) can predispose the forage to mycotoxin contamination during ensiling (Adams, 1977; Driehuis et al., 2008; Alonso et al., 2013). Post-fermentation production of mycotoxins is mainly caused by ***Penicillium*** and ***Aspergillus***, with patulin and aflatoxin B1 usually the main mycotoxins produced during the storage period (Alonso et al., 2013)

In a survey in southern Brazil, total fungal counts increased during the fermentation process in more than half of the samples of corn silage, with species like ***A. flavus*** and ***A. fumigatus*** being relatively abundant (Keller et al., 2012). Growth of those fungi was especially high at the sides of the silos, where pH was higher, density lower, and there was presumably greater access

to oxygen. However, in an Argentinian survey (Gonzalez-Pereyra et al., 2011), high levels of aflatoxin B1 were only detected in samples from the middle section of the face of corn silages (Figure 25). No explanation was given for this unusual occurrence as samples from the middle of the face of bunker silos were said to be well packed with no visible molds.

Low oxygen concentration and high acidity (low pH) in silage inhibit the growth of mycotoxin-producing fungi. These conditions need to be maintained to ensure continued preservation of the silage. All silos will allow some ingress of oxygen, but proper sealing of the silo, for example with plastic incorporating an oxygen barrier film, will help minimize oxygen ingress. Integrity of this plastic must be checked periodically and any punctures repaired and displacement corrected.

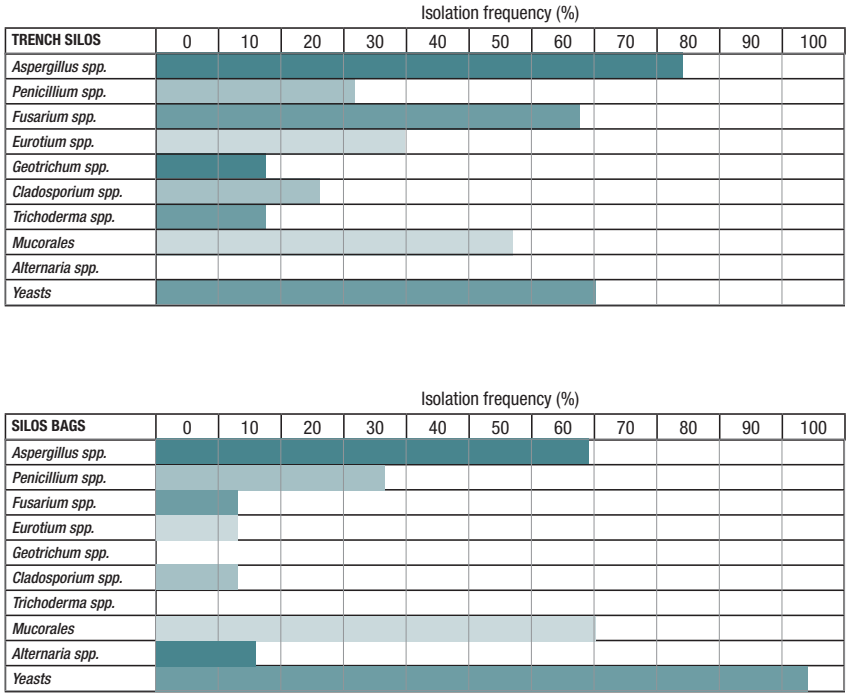
Figure 25: Aflatoxin B1 concentration in corn silage samples from the middle sections of the face of several surveyed silos. Two thirds of samples from the middle section had AFB1 levels exceeding regulatory limits (GMP – good management practice level and FDA action level for dairy feeds).



(Gónzalez Pereyra et al., 2008)

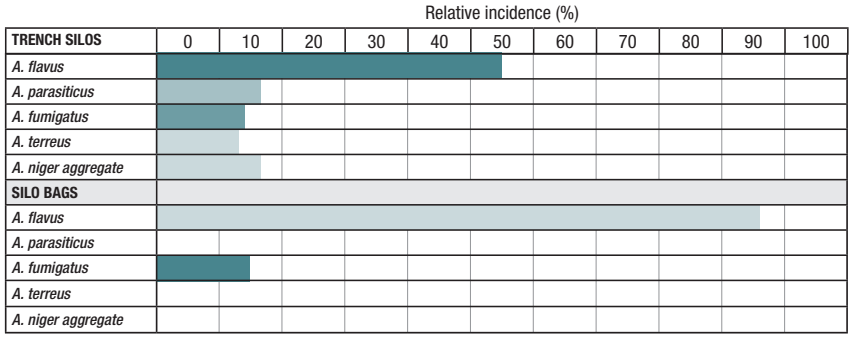
In a survey in Argentina, bunker and bag silos were compared in relation to the diversity of molds and mycotoxins present (Figure 26 & 27). The main fungal contamination in trench or bunker silos was from *Aspergillus* and *Fusarium* species, while bag silos were mainly contaminated with *Aspergillus*, and *Penicillium* species and also consistently contained higher yeast populations (Gónzalez Pereyra et al., 2011). *Aspergillus* and *Fusarium* contamination was detected with less frequency in silo bags, compared to trench silos. The survey suggested that silage defacers are the best feedout technique to maintain compaction of the silage and prevent oxygen infiltration into deep parts of the silo.

Figure 26: Frequency (%) of isolating different fungal genera, yeasts, and Mucorales from trench (bunker) and bag silo corn silage samples in Argentina.



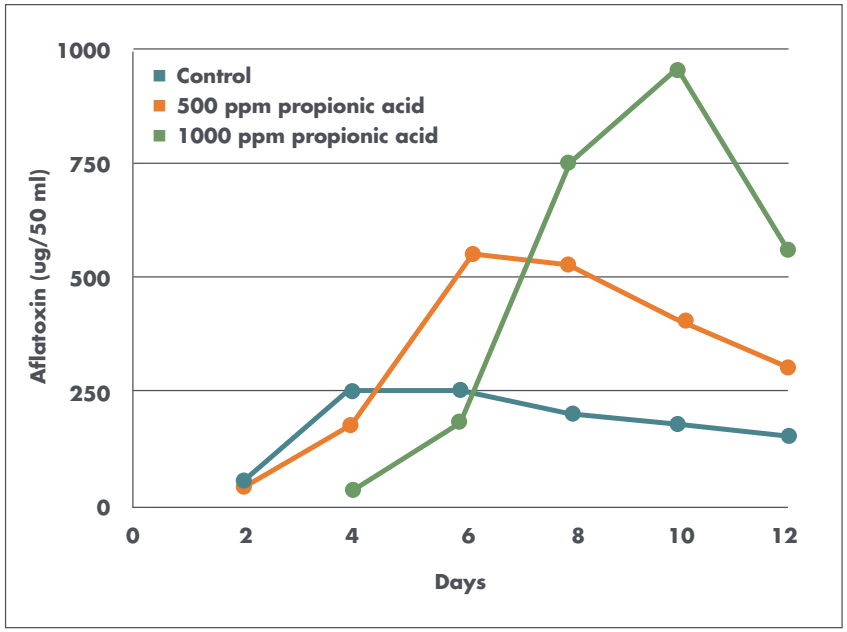
Gónzalez Pereyra et al., 2011

Figure 27: Frequency (%) of isolating *Aspergillus* species isolated from trench and silo bag corn silage samples



Gónzalez Pereyra et al., 2011

Figure 28: The influence of propionic acid on aflatoxin production by *Aspergillus flavus*



(BASF Keeping Current 894: Efficacy of low levels of mold inhibitors)

PREVENTING MYCOTOXICOSES

Complete detoxification of silage contaminated with mycotoxins is not practical. Since mycotoxins are produced by molds that depend on oxygen for growth, any steps that ensure and accelerate oxygen removal from silage at filling or minimize oxygen ingress into silos are very important. The following agronomic and silage management practices are recommended to minimize mold growth and mycotoxin production:

- Avoid zero till, as this leaves high levels of crop residues in the field, providing a harbor and growth source for molds.
- Plant insect and disease-resistant varieties and practice crop rotation.
- Avoid or minimize the effects of plant stressors (e.g. inadequate fertilization, insect, bird or hail damage, lodging, flooding and drought) that predispose to mold infestation and mycotoxin production.
- Use recommended fungicide treatments.
- Clean bunkers prior to use.
- Timely harvesting avoids ensiling mature, dry forages that are difficult to pack and inherently contain higher populations of yeasts and molds.
- Make sure that crop moisture level is on target with silage goals to facilitate packing given the storage structure employed.
- Use an inoculant proven to provide a fast fermentation: the lactic bacteria in inoculants help to scavenge oxygen from the silage mass initially, and then deliver the necessary rapid pH reduction due to lactic acid production.

- Use additives proven to minimize mold growth, such as ***Lactobacillus buchneri*** 40788 inoculants, or apply mold inhibiting organic acids like propionic acid. It is very important to follow manufacturer's recommended application rates when using organic acids or the situation can actually be made worse (Figure 28).
- Use sharp knives at harvest to ensure a good chop length and enhance packing. Aim for a fill rate of 1 minute per ton and a packing density of at least 15 lbs. of dry matter per cubic foot or 40 lbs. fresh forage per cubic foot.
- Seal silos promptly and effectively on the day they are filled.
- Weigh down plastic adequately (e.g. more than 20 tires per 100 square feet, Bolsen and Bolsen, 2004).
- Inspect bags or cover plastic regularly and seal any holes promptly with proper silage tape.
- Feedout at a rate that prevents heating and spoilage and minimizes exposed faces that are undisturbed for days (12 inches per day).
- Maintain a straight silo face using a shavers or a silage rake.
- Discard all spoiled (mold contaminated) silage.

SUGGESTED TREATMENTS FOR MYCOTOXICOSES

- Withdraw the problem silage from the ration where possible.
- If this is not possible, dilute the amount of the problem silage fed.
- Ensure the levels of dietary antioxidants (vitamins A and E, selenium and zinc) are adequate.
- Ensure the ration is balanced to provide adequate nutrients.
- Use proven mycotoxin absorbent(s) such as aluminosilicate and montmorillonite clays (Kutz et al., 2009; Queiroz et al., 2012) and glucomannans or mannanoligosachharides (Diaz et al., 2004). However, such commercial products differ in efficacy, and do not bind all mycotoxins equally well. Clay-based products have been more effective at sequestering aflatoxins than other sequestering agents, but they may be less effective on other mycotoxins. Certain binders may reduce bioavailability of minerals and vitamins in the diet. Only products that have been shown to be effective in independent research trials should be used.

Recent experiments indicate that the microflora in silage could either inhibit fungal growth or detoxify some of the mycotoxins present in the forage. Most of the current information concerns inhibition of fungal growth by lactic acid bacteria following the production of organic acids, like acetic and propionic acid. Production of low-molecular weight compounds, like phenyllactic acid (Svanström et al., 2013), or reuterin (Dalié et al. 2010) and antimicrobial peptides could also reduce fungal growth (Dogi et al., 2013). Enzymatic degradation of mycotoxins could lower the contamination rate and microbes that degrade fumonisin and zearalenone have been isolated from ***F. graminearum*** infested-silage (McCormick, 2013). Recent reports also indicate that silage lactic acid bacteria can sequester aflatoxin B1 in silage (Ma et al., 2015 a, b). There is little current information on the potential use of these strategies to reduce mycotoxin contamination in silages, therefore, more research is required on how to use these agents to increase silage safety.

APPENDIX I

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APPENDIX II

SILAGE TROBULESHOOTING: PROBLEMS, CAUSES, AND SOLUTIONS

PROBLEM	CAUSES	MANAGEMENT AND FUTURE AVOIDANCE
High pH silage (see Figure 3)	A number of possible causes: ▪ Slow fermentation: smell and look at VFA profile for indicators (butyric etc.) ▪ Yeast growth: look for indicators in smell (no smell or slightly alcoholic), VFA profile and microbial analyses. ▪ *Bacillus* growth: earthy smell, may be heating.	Management is largely down to what else is going on. If silage is not heating, feed rate needs to be high and/or a TMR treatment used. If silage is butyric, feed rate must be carefully controlled. Performance is likely to be compromised due to energy lost from silage. Avoidance: Total management approach -harvest stage, chop length, speed of fill, pack rate, plus use a good additive.
Silage heating or heated	▪ Yeast growth (main initiators of heating). ▪ *Bacillus* growth. ▪ *Acetobacter* growth: mainly seen in cereal silages.	Managing needs high feed rate, good face management, maybe also use of a TMR treatment. Avoidance: Focus on management—packing, speed of fill, chop length, etc., plus use an aerobic spoilage inhibitor on the silage.
Moldy silage	All mold comes in from the field and grows in silage because air is present. Air can be due to poor packing (e.g., balls or lumps of mold in silage mass), delays during filling (e.g., bands of mold in silage: fill lines), poor sealing (mold at top and/or sides) or slow feedout (mold across face). Large diseased areas in the field at harvest.	Be very careful! If any doubt, throw away moldy silage: by the time it's moldy it has lost most of its available energy. See also LAN Mold Guide. Avoidance: Exclude air in the silage, use fungicides properly in the crop in in the field, and use a proven aerobic spoilage inhibitor on the silage.
Silage pH too low	This usually results from the activity of "wild" lactobacilli naturally present in the silage and often results after a slow initial fermentation (usually a fast fermentation will prevent the wild lactobacilli becoming established).	May need to be careful what is fed to avoid acidosis, etc. Avoidance: Largely management (fill rate, packing, etc.) and use an inoculant with a good homolactic LAB.
High ammonia	Some lactic bacteria (e.g. *Enterococcus/ Streptococcus faecium*) break down protein, so can cause a higher ammonia level in an otherwise well-preserved silage. High ammonia can also result from a clostridial silage (strong fecal smell) or from entero-bacteria. High ammonia can result from over-application of fertilizers (total crude protein will be unrealistically high).	Requires care when feeding. If silage is butyric, be careful with rate of inclusion in ration. If not butyric, be careful with level of NPN in ration. Avoidance: If fertilizer problem,man fertilization better. If clostridia, avoid soil inclusion (ash <8%), harvest drier (30% DM), and use a homolactic LAB inoculant.

APPENDIX III

GLOSSARY OF SILAGE SMELLS

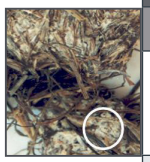
SMELL	PROBABLE CAUSE	MANAGEMENT ISSUE
Sweet Acid	Probable strong fermentation: check pH, could be too low	Could have stability problems when fed out. Check yeast and mold levels.
Acetic/ Vinegar	Elevated acetic acid level: check VFAs etc. 1) High lactate, acetate and propionate: good stable silage, feeds well. 2) Lower acetate, some ethanol, maybe some butyric, iso-butyric (messy VFA profile), also some ammonia. Classic slow fermentation: may or may not be stable, intakes not ideal, lower performance.	Type 1: Excellent silage, feeds well, animals perform well. Type 2: Silage may not be stable, potential palatability problems, animals do not perform ideally.
Fecal/ putrid/ decaying	Clostridial silage: slow fermentation and?or contamination (ash>8%) has resulted in clostridia dominating the fermentation and producing butyric acid (classic smell is mouse droppings), ammonia, amines (e.g. putrescine, cadaverine). Silage will be wet, pH may be elevated or may be low.	Silage will be very stable but intakes will be low. Forcing high intakes can cause health and fertility problems. Spread out to aerate and reduce butyric acid levels. Feed as low proportion of ration, mask with suitable flavor (e.g. butterscotch, caramel). Do not feed to pregnant cows, transition cows or cows in first 100 days of lactation.

GLOSSARY OF SILAGE SMELLS

SMELL	PROBABLE CAUSE	MANAGEMENT ISSUE
Earthy	*Bacillus* growth: pH will be high.	Silage will eat and may also go moldy. Must be fed quickly, removing moldy material. Consider treating TMR.
No smell to alcoholic or fruity/ yeasty/ bread odor	Yeast growth, consumption of VFAs. pH will be elevated, may be some alcohol on analysis. Micro will probably show high yeast levels.	Silage very likely to be warm, hot or likely to heat. May also be or go moldy. Feed carefully as above.
Tobacco/ burnt odor	Silage has undergone excessive heating due to yeast and/or *Bacillus* growth. May also be moldy. Analysis shows little or no VFAs or other volatiles. May have a high level of bound/heat damaged protein (ADIN): this indicates temperatures have been in excess of 100F.	May have reasonable/high intake (cows like the taste) but will not perform well since most of the energy has already gone.
Musty/ moldy	Molds are growing in the silage, probably visibly. Silage as already heated due to yeast growth with losses of dry matter and nutrients.	Remove and discard moldy silage.

APPENDIX IV

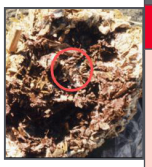
GUIDE TO COMMON SPOILAGE MOLDS



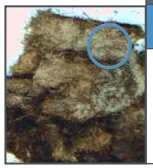
Color	Appearance	Consequence	Toxin
WHITE			
Geotrichum	Powdery white, as on the outside of Camembert cheese	Depressed Intake	No
Rhizopus	Appearance similar to Mucor	None	No
Byssochlamys	Fluffy, powdery white	Impaired rumen function	Patulin
Mucorales	Black points	Depressed intake	No

Color	Appearance	Consequence	Toxin
WHITE TO BLUE-GREEN			
Penicillium urticae	Goes from white to powdery green when exposed to air (due to sporulation)	Depressed intake	Unknown toxin Neurotoxin
P. Citrinin		Kidney damage, poor performance, weight loss	
P. roquefortii	Deep blue spores, tends to dominate air-tight storage	High level of spores can cause severe respiratory problems	
P. viridicatum		Kidney damage in monogastrics, little effect on ruminants	Ochratoxin

GUIDE TO COMMON SPOILAGE MOLDS



Color	Appearance	Consequence	Toxin
RED			
Fusarium	Downy white at the beginning, red to purple colored after sporulation	Depressed Intake Diarrhea	Zearalenone (Oestrogenic) DON (vomitoxin)
Monascus	Blood red	Ruminal troubles	citrinin (rare)
F. tricinctum	White, fluffy, powdery through to red	Diarrhea, poor performance	Trichothecenes
Giberella zea	Red-orange spores	Feed refusal, hemorrhaging, reproductive disorders. Mainly affects pigs.	Vomitoxin



Color	Appearance	Consequence	Toxin
BLUE/GREY			
Aspergillus fumigatus	Diffuse	Abortion Pulminary Mycosis (Farmer's Lung)	Unknown toxin Neurotoxin

APPENDIX V

GLOSSARY OF SILAGE TERMINOLOGY

1. Forage: the crop prior to ensiling (e.g. forage corn, forage peas, alfalfa forage).

2. Silage: the crop after it has been ensiled (e.g. corn silage, pea silage, alfalfa silage).

3. Haylage: term generally used for alfalfa or grass silage made at a higher dry matter level (e.g. >30% DM), though the use of the term can vary! Some refer to any grass or alfalfa ensiled material as haylage regardless of DM, in the Midwest, generally haylage is only used for ensiled alfalfa, the makers of Harvestores insist only material made in a Harvestore is haylage.

4. Ensiling: used to describe the process where a forage is put into a storage structure, becomes anaerobic and is acidified by the production of acids due to the action of bacteria either on the crop at harvest or added as an inoculant.

5. Direct cut: used to describe a silage that is cut and harvested at the same time, i.e. the forage is not allowed to sit in a windrow and dry down.

6. Wilting: the process where forage is left in the field to dry down, usually in windrows, to raise the dry matter level in the crop, prior to being chopped and ensiled.

7. Windrow: forage collected into loose piles, ranging from inches to several feet in height, running along the length of the field in rows, allowing the wind to pass through the forage and help the forage dry down.

8. Dry matter: once all the moisture is removed from the forage, what is left is the dry matter. Dry matter is measured as a percentage by weighing the fresh forage, drying it in an oven, a microwave oven or using a Koster tester and re-weighing the material when it is dry. The dry matter content is calculated as: Dry Matter (DM) = (Dry weight/ Fresh Weight) x 100 % Moisture content (%) is obtained by: 100 - %DM = % moisture

9. Length of cut: there is a setting on the forage harvester which allows the operator to set the theoretical length of cut (TLC). General recommendations are to set the TLC to 3/8" -1/2" for alfalfa and grass, 1/2" - 3/4" for corn, but the particle size distribution achieved should always be checked (e.g. using the Pennsylvania State Forage Particle Separator).

10. Fermentation: when the forage is put into the storage system it initially has some oxygen trapped in. This oxygen allows microorganisms to grow aerobically and produce carbon dioxide (respiration): the plant itself also continues to respire. Once the oxygen supply is exhausted the microbes that absolutely need oxygen to grow (obligate aerobes) cease to grow and the plant ceases respiration. Microbes that can grow without oxygen present (anaerobes and facultative anaerobes) begin to grow fermentatively, producing various fermentation products. Yeasts will produce alcohol, lactic acid bacteria will produce predominantly lactic acid, propionic bacteria produce propionic acid, acetogenic bacteria produce acetic acid, clostridia produce butyric acid.

11. Volatile fatty acids (VFAs): these are acids that are produced by microbes in the silage from sugars and other carbohydrate sources. By definition they are volatile, which means that they will volatilize in air, depending on temperature. Thus, lactic acid is NOT a volatile fatty acid, while acetic and propionic and butyric are. Many use the term VFAs incorrectly to include lactic acid. To include lactic, the term "fermentation acids" should be used.

12. Lactic acid: lactic acid is the most acidic of the common fermentation acids and so is the main driver of the initial pH drop responsible for "pickling" the crop and the initial ensilage of the crop. It is produced by lactic acid bacteria, which can vary dramatically in efficacy of production and in levels on the forage crops ensiled. Hence, it is important to inoculate a forage crop with high numbers (100,000 CFU/g minimum) of efficient homolactic lactic acid producers if a fast pH drop is required. However, lactic acid has no effect against yeasts and molds, beyond reducing pH, and many common silage yeasts can actually use lactic acid to grow on.

13. Acetic acid: is the acid that is present in vinegar. It has a strong ability to prevent growth of yeasts and so should ideally be present in silages at a reasonable level to prevent heating and spoilage. It can be produced in silage in a number of ways, mainly by lactic acid bacteria. Acetic acid can be an indicator of a slow, inefficient fermentation driven by heterofermentative lactic acid bacteria. This type of fermentation can result in the production of other products in the silage that can depress intakes and means that energy has been wasted (see "Homofermenters and Heterofermenters" below). However, acetic acid can also be produced efficiently by homofermentative bacteria,from five-carbon sugars (e.g. xylose) and by the anaerobic conversion of lactic acid to acetic acid by Lactobacillus buchneri. In these situations the fermentation is efficient and the potential intake depressing compounds are not produced.

14. Propionic acid: is a known mold inhibitor, used to treat many feedstuffs to prevent molding. It can also be produced in the silage, by fermentation of sugars and/ or lactic acid by propionic acid producing bacteria and/ or as a co-product in the conversion of lactic acid to acetic acid by Lactobacillus buchneri.

15. Butyric acid: the main source of butyric acid in silage is fermentation by clostridia, which are present on the crop in relatively small numbers at harvest. Numbers in the ensiled forage can be dramatically increased by the inclusion of soil, picked up either by cutting the crop too low or during raking or tedding, or on packing tractor wheels in wet conditions. Soil can contain up to 10 billion CFU of clostridia per gram. In addition to producing butyric acid, which can give the silage a very strong, persistent fecal smell, clostridia can also break down proteins, leading to significant loss of protein and the production of biogenic amines, e.g. histamine, putrescine, cadaverine, that can affect herd health and/ or production and produce odors associated with putrification or decay.

16. Iso-Butyric acid: is an isomer of butyric acid, usually present because of the deamination of the amino acid valine by clostridia (though it is also known to be produced by Lactobacillus brevis).

17. Ethanol: is primarily produced by the fermentative activity of yeasts, but is also produced by heterofermentative lactic acid bacteria. If the level of ethanol in the silage is relatively low and there are reasonable levels of lactic and acetic acids, the source is probably heterofermentative LAB. If the level is high, the source is probably from yeasts. In any event, look also at the bound protein level (ADICP). If ADICP is greater than 10% of the CP, then there has been heating and the ethanol most likely came from yeasts (Caution! - the ethanol level may be low due to being volatilized because of the heating).

18. Soluble protein: is produced by the breakdown of proteins into amino acids, etc. High levels of soluble protein indicate excessive protein degredation and may also be accompanied by high amonia levels and other indicators of a bad fermentation (e.g. the fermentation acid profile).

19. Ammonia nitrogen: high levels of ammonia nitrogen show that there has been excessive protein degradation, either due to prolonged wilting (the plant will degrade itself lying in the field) or due to microbial activity. Ammonia should preferably be <15% of the CP in corn silage, <10% in grass and alfalfa silages and haylages. Excess microbial proteolysis (protein degradation) could be due to clostridia (look for the butyric acid level also to be high: >1% DM) or due to other proteolytic bacteria (e.g. Enterococcus faecium).

20. Homofermenters and heterofermenters: lactic acid bacteria can be broadly categorized into two groups based on how they ferment hexose (6-carbon) sugars like glucose and fructose.

Homofermentative LAB convert each molecule of 6 carbon sugar into two 3 carbon molecules of lactic acid:

Glucose 2 Lactic acid + 2 H2O
Fructose 2 Lactic acid + 2 H2O

Heterofermentative LAB produce a mixture of end products from 6 carbon sugars:

Glucose 1 Lactic acid + 1 Ethanol + 1 CO2 + 1 H2O and
3 Fructose 1 Lactic acid + 1 Acetic acid +
2 Mannitol + 1 CO2 + 1 H2O

So, using a mixture of 3 glucose and 3 fructose, the end products of the two types of LAB would be:

Homofermenters: 12 Lactic acid + 12 H2O
Heterofermenters: 4 Lactic acid + 1 Aectic acid + 3 Ethanol
+ 2 Mannitol + 4 CO2 + 4 H2O

The heterofermentative LAB produce significantly less acid (slower pH drop) and also produce carbon dioxide (loss of dry matter and energy), ethanol (depending on levels it can increase or decrease palatability) and mannitol (decreases palatability).

21. Yeasts and molds: both are fungi: yeasts growing as single cell organisms while molds grow as multicellular filaments. Both occur widely in soil and water and on vegetation, increasing in numbers on vegetation as the crop ages or gets damaged (e.g. frost, hail, drought) and during wilting. In addition to being able to grow on free sugars, both yeasts and molds secrete extracellular enzymes which break down the complex plant materials into simple sugars which can then be used for growth. Many of the yeasts found on plant material contain carotenoid (orange to red) pigments to protect them against UV exposure and so can be responsible for some of the colors seen on silage faces. While yeasts can grow aerobically, they can also grow fermentatively (anaerobically), with ethanol being one of the major products. Other products that yeasts can produce in anaerobic growth conditions include n-propanol, iso-pentanol, acetic, propionic, butyric and iso-butyric acids, as well as small amounts of lactic acid. In the presence of air, yeasts will oxidize sugars fully, producing carbon dioxide and water and generating heat.

Many yeasts can also use lactic acid for growth, again oxidizing it fully and generating heat. Yeasts are responsible for the vast majority (>95%) of heating silages: a yeast population >100,000 CFU/ gram in the silage will almost certainly mean that the silage will heat as it is exposed to air during feedout. Yeast growth can be inhibited by acetic acid.

The conditions normally associated with stable silage, low pH and anaerobic conditions, do not favor growth of molds. Generally they are only a problem where air exposure has occurred, e.g. at the top and on the sides of bunkers or piles, where there have been air leaks into the silage, where packing has been poor (e.g. localized lumps of moldy silage), at surfaces left exposed during filling and at the surface of the silage during feedout. As the silage moves towards the surface, if there are high numbers of yeasts present these can grow on the lactic acid present, raising the pH and the silage temperature, promoting the subsequent growth of molds. Mold growth is undesirable, since the molds will fully oxidize both sugars and lactic acid, and will also break down (hydrolyze) and fully oxidize cellulose and other cell wall components, resulting in huge dry matter and energy losses. In addition, many of the molds commonly found in silages can produce mycotoxins, which can cause significant health and/ or reproductive problems and dramatically reduce performance. Finally, molds produce spores that become airborne when the silage is disturbed and can cause respiratory problems if they are inhaled (both for the cows and for the producer and farm workers). Mold growth can be inhibited by propionic acid.

22. Buffered propionic acid: is produced by mixing propionic acid with a base, e.g. ammonium hydroxide, to produce a salt, e.g. ammonium propionate. In concentrated solution this will be non-corrosive, but as the mixture hits more moisture, either by dilution or in the crop at harvest, the salt dissociates, forming ammonium ions and propionate ions and becomes as acidic as propionic acid. Buffered propionic acid can be effective in preventing aerobic spoilage, as long as it is used at the recommended level (4 - 6 lb/ ton fresh weight) but is not effective as a general acidifier to ensile forage (rates of use would be too high and so cost prohibitive). Low levels of propionic acid can stimulate the production of some mycotoxins.

23. Anhydrous ammonia: the addition of anhydrous ammonia to forage raises the pH of the forage and so tends to inhibit all microbial activity. The effect on yeasts and molds is permanent inhibition, provided the product is applied at recommended rates (7 - 10 lb/ ton of forage DM). Lactic acid bacteria, and enterobacteria, will eventually recover and the silage will ferment, though there will be a considerable delay in the fermentation, which can lead to increased dry matter losses. Ammonia is a hazardous gas and needs to be handled with care.

24. Inoculants: are additives containing bacteria selected to grow quickly and dominate the bacterial population in the silage. Traditional inoculants contain homofermentative LAB, e.g. Lactobacillus plantarum, Pediococcus spp., to increase lactic acid production and so increase the rate of pH drop and decrease the production of acetic and butyric acids. Newer inoculants have been developed containing bacteria proven as aerobic stability enhancers, e.g. Lactobacillus buchneri, either on their own or in combination with the traditional inoculant organisms.

25. Aerobic instability: silage that heats on exposure to oxygen suffers from aerobic instability. In research trials the length of time a silage is stable is measured by the time it takes to heat by a specific amount, most commonly 2ºC. As previously mentioned (see "Yeasts and Molds" above) most of the heating events seen in silage result from the growth of yeasts. When determining in the field if a silage is heating, it is important to note and record the ambient temperature on the day the silage was made. It is normal for a silage to increase in temperature by 15 - 20ºF during a good ensiling process. So, if the forage was harvested on days when the temperature averaged 80ºF it would not be abnormal for the silage to be 95-100ºF. However, if the same silage is 120ºF, then it is heating. Just because the silage "steams" as it is removed during feedout in winter does not necessarily mean that it is heating!

26. Secondary fermentation: literally means any fermentation that takes place after the primary fermentation (i.e. after the lactic acid production). However, some use secondary fermentation only to refer to clostridial fermentation in the silage. Others use the term only to describe fermentation of the silage by yeasts and so the onset of aerobic instability. Technically both are correct, provided there has been an initial lactic fermentation.

27. Feedout rate: the rate at which the silage is fed out, generally expressed in term of inches per day that the silage surface is removed. Conventionally it is recommended that feed out rates are a minimum of 6" per day. In practice, feedout rates should be maintained at whatever is necessary to keep the silage stable.

28. Fermentation analysis: in order to get an idea of the quality of the silage and the fermentation pattern we take samples and submit them to approved laboratories (e.g. CVAS, Dairyland) for analysis. There are a number of features we can request in the analysis, all of which add to the cost, so it is important to understand what we are looking for from the analysis so that we do not pay for things we do not need. If we have a good, well preserved silage and we are doing the analysis just to show the producer the feeding quality of the silage, then limit the analysis to the "Feed" analysis. This will show things like the dry matter of the silage, pH, fiber and lignin levels, starch, protein levels (including total crude protein, soluble and bound protein) and the derived parameters like net energy figures. If the producer is unhappy with silage quality, then in addition to the above, add ash (shows if there was soil, or possibly slurry, in the forage: take 7 off the ash and the rest is from something other than the plant, e.g. ash at 12%, 12-7 = 5%, which is 100 lb/ton of silage DM of ash coming from soil, or slurry, potentially sources of clostridia [soil] and/ or enterobacteria [slurry]). In addition, have the fermentation analyses done (include 1, 2-propanediol if it is a silage treated with Lactobacillus buchneri) and also consider microbial analyses (usually only if yeasts are the suspected cause).

29. CFU: colony forming unit. When we count microorganisms we do so by diluting them and then putting the diluted suspension onto agar (jelly) plates, incubating them at the right temperature and then counting the number of colonies, or "spots", on the plate. Each colony may have formed from one cell being on that point on the plate and multiplying up, or could be from a clump or cluster of cells that were stuck together landing on the spot and multiplying. So, we count the number of colonies we see, multiply by the dilution and report the result as CFU per gram, since the CFU could have been one cell or a clump of many originally.

APPENDIX VI

ESTIMATED FRESH WEIGHT FORAGE CAPACITIES

1. Bunkers and trenches:
(All weights and capacities are in tons fresh weight)

Wall height	Avg width	Corn Silage, 65% (15 lb DM/cu ft) Wall lenght			Haylage, 60% (14 lb DM/cu ft) Wall lenght			HMC, 30% (45 lb DM/cu ft) Wall lenght			Earlage, 38% (35 lb DM/ cu ft) Wall lenght		Snaplage, 42% (30 lb DM/cu ft) Wall lenght	
		60	80	100	60	80	100	60	80	100	60	100	60	100
8	20	169	250	331	138	204	270	253	375	497	222	436	203	400
	30	252	373	494	206	305	404	378	560	742	332	651	304	597
12	36	353	571	789	288	466	644	529	856	1183	465	1039	426	952
	60	587	949	1311	480	775	1071	881	1424	1967	774	1727	709	1582
16	36	NA	619	898	NA	505	734	NA	928	1347	NA	1183	NA	1084
	60	NA	1030	1495	NA	841	1221	NA	1545	2242	NA	1969	NA	1804

Note: Calculated using the spreadsheet available at fyi.uwex.edu/forage/harvest/#inventory and assuming:
Top width = avg width (measured at half wall height) + 2 ft
2 ft of dome height above the wall when avg width ≤30 ft
3 ft of dome height above the wall when avg width ≥36 ft
4:1 (lenght:height) filling ramp - included in the wall lenght for calculations
Packing density assumptions as shown on the table in lb DM/cu. ft.

2. Upright silo capactiy (tons fresh weight):

		Haylage		Corn Silage		HMC (ground)		Earlage 35%	Snaplage 40%
Dia (ft)	Hght (ft)	50%	60%	60%	65%	25%	30%		
16	60	186	247	227	259	317	356	316	343
16	65	204	270	248	284	345	387	345	374
18	60	244	323	293	335	404	454	406	439
18	70	291	387	349	398	475	533	478	518
20	60	310	410	369	420	503	564	506	548
20	80	434	575	511	580	679	763	685	743
24	70	563	743	650	735	860	965	849	971
24	90	760	1001	862	970	1115	1254	1135	1231

Source: Savoie, Philippe, and Jan C. Jofriet. "Silage Storage." Silage Science and Technology. Vol. 42. Madison: American Society of Agronomy, 2003. 419. Print. Agronomy.

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Lallemand Animal Nutrition is committed to optimizing animal performance and well-being with specific natural microbial product and service solutions. Using sound science, proven results and knowledge from experience, Lallemand Animal Nutrition:

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