

Principles of Silage Making

John Jennings
Professor - Extension
Forage Specialist

Introduction

Silage is produced by harvesting a forage crop at a high moisture content (greater than 50 percent) and subsequently fermenting that crop in pit, tower, bunker, trench or plastic silos. Ideally, this process should occur in the total absence of oxygen.

Over the last several decades, two primary factors have contributed to the increased production of silage in North America. First, silage-making is much less weather dependent than hay-making. Some forages such as corn or sorghum can be direct cut. After mowing, most other forages can be adequately wilted for silage production in less than 24 hours. This greatly reduces the risk of weather damage to the forage crop.

Secondly, production of silage has been relatively easy to mechanize. This makes the practice quite attractive to large-scale livestock enterprises, particularly those that are based on confinement feeding. However, the efficient production of precision-chopped silage requires a much larger financial investment in equipment, relative to costs associated with hay-making or grazing systems.

Regardless of the amount of capital invested, the purchase and subsequent use of expensive silage-making equipment will not improve forage quality. Forages harvested at advanced stages of maturity will always be poor in quality. To make high-quality silage, producers always must start with high-quality forage.



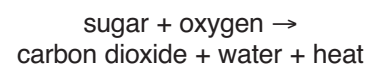
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Eliminating Oxygen From the Silage Mass

If good forage quality is assumed, the most important factor necessary to achieve a desirable silage fermentation and subsequently maintain high-quality silage within the silo for indefinite periods of time is the elimination of oxygen (air) from the silage mass. This is important for several reasons.

1. Limiting plant cell respiration.

At harvest, plant cells do not immediately “die”; they continue to respire as long as they remain adequately hydrated and oxygen is available. The oxygen is necessary for the physiological process of respiration, which provides energy for functioning cells. In this process, carbohydrates (plant sugars) are consumed (oxidized) by plant cells in the presence of oxygen to yield carbon dioxide, water and heat:



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Once in the silo, certain yeasts, molds and bacteria that occur naturally on forage plants can also reach populations large enough to be significant sources of respiration. In the silage mass, the heat generated during respiration is not readily dissipated, and therefore the temperature of the silage rises.

Although a slight rise in temperature from 80° to 90°F is acceptable, the goal is to limit respiration by eliminating air (oxygen) trapped in the forage mass. Some air will be incorporated into any silo during the filling process, and a slight increase in silage temperature is likely. These temperature increases can clearly be limited by harvesting at the proper moisture content and by increasing the bulk density of the silage (Table 1). Generally, it is desirable to limit respiration during the fermentation process by using common sense techniques that include close inspection of the silo walls prior to filling, harvesting the forage at the proper moisture content, adjusting the chopper properly (fineness of chop), rapid filling, thorough packing, prompt sealing and close inspection of plastics for holes.

Temperature rise (°F) after a silo is tightly sealed at various compaction levels (bulk densities) and dry matter contents. Source: R.E. Pitt. 1983. Trans. ASAE 26:1522.

Bulk Density (lbs/ft ³)	Dry Matter Content (%)					
	20	30	40	50	60	70
	----- °F -----					
20	4.8	5.3	6.0	6.8	7.8	9.0
30	2.5	2.8	3.2	3.7	4.3	5.0
40	1.4	1.6	1.9	2.2	2.5	3.0
50	0.7	0.8	1.0	1.2	1.5	1.8
60	0.2	0.3	0.5	0.6	0.8	1.0

Some forage crops, particularly grasses and small grains with hollow stems, will naturally trap more air in the silage mass when they are ensiled. Rye silage is particularly bulky and quite difficult to pack. Special care should be used to ensure that these types of forages are well packed prior to sealing the silo. With good management practices, oxygen may be eliminated from the silage in 4 to 6 hours.

Generally, it is easier to limit respiration (by excluding air) with direct-cut, dense crops of relatively high moisture content (corn or sorghum) than with wilted forages. Producers with limited silage-making experience will often overwilt (less than 50 percent moisture) traditional hay crops prior to ensiling. This makes them more difficult to pack properly in the silo. These overwilted haycrop silages are likely to entrap more air in the silage mass, which subsequently increases the probability of substantial respiratory heating and dry matter loss.

Most forages need only to be wilted to 60 to 70 percent moisture to ensure a good fermentation, although effluent production in certain silo types (particularly towers) can sometimes be a problem if

the silage crop exceeds 65 percent moisture. Most forages can be wilted to satisfactory moisture contents and ensiled safely within 24 hours of mowing whenever good drying conditions exist.

2. Effects on fermentation.

The oxidation of plant sugars by respiratory processes also negatively affects fermentation characteristics in the silo. Plant sugars serve as the primary substrates (fuels) for the lactic acid-producing bacteria that should dominate silage fermentation. The production of lactic acid by these bacteria reduces the pH (increases acidity) of the silage and is a key factor in the stability and long-term preservation of the silage. Excessive or prolonged respiration can limit the availability of this primary substrate necessary for production of lactic acid, thereby decreasing the potential for a good fermentation.

3. Effects on nutritive value.

Excessive respiration within the silage mass can also negatively affect the nutritive value of the fermented silage. The oxidation of plant sugars reduces the energy value of the forage and indirectly increases concentrations of forage fiber components, which are the least digestible parts of the plant. Furthermore, excessive temperatures (greater than 110°F) can result in the formation of Maillard reaction products, which are nitrogen- (protein-) containing compounds that are generally assumed to be indigestible in the ruminant digestive system. This is a more serious problem in silages than in hays because water content enhances this reactive process.

4. Effects on silage stability in the silo.

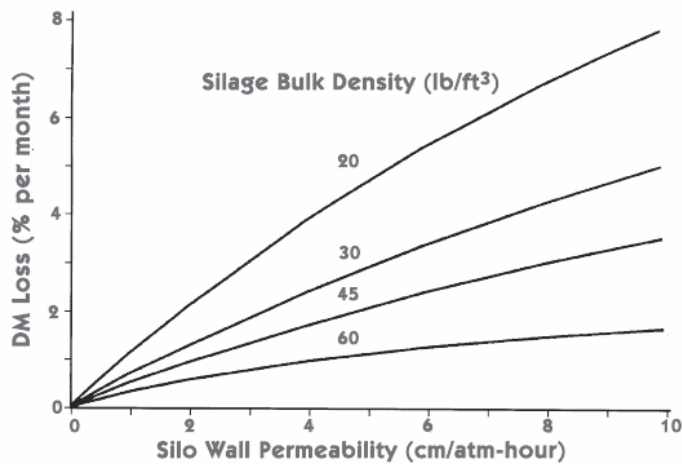
Silage that has been properly fermented will have a much lower pH (be more acidic) than the original forage. This fermentation characteristic is maximized when sugars are primarily fermented to lactic acid.

Rapid reduction of silage pH and subsequent maintenance of this condition is critical to the long-term stability of the silage. Properly fermented silage will remain relatively stable for indefinite lengths of time, provided that air cannot gain access to the silage mass. If air (oxygen) is allowed access to stable silage, populations of yeasts and molds will increase and cause heating in the silage mass via respiration. This can cause substantial dry matter losses and also reduce silage nutritive value in a manner similar to that described for respiratory activity that occurs during the filling phase. Thorough packing (high silage bulk density) will reduce the infiltration of air into the silage mass and limit dry matter losses (Figure 1). Some species of molds found under these conditions can produce mycotoxins and other substances that negatively affect animal health.

5. Effects on silage stability in the bunk.

Similar processes occur when the silage is fed; however, under these circumstances, air (oxygen) is available in virtually unlimited supply to microorganisms associated with the silage. The

Figure 1. Dry matter loss in a 20 foot diameter tower silo as dependent on silo wall permeability to oxygen and silage bulk density. Source: R.E. Pitt. 1986. *J. Agr. Engr. Res.* 35:193-205.



time interval between the removal of silage from the silo (oxygen access) and the onset of spontaneous heating in the feedbunk is dependent on four factors: (1) numbers of aerobic (requiring oxygen) microorganisms in the silage; (2) time exposed to air prior to feeding; (3) silage fermentation characteristics (well-fermented silages have a longer bunk life); and (4) climatic conditions.

Generally, achieving a good silage fermentation that is dominated by the production of lactic acid will increase the stability of silages in the feedbunk. Well-fermented silages will usually have a longer bunk life than silages with poor or restricted fermentations. Ultimately, aerobic microorganisms present on the silage at feedout will cause spontaneous heating and decrease bunk life. Establishing and maintaining anaerobic (no oxygen) conditions in the silo during harvest and storage will reduce the proliferation of these microorganisms.

During feedout, producers should work to limit the time that silage is exposed to the air prior to feeding. This time interval can be limited by several management factors. First, high silage bulk density will help to limit the diffusion of oxygen into the silage mass after a fresh face of silage has been exposed. Loosely packed silages will be exposed to the air much sooner via simple diffusion of air through the silage mass than will tightly packed silages.

Secondly, the rate of feedout should be adjusted whenever possible to keep a fresh silage surface in the silo. It is undesirable to dig large quantities of silage loose in a trench or bunker silo and then spend days feeding it. This practice allows heating to begin before the silage even reaches the bunk.

Producers constructing new silos, particularly trench or bunker types, should give serious thought to silo width prior to construction. Many of these silos are built much too wide because it is more convenient to load the silage into feedwagons on a solid concrete surface within the trench rather than backing the loader

out of the silo and loading in the mud during inclement weather. However, producers can pay dearly for this convenience if they do not have sufficient cattle numbers to feed the silage fast enough to maintain a fresh forage face across the wide silo.

The bunk life of silages is also reduced during hot weather because high temperatures will accelerate the growth of aerobic microorganisms associated with the silage.

Other Considerations

Moisture Content

One of the major factors affecting the fermentation process is the moisture content of the forage. Generally, the optimum moisture content for precision-chopped silage is about 65 percent. This degree of hydration will facilitate the fermentation process and will usually help to eliminate oxygen from the silage mass during packing.

Ensiling forages at moisture contents greater than 70 percent is not recommended. High forage moisture levels at ensiling may cause silage effluent to be produced and favor undesirable (clostridial) fermentations. These silages are less acidic and have high concentrations of butyric acid and ammonia nitrogen. Silages dominated by this type of fermentation have a strong, rancid odor and are poorly consumed by cattle. This is an especially important consideration when the silage crop also has (1) high nitrogen or crude protein content, (2) high buffering capacity (is resistant to pH changes) and/or (3) low sugar content. In the U.S., unwilted alfalfa is probably the forage crop that best meets these conditions and is most likely to undergo a clostridial fermentation. If careful attention is given to harvesting grasses at the proper moisture content, the risk of clostridial fermentations in Arkansas forages is relatively low.

In contrast, ensiling forages when the moisture content is low (less than 50 percent) can result in restricted fermentations, thereby producing less stable silages that have lower lactic acid concentrations and are less acidic (higher pH). Typically, it is also more difficult to exclude oxygen from the silage mass during the filling and packing processes. In these silages, maintaining the integrity of the silo walls is absolutely critical to the long-term preservation of the silage. Evidence of mold and spontaneous heating are more common in these silages.

Plant Factors

Grasses fertilized with high rates of nitrogen generally do not ensile as well as forages fertilized at moderate levels. Grasses that are heavily fertilized with nitrogen typically have higher nitrogen (crude protein) concentrations and lower concentrations of fermentable sugars. These sugars are the primary substrates in the fermentation process for lactic acid-dominated silages.

Plants convert energy from the sun into sugar; therefore, concentrations of plant sugars are generally

higher in the afternoon and evening (after several hours of intense sunlight). Sugar concentrations are reduced overnight by respiratory processes within the plant and will be lower the following morning. Extended periods of cloudy or overcast weather will also reduce concentrations of plant sugars. Plant maturity, particularly as it affects leaf to stem ratio, will also affect the concentrations of plant sugars found in many forage grasses.

Cool-season grasses store sugars as fructans, which are water soluble carbohydrates that tend to collect in the stems. As plants mature, the proportion of stem in the plant increases and concentrations of plant sugars will increase concurrently; however, this observation is also likely to be related to increased daylength and the cessation of rapid vegetative growth.

Toxic Compounds

Plants produce a number of compounds that are toxic to livestock. In Arkansas, the toxic effects of the ergot alkaloids produced by the symbiotic association of the fungal endophyte *Neotyphodium coenophialum* with tall fescue are widely known. Unfortunately, these compounds are relatively stable in the acidic environment created by the fermentative process.

Nitrates can accumulate in some forage plants under unfavorable growing conditions. This potential is maximized when crops such as corn, sorghum and other grasses are heavily fertilized with nitrogen and then suffer various stresses during growth that may include hail, drought, frost, cloudy weather or soil fertility imbalances. Normally, nitrates accumulate in the lower portions of these plants.

Stressed plants should be harvested at high stubble heights (8 to 10 inches) to limit the inclusion of nitrates in the silo. When droughty conditions are followed by a rain, producers should wait about three days before harvesting. High-nitrate forages can also produce lethal gases in the silo during the fermentation process. Generally, the fermentation process converts about 50 percent of forage nitrate to other nontoxic forms.

Prussic acid may accumulate in sorghum, sudangrass, johnsongrass and sorghum-sudan hybrids. Pearl millet does not produce prussic acid. Toxic levels

of prussic acid are likely to occur immediately after a killing frost or in the tender young growth of plants immediately after a drought. Herbicides, particularly 2, 4-D, may also temporarily increase levels of prussic acid. To avoid problems, wait to harvest these crops until they sufficiently mature. Generally, minimum plant heights are 18 to 20 inches for sudangrass, 30 to 32 inches for sorghum-sudangrass hybrids and late boot to early-heading stage for forage sorghums. After a killing frost, wait a week before harvesting. The fermentation process will not reduce prussic acid concentrations; however, field wilting before ensiling will reduce concentrations by 50 to 70 percent.

Silage Additives

Generally, silage additives can be grouped into four categories: (1) bacterial inoculants; (2) enzymes; (3) substrate sources; and (4) inhibitors. Bacterial inoculants are probably the most common additives in the United States. These additives inoculate the forage with desirable types of lactic acid-producing bacteria, thereby encouraging the fermentation process to produce lactic acid as the primary end-product. Enzyme additives usually degrade plant cell walls and sometimes starch. In theory, the degradation of plant cell walls should reduce the concentrations of neutral and acid detergent fiber in the silage and, at the same time, release additional sugar, which is the primary substrate for lactic acid-producing bacteria. Substrate sources are primarily sugars, such as molasses, glucose, sucrose and dextrose that also provide additional substrate for lactic acid-producing bacteria. Silage inhibitors have frequently been used in extremely wet silages produced in northern Europe, where drying conditions are often poor. These products, such as formic, propionic, hydrochloric and sulfuric acids, are primarily organic acids that effectively sterilize the silage.

Summary

1. Harvest forages as precision-chopped silage at about 65 percent moisture.
2. Achieve an anaerobic (no oxygen) environment as quickly as possible to limit respiration, spontaneous heating, dry matter loss and mold development and improve bunk life.
3. Remember that ensiling poor-quality forages will not improve forage quality.

The products shown and trade names mentioned in this publication do not signify that these products are endorsed or approved to the exclusion of comparable products.

Portions of this fact sheet were adapted from K.K. Bolsen. 1995. Silage: Basic Principles. In R.F. Barnes et al. (ed.) *Forages Vol. II*. Iowa State Univ. Press, Ames, IA.

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DR. JOHN JENNINGS is a professor - Extension forage specialist with the University of Arkansas System Division of Agriculture, Department of Animal Science, Little Rock..

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