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The Ensiling Process and Additives

Proper ensiling includes controlled fermentation, which converts perishable wet forage plants to a stable, stored feed energy source. Good ensiling management is required for high silage quality and dry matter (DM) recovery. To guide silage management practices, it is important to understand the biological and chemical processes that occur during ensiling, their effects on silage quality, and how these processes can be controlled.

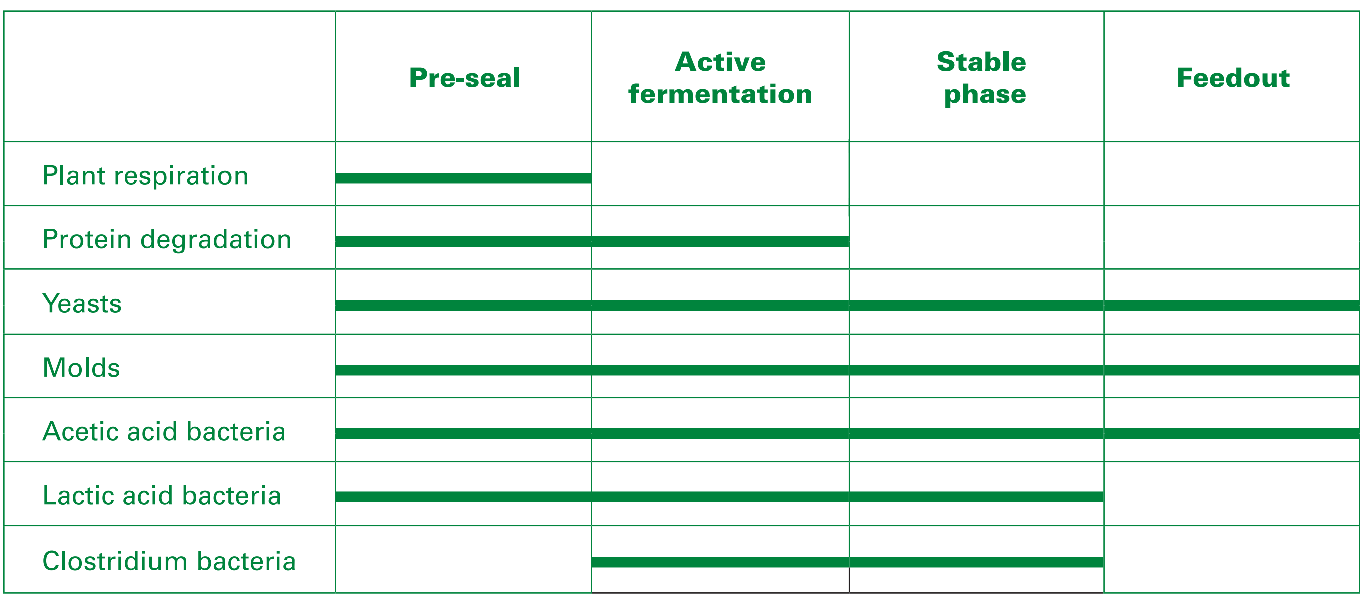
The Ensiling Process

There are four phases during silo storage of forage: pre-seal, active fermentation, stable phase, and feedout (Figure 1).

Pre-seal

Plant and microbial respiration dominates during the chopping, filling, and packing steps, causing changes and nutrient losses from the chopped crop. Respiration is a wasteful process, because it uses sugar and oxygen to release carbon dioxide, water, and heat. Since sugars are highly digestible, their respiration causes losses of energy and dry matter (DM). Sugars are also the main food for lactic acid bacteria.

The activity of lactic acid bacteria ferments sugar to lactic acid, which decreases the pH to a low of 4.0 to 4.2, a level normally required for good quality silage. The heat produced by respiration raises silage temperature and increases the rate of microbial processes, both good (fermentation) and bad (respiration). Respiration rate increases with temperature, and reaches its



Source: Adapted from R. E. Muck and R. E. Pitt, 1993, "Ensiling and its effect on crop quality," p. 57. In *Proceedings of the National Silage Production Conference*, Syracuse, NY. 23-25 Feb. 1993. NRAES Cooperative Extension, Ithaca, NY.

Figure 1. Biological processes during ensiling.

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maximum around 115°F in forage with a moisture content between 50 and 70 percent. A rise in temperature above about 120°F can lead to an undesirable high-temperature reaction that causes heat-damage-browning or the Maillard reactions, and decreased silage digestibility. Silage producers can reduce respiration losses by first rapidly wilting the forage crop to 60 to 70 percent moisture for chopping. Drier silage is difficult to pack and allows air to circulate in the chopped forage, which extends the period of respiration losses and heating.

The next management step toward making good silage is to chop the forage at the proper particle length. The recommended cutting length is 3/8 to 1/2 inch. When forage is too coarsely chopped, it is difficult to pack tightly, maintains excess air, and allows respiration to continue for an extended period. Chopping too finely wastes fuel and may adversely affect the normal rumen function of cattle that eat the silage. Even with chopper knives set to cut at 3/8 to 1/2 inch, there will be some longer particles useful in ruminant feeding.

To further reduce respiration losses shorten the filling period, pack the chopped forage tightly, and cover and seal the silo as soon as possible.

Active Fermentation

Processes during this phase occur under anaerobic (oxygen-free) conditions and should be dominated by growth of lactic acid bacteria. This period lasts for one to four weeks and is characterized by a pH decline to around 4.0. During the first days of ensiling, however, plant enzymes and acetic acid producing bacteria compete with lactic acid bacteria for sugars and proteins. Plant enzymes break down proteins to soluble nonprotein nitrogen (NPN). Protein breakdown is highest during the first day after sealing and decreases rapidly as oxygen is used up, with very little protein breakdown occurring after one week of proper ensiling. Maximum protein breakdown occurs at a pH of 5.5 to 6.0, the typical pH of a freshly chopped crop at ensiling. A very rapid fermentation or addition of an acid at ensiling (which will be discussed in a later section) to rapidly decrease pH to 4.0 can reduce protein breakdown considerably. After ensiling, NPN in the silage can range from 20 percent to as much as 85 percent of total N.

The two main groups of lactic acid bacteria are homofermenters, which produce only lactic acid from sugar; and heterofermenters, which produce carbon dioxide, ethanol, acetic acid, and lactic acid. The homofermenters are the most desirable because their activity does not cause DM loss as do heterofermenters. High levels of less desirable acetic acid and ethanol reduce the palatability of silage and, thus, animal intake. When oxygen is present, heterofermenting bacteria produce less lactic and more acetic acid and, in the absence of sugar, convert lactic to acetic acid.

This becomes important when producers open a silo after several weeks to put additional forage on top of the ensiled crop. At that time, lactic acid bacteria are usually the dominant microorganisms in the fermenting silage, and exposure to added oxygen can cause a rapid reduction in lactic acid and increased acetic acid concentrations, reducing silage palatability. Well-fermented silage has a lactic acid concentration of 6 to 8 percent of DM. Consequently, an extended homofermentation is desirable for both crop preservation and animal performance.

Large numbers of lactic acid bacteria occur naturally in plants and grow best under warm, humid conditions. As a result, high counts of lactic acid bacteria occur on corn and alfalfa and remain high for two to three days during wilting of alfalfa. Most lactic acid bacteria grow well above 60°F with fastest growth rates at temperatures between 80° and 100°F. When moisture content is less than 40 percent, their growth is very slow, and fermentation may not be complete until alfalfa is stored for 4 to 5 weeks. At 70 percent moisture, most fermentations are finished within one to two weeks, except under cold (< 50°F) conditions.

Clostridium bacteria and other undesirable bacteria are present on the chopped crop, especially if it has been contaminated with soil or manure. Growth of these clostridium bacteria and yeasts are undesirable in silage fermentation. They can convert lactic acid to foul smelling butyric acid and produce ammonia from plant protein. A clostridial silage is characterized by butyric acid levels greater than lactic acid levels, ammonia-N levels greater than 10 percent of total N, pH above 5.0, and a "rancid butter" odor. Clostridial fermentation may sometimes dominate in silage with a moisture content above 70 percent.

Stable Phase

When lactic acid bacteria have used up all the sugar in the crop or when pH gets low enough to stop their growth (4.0 – 4.2 or lower), the stable phase begins. As long as the silo remains sealed and anaerobic, little biological activity occurs during this period. However, as oxygen slowly enters through silo walls and covers, this can cause the growth of yeasts, molds, and aerobic bacteria at the exposed surfaces of silos. Listeria bacteria grow in silage exposed to oxygen, such as air entering through small leaks in plastic covers or around doors in a tower silo. In extreme cases, listeria can cause disease of the nervous system in both animals and humans and induce abortions or cause death.

Feedout

After the silo is opened and during feedout, the surface is reexposed to oxygen where yeast, mold, and aerobic bacteria can again deteriorate silage. These organisms convert remaining plant sugars, lactic acid, or other energy-rich nutrients in the silage to carbon dioxide, water, and heat. Because fermentation acids are destroyed during aerobic spoilage, silage pH increases to levels sometimes exceeding 7.0. Heating and a yeast aroma are the most common symptoms of aerobic deterioration of silages. Thus, feedout spoilage causes increased DM losses, degraded feed, and a higher risk of toxic organisms and their spoilage products.

Aerobic feedout losses are minimal, however, when good feedout management is practiced. Remove a minimum of 2 inches of silage per day in the winter and 4 inches of silage per day in the summer from tower silos. For bunker silos, it is best to remove at least 4 inches per day in the winter and 6 inches per day from the silage surface in the summer. Also, feed silage to the livestock in small portions two to four times per day instead of in one big portion.

Silage Additives

Producers hear and read advertisements and promotions about products to help make better silage. To determine whether to use a silage additive or which one is best, it is important that you know how the additive influences silage fermentation. Remember that an effective additive may help make good silage better, but it will not make poor silage good. Commercial silage additives can be divided into five categories: bacterial inoculants, enzymes, nonprotein nitrogen (NPN) sources, acids, and sugar sources.

Bacterial Inoculants

These are the most common silage additives in the United States and are primarily homofermenter lactic acid bacteria. Effectiveness of the applied inoculant depends on the natural lactic acid bacterial population, the sugar content of the crop, and strains of bacteria in the inoculant. The inoculant must provide at least a tenfold increase in the lactic acid bacteria number in the silo to be economically practical.

Currently there is no method for quick determination of natural lactic acid bacteria numbers on the chopped crops. A common recommendation for the addition of inoculant lactic acid bacteria is to add a minimum of 100,000 colony-forming units (CFU) of lactic acid bacteria per gram of fresh forage. The sugar levels in wilted (< 65 percent moisture) legumes or grasses and in sugar-rich crops, like corn and sorghum, are generally adequate to supply the needs of fermenting bacteria. However, alfalfa silage at 70 percent moisture is somewhat low in fermentable sugars. An inoculant combined with a sugar source, such as molasses, whey, and cereal grains, usually results in a faster pH decline than inoculant alone on higher moisture alfalfa or forage grass silage.

Corn at ensiling has higher natural populations of lactic acid bacteria than in traditional hay crops. Therefore, inoculants are most successful in alfalfa and grass silages, while their success in corn is less consistent. Some strains of a bacterial species have been selected for use on particular crops. Therefore, buy the inoculant product that is selected for the crop you are ensiling. If that is not possible, try a product for a similar crop within the same classification (i.e. legumes and grasses).

A relatively new approach in silage inoculant additives is to include a heterofermenter bacteria in the inoculant to direct the fermentation to aid in preventing spoilage during feedout and improve 'feed bunk stability.' The bacteria *Lactobacillus buchneri* has been demonstrated to improve aerobic stability of silages by reducing the growth of yeasts. The beneficial impact of *L. buchneri* appears to be related to the production of acetic acid. Aerobic stability is likely improved because acetic acid inhibits growth of specific species of yeast that are responsible for heating and spoilage upon exposure to oxygen as compared to untreated silages. Treating silage with *L. buchneri* most likely would be beneficial under circumstances where problems with aerobic instability are expected. Corn silage, small grain silage and high moisture corn are more susceptible to spoilage once exposed to air than legume or grass silage, and therefore *L. buchne*ri inoculation may be a benefit.

Enzymes

Ensiling products sometimes contain inoculants with added enzymes or enzymes alone. These products usually consist of fiber-degrading enzymes, such as cellulases, hemicellulases, amylases, and pectinases. The main goal of these enzymes is to convert the fiber or starches in silage to sugar. This allows a mature forage to act like a less mature, higher quality forage when fed to cattle. Released sugar also can be used for fermentation by lactic acid bacteria. Enzymes have the greatest effect on fiber degradation of grass silage, and are less effective on alfalfa with its more resistant fiber.

The reduction of fiber concentration by enzymes has not resulted in consistent improvement of DM digestibility or animal performance. One disadvantage of enzyme additives is that feedout stability may be reduced if an excess amount of sugar is produced by the enzymes. Enzyme products are less effective in drier (< 60 percent moisture) silages and are most appropriate for forages with 60 to 70 percent moisture. More research is needed on enzyme products to understand the reason for inconsistent animal responses and to determine the right mixture of enzymes needed for consistent response in alfalfa.

Nonprotein Nitrogen Sources

Both ammonia and urea are common additives for improving corn, sorghum, and other cereal silages with low protein concentrations. These additives are used to increase the measured crude protein concentration of silage and to improve aerobic stability during feedout. Application rates are typically 5 to 10 pounds of anhydrous ammonia or 10 to 20 pounds of urea per ton of fresh chopped forage. Addition of NPN raises the pH of the crop, with ammonia having the greatest effect.

The high pH is toxic to yeasts, molds, and many bacteria, so NPN improves aerobic stability of the silage. Protein-degrading bacteria also are inactivated by a high pH, resulting in a silage with a high crude protein concentration. To minimize growth of clostridia! bacteria and to reduce DM losses, the NPN should only be added to silage with less than 70 percent moisture. Urea is preferred over ammonia because urea is safer and easier to handle since no special application equipment is required.

NPN improves silage digestibility, but its feeding value varies with the sugar concentration in the ration because the ruminant animal needs carbohydrates in the ration to convert NPN to true protein. Therefore, when feeding rations high in NPN you should work with a nutritionist to determine if it would be advantageous to include a source of sugar or starch supplement, such as corn grain and molasses.

Acids
European farmers frequently use direct acidification of silage with acid to immediately lower the pH to preservation levels. Acids, like propionic and formic acid, are used most often on crops with a moisture content above 70 percent, on crops with low sugar content, and on high moisture shelled corn. Under these conditions, a low pH is needed to prevent clostridial growth. Formic acid can improve protein preservation of silage by an immediate acidification, which inactivates protein-degrading bacteria. Propionic acid can improve DM recovery and feedout stability of silage by inhibiting yeast and mold growth. Typical acid application rates range from 0.3 to 1 percent of fresh silage weight.

Sugar Sources
Whey, molasses, and cereal grains are sometimes used to guarantee adequate preservation of low energy crops. Additions of 1 to 10 percent dried whey of fresh silage weight have been successful in improving fermentation of low sugar forage crops, such as alfalfa and grass. Molasses, applied at 2 to 5 percent of fresh silage weight, improves fermentation in high moisture (> 70 percent) crops and in crops with naturally low sugar content, such as alfalfa. The addition of molasses combined with an inoculant to a low sugar crop may improve conditions for fermentation of sugar to lactic acid.

Summary
To achieve good silage fermentation, the crop must be harvested at the proper moisture (60 to 70 percent) level. Silage that is too wet causes seepage losses from the silage and growth of undesired microorganisms, which result in a less palatable feed for ruminants. Too dry (< 50 percent moisture) silage, however, increases DM losses due to respiration and heating and reduces the opportunity for lactic acid bacteria to grow. The key for successful ensiling is to chop the forage to a minimum cutting length of 1/2 inch, pack the forage tightly in the silo, and seal the silo well to prevent air passages through covers and walls.

When these conditions are met, silage quality can be further improved with silage additives. Bacterial inoculants can increase the number of lactic acid bacteria in the silage. The desirable lactic acid bacteria use sugar to produce lactic acid, which decreases pH to 4.0 to 4.2. A rapid pH drop results in stable, high quality silage. Fiber degrading enzymes, which break down fibers to sugar, can be used alone or in combination with an inoculant to increase concentration of fermentable sugars in low sugar crops, such as grasses and legumes. Sugar concentration also can be raised with molasses, whey, or cereal grains. Nonprotein nitrogen products are used in crops with low protein concentrations, such as corn and sorghum, to increase their crude protein level and to improve silage stability during feedout. Acids are most useful in high moisture (> 70 percent) grasses and legumes with low sugar concentrations, where a rapid pH drop is needed to prevent growth of undesirable microorganisms. Formic acid can preserve protein and propionic acid can improve feedout stability of the silage.

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