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# Silage Preservation

## The Role of Additives

By Randy Shaver

Forage crops — legumes, grasses, whole-plant corn — form the cornerstone of dairy feeding programs. Most are stored as hay or silage. Ensiled forages offer lower field losses and are easily incorporated into mechanized harvest, storage and feeding systems.

Preserving forage as silage depends on exclusion of oxygen from the forage mass and reduction of pH through bacterial fermentation. Ensiling involves a series of events that are uncontrolled after the forage enters the silo. Good management practices in filling the silo help to ensure that these events occur, and acceptable silage results.

Numerous silage additives — acids, bacterial inoculants, enzymes — have been developed to aid ensiling and help reduce storage losses. This publication will discuss when and where these additives may be of benefit to dairy producers.

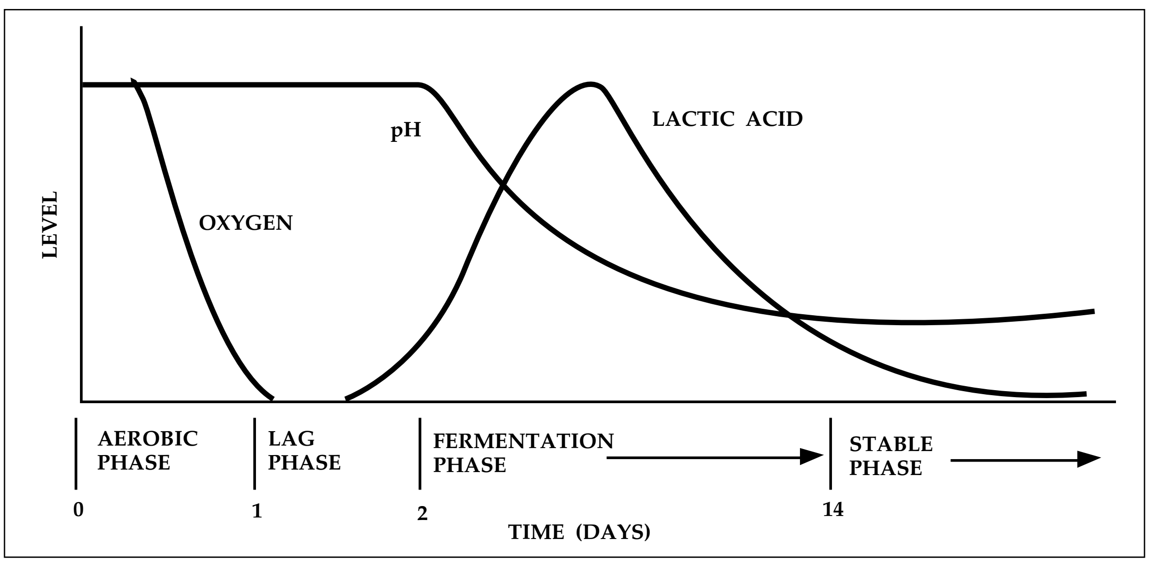
## Ensiling

*The four stages of ensiling are presented in Figure 1.*

**Phase 1 (aerobic phase).** Plant respiration continues after chopping. Plant cells take in oxygen from the surrounding air and give off carbon dioxide. Naturally occurring aerobic bacteria quickly begin to degrade the ensiled forage. Degradation and cell respiration use up the oxygen present in the forage, which quickly reaches an anaerobic (oxygen-free) state.

The amount of oxygen trapped in the forage mass depends on fiber level, moisture content, rate of silo filling, and fineness of chop. Mold will not form if all trapped oxygen is converted to carbon dioxide and no additional oxygen enters the mass. Cell respiration initially raises the temperature. The anaerobic lactic acid-producing bacteria, which dominate Phase 3, work best at silage temperatures of 80 degrees to 100 degrees F. Excessive oxygen entrapment and/or delayed sealing can create

**Figure 1. Phases during ensiling and storage. (Pitt and Shaver, 1990)**



temperatures of more than 100 degrees F, and may reduce the nutritive value of ensiled forage.

**Phase 2 (lag phase).** Plant cell membranes break down, allowing bacteria to grow in the cell juices.

**Phase 3 (fermentation phase).** Lactic acid-producing bacteria begin to dominate the fermentation process, after silage pH drops to 5.5 to 5.7 from 6.5 to 6.7 at ensiling. The rate of pH decline determines the duration of Phase 2; Phase 2 and 3 normally merge by day three.

Proper lactic acid production requires a pH of 5.5 to 5.7, sufficient numbers of viable lactic acid bacteria, adequate available carbohydrate, sufficient moisture, and anaerobic conditions. As we will see, additives can influence the number of bacteria and the amount of available carbohydrate. Proper management will ensure sufficient moisture and anaerobic conditions.

Lactic acid production lowers silage pH to 4.4 to 5.0 in silages with high buffering capacity and low available carbohydrate (primarily legumes). Silages with low buffering capacity and more available carbohydrate (corn, other cereal grains, or grass) will have a final pH of 3.8 to 4.2. Phase 3 lasts about two weeks, and temperature of the mass gradually declines to 80 degrees to 85 degrees F during this period.

**Phase 4 (stable phase).** Low pH stops bacterial action and the silage stabilizes. If insufficient lactic acid is formed, undesirable bacteria (clostridia) may produce butyric acid and break down protein. This does not occur unless both silage pH (above 5.0 to 5.5) and moisture content (above 70%) are high enough to allow these undesirable bacteria to grow.

Criteria for desirable fermentation include:
**1**. rapid decline in pH,
**2**. low final pH,
**3**. rapid rate of lactic acid production, and
**4**. more than 65% to 70% of the total organic acids as lactic acid.

# Silage Additives

Silage additives fall into two main categories: fermentation inhibitors and stimulants.

## Inhibitors

Silage inhibitors inhibit either aerobic or anaerobic processes. ***Aerobic inhibitors*** suppress the growth of yeasts, molds and aerobic bacteria. They extend silage bunklife and prevent spoilage in the silo during periods of slow feedout. Aerobic inhibitors include propionic acid and anhydrous ammonia.

Apply propionic acid to hay-crop silages at 10 lb to 20 lb per ton of fresh forage.[14] Check the concentration of propionic acid on the product label and follow label instructions to ensure proper application rates. Benefits are most likely in excessively wilted forages, which are more likely to have heat-damaged protein, storage losses, molding and aerobic deterioration on feedout.[14]

Apply anhydrous ammonia at 7 lb per ton of 65% moisture corn silage to increase the crude protein (CP) content from 8% to 12%. Adding 10 lb urea per ton of corn silage will produce about the same increase in CP content, but Michigan State workers reported better fermentation, dry matter recovery and bunk life for ammonia-treated corn silage when compared to urea-treated or untreated corn silage. UW-Madison/USDA researchers saw little benefit to adding anhydrous ammonia to 65% - 70% moisture alfalfa silage.

***Anaerobic inhibitors*** tend to restrict undesirable bacteria (clostridia), plant enzymes (proteases), and possibly lactic acid bacteria. Acids reduce pH of the forage at the time of application. However, in the United States, acids generally are not added in sufficient amounts to significantly acidify the forage. Other inhibitors, such as formaldehyde, may act only to protect plant proteins. Formic acid or sulfuric acid, alone or in combination with formaldehyde, are popular additives in Europe for direct-cut silages.[7]

Acids are expensive, difficult to handle, and corrode equipment. Buffered acid products, such as ammonium propionate, are less volatile and corrosive, but still costly to apply. U.S. regulatory agencies have been slow to clear formaldehyde and related compounds for use in silage additives. Anaerobic inhibitors are rarely used as silage additives in the United States. Wilted silage is preferable over direct-cut for most U.S. climates. Fermentation stimulants offer the most potential as additives for silages wilted to 50% - 70% moisture.

## Stimulants

There are two types of fermentation stimulants: microbials and substrate suppliers. Microbials or bacterial inoculants speed up lactic acid production, resulting in a lower pH. Substrate suppliers are enzyme additives that break down complex

## ENSILING GUIDELINES

*Management Recommendations*

*To help ensure a desirable fermentation, minimal storage losses, and good quality silage:*

***Harvest at the proper stage of maturity.***

- ♦ Alfalfa at the mid- to late bud stage.
- ♦ Red clover at the first flower to 1/10th bloom stage.
- ♦ Grasses at the late boot to early head stage.
- ♦ Corn silage when the milk line is 1/2 to 2/3 of the way down the kernel.
- ♦ Sorghum silage at medium dough stage.
- ♦ Sorghum-sudangrass silage at the boot stage or about 3 to 4 feet tall.
- ♦ Small grain silage at the early head stage.

***Chop at the proper moisture content.***

- ♦ Haycrop silage:
  Horizontal silos — 60% to 70% moisture.
  Concrete upright silos — 50% to 60% moisture.
  Oxygen-limiting silos — 40% to 50% moisture.
- ♦ Corn silage: 60% to 70% moisture.
- ♦ Sorghum and sorghum-sudangrass silage: 55% to 65% moisture.
- ♦ Small grain silage: 55% to 65% moisture.

***Chop at the proper theoretical length of cut (TLC).***

- ♦ Haycrop silage: 3/8″ TLC with more than 20% of the particles over 1 1/2″ long.
- ♦ Corn, sorghum and small grain silage: 1/4″ to 3/8″ TLC.

***Fill the silo rapidly. Enhance compaction.***

- ♦ Tower — Top off with one or more feet of wet forage.
- ♦ Bunker — Compress forage with tractor.
- ♦ Bags — Use good filling machine.

***Seal silo carefully.***

- ♦ Tower and bunker silos — cover with plastic and seal cracks in walls. Secure plastic on bunker silos so that the plastic tarp will not draw air into the silage under windy conditions.
- ♦ Bags — seal ends carefully and repair or replace damaged bags.

***Leave silo sealed for at least 14 days.***

carbohydrates (cellulose, hemicellulose and starch) in the forage to the simple sugars (substrates) that can be used by lactic acid bacteria. Alternatively, additional substrate for lactic acid bacteria, such as molasses, can be applied directly to the forage.

## Bacterial Inoculants

Bacterial inoculants rapidly lower pH to help prevent protein breakdown in the ensiled forage. This low pH (high acidity) also suppresses the growth of undesirable organisms that can reduce the intake and nutritive value of silage.

The bacteria needed for fermentation are normally present on forage tissue. Numbers of lactic acid bacteria on the standing crop and in the swath just after cutting are generally low. Higher numbers occur on the chopped forage just prior to ensiling, apparently due to either growth as the forage wilts in the field or inoculation during the chopping process.

However, under certain harvest conditions, there may not be enough desirable bacteria in the chopped forage for ideal fermentation. Air temperature at the time of chopping, wilting time, and average wilting temperature can all affect the number of lactic acid bacteria present. Chopped forage at the time of ensiling normally has from 100 to 100 million lactic acid bacteria per gram of fresh forage.[7] Inoculants have the best chance of improving ensiling when numbers of naturally occurring lactic acid bacteria are low (less than 10,000 organisms per gram).

The organisms in silage inoculants should: (1) grow rapidly and dominate other organisms likely to occur in silage; (2) produce only lactic acid; (3) be acid-tolerant and produce a low final pH; (4) be able to ferment glucose, fructose and sucrose; and (5) not break down organic acids or protein.

European researchers have concluded that not many common silage organisms meet all of these criteria. *Lactobacillus plantarum* is the species most often found in commercial silage inoculants, since it grows rapidly and quickly lowers pH.

Bacteria that produce only lactic acid rapidly acidify silage, and the silage loses less dry matter during fermentation. These lactic acid bacteria include *Streptococcus*, *Pediococcus* and *Lactobacillus* species. *Streptococcus* and *Pediococcus* grow rapidly and dominate the initial fermentation, while the lactobacilli dominate below pH 5. A mix of these species can produce lactic acid over the entire pH range found in silage, and may offer more potential than inoculants containing only a single species.

Many strains with different fermentative capacities exist within each species, making comparisons difficult. Thus, two inoculants containing different strains of *Lactobacillus plantarum* may not affect fermentation to the same degree.

### *Inoculants -Research*

Commercial inoculants generally improved ensiling in research trials[10, 1, 2, 3] using laboratory, bunker and tower silos. The inoculants produced a more rapid drop in pH, higher lactic acid content, and slightly lower final pH, and the improved fermentation resulted in slightly higher dry matter recoveries (1% to 2% on average) from the silo. In a review of 35 trials, Kansas State workers found that microbial inoculants improved silo dry matter recovery 1.7% on average, with a range of -3.5% to +9.8%.

Much of the nitrogen (N) in silage is either non-protein nitrogen (NPN) or protein that is degraded by rumen bacteria. Plant enzymes called proteases solubilize the true protein in silage, which can reduce the amount of true protein present to bypass the cow's rumen for digestion and absorption in the small intestine. These proteases act more quickly in legumes and high moisture silages than in grasses and low moisture silages. Increases in soluble protein content (% of CP) of legume and grass forage during ensiling ranged from 33% to 45% and 21% to 30%, respectively, as moisture content increased from 50% to 70%.[8] Rapid reduction in silage pH and low final pH help inhibit protein solubilization.

Woodford[16] saw a reduction in NPN as a percent of total N from 60% to 55% on average when he applied inoculants to 70%-moisture alfalfa silages stored in bunker silos. Laboratory silos also showed a reduction in the NPN fraction of inoculated alfalfa silages. However, this was a modest reduction relative to the large amount of NPN present in alfalfa silage. Further, research has not shown that this reduction in NPN and soluble protein actually results in less rumen-degradable protein for inoculated silages.

The fraction of crude protein that is degraded in the rumen to peptides, amino acids and ammonia ranges from 70% to 85% in silages.[9] Soluble and degradable protein levels are highest for high-moisture, high-protein alfalfa forages. These forages offer the best opportunity for inoculants to improve protein fractions, but the improvements in research trials have been small.

Differences in dry matter intake and milk yield between inoculated and untreated alfalfa silages were generally not statistically significant in UW-Madison/USDA trials.[10] However, milk yield increased by 3% when inoculation increased the number of lactic acid bacteria by tenfold or more. This means that if the forage contains a large number of naturally occurring lactic acid bacteria or if the inoculant does not contain enough live lactic acid bacteria, a milk response is highly unlikely. A summary of 15 comparisons[5] reported a 1.8 lb (3.1%) increase in milk yield when bacterial inoculants improved alfalfa silage fermentation. There was no effect on milk yield when the inoculants did not improve fermentation.

### *Inoculants - Recommendations*

Inoculants applied at the rate of 100,000 colony-forming units (CFU) per gram of ensiled forage will likely be most effective when alfalfa is wilted for one day or less, or when average wilting temperatures are below 60 degrees F.[10] This is because naturally occurring lactic acid bacteria were almost always below 10,000 CFU per gram of chopped forage under these conditions, and inoculants produced at least a tenfold rise in bacterial numbers.

Inoculation will cost about 60 cents to 80 cents per ton of fresh forage. Assuming that an average of 24 lb of dry matter from silage is consumed per day over a lactation, bacterial inoculants would cost about 1.5 cents to 2 cents per cow per day. The feeding value of alfalfa silage must increase 1.5% to 2% to offset the direct cost of the inoculant. Best chances for success may be with first and fourth cutting alfalfa, since cooler wilting conditions minimize the numbers of naturally occurring lactic acid bacteria.[10]

Inoculants are less likely to improve corn silage, because corn's high content of available carbohydrate and low buffering capacity generally allows good fermentation. However, a summary of 22 trials[1, 2] reported better silage fermentation and dry matter recovery from the silo when inoculants were added to corn and sorghum silages. Inoculants may reduce deterioration on feedout, thereby improving bunk life and silage acceptability.

Apply a minimum of 100,000 CFU live lactic acid bacteria per gram of fresh forage. Check the label and manufacturer's recommended application rates to be sure that this level is being added. For example, a granular product guaranteeing 90 billion CFU per pound with a recommended application rate of 1 lb per ton of forage would supply 100,000 CFU per gram. This is calculated as follows: a) 2,000 lb/ton x 454 g/lb = 908,000 g/ton = $9 \times 10^5$ g/ton; b) 90 billion CFU/ton = $9 \times 10^{10}$ CFU/ton; and c) $9 \times 10^{10}$ CFU/ton ÷ $9 \times 10^5$ g/ton = 100,000 CFU/g.

Follow the manufacturer's storage and handling directions to ensure product stability. Not all bacterial inoculants are equally effective, so use a good quality product from a reputable company. Request research data from a series of trials with evidence of proper statistical analyses to substantiate sales claims. Contact your county UW-Extension agent if you have questions about research data or sales claims.

Inoculants applied as liquid suspensions will more evenly distribute the bacteria across the forage and allow them to start working more rapidly. Application at the field chopper rather than at the silo blower allows the bacteria in the inoculant to get a head start on naturally occurring bacteria. This is generally where inoculants are applied to silage stored in bunker silos.

## Substrate Suppliers (Enzyme Additives)

Enzyme additives break down complex carbohydrates in forage into simple sugars, or substrates, that can be readily fermented by lactic acid bacteria. Enzyme additives containing cellulases, hemicellulases and amylases to break down cellulose, hemicellulose and starch have been developed. *Aspergillus oryzae*, *Aspergillus niger* and *Bacillus subtillus* cultures and their fermentation products are included in some silage additives as a source of enzymatic activity. Various combination products containing both enzymes and lactic acid bacteria have also been developed. In theory, these additives should complement each other, with the enzymes providing additional substrate for the added bacteria to ferment. This should result in a more rapid pH drop and lower final pH.

Enzyme or substrate additives have the best chance for success when plant sugars are low, provided that sufficient numbers of lactic acid bacteria are present. Typical sugar contents are 4% to 15% for legume, 10% to 20% for grass, and 8% to 30% for whole-plant corn forages.[6] Minimum initial sugar requirements for complete fermentation exceed typical sugar contents when moisture content exceeds 60% for legumes, 75% for grasses, and 80% for corn silage.[6] Enzyme or substrate additives would only be expected to improve ensiling for direct-cut hay-crop forages or legumes wilted to more than 65% moisture. Researchers are also looking at whether enzyme additives containing cellulase and hemicellulase can reduce the neutral detergent fiber (NDF) content of forages in the silo. This would improve silage digestibility and intake potential, particularly for high fiber hay-crop silages.

### *Enzyme Additives - Research*

Woodford[16] concluded that cellulase enzyme improved fermentation of alfalfa silages containing 65% to 75% moisture when fermentable substrate was limiting. When both naturally occurring lactic acid bacteria and fermentable substrate were limiting, bacterial inoculant plus substrate supplier gave an additive improvement in fermentation. Maine researchers[11] saw improved fermentation when enzyme additives containing cellulase or cellulase/xylanase were added to 72%-moisture mixed grass/legume forage. Cellulase enzyme reduced silage NDF content and increased intake of dry matter, but had no effect on milk yield. A cellulase/xylanase enzyme mixture added to 70%-moisture mixed grass/legume forage reduced silage NDF content and increased dry matter intake and milk yield when compared to control and inoculated silages in another trial.[12] NDF and acid detergent fiber (ADF) digestibilities in continuous-culture fermenters were highest for the enzyme-treated silage.[13] Woodford[16] also reported that cellulase enzyme reduced silage NDF content, but found no effect on milk yield. Reduction in NDF content in the silo ranged from 4 to 7 percentage units across Maine and Wisconsin USDA trials for 45% to 50% NDF forages.

Enzyme additives did not improve ensiling, dry matter intake or milk yield in four comparisons.[5] Bacteria/enzyme additives improved ensiling and dry matter intake, but had no effect on milk yield in four comparisons.[5] Kansas State researchers[1, 2, 15] saw little improvement in fermentation when various enzyme products were added to alfalfa silages.

### *Enzyme Additives and Substrates - Recommendations*

Enzyme additives are not recommended because of variable results and high cost. Enzymes added at rates used in research trials would cost $3 to $3.50 per ton of fresh forage. Use enzymes only where substrate supply prevents adequate preservation (direct cut hay-crop forages or legumes wilted to more than 65% moisture) and sufficient numbers of lactic acid bacteria are present or have been added. Adding enzymes at lower rates, or adding fungal cultures and their fermentation products, to bacterial inoculants may increase the cost of the inoculant only 20 cents to 40 cents per ton of fresh forage, but enzyme activities in these products may not be sufficient for them to be effective. Enzyme additives may reduce NDF content of forages in the silo and improve digestibility, intake and milk yield, but this needs further study.

Adding molasses to legumes (80 lb/ton) and grasses (40 lb/ton) that are low in fermentable substrate can improve lactic acid production and thus ensiling. Corn silage does not need added molasses. Molasses is hard to handle and is usually diluted with water (2:1) to facilitate application. Do not add liquid molasses to high moisture silage, since it may cause excessive run-off. Use molasses only in situations where substrate supply prevents adequate preservation.

## Conclusion

Additives may aid in the preservation of forage, but they cannot compensate for poor ensiling practices. Use of an additive should always be associated with good management practices. Remember to ensile at the correct stage of maturity, moisture level and chop length, fill the silo rapidly and pack properly. Following these management practices will improve ensiling and increase the effectiveness of an additive or reduce the need for an additive. Remember to evaluate an additive based on its effect on ensiling and livestock performance, as well as cost and return on investment.

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