Silage Fermentation

The fermentation process that preserves forages is very complex. Silage fermentation requires four basic elements to ensure a successful, high quality, stable silage:

1. Anaerobic conditions
2. Proper moisture
3. Sufficient plant sugars
4. Proper bacteria

These elements are interdependent. If one element is missing or marginal, chances for successful silage decrease significantly.

Phases of Silage Fermentation

Phase I, or the **Aerobic Phase**, represents the time from when the silage is blown into the silo until the oxygen in the silage mass is depleted. In this phase, plant enzymes break down plant sugars or water soluble carbohydrates (WSC) to carbon dioxide, heat and water. Bacteria, yeasts, and molds grow rapidly and also break down WSC to carbon dioxide, heat and water. As long as oxygen is present, these spoilage organisms will continue to grow. Once yeast and molds are present, they will remain in the silage. When the silage is again exposed to oxygen (silo opening, feeding) these organisms will grow again, causing heating, spoilage and reduced bunk life.
If Phase I is prolonged, a number of negative effects can occur:

- Heat generated by respiration causes protein damage if temperatures exceed 115°F.
- Dry matter is lost (represented by production of CO_2) as plant sugars are burned up.
- Water soluble carbohydrates, needed for the production of lactic acid, are lost with no benefit to the fermentation.
- NDF and ADF, as a percentage of silage dry matter, increases.
- Energy content of the silage decreases.
- Palatability is negatively affected.
- Good silage management will help to reduce time spent in this phase; i.e., proper DM, rapid silo filling, distribution, packing.

Phase II begins when oxygen in the silo is depleted and anaerobic bacteria take control of the fermentation. During this phase, WSC are converted by bacteria to acetic acid (a weak acid), some lactic acid, alcohols and carbon dioxide. pH of the silage begins to decrease but the fermentation is not very efficient. When Phase II is prolonged, the following negative effects are observed:

- Dry matter loss increases.
- Water soluble carbohydrates needed for lactic acid production are decreased.
- There is an increased opportunity for clostridial growth which can result in decreased dry matter, less stable and less palatable silage.

The best means of reducing losses in this phase is to maximize production of lactic acid, thereby rapidly lowering pH efficiently.

Phase III is a continuation of the anaerobic fermentation but is dominated by homofermentative lactic acid bacteria (bacteria that produce only lactic acid). Domination of the silage fermentation by lactic acid begins around a pH of 5. WSC are converted to lactic acid and the forage pH is driven down below 4.5.

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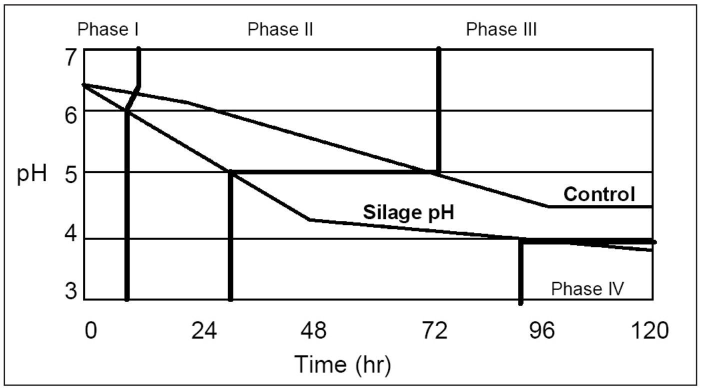
Phase IV is reached when the pH is driven down to 4.5 or lower. This is considered stabilized silage. At this point, the silage mass can be kept for a considerable period of time as long as oxygen and moisture are kept out.

Figure 1. Silage Fermentation Phases



The longer silage stays in Phase I and Phase II, the greater the loss of nutrients. Ideally, the sooner the pH is lowered, the better the chances are of preventing yeast, mold, clostridia and listeria growth.

Proper Moisture

The ensiling moisture of forage plays a critical role in success of the fermentation. When forage moisture is too low, air can remain entrapped within the silage mass. This encourages growth of spoilage organisms and causes excessive heating, and loss of WSC and DM. Silage made too dry often has a dark brown to black color and a burned, tobacco odor. If forage moisture is below recommended levels, it may be necessary to add water to the silage.

When forage moisture is too high, runoff and spoilage become serious problems. Generally, when DM content is at least 30 percent in bunker silos and at least 35 percent in tower silos, seepage will not occur. Effluent from silage will contain about 4-6 percent DM, including WSC and proteins. Loss of WSC can have a negative impact on fermentation (see Sufficient Plant Sugars). Loss of protein means increased cost associated with purchased protein when balancing rations.

In addition, wet silages encourage the growth of spoilage organisms, including clostridia, which produce undesirable by-products. When moisture levels are too high, especially in alfalfa haylage, there may not be sufficient WSC to achieve a stable pH. Wet silages are often slimy and have an ammonia odor.

Silage which has undergone clostridial fermentation will have high DM loss, poor intake by livestock caused by negative palatability factors (butyric acid smell), high pH (5.0 or above), high levels of ammonia-nitrogen (from the breakdown of plant proteins) and a strong rancid smell. Ensiling at the proper moisture creates the best environment for lactic acid-producing bacteria to dominate and control the silage fermentation.

Table 1. Recommended Moisture Levels at Ensiling (%)

Crop	Upright Conventional	Upright Oxygen-Limiting Silo	Bunker or Trench	Silo Bag
Corn	60-68	40-65	65-70	60-70
Sorghum	60-68	40-65	65-70	60-70
High Moisture Shell Corn	27-35	25-30	30-35	27-33
High Moisture Ear Corn	37-42	35-40	40-45	37-42
Small Grains	60-65	55-68	65-68	65-68
Alfalfa	50-65	40-65	60-68	50-68
Grasses	55-65	45-60	60-68	55-65

In upright silos, reduce the recommended moisture 2 percent for every 10 feet in height.

Length of Cut

Corn Silage - A fine chop with a 3/8in to 1/2in theoretical cut is recommended. Chop at 1/2in cut when the moisture level is 60 percent or greater. Chop at 3/8in cut when the moisture level falls below 60 percent.

Processed Whole Plant Corn Silage - Chop at 1/2in to 1in theoretical length of cut.
Alfalfa and Grasses - Chop at a theoretical cut of 3/8in when the moisture level is 60 percent or greater and the material is stored in a large diameter structurally sound silo. If conditions for a proper pack are not optimum, chop at 1/4in. Do not use a recutter screen.

Oatlage - Chopper knives should be set at 3/8in theoretical cut under normal conditions. If moisture levels are below 70 percent, set the chopper for a 1/4in theoretical cut. A fine chop with extremely sharp knives is absolutely necessary when working with hollow stem forages.

Sufficient Plant Sugars

Plant sugars, or WSC, are the fuel that runs a fermentation. If the plant material does not have adequate levels of WSC, the fermentation may stop short of achieving the desired pH necessary to stabilize the silage. The amount of WSC needed to achieve the goal of stabilized silage will be highly variable due to conditions under which the forage is ensiled.

Inadequate levels of WSC may result when:
- Stressed or overwilted forage is ensiled
- Extended aerobic conditions occur
- Forage moisture is excessive
- Forage has high buffering capacity
- Clostridial fermentation occurs

Typical plant sugar levels at harvest vary by species and within plant type (Table 2). If plant sugar levels are on the low side of the normal range, and DM content of the forage is too low, success of the fermentation may be restricted. Unstable silage will have higher DM loss, shorter bunk life and is more likely to undergo secondary or clostridial fermentation.

Table 2. Sugar Requirements for Maximum pH Reduction and Typical Sugar Contents at Harvest*

DM (%)	Alfalfa	Grass	Corn
17	34	28	**20**
20	25	**19**	**14**
25	21	**14**	**10**
30	17	**10**	**7**
35	**14**	**7**	**5**
40	**10**	**5**	**4**
45	**7**	**3**	--
50	**6**	**2**	--

*Typical Sugar Content at Harvest (% DM)

Alfalfa	4-15
Grass	10-20
Corn	8-30

Bold Type indicates ranges in which typical sugar levels are sufficient for maximum pH reduction.

Leibensperger and Pitt, Journal of Dairy Science, Vol. 71:1220.

If weather conditions do not allow for sufficient field wilting prior to harvest, ensile with an effective bacterial inoculant. Add 30-50 lbs. of either dry or wet molasses or 100-200 lbs of a dry feedstuffs per ton of chopped forage. Finely ground grains, wheat, midds, and beet pulp mixed in at ensiling are possibilities.

Proper Bacteria

For efficient silage fermentation, proper bacteria are those that:

- are homofermentative, meaning they produce mainly lactic acid
- can compete with other bacteria
- produce large amounts of lactic acid rapidly
- show rapid growth
- grow at low pH (below 4.0)

Unfortunately, many other types of microorganisms are present in silages. In addition, beneficial bacteria are not always present in very large numbers.

The number of lactic acid bacteria (LAB) vary considerably with harvest conditions. For example, the number of bacteria (designated as CFU or Colony Forming Units) found on wilting forage are higher during warm, moist weather than during cool, dry weather. Consequently, the number of bacteria per gram of fresh forage can range from less than one hundred to several million CFU.

The addition of microbial inoculants supplements the naturally occurring lactic acid bacteria found on forage. Numerous studies have shown that when added in sufficient numbers (at least 100,000 CFU/g of fresh forage), the rate of silage pH drop can be increased.

When evaluating a microbial inoculant, ask the following questions:

1. What bacteria does it contain?
2. What inoculation level is used?
3. What university work supports this product?

Anaerobic Conditions

Oxygen is a silage's worst enemy. In the presence of oxygen, plant material and aerobic bacteria continue to respire. Respiration is the process by which plants or bacteria use oxygen and stored WSC (water soluble carbohydrates) to form carbon dioxide, water and heat.

Respiration

$$\begin{matrix}\text{Carbohydrates} \\ \text{Oxygen}\end{matrix} \xrightarrow[\text{Bacteria}]{\text{Plant Enzymes}} \begin{matrix}\text{Carbon Dioxide} \\ \text{Water} \\ \text{Heat}\end{matrix}$$

Under conditions of good management (proper moisture, chop length and packing) respiration is very short, lasting 10-24 hours. Problems occur when the process is extended due to prolonged exposure of forage to oxygen. Excessive exposure to oxygen can result when:

1. Forage is put up too dry. Drier forage packs less densely, trapping oxygen in the silo. A finer particle chop, and/ or oxygen-limiting structures should be used.
2. Forage is poorly distributed in silo. Coarser material collects near outer edges and traps more oxygen, forming "hot spots." Distribution equipment should be checked.
3. Forage chop is too long. Coarser material does not pack tightly and traps more oxygen. Use a finer chop. (Moisture content and nutritional needs may influence chop length).
4. Inadequate packing. Good packing reduces air spaces in the silage mass and reduces oxygen exposure.
5. Slow fill rate. Slow filling results in longer exposure of forage to oxygen.
6. Poor condition of silo. Cracks in the walls or around doors and uncovered silos will allow oxygen to penetrate the silage.

All of the items listed above can be addressed by using good silage management practices. But what is the incentive or justification to change or correct current practices that do not adequately minimize exposure to oxygen? The answer lies in understanding the potential "cost" of not following proper management practices.

When excessive respiration occurs, the plant metabolizes or "burns" WSC, converting them to heat, carbon dioxide and water. Since WSC are necessary for the production of lactic acid and a stable silage, depletion of WSC during respiration endangers the successful ensiling of forage (see Sufficient Plant Sugars).

Heat generated by the "burning" of WSC can result in a decrease in available protein in the forage. Damage to protein (protein becomes bound and is unavailable to the animal) begins to occur when forage temperatures exceed 115oF. Overheated proteins are less digestible by the cow. Silage that has overheated is often described as "caramelized" and laboratory assays will show high levels of ADIN (acid detergent insoluble nitrogen).

In addition to damage caused by heating, plant proteins are also broken down to ammonia by plant enzymes during respiration. If these enzymes remain active for extended periods, silage with high ammonia levels and lower quality protein values will result. Plant enzymes are inactivated by low forage pH.

In addition, as long as oxygen is available, spoilage organisms such as molds, yeasts and aerobic bacteria will grow, causing heat production, protein degradation and reduced palatability. These organisms are inhibited when oxygen in the silo is depleted. As the feed is exposed to oxygen during feedout, they begin to grow, causing silage in the bunk to heat. Laboratory studies estimate these Dorr losses are about 1.5 - 3.0 percent per day for each 8-12oC rise in silage temperature above ambient.[1] If the growth of these spoilage organisms is restricted during the start of the fermentation, bunk life can be significantly improved at feedout.

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[1] Woolford, M.K. 1984. The Silage Fermentation. Mercel Dekker, Inc., New York, NY.