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Silage Fermentation and Preservation

J.W. Schroeder
Extension Dairy Specialist

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Fermentation Process

Harvesting forages as silage is a compromise between reducing labor requirements and field losses and reducing losses in the fermentation process that eventually will preserve the crop. Ideal fermentation is dependent upon decisions and management practices implemented before and during the ensiling process. The primary management factors that are under the control of the producer are:

- Stage of maturity of the forage at harvest
- Type of fermentation that occurs in the silo or bunker
- Type of storage structure used and methods of harvesting and feeding

During the ensiling process, some bacteria are able to break down cellulose and hemicellulose to various simple sugars. Other bacteria break down simple sugars to smaller end products (acetic, lactic and butyric acids). The most desirable end products are acetic and lactic acid. As the bacteria degrade starches and sugars to acidic and lactic acids, dry matter is lost.

Attention to details such as speed of harvesting, moisture content, length of chop, silage distribution and compaction can influence the fermentation process and storage losses greatly. Efficient fermentation ensures a more palatable and digestible feed, which encourages optimal dry-matter intake that translates into improved animal performance. Making consistent, high-quality silage requires sound management decisions and attention to details.

Making sure that bacteria responsible for the production of acetic and lactic acid grow and multiply immediately after storing the forage is important for maximum quality haylage. Proper packing of the hay and voiding of air (oxygen) provides the environment needed by bacteria to break down fiber components and sugars. Oxygen must be removed from the haylage to maximize reproduction of acetic and lactic acid-producing bacteria. Microbes (bacteria) responsible for fermentation need anaerobic (absence of air) conditions.

As bacteria consume sugars, end products produced (acetic and lactic acid) cause the pH to drop.

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A critical time during the ensiling process occurs after the initial three to five days; ensiling requires about 15 to 20 days for completion. The success of the ensiling process is determined during these two weeks. The amount of lactic acid gradually increases as lactic acid-producing bacteria break down simple sugars. The pH drops to between 3.8 to 4.2. At such acidic conditions, further bacterial action is stopped.

The critical difference between silage and haylage is the effect of moisture content of the forage during this two-week fermentation process. If the forage is too dry, fermentation is restricted and the pH cannot drop sufficiently. If the pH of the haylage does not drop sufficiently, spoilage will occur.

The following six phases describe what occurs during ensiling, storage and feed-out of fermented forages:

Phase I

As the forage is harvested, aerobic organisms predominate on the forage surface. During the initial ensiling process, the freshly cut plant material, and, more importantly, the aerobic bacteria, continue to respire in the silo structure. The oxygen utilized in the respiration processes is contained within and between the forage particles at the time of ensiling.

This phase is undesirable because the aerobic bacteria consume soluble carbohydrates that might otherwise be available for the beneficial lactic acid bacteria or the animal consuming the forage. Although this phase reduces the oxygen to create the desired anaerobic conditions, the respiration process produces water and heat in the silage mass. Excessive heat buildup resulting from an extended Phase I period can greatly reduce the digestibility of nutrients such as proteins.

Another important chemical change that occurs during this early phase is the breakdown of plant proteins. Proteins first are reduced to amino acids and then to ammonia and amines. Up to 50 percent of the total plant protein may be broken down during this process. The extent of protein breakdown (proteolysis) is dependent on the rate of pH decline in the silage. The acid environment of the silage eventually reduces the activity of the enzymes that break down proteins.

Phase I ends once the oxygen has been eliminated from the silage mass. Under ideal crop and storage conditions, this phase will last only a few hours. With improper management, this phase could continue for several weeks.

The primary objective at ensiling time is to manage the crop so air infiltration is minimized, thereby shortening the time required to achieve an anaerobic environment. Key management practices are proper maturity, moisture, chop length and rapid filling, with adequate packing and proper sealing of the storage structure.

Phase II

After the oxygen in the ensiled forage has been utilized by the aerobic bacteria, Phase II begins. This is an anaerobic fermentation in which the growth and development of acetic acid-producing bacteria occurs.

These bacteria ferment soluble carbohydrates and produce acetic acid as an end product.

Acetic acid production is desirable because it can be utilized by ruminants in addition to initiating the pH drop necessary to set up the subsequent fermentation phases. As the pH of the ensiled mass falls below 5, the acetic bacteria decline in numbers as this pH level inhibits their growth. This signals the end of Phase II. In forage fermentation, Phase II lasts no longer than 24 to 72 hours.

Phase III

The increasing acid inhibits acetic bacteria and brings Phase II to an end. The lower pH enhances the growth and development of another anaerobic group of bacteria, those producing lactic acid.

Phase IV

This is a continuation of Phase III as the lactic-acid bacteria begin to increase, ferment soluble carbohydrates and produce lactic acid. Lactic acid is the most desirable of the fermentation acids and, for efficient preservation, should consist of greater than 60 percent of the total silage organic acids produced.

When silage is consumed, lactic acid also will be utilized by cattle as an energy source. Phase IV is the longest phase in the ensiling process because it continues until the pH of the forage is sufficiently low enough to inhibit the growth of all bacteria. When this pH is reached, the forage is in a preserved state. No further destructive processes will occur as long as oxygen is kept from the silage.

Phase V

The final pH of the ensiled forage depends largely on the type of forage being ensiled and the condition at the time of ensiling. Haylage should reach a final pH of around 4.5 and corn silage near 4. The pH of the forage alone is not a good indicator of the quality of the silage or the type of fermentation that occurred.

Forages ensiled at moisture levels greater than 70 percent may undergo a different version of Phase IV. Instead of lactic acid-producing bacteria developing, large populations of clostridia bacteria may grow in the silage. These anaerobic bacteria produce butyric acid rather than lactic acid, which results in sour silage. With this type of fermentation, the pH may be 5 or above.

Phase VI

This phase refers to the silage as it is being fed out from the storage structure. This phase is important because research shows that nearly 50 percent of the silage dry-matter losses occur from secondary aerobic decomposition. Phase VI occurs on any surface of the silage that is exposed to oxygen while in storage and in the feed bunk.

High populations of yeast and mold or the mishandling of stressed crops can lead to significant losses due to aerobic deterioration of the silage. Proper management is vital to reduce these losses and improve the bunk life (aerobic stability) of the silage.

General Silage Management Factors

- **Maturity and moisture –** Recommendations vary with different silage crops (Table 2). Proper maturity assures adequate fermentable sugars for silage bacteria and maximum nutritional value for livestock. Maturity also has a tremendous impact on moisture with unwilted forage crops such as corn silage. Adequate moisture for bacterial fermentation is essential and aids in packing to help exclude oxygen from the silage.

- **Length of cut –** The most desirable length of cut is ¼ to ½ inch, depending upon the crop, storage structure and amount of silage in the ration. This will give ideal compaction of the silage and yet allow for ease of unloading from an upright silo. Setting the chopper to cut any finer could have a negative impact upon milk fat production and the

Table 1. Six phases of silage fermentation and storage.

	Phase I	Phase II	Phase III	Phase IV	Phase V	Phase VI
Age of silage	0-2 days	2-3 days	3-4 days	4-21 days	21 days-	
Activity	Cell respiration; production of CO_2, heat and water	Production of acetic acid and lactic acid ethanol	Lactic acid formation	Lactic acid formation	Material storage	Aerobic decomposition on re-exposure to oxygen
Temperature change*	69-90 F	90-84 F	84 F	84 F	84 F	84 F
pH change	6.5-6.0	6.0-5.0	5.0-4.0	4.0	4.0	4.0-7.0
Produced		Acetic acid and lactic acid bacteria	Lactic acid bacteria	Lactic acid bacteria		Mold and yeast activity

*Temperature dependent on ambient. Ensiling temperature generally is 15 higher than ambient.
Adapted from McCullough.

Table 2. Harvest and moisture recommendations.

Crop	Maturity	Silo Type Bunker	Stave	Sealed	Length of Cut
		% moisture			inches
Corn silage	milk line ½-⅔ down the kernel	67-72	63-68	50-60	⅜-½
Alfalfa	mid-bud 1/10 bloom, wilt to	65-70	60-65	50-60	¼-⅜
Cereal silage	milk or soft dough, wilt to	67-72	63-68	50-60	¼-⅜
Grasses	when first stems head out	67-72	63-68	50-60	¼-⅜
Clover	¼ to ½" bloom, wilt to	67-72	63-68	50-60	¼-⅜
Forage sorghum	grain medium to hard dough or as leaves begin to lose color	70-75	65-70	50-60	⅜-½

incidence of displaced abomasums in dairy cattle due to an inadequate scratch factor.

Chopping forages too long makes compaction difficult and air will remain trapped in the silage, resulting in heating and spoilage (Phase I). A recutter screen generally is not recommended unless the silage is too dry because it increases the power requirement and will slow harvesting.

- **Filling, packing, sealing –** The crop should be harvested and the silo filled as rapidly as possible. Filling delays will result in excessive respiration and increased silage losses. Packing should begin immediately when storing silage in bunker silos. A wheeled tractor is preferred as a packing vehicle because it will supply greater weight per surface unit than a tracked vehicle. The silo should be sealed with an air-tight cover once it is filled to prevent penetration of air and rainfall into the silage. A good grade of plastic weighted down with discarded tires generally will provide an adequate seal.
- **Additives –** Most silage additives marketed in the U.S. are designed to aid fermentation by providing fermentation bacteria, enzymes or fermentable substrate. Although not a replacement for good management, they are tools to help ensure that the ensiling process stays within acceptable boundaries.

Manage the Feeding Face

Face management requires skill and is a real problem in the U.S. Many bunker, trench and drive-over pile silos are too large to manage correctly. The silage face should be maintained as a smooth surface that is perpendicular to the floor and side walls in bunker and trench silos. This technique will minimize the square footage of surface exposed to air. An average daily removal rate of 6 to 12 inches from the face should prevent heating and spoiling of exposed silage. Well-packed silage reduces the distance that oxygen can penetrate in an exposed silage face.

Dispose of the Spoilage

Even the best-managed silage always will have some spoilage. The temptation is to feed spoiled silage, but it is always a mistake and can destroy the forage mat in a cow's rumen. In tests at Kansas State University, fistulated cows fed spoiled silage didn't ruminate, reducing chewing and saliva production. Instead, always throw out the spoilage. You can't afford to use it.

Additions to Silage

Various additions to silage have been suggested as methods to improve or alter the fermentation process. These materials may be referred to as additives, conditioners and preservatives.

- **Additive –** A material that adds nutrients to silage
- **Conditioner –** A material that absorbs excess moisture from chopped forage or increases the moisture content of excessively dry forage
- **Preservative –** A material that stimulates the fermentation process or a material that inhibits fermentation

The benefits obtained from silage additives, conditioners and preservatives depend upon their influence on the silage fermentation process. These benefits usually are measured by the reduction in fermentation losses and/or improvement in silage quality and feeding value.

Silage additives, conditioners and preservatives function in the following ways:

- Add dry matter to reduce moisture content
- Add water to increase moisture content
- Alter the rate, amount and kind of acid production
- Acidify the silage
- Inhibit bacterial and mold growth
- Culture silage (inoculants) to stimulate acid production
- Increase nutrient content of the silage

Add Dry Matter to Reduce Moisture Content

The objectives of adding dry matter are to reduce seepage losses and provide a more suitable medium for the fermentation process. The goal of producers should be to harvest corn and sorghum for silage at the proper growth stage or at physiological maturity when plant moisture content is ideal for silage. Grasses and legumes should be wilted or dried in the swath to an average of about 65 percent moisture or less, depending on the type of storage used.

If forage crops must be harvested too wet for silage, the following guideline for dry-matter addition may be used: Cereal grains, coarsely ground and chopped air-dried alfalfa, or grass forage will decrease the moisture content of wet forage approximately 5 percentage units for each 150 to 200 pounds of material added per ton of wet forage weight.

Add Water to Increase Moisture Content

If forage crops to be stored as silage become too dry, packing to exclude air is difficult. Under such conditions, water must be added to raise the moisture content to the desired level or severe dry-matter losses will result.

The amount of water required to increase forage moisture content 1 percentage unit is approximately 5 to 6 gallons per ton of ensiled material.

Altering the Rate, Amount and Kind of Acid Production

Acid production is essential in the keeping qualities of silage. The rate, amount and kind of acid produced are influenced by the moisture content of the chopped forage and the readily available carbohydrate content of the forage.

Corn silage harvested at the proper growth stage or at physiological maturity has a high level of readily available carbohydrates for lactic acid production. If legumes and grass crops are not wilted in the field to an average of 65 percent moisture or less, depending on the type of storage, then the addition of a carbohydrate-rich feedstuff will enhance fermentation.

Molasses is an excellent carbohydrate or sugar source for legumes and grasses containing 75 to 80 percent moisture. For legumes, about 80 pounds of molasses per ton is required, and for grasses 40 pounds generally is used.

Cereal grains are another source of carbohydrates. These materials, when added at 150 to 200 pounds per ton of wet forage, also will reduce the moisture content of the chopped forage approximately 5 percentage units.

Acidifying the Silage

Acidifying silage, using a strong acid, has been practiced in Europe on high-moisture grass silage. The purpose was to produce an immediate acid condition rather than waiting for the silage to produce its own acid. This practice is not recommended in the U.S. because of its high cost, the corrosive nature of the acids and low forage palatability.

Inhibit Bacteria and Mold Growth

While acid formation and the exclusion of oxygen stop bacterial growth, several chemicals used as silage preservatives also inhibit undesirable bacterial and mold growth. Acids, such as formic and propionic, enhance the preservation of forage.

The major benefit of adding weak acids to silage appears to be in reducing spoilage in open-storage structures. Formic acid is added to hay crop silages at 0.45 percent of the wet weight or 2.25 percent of the dry-matter weight. Propionic acid is added at the rate of 0.5 to 1 percent of the wet forage weight.

"Culturing" Silage (inoculants)

A number of commercial products, referred to as fermentation aids and/or inoculants, are available for adding to silage at the time of ensiling. Because silage is a product resulting from the action of bacterial enzymes on the material stored, attempts have been made to alter or regulate silage fermentation through the addition of materials containing bacteria, yeasts and molds.
The primary purpose for adding bacterial inoculants is to increase the number of lactic acid-producing bacteria, thus encouraging more lactic acid production and a well-preserved forage mass.

Research using various bacterial inoculants indicates highly variable results. Products showing consistent, positive results achieve about a 5 percent increase in dry-matter preservation. Therefore, the cost of the inoculant per ton compared with the dollar value of the dry matter saved will determine the profitability of using a silage inoculant.

The addition of bacterial inoculants to corn silage harvested at the proper growth stage and moisture content has not shown consistently positive results. With good natural fermentation, making substantial improvements in fermentation by using an inoculant is difficult. Results have been more positive when inoculants have been added to alfalfa, a low-carbohydrate forage, and sorghum silages.

Increasing the Nutrient Content of Silage

Various materials added to silage will increase nutritive value to the extent that they contain nutrients. Increasing the nutrient content of silage will greatly affect the final cost of the product produced.

Materials such as cereal grains, molasses, dry forages, limestone, urea and anhydrous ammonia are examples of nutrient additions to silage. Commercial products that contain one or more of these materials also are available.

Limestone (calcium carbonate) sometimes is added to corn silage to increase the calcium content and extend the fermentation process. The rate frequently added is 10 to 20 pounds per ton of corn silage.

Urea and anhydrous ammonia, nonprotein nitrogen (NPN) sources, sometimes are added to corn silage to increase the protein content. The various NPN sources listed in Table 3, when applied at the suggested rate per ton of stored forage, usually will increase forage protein content about 4 percentage units on a dry-matter basis.

Adding Urea to Corn Silage

The following are some points to keep in mind before you add urea to corn silage to increase its protein content:

- Evenly distributing the ensiled material is critical.
- Only about 30 percent of the urea is hydrolyzed in the silo; the "preservative" effects are minimal.
- The use of urea in the silo "locks" the producer into a feeding system that cannot be altered.
- Animal performance trials, for the most part, have been disappointing.

If you need NPN (urea) in the ration, the best way to get it there is to add feed-grade urea to the total mixed ration. The only time to put it into the silo is if you have no other way to mix it into the ration.

Table 3. Nonprotein nitrogen sources for adding to corn silage and suggested application rates.[1]

NPN Sources	Form	% Nitrogen	Application Rate
			(lbs/wet ton)
Urea	dry	45	10
Mono-ammonium phosphate	dry	11	20[2]
Pre-mixed ammonia-water	liquid	20-30	17-25
Anhydrous ammonia	gas	81	6-7
Ammonia, cold flow	gas-liquid	81	6-7

[1] Commercial products should be applied at a rate to provide 5 pounds of actual nitrogen/ton of forage.

[2] Add 5 lbs. dry urea to provide 5 lbs. of nitrogen.

Ammoniating Corn Silage

Ammoniating feed can be easy, pleasant, safe and profitable if you take a few simple steps to ensure that the job is done properly. Here are some tips:

- Test feeds before you ammoniate as a way to check results. If ammoniation doesn't boost protein by at least three points, you haven't ammoniated properly and you won't get the benefits.
- To apply the 7 pounds per ton recommended for corn silage, you must start with a 10- to 12-pound application rate to cover losses. Be sure the float gauge on your supply tank works and check it frequently to ensure that you are using enough ammonia for the silage processed.
- Ammonia weighs 5 pounds per gallon, so you need a little more than 2 gallons per ton of corn silage. Be sure you use enough and adjust the regulator setting if you're not.
- Use a cold-flow converter, which you can buy or make. Putting ammonia on at the chopper helps greatly. But if you put it on at the silo, try to use a blower that augers feed from the hopper back to the thrower. Augers help blend the feed and ammonia, and augers are more efficient ammoniators than spinning pans that "throw" feed.
- Adding water at the blower to help retain the ammonia is almost essential, especially with dryer silage. If you ammoniate at the blower, add water.
- Be sure that hoses "downstream" from the regulator are short and drop straight down without kinks or loops to trap ammonia. Make sure that the ammonia evacuates quickly from the system when the regulator is cut off to minimize wasted material and unnecessary odors.

When properly rigged, ammonia is safe and relatively pleasant to handle. If it is improperly set up, you will not be able to understand how anyone could stand the stuff, much less use ammonia.

Precautions

You must take several precautions when ammoniating corn silage. Keep equipment in top shape, especially hoses.

Hoses should not be left under pressure for extended periods. They should be stored inside, out of sunlight. Replace hoses every three to five years, and remember that 90 percent of ammonia accidents on farms occur from broken hoses.

Most other ammonia accidents occur when ammonia equipment is hooked up, moved or unhooked.

Corrosion to equipment is a problem, too, but a manageable one. Ammonia is not corrosive to most steel, although it does remove paint, so it exposes unloaders more quickly to the corrosive effect of the silage. Ammonia is harmless in choppers, but it is rough on electrical equipment, and you should take precautions to protect the equipment.

Keep spare parts, such as collector rings, rollers, plugs and switches, on hand. Use stainless steel screws to hold the collector ring in place. Seal motors that are in a silo with silicone sealer, especially where the cord enters the motor housing and around the capacitor box. If an ammonia user prepares for electrical problems, he/she will have less trouble than one who is unprepared.

Significantly, ammonia is only corrosive to copper, brass and zinc, and only when being applied. Once silage has been treated with ammonia, it is less corrosive than untreated silage.

Other publications in the Quality Forage series

- ➤ AS1250 "Forage Nutrition for Ruminants"
- ➤ AS1251 "Intrepreting Composition and Determining Market Value"
- ➤ AS1252 "Haylage and Other Fermented Forages"
- ➤ AS1253 "Corn Silage Management"
- ➤ AS1255 "Storage, Sampling and Measuring"
- ➤ AS1256 "Stressed or Damaged Crops"

References

In addition to sources cited, materials were adapted with permission from Pioneer Forage Manual, which no longer is in print.

For more information on this and other topics, see www.ag.ndsu.edu

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