

Penn State **Extension**

FROM HARVEST TO FEED: UNDERSTANDING SILAGE MANAGEMENT



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Cooperative Extension
College of Agricultural Sciences

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INTRODUCTION

Feeding adequate quantities of high-quality forages is the basis of profitable milk and livestock production. Forage production, harvest, storage, and feed practices have changed greatly over the past 50 years in Pennsylvania, and silage has become a staple forage, as shown in Table 1.

Compared to hay production, silage increases the potential yield of nutrients from available land, decreases feed costs, lowers harvest losses, and often increases forage quality. Silage can also reduce labor needs through greater mechanization of harvesting and feeding.

High-level management and sizeable financial outlays are necessary to efficiently produce, harvest, store, and feed silage. The information in this publication should enable you to make more effective decisions about harvesting, managing, and feeding silage.

Advantages of silage

Relative nutrient yield. Of the feed crops adapted to Pennsylvania, corn harvested as silage yields the greatest quantities of energy per acre, and alfalfa produces the greatest quantities of protein per acre. Both alfalfa and grass usually provide more energy and protein when harvested as silage than as hay.

Reduced field losses. Direct-cutting of hay-crop silages avoids extended weather damage and leaf shattering; even wilting hay-crop silages may result in reduced losses when compared to dry hay. Losses from ear dropping and grain shattering that occur during corn silage harvest are lower than those occurring during grain harvest.

Flexible harvest dates. Producers can decide late in the growing season how much corn to harvest as silage or as grain. Small grains and other annuals such as sorghum-sudan hybrids also may be harvested as silage or grain.

Efficient use of labor. Timing of harvest and scheduling of labor can be extended by planting crop varieties of differing maturities. Combining various crops, such as grasses, legumes, and corn, can spread labor and management demands over the entire cropping season. Silage systems are also more mechanized and less labor-intensive than dry hay systems, which can increase labor productivity.

Table 1. Pennsylvania silage production¹ from 1970 to 2002.

Silage Crop	Year						
	1970	1980	1990	1999	2000	2001	2002
Hay ²				2.30	3.88	2.79	2.46
Corn	4.93	6.27	6.24	6.20	7.82	7.84	6.44
Sorghum					0.077	0.050	0.049

Source: Pennsylvania Agricultural Statistics Service.

¹Million tons.

²Includes all types of forages harvested for haylage or green chop; dry hay is not included.

Disadvantages of silage

Storage losses. Silage storage losses can be high if crops are not harvested at the proper moisture content, facilities are inadequate, the crop is not chopped correctly and packed well, and/or silos are not sealed properly.

Potential spoilage. Silage must be fed soon after removal from storage to avoid spoilage due to exposure to oxygen. Storage facilities with an exposed silage surface must be sized to match the feeding rate to prevent spoilage. Also, when silage feeding is discontinued for a long period, resealing is required to avoid greater storage losses and spoilage problems.

Intensive management. Producing high-quality silage requires intensive management of all aspects of the ensiling process. Poor silage management practices can result in reduced feed quality, low milk production, and increased risk of health problems. Proper management practices help to limit these risks.

Handling and storage costs. Silage is bulky to store and handle; therefore, storage costs can be high relative to its feed value. Storage facilities are specialized and have limited alternative uses. Silage is costly to transport relative to its bulk and low density of energy and protein. Therefore, transportation costs often limit the distance silage can be moved.

Investment costs and cash flow. The machinery and equipment investment per ton of silage harvested, stored, and fed can be high unless a large quantity is handled annually. Furthermore, inadequate cash flow during the financing period may

cause difficulties in carrying out what appears to be a profitable investment. This situation has led to the development of a custom operations industry in many areas.

Few market outlets. There are few ready off-farm markets for silage in most areas, except for close neighbors. Moving silage from one silo to another is risky, especially for haylage. Therefore, when a crop is harvested as silage, the farmer is usually committed to feeding it to livestock.

SILAGE FERMENTATION

The goal of making silage is to preserve forage nutrients for feeding at a later date. This is accomplished by the conversion (by fermentation) of plant sugars to organic acids. The resulting acidity effectively “pickles” the forage. Production of quality silage requires minimum nutrient loss, despite the dynamic and sensitive process of silage fermentation. This process is controlled by five primary factors:

1. Forage moisture content
2. Fineness of chop
3. Exclusion of air
4. Forage carbohydrate (sugar) content
5. Bacterial populations, both naturally occurring and supplemental

Phases of normal fermentation

The conversion of fresh forage to silage progresses through four phases of fermentation that are normally completed within 21 days of ensiling (Figure 1). A fifth phase may occur if improper silage production practices cause undesirable or abnormal silage fermentation.

Phase 1—plant respiration. The respiration phase begins as soon as forage is mown. This phase is also called the aerobic phase because it can only occur in the presence of oxygen. When cut, green plants continue to live and respire for several hours (or longer if packed poorly in storage). The plant cells within the chopped forage mass continue to take in oxygen because many cell walls are still intact, and plant enzymes that breakdown proteins (proteases) continue to function. At the same time, aerobic bacteria naturally present on the stems and leaves of plants begin to grow. These processes consume readily available carbohydrates stored in the plant and produce carbon dioxide, water, and heat.



The heat produced by aerobic bacteria causes an initial rise in silage temperature; normal fermentation results in initial temperatures that are no more than 20°F greater than the ambient temperature at ensiling.

The respiration phase usually lasts three to five hours, depending on the oxygen supply present. From a management standpoint, the primary goal is to eliminate oxygen as soon as possible and keep it out for the duration of the storage period.

Practices that help rapidly exclude air from

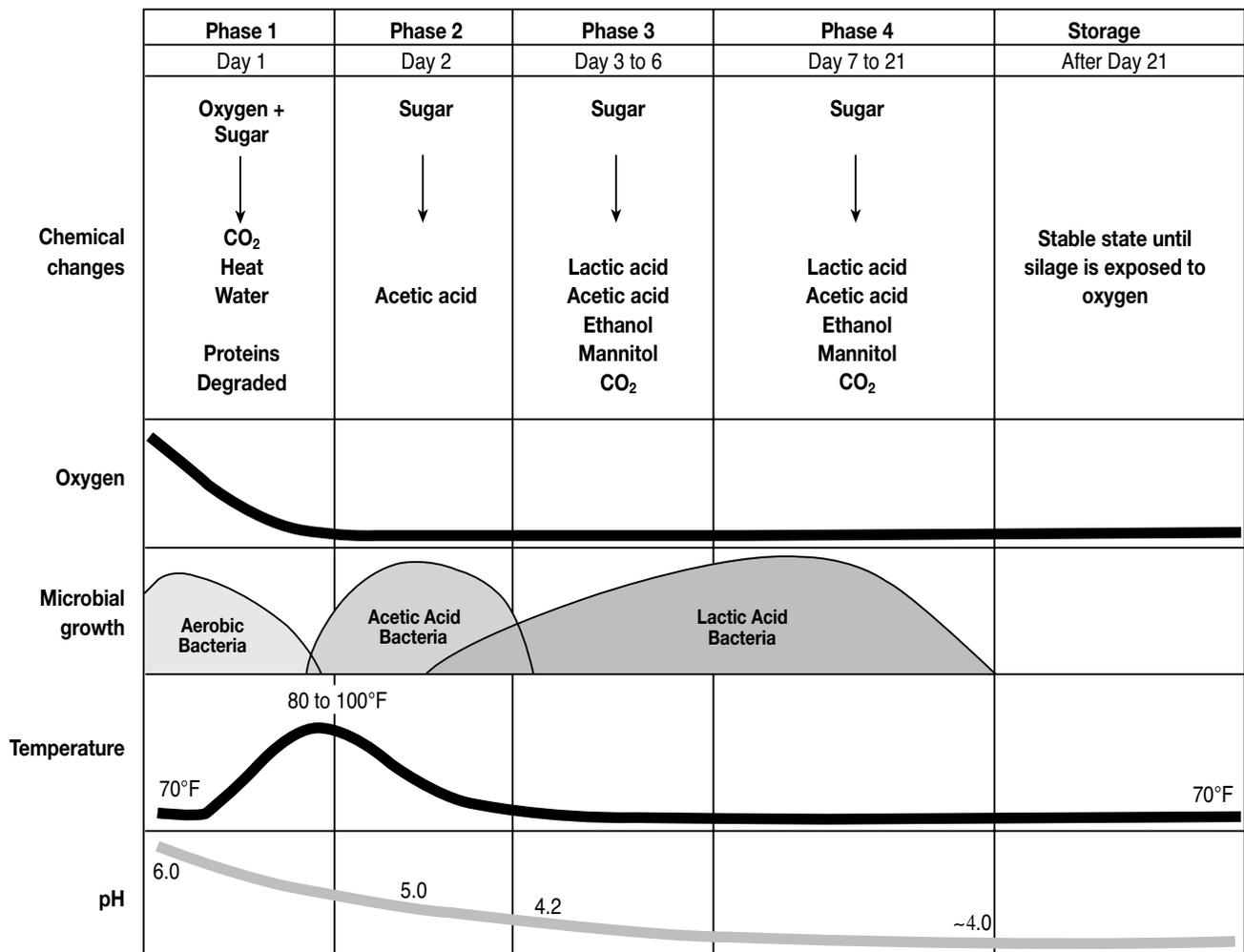
the silage mass include chopping forage at proper particle length (about $\frac{3}{8}$ to $\frac{3}{4}$ of an inch), harvesting at proper moisture for the crop and the storage structure, packing adequately by distributing silage evenly and compacting silage well, and sealing the storage structure immediately.

Phase 2—acetic acid production. This phase begins as the supply of oxygen is depleted, and anaerobic bacteria that grow without oxygen begin to multiply. The acetic acid bacteria begin the silage “pickling” process by converting plant carbohydrates to acetic acid. This acidifies the forage mass, lowering the pH from about 6.0 in green forage to a pH of about 5.0. The lower pH causes the acetic acid bacteria to decline in numbers, as they cannot tolerate an acidic environment. The early drop in pH also limits the activity of plant enzymes that break down proteins. This phase of the fermentation process continues for one to two days and merges into phase 3.

Phase 3—initiation of lactic acid production. The third phase of the fermentation process begins as the acetic acid-producing bacteria begin to decline in numbers. The increased acidity of the forage mass enhances the growth and development of lactic acid-producing bacteria that convert plant carbohydrates to lactic acid, acetic acid, ethanol, mannitol, and carbon dioxide. Homolactic bacteria are preferred because they can convert plant sugars to lactic acid exclusively. Bacterial strains within this group grow in anaerobic conditions, and they require low pH.

Phase 4—peak lactic acid production and storage. The fourth and longest stage of the fermentation process is a continuation of phase 3; lactic acid production continues and peaks during this time. Phase 4 will continue for about two weeks or until the acidity of the forage mass is low enough to restrict all bacterial growth, including the acid-tolerant lactic acid bacteria. The silage mass is stable in about 21 days, and fermentation ceases if outside air is ex-

Figure 1. Phases of normal fermentation.



cluded from the silage. However, improper ensiling practices will result in an undesirable continuation of the process, as discussed below.

If silage has undergone proper fermentation, the expected pH will range from 3.5 to 4.5 for corn silage and 4.0 to 5.5 for haylage, depending on forage moisture content. The remainder of phase 4 is the material storage phase. Generally, lack of oxygen prevents the growth of yeast and molds and low pH limits the growth of bacteria during storage.

Undesirable fermentation

Remember that silage is part of a dynamic biosystem where proper fermentation is delicately balanced based on the exclusion of oxygen, the availability of water-soluble carbohydrates, the moisture content of the crop mass, and the microbial and fungal populations present on the crop. These factors affect the rate or extent of fermentation and the nutritional value of silage.

Excessive oxygen. The presence of oxygen in the forage mass increases the rate at which plant carbohydrates are converted to heat and carbon dioxide. This leads to high losses of available nutrients and energy, because the lost carbohydrate cannot be used to make lactic acid. Respiration typically increases neutral detergent fiber (NDF) and acid detergent fiber (ADF) and decreases net energy for lactation (NE_L) of silage. These changes reduce forage quality.

Respiration not only depletes plant sugars, but the heat produced can limit the activity of lactic acid bacteria and cause protein to bind to lignin. The ideal temperature for acid-producing bacteria activity is about 80 to 100°F. Excessive oxygen trapped in the forage mass will cause initial temperatures to rise well above 100°F and limit lactic acid production. In addition, excessive heating encourages the growth of undesirable fermentation bacteria, yeasts, and molds.

Heating soon after ensiling also can lead to Maillard browning, which lowers protein quality and digestibility. During browning, proteins combine with plant sugars to form a brown lignin-like compound. This increases the level of bound protein and ADF in the silage. Forages with moisture contents of 20 to 50 percent are most susceptible to browning. Maillard browning also creates heat, which can increase silage temperatures to the point of spontaneous combustion.

Finally, excessive oxygen and the resulting high silage temperatures increase the rate at which proteases convert crude protein to soluble protein (am-

monia, nitrates, nitrites, free amino acids, amines, amides, and peptides). High levels of soluble protein in forages can create imbalances in the rumen if the ration is not properly balanced for degradable and undegradable protein.

Low plant sugar levels. The production of acid, especially lactic acid, is the most important change in the fermentation process. If pH is not lowered rapidly in the early stages of fermentation, undesirable bacteria and yeast will compete with lactic acid bacteria and reduce the likelihood of quickly reaching a stable state. For this reason, many aspects of silage management focus on lowering pH rapidly to encourage the proliferation of lactic acid bacteria.

To produce lactic acid, bacteria must have sugar available, and if sugars are depleted during fermentation, lactic acid production stops. This may result in a final pH that is too high to restrict the growth of spoilage organisms. Two factors dictate the amount of sugar required for maximum fermentation: water and crop species.

In wet forage, a lower pH is needed to prevent undesirable bacteria growth. This means more sugar must be available for conversion to acid. Legumes have a natural buffering capacity and require more acid to reach a low pH than grasses or corn. The combination of low sugar content at harvest and high buffering capacity means alfalfa is especially prone to incomplete fermentation. Plant sugar levels required for maximum fermentation of various crops are presented in Table 2.

Table 2. Plant sugar required for maximum fermentation at various dry matter (DM) levels¹.

DM (%)	Minimum initial sugar requirement (% 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 range ²	4–15	10–20	8–30

Source: Pitt. 1990. *Silage and Hay Preservation*. NRAES-5.

¹Boxes indicate dry matter range over which typical sugar contents are sufficient for maximum fermentation.

²Sugar content expected at harvest.

Phase 5—butyric acid production. Provided the ensiled forage contains an adequate supply of readily available carbohydrates, fermentation in the silo will not progress to phase 5 when proper production practices are followed. This phase involves the production of butyric acid and other undesirable products, such as ammonia and small proteins called amines. Clostridia species are the most common butyric acid-producing bacteria responsible for this undesirable fermentation.

Clostridia are spore-forming bacteria that normally live in manure and soil and can grow in silage when oxygen is absent. They typically multiply in silage after most of the acetic and lactic acid bacteria stop growing. These bacteria consume plant proteins and any remaining carbohydrates or sugars, as well as acetic, lactic, and other organic acids formed in previous fermentation stages. Butyric acid is a sour-smelling, low energy acid that tends to decrease feed intake. Therefore, growth of clostridia increases losses of digestible dry matter and produces sour-smelling silage with low nutritional value and limited palatability.

Different species of clostridia have varying effects on fermentation (Table 3). Some species ferment lactic acid and sugars to produce butyric acid, gaseous carbon dioxide, and hydrogen while others can ferment free amino acids to acetic acid and ammonia. These compounds raise silage pH.

Sugar → butyric acid + carbon dioxide + hydrogen gas

Lactic acid → butyric acid + carbon dioxide + hydrogen gas

Amino acids (alanine + glycine) + water → acetic acid + ammonia

A variety of other non-protein nitrogen compounds are created when clostridia break down plant proteins, and some, including putrescine and cadavarine, have especially unpleasant odors. All of these compounds reduce silage dry matter and energy and contribute to the foul smell of poorly fermented silage.

Moisture content greater than 70 to 72 percent and low initial carbohydrate levels set the stage for phase 5 of the fermentation process. Legume crops, such as alfalfa, contain relatively low levels of carbohydrates compared to corn silage and require field wilting to increase the concentration of carbohydrates and reduce moisture content in the forage mass. High water-soluble carbohydrate levels in corn silage generally result in a rapid decline in pH that inhibits growth of clostridia. The best preventative actions to avoid clostridial fermentation are drying forage to at least 30 percent dry matter or

Table 3. Clostridial species often found in silage.

Species ¹	Characteristics
<i>C. tyrobutyricum</i>	
<i>C. sphenoides</i>	Ferment sugars and lactic acid.
<i>C. bifermentans</i>	
<i>C. sporogenes</i>	Ferment amino acids.
<i>C. perfringens</i>	Ferments sugars, lactic acid, and amino acids. May produce toxins that cause enterotoxemia.
<i>C. botulinum</i>	May produce toxins that result in death.

Source: Pitt. 1990. *Silage and Hay Preservation*. NRAES-5.

¹C. indicates *Clostridium*.

using silage additives if forage dry matter is below 30 percent. Also, allowing 21 to 28 days between spreading manure and harvesting silage can help reduce the number of clostridia present on the forage at the time of ensiling.

Characteristics of silage that has undergone clostridial fermentation include pH above 5, high ammonia-nitrogen levels, more butyric acid than lactic acid, and a strong, unpleasant odor. Some clostridia may produce toxins, including those that cause enterotoxemia. Cows fed this silage typically eat less or go off-feed completely, produce less milk, and have increased incidence of metabolic diseases such as ketosis or displaced abomasum.

HARVEST GUIDELINES TO MAXIMIZE FORAGE QUALITY AND MINIMIZE LOSSES

Pre-harvest preparations

Silo maintenance. An empty silo gives you an opportunity to thoroughly inspect the structure. Before each harvest, clean out all old feed and inspect the inside surfaces of each silo. Silage acids can erode concrete or unprotected metal and can cause severe silo deterioration when seepage occurs. Patch any cracks or holes to keep the walls, floor, and roof air- and water-tight. Concrete can be coated with plastic, epoxy, or latex masonry paint to extend its life. Also, clean and open drains to allow silage effluent to move away from silage.

Check the integrity of door seals, ladders, and cages on upright silos, and inspect the unloader bearings, drive machinery, and cables. Lubricate and adjust unloaders according to the manufacturer's recommendations.

This is also a good time to look at the silo's structural integrity, because older silos can be a hazard if they are not maintained properly. Some silos that look fine may actually be ready to collapse. All silos over 10 years old should be checked periodically by a trained professional. A quick inspection may save lives and thousands of dollars in lost feed and damaged property.

Service all equipment. Few things are more frustrating than watching crops mature while waiting for replacement parts. Proper maintenance and planning can help you avoid such delays. Before each harvest, all equipment should be serviced and tested to be sure it functions correctly. Change filters and oil and lubricate all the necessary places, following the manufacturer's recommendations.

Also inspect hydraulic hoses and fittings; replace any that are leaking, stiff, cracked, or have a soft or blistered cover. Replace any worn gears, belts, chains, bushings, and sprockets, and order replacement or spare parts.

Sharpen and replace knives as needed; dull knives and worn parts increase operating costs and harvester power requirements, 40 percent of which are for the cutter head. Properly adjusting the number of knives and the feed roll to cutter head speed ratio improves the quality and accuracy of the cut and avoids tearing forage. Dull knives also tend to tear plant cells, which can increase seepage. Check the cutterbar surface to be sure it is sharpened, not rounded.

Moisture content and maturity

Harvesting silage crops at the right moisture content and stage of maturity is important for at least three reasons: (1) to get the maximum yield of nutrients per acre, (2) to minimize field and storage losses, and (3) to ensure high palatability and maximum intake by animals. In addition, harvesting forages at the correct moisture content can reduce or eliminate seepage.

Corn. Harvest corn silage when whole-plant moisture reaches 55 to 70 percent, depending on the storage structure (Table 4). Moisture content is a more reliable indicator of corn silage quality than maturity. Typical nutrient composition of corn silage at various moisture levels is presented in Table 5.

As the corn plant matures, the grain content increases, but the digestibility of the starch declines. Often, the energy content of mature silages is diminished and the available energy is lower than silage harvested at one-half milk line, even though the fiber content is lower in the more mature silage. More mature silages also will tend to have lower sugar contents and lower fiber digestibility than those harvested near one-half milk line.

Table 4. Recommended moisture content of silage crops by storage structure.

	Alfalfa	Grass	Corn silage	Small grains
Horizontal silo	65–70%	65–70%	65–70%	60–70%
Conventional upright	60–65%	60–65%	63–68%	63–68%
Oxygen-limiting upright	40–55%	40–55%	55–60%	55–60%
Bag	60–70%	60–70%	60–70%	60–70%
Balage	50–60%	50–60%	—	—
Pile or stack	65–70%	65–70%	65–70%	60–70%

Corn maturity is determined by the stage of kernel development, which can be characterized by the position of the kernel milk line (Figure 2). The milk line appears as a whitish line separating the kernel starch and milk. It appears near early dent and moves down the kernel as the grain matures. The milk line stage associated with specific moisture contents will vary among seasons, but generally the crop will approach 70 percent moisture at one-quarter milk line, which is when all the kernels are dented and milk line has descended 25 percent of the way down the face of the kernel. The crop will reach 65 percent moisture sometime around one-half milk line, when the milk line has descended half way down the face of the kernel. Usually when the milk line has descended three-quarters to all the way down the corn kernel and reached the black layer stage, the moisture content is in the 55 to 60 percent range.

The relationship between milk line and whole plant moisture can be used to signal the start of harvest. When the corn reaches one-quarter milk line it is time to start testing whole plant moisture. The moisture content can then be used to estimate the predicted harvest date using a drydown rate of 0.5 to 0.6 percent per day. For example, if corn at one-quarter milk line tests 70 percent moisture, you can estimate the number of days needed for the crop to drydown to 65 percent moisture.

Simply subtract the targeted moisture level from the current level and divide by the average drydown rate. If the moisture content is 70 percent, then 8 to 10 days will be required to reach 65 percent moisture.

$$70 - 65 = 5\% \text{ drydown needed}$$

$$5\% \div 0.5\% \text{ per day} = 10 \text{ days or}$$

$$5 \div 0.6\% \text{ per day} = 8 \text{ days}$$

Be sure to test the actual moisture content again just before harvest.

Perennial hay crops. For hay-crop silage, the crop is field-wilted to achieve the desired moisture levels presented in Table 4. Stage of maturity at the time of harvest is the single most important factor influencing the feeding value of hay-crop silage. This is especially true for the first cutting of both legume and grass forages. As legumes and grasses mature, the proportion of leaves to stems shifts away from leaves toward more stems. As a result, fiber and lignin levels in the whole plant increase, while protein and energy decrease (Figure 3). Digestibility of fiber also declines as the amount of lignin increases. These changes in nutrient content are also shown in

Table 5. Changes in nutrient composition of corn silage with advancing maturity.

	DM	CP	NE _L	NDF	ADF	Lignin
Maturity ¹	%	%	Mcal/lb	%	%	%
Immature	23.5	9.7	0.62	54.1	34.1	3.5
Normal	35.1	8.8	0.66	45.0	28.1	2.6
Mature	44.2	8.5	0.61	44.5	27.5	3.1

Source: *Nutrient Requirements of Dairy Cattle*, 2001.

¹Maturity was categorized by dry matter content (% DM): Immature, <25% DM; Normal, 32–38% DM; Mature, >40% DM.

Figure 2. Kernel milk line position determines corn maturity. The cob cross-section on the left shows one-half milk line. The cob on the right shows a less mature ear.

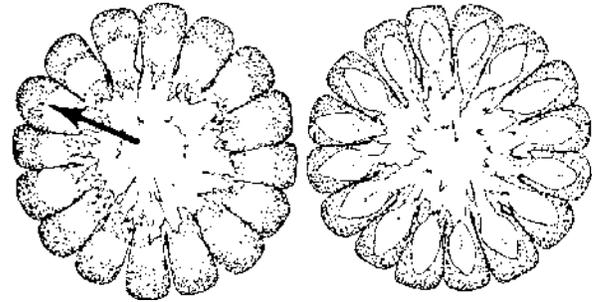


Figure 3. Changes in legumes and grasses with advancing maturity.

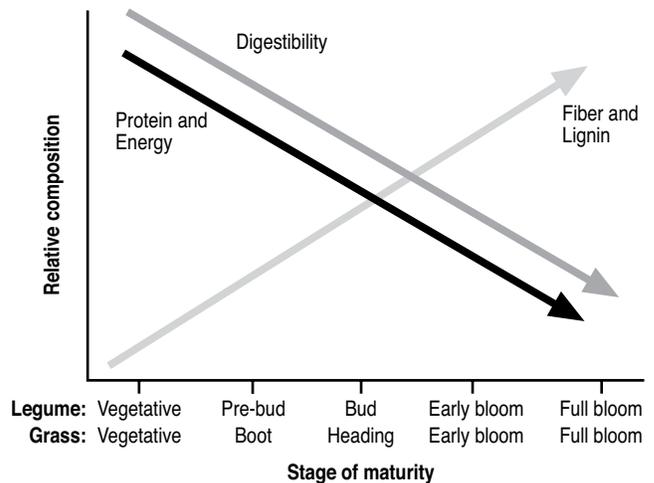


Table 6. For dairy-quality silage, consider harvesting alfalfa in the bud to early bloom stage and grasses in the boot stage. Harvesting at this stage maximizes yield of digestible dry matter (Figure 4).

Table 6. Changes in nutrient composition of legume and grass silage with advancing maturity.

	DM	CP	NE _L	NDF	ADF	Lignin
Maturity ¹	%	%	Mcal/lb	%	%	%
Legumes						
Immature	41.2	23.3	0.61	36.7	30.2	6.2
Mid-Maturity	42.9	21.9	0.55	43.2	35.2	7.3
Mature	42.6	20.3	0.50	50.0	40.9	8.4
Cool-season grasses						
Immature	36.2	16.8	0.59	51.0	32.9	4.8
Mid-Maturity	42.0	16.8	0.53	58.2	35.2	6.8
Mature	38.7	12.7	0.48	66.6	41.1	7.4

Source: *Nutrient Requirements of Dairy Cattle*. 2001.

¹Maturity was categorized by neutral detergent fiber content (% NDF). For legumes: Immature, <40% NDF; Mid-Maturity, 40–60% NDF; Mature, >46% NDF. For cool-season grasses: Immature, <55% NDF; Mid-Maturity, 55–60% NDF; Mature, >60% NDF.

Figure 4. Dry matter yield of legumes and grasses as maturity advances. Dark gray area represents digestible dry matter. Light gray represents indigestible dry matter. Arrows indicate maximum dry matter yields; the white arrow shows digestible dry matter and the black arrow shows total dry matter.

Source: Adapted from *Forages: The Science of Grassland Agriculture*. 1985

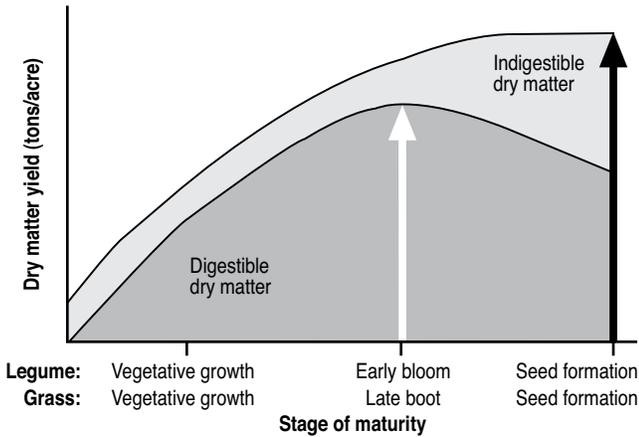
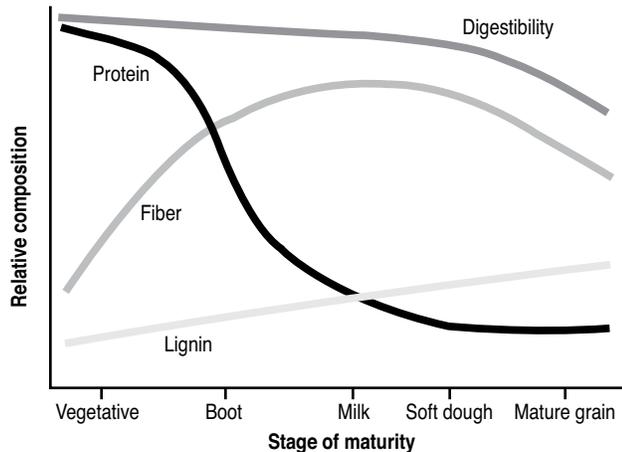


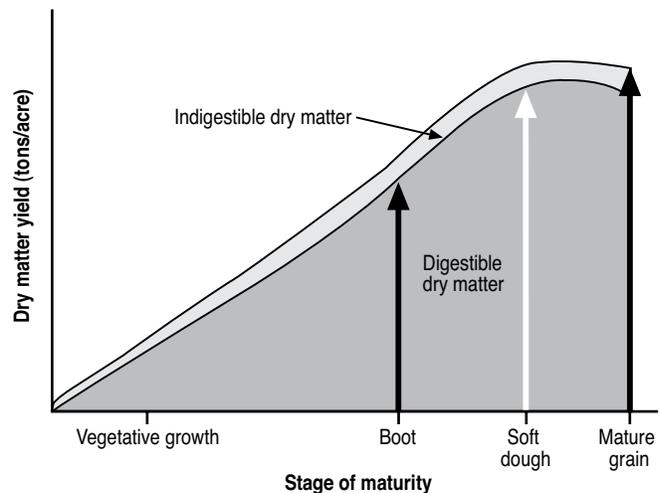
Figure 5. Changes in small grain components with advancing maturity.



Small grains. Since small grain forage in the boot stage often contains more than 85 percent moisture, it must be wilted and conditioned like a legume or legume-grass silage. Generally, small grain silages are cut, wilted to 60 to 70 percent moisture, and then chopped (Table 4). Barley also may be direct-cut once whole plant moisture reaches 70 percent.

As they mature, small grains change from vegetative growth to grain production. This creates unique changes in forage composition, digestibility, and yield (Figure 5). Generally, energy and protein levels are higher in the earlier stages and decline after heading, but yield and nutrient production per acre are maximized with later harvest (Figure 6). For silage production, harvest can occur at the boot stage or the soft dough stage. At the boot stage, forage yield is greater than any previous stage, and the whole plant is very leafy and highly digestible. By the soft dough stage, grain fill is almost complete and total yields of digestible dry matter are greatest. Depending on the grain-to-stem ratio, digestibility at the soft dough stage may be lower than the boot stage. Table 7 clearly demonstrates the changes in barley silage as it matures. Notice that yield is much greater at the soft dough stage, but silage nutrient composition is similar for boot and soft dough. This research also showed no difference in milk production when cows were fed barley harvested at soft dough or at boot stage.

Figure 6. Dry matter yield of small grain forage as maturity advances. Dark gray represents digestible dry matter. Light gray represents indigestible dry matter. Arrows indicate maximum dry matter yields; the first black arrow shows leafy, vegetative dry matter, the white arrow shows digestible dry matter, and the second black arrow shows total dry matter.



Small grain species vary somewhat in their nutritive content for silage at the same stage of growth (Table 8). Cutting rye early in the boot stage is important to maintain forage quality. Harvest of barley, oats, and wheat can be delayed until soft dough stage to increase forage yield.

Annual crops. Forage and grain sorghum should be harvested at 60 to 70 percent moisture, depending on the structure that will be used to store the crop (Table 4; use the same moisture targets as corn silage). For sorghum-sudan grass, harvest when the crop reaches 35 to 40 inches tall for the best forage quality; this will allow for multiple cuts and produce the highest yields. Harvesting sorghum-sudan at this height typically produces thick windrows that dry slowly. Therefore, it is recommended to cut the crop at the low end of this range and during good drying conditions.

Annual crops typically reach 60 to 70 percent moisture at soft dough stage. However, in some seasons, maturity may be delayed and a frost may be necessary to reduce moisture to the desired level. After a killing frost, wait four days before harvesting to avoid the possibility of prussic acid poisoning.

Sudangrass is sometimes grown with soybeans for silage. When ensiling this mixture, harvest when the sudangrass is at early head to early bloom stages. Millets, when grown for silage in Pennsylvania, should be cut between early heading and early bloom.

Typical nutrient composition of annual crops is shown in Table 9. Forage or grain sorghum hybrids are best suited for silage, while sudangrass and sorghum-sudan are better for hay or grazing.

Soybeans for silage. While they are usually grown for grain, soybeans can also be harvested for silage. The ideal time to harvest is at full seed (the R6 stage), when the beans are full-size and the pods and leaves are still green. The crop at this stage often contains 75 to 80 percent moisture and will require some wilting to achieve the desired moisture for ensiling. At later stages, potential for leaf and bean loss increases, and stems become more fibrous and less digestible.

Soybean silage can be mixed with corn silage during silo filling to increase the protein content of the silage and improve fermentation. Although mixing crops limits the ability to vary the use of the individual feeds in the ration for different livestock, this practice is recommended because it is often difficult to obtain uniform feed quality when ensiling soybeans alone.

Table 7. Yield and quality of barley silage harvested at boot or two cutting heights at soft dough stage.

	Boot	Soft dough (6 inches)	Soft dough (10 inches)
Yield (lb DM/acre)	3,295	7,813	5,614
ADF, % DM	31.1	33.9	29.3
NDF, % DM	49.1	52.6	53.8
CP, % DM	16.6	9.1	8.9
Lignin, % DM	5.7	6.9	6.0

Source: Acosta, et al. 1991. *Journal of Dairy Science*. 74:167–176.

Table 8. Typical composition (dry matter basis) of small grain forages fed as silage.

Silage type	DM %	CP %	NE _L Mcal/lb	NDF %	ADF %	Lignin %
Barley ¹	35.5	12.0	0.56	56.3	34.5	5.6
Oats ¹	34.6	12.9	0.52	60.6	38.9	5.5
Rye ²	29.7	16.1	0.58	57.8	34.9	4.5
Triticale ¹	32.0	13.8	0.53	59.7	39.6	5.8
Wheat ³	33.3	12.0	0.53	59.9	37.6	5.8

Source: *Nutrient Requirements of Dairy Cattle*. 2001.

¹Headed.

²Vegetative.

³Early head.

Table 9. Typical composition (dry matter basis) of summer annual forages fed as silage.

Silage type	DM %	CP %	NE _L Mcal/lb	NDF %	ADF %	Lignin %
Sorghum ¹	28.8	9.1	0.50	60.7	38.7	6.5
Soybean ²	40.4	17.4	0.59	46.6	36.9	6.5
Sor-sudan ³	28.8	10.8	0.49	63.3	40.7	5.9
Sudangrass ⁴	30.6	12.3	0.49	61.4	40.3	5.8

Source: *Nutrient Requirements of Dairy Cattle*. 2001.

¹Grain type.

²Early maturity.

³Sorghum-sudangrass hybrid.

⁴Source: Dairy One Forage Lab. *Summary of crop year 2002*.

Soybeans also can be made into round bale silage. Wrap bales three to four times with plastic to avoid stems poking through the plastic wrap. Harvesting for forage is especially well suited to frost damaged soybeans that will not produce quality grain. Harvesting soybeans for silage can also enable earlier seeding of fall crops, such as wheat or rye.

Testing forage moisture content. To meet the guidelines presented in Table 4, it is necessary to test forage samples to determine moisture content prior to harvest. Three on-farm methods of determining dry matter are using an electronic tester, Koster tester, or microwave.

Electronic testers estimate moisture by measuring the electrical conductivity of the forage. These testers can take several readings over a short period of time, but typically they must be calibrated or measurements must be converted. Electronic testers also tend to be more variable and less accurate than the other methods.

Koster testers and microwaves are both used to dry a forage sample. The moisture content is calculated using the change in sample weight before and after drying. The Koster tester has three parts: the drying unit, sample container, and scale. Fresh forage is placed in the sample container and dried for a specific length of time. The dry matter, or moisture content, of the sample is then read from the scale. When using a Koster tester, follow the drying guidelines provided by the manufacturer. Also, the scale that comes with the Koster tester is not particularly accurate. Consider purchasing a small digital scale that is accurate to one-tenth of a gram.

Use of a microwave is recommended for estimating forage moisture levels because the method is simple, inexpensive, and accurate. See Appendix 1 for step-by-step instructions explaining how to use a microwave to determine forage moisture content.

Chop length and particle size

Chop length for silage affects compaction and fermentation in the silo and roughage value and rumen function in the cow. The recommended theoretical length of cut (TLC) is $\frac{3}{8}$ to $\frac{3}{4}$ of an inch for corn silage and $\frac{3}{8}$ to $\frac{1}{2}$ of an inch for alfalfa silage. Chopping too long makes compaction difficult, trapping air in the forage mass and resulting in silage that heats and spoils. Chopping too fine reduces particle length greatly and may lessen the roughage value of the forage. Chopping the crop at the proper length produces forages that can be combined to achieve

Table 10. Recommended forage particle size distributions using the Penn State Particle Separator.

Screen	Pore size (inches)	Particle size (inches)	Corn Silage ²	Haylage
Upper Sieve	0.75	> 0.75	3–8	10–20
Middle Sieve	0.31	0.31–0.75	45–65	45–75
Lower Sieve ¹	0.05	0.07–0.31	30–40	20–30
Bottom Pan		< 0.07	< 5	< 5

¹These pores are square, so the largest opening is the diagonal, which is 0.07 inches. Only particles less than 0.07 inches in length can pass through the lower sieve.

²Recommendations apply to processed and unprocessed corn silage.

the desired particle length in a total mixed ration (TMR).

Chop a small amount of forage and evaluate the actual particle length with a particle separator before harvesting the entire crop. Adjust the TLC as needed to meet the recommendations in Table 10. Keep in mind that harvest time is the only opportunity to make forage particles longer. Once the crop is cut, storage, mixing, and feeding can only reduce particle size.

Corn silage. Three to 8 percent of corn silage particles should be retained on the upper sieve of the separator (Table 10). Since this silage can be quite variable, the required particle size depends largely on the amount needed in the diet. When corn silage is the primary forage, the proportion of particles on the top sieve should be at the upper end of this range. However, large stalk and cob pieces should be avoided because they are easily sorted out of a TMR.

The chop length of corn silage must balance good packing and fermentation with extremely short, pulverized forage. This means 45 to 65 percent of the silage material should remain on the middle sieve and 30 to 40 percent on the lower sieve of the separator. If the last screen is used for corn silage, no more than 5 percent should be recovered in the bottom pan. As corn silage makes up a greater proportion of the ration, more material should remain in the middle two sieves and less in the top sieve and bottom pan.

Haylage. Haylage varies due to the type and use of machinery, sward type and density, and, most of all, the dry matter of the crop harvested. Ten to 20 percent of the crop should be in the upper sieve of the particle separator (Table 10). Particle size recommendations may need to be altered based on silo type.

Forages stored in upright, sealed silos usually fall at the lower end of the range (10 percent). Bunker silos can handle longer material, up to 20 percent on the upper sieve. The middle sieve should contain 45 to 75 percent of the material, and the lower sieve 20 to 30 percent. As with corn silage, no more than 5 percent of the material should remain on the bottom pan.

Measuring the particle length of individual forages is only one part of the solution. Measuring the particle size of a single forage is similar to analyzing it for crude protein. Recommended ranges exist for individual forages, but the real value of the particle size measurement is combining forages to achieve the proper TMR particle size, which is much like combining feeds to achieve the proper protein level.

Oxygen exclusion

Harvest and fill quickly. Plant respiration continues after cutting until all oxygen is excluded from the silo. Therefore, the longer cut forage lies in the field, the greater respiration losses will be. As forage is added to the silo, the weight of the material forces oxygen out of the forage mass. As discussed previously, oxygen trapped in the forage mass will cause excessive heating, which may decrease the digestibility of protein in the forage. In addition, rapid harvest ensures that the majority of forage is at the correct moisture and maturity. If harvest stretches out over an extended period, nutrient and moisture content can change drastically. Heat damage can be minimized by avoiding moisture contents over 70 percent and less than 40 percent.

Achieve adequate density. Silage density depends on several factors, including plant species, crop maturity, moisture content, length of cut, silo type, silo filling method, distribution, and compaction. Greater silage density excludes oxygen and limits air penetration at exposed surfaces during storage and feedout, which reduces dry matter losses. Greater density also increases silo capacity, which reduces storage costs per ton.

Gravity compacts forage naturally in deep silos, particularly in upright silos where density increases dramatically from top to bottom. In vertical silos, bulk density is close to 20 pounds per cubic foot (lb/ft³) at the top and 60 lb/ft³ or more near the base. Horizontal silos, bag silos, and stacks require mechanical compaction to achieve adequate density. In horizontal silos,

the average bulk density ranges from near 60 lb/ft³ for finely chopped, high moisture crops packed with heavy tractors in deeper silos, to 25 lb/ft³ or less for drier and longer-chopped hay crops in more shallow silos with moderate packing. A bulk density of 40 lb/ft³ in horizontal silos is ideal (dry matter density of 14 lb/ft³). Table 11 presents ranges for density and dry matter of alfalfa haylage and corn silage stored in horizontal silos.

Bulk density and the dry matter density of silages are linked closely to forage moisture content. Oxidation, molds, and spoilage increase as the bulk density approaches 30 lb/ft³, and heat damage is probable in forage at 50 percent moisture. Seepage, which greatly reduces water-soluble nutrients, occurs as bulk density approaches that of water (62.4 lb/ft³) and will occur if moisture is greater than 70 to 75 percent.

Seal rapidly and tightly. Exposure to air early in the fermentation process delays the drop in pH and prolongs the time needed to achieve stable silage. Exposure to oxygen any time after normal fermentation is complete allows the growth of yeasts and molds that spoil silage. Even a densely packed silage mass can undergo aerobic spoilage if it is exposed to air. In addition to excluding air, covers prevent rain from entering the silage mass. Rainfall leaches nutrients (water-soluble carbohydrates, protein, and vitamins) from the silo. Conventional upright silos should be covered with weighted plastic and sealed until they are opened for feeding. Oxygen-limiting silos should be sealed shortly after filling. Horizontal silos should be covered with plastic immediately and weighted to prevent air infiltration under the cover. Properly seal the edges and slope the silage mass to drain water away from feed. Silage bags should be sealed as they are filled, and balage should be wrapped or bagged immediately after baling. Check plastic covers every two weeks during storage and immediately patch any holes.

Table 11. Typical relationships between density and dry matter for corn silage and alfalfa haylage stored in horizontal silos.

	Alfalfa haylage (87 silos)		Corn silage (81 silos)	
	Avg. ± SD ¹	Range	Avg. ± SD ¹	Range
Dry matter, %	42 ± 10	24–67	34 ± 5	25–46
Bulk density, lb/ft ³	37 ± 11	13–61	43 ± 8	23–60
Dry density, lb DM/ft ³	14.8 ± 3.8	6.6–27.1	14.5 ± 2.9	7.8–23.6
Particle size, inches	0.46 ± 0.15	0.27–1.23	0.43 ± 0.08	0.28–0.68

Source: Muck and Holmes. 2000. *Applied Engineering in Agriculture*. 16:613–619.
¹Average and standard deviation.

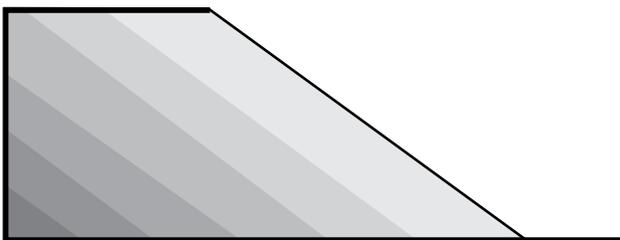
Management practices specific to silo type

Filling and packing horizontal silos. Although some natural compaction occurs in deep horizontal silos, thorough mechanical packing is required to achieve adequate density and limit excess air infiltration. Filling and packing methods greatly affect dry matter density. Fill horizontal silos using a progressive wedge technique (Figure 7), which exposes less surface area than horizontal layers and allows thin layers for better compaction than thick, vertical layers. Using the progressive wedge method, each load of silage is pushed up the silage face to form a slope with 30 to 40 percent grade and leveled into layers about 6 inches deep. These thin layers are crucial to properly pack the silo. Other important aspects of proper packing are the weight of packing tractors and the amount of time devoted to packing. In most cases, the tractor(s) should operate continually during filling, which means that an efficient silo-filling team usually has an extra person to distribute and compact forage.

Wisconsin researchers have developed a spreadsheet that enables users to estimate silage density based on the factors described above. This spreadsheet can be used to locate weak links in the silo filling process and experiment with solutions to increase silage density such as slowing delivery rate, adding packing tractor weight, increasing the time spent packing, changing the thickness of layers, or increasing silage depth. This spreadsheet can be found at www.uwex.edu/ces/crops/uwforage/storage.html.

A wheel-type tractor compacts silage more than a crawler-type tractor, because the wheels concentrate its weight over a smaller area, which applies more pressure to the silage. It may be worthwhile to continue packing about one-half hour after the last load for the day has been put in the silo and to start packing again the next filling day about one-half hour before the first load is added.

Figure 7. In the progressive wedge filling method, thin layers are pushed up the silage face to build a slope of 30–40°.



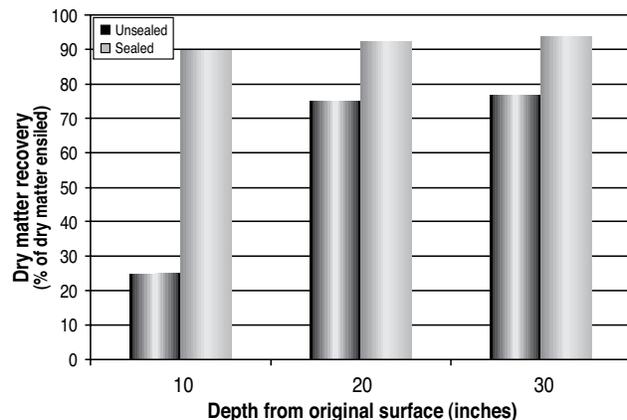
To pack silage safely, keep a respectable distance from unsupported edges, use tractors with a roll over protection system, and wear a seat belt. To reduce the risk of rolling the packing tractor, avoid backing off the silage pile; instead, back onto the pile and drive forward off of it.

To complete silo filling, crown silage one-eighth of the silo width to divert precipitation away from the silage mass and put higher-moisture silage on the top layer to achieve a tighter pack.

Covering horizontal silos. The data in Figure 8 illustrates the importance of covering horizontal silos and shows the results of Kansas research into feed storage losses. Silage stored in small bunker silos for 180 days was evaluated at three depths from the original surface. In covered bunker silos, almost 90 percent of the dry matter was recovered at all three depths (10 percent losses). However, in uncovered silos only 25 percent of the dry matter was recovered in the top 10 inches, which equals 75 percent storage loss at the top of the silo. Dry matter recovery was improved at greater depths, but losses still exceeded 25 percent.

Figure 8. Corn silage dry matter recovered at three depths after 180 days in small bunker silos.

Source: Bolsen. 1997. *Silage: Field to Feedbunk*. NRAES-99.



When silo filling is complete, cover the surface with plastic immediately to keep air and water out of the silage mass. Plastic should be 4 to 6 mil thick and preferably contain ultraviolet blocking compounds. Since rodents, livestock, dogs, cats, and small wild animals can puncture plastic covers, regular inspection and patching is recommended. Mowing around the silo may discourage rodents.

Plastic covers must be weighted to prevent air infiltration under the plastic. All edges also must be secured to avoid billowing or flapping, which can pump air over the entire silage surface and greatly increase spoilage. Typically, used tires are placed close together on the plastic and the edges are weighted with sandbags or soil. The number of tires needed to weight the plastic can be calculated at a rate of 0.25 tires per square foot; place tires so they touch other tires on all sides.

Although full-casing tires commonly have been used to weight silo covers, they have some drawbacks. These tires are heavy and bulky, and they can hold water, which increases their weight and provides a breeding ground for mosquitoes. The use of half tires or sidewall disks can reduce the number of tires needed, limit mosquito breeding grounds, and enable neater stacking when tires are not in use.

The progressive wedge filling method allows silage to be covered with plastic as it is packed, which is highly beneficial if harvest is delayed due to rain.

Although covering silage with plastic and tires requires time and labor, it is the only method that has been shown to consistently reduce silage losses. Many alternative covers have been suggested, including candy, lime, molasses, sod, manure solids, straw, soil, limestone, and sawdust. Commonly, silos are left uncovered, which essentially is using the top layer of silage as a cover.

The cost of various covers can be estimated based on silage value and spoilage losses. Keep in mind that although visible spoilage (black layer) may be limited to 1 to 2 inches, this layer may have been 2 to 4 inches of high-quality forage when the silo was filled. In addition, spoilage research shows that losses are not limited to the top layer of silage. The transition layer between spoiled and unspoiled silage may be 1 to 2 feet deep and may undergo losses of 20 to 30 percent.

Sealing upright silos. In upright silos, use a distributor to create a level, uniform fill, which reduces separation of particles and packs at a higher density. Immediately after filling the silo, manually level the surface and walk over the silage until it is tightly

packed. In concrete silos, cover the silage surface with 4 to 6 mil plastic and weight it with at least 12 inches of wet forage. Oxygen-limiting silos should be sealed according to the manufacturer's recommendations.

Silo gas in uprights. Nitrogen dioxide forms when nitric oxide, released from nitrates in plants, combines with oxygen. The resulting gas is yellow, red, or brown and has a bleach-like odor. This dense gas sinks into low-lying areas such as low spots in the silo, chute, or an attached feed room. Inhaling silo gas can severely damage the nose, throat, and lungs; exposure to silo gas may result in chronic respiratory problems, fluid buildup in the lungs, or, at high levels, instant death. Ensiling ammoniated or drought-stressed forage is particularly dangerous because these crops contain more nitrates. Carbon dioxide build up in the silo also may occur during the respiration phase; inhaling concentrated carbon dioxide can cause asphyxiation.

The highest risk period for silo gas formation is 12 to 60 hours after filling the silo, but gas may be produced up to 3 weeks after filling. If you must enter the silo to level or cover silage, go in immediately after the last load is added. Run the blower for 15 to 20 minutes before entering the silo, and while anyone is working in it, to evacuate gas. Avoid reentering the silo for the next 60 hours.

Working with bag silos. Successful storage of silage in bags depends very heavily on the integrity of the plastic. Bags should be placed on sites with good drainage, preferably on a concrete or asphalt pad. The site must drain away from the open end of the bag, and should be clean and weed-free to minimize rodent populations. Inspect bags for damage every 2 weeks and immediately patch any holes. Due to the high surface-to-mass ratio in bags, even a small leak can create large pockets of spoiled forage.

Another factor that affects the quality of forage in silo bags is forage density, which is largely controlled by the operator of the bagging machine. Be sure to follow the manufacturer's recommendations and ensile forage at the proper moisture content.

Building silage piles. In the past, silage stacks were primarily used for temporary storage. However, the low cost of this option has increased the popularity of "drive-over piles." Managing silage stacks or piles is similar to managing horizontal silos. In fact, piles may be considered "wall-less" bunker silos, which means the two primary concerns are packing and covering the pile (see discussion of horizontal silos).

Drive-over piles are usually wide and low because it is dangerous to run a tractor close to a steep edge. The recommended slope is 3 feet in length for every 1 foot in height, often with a maximum height of 18 to 20 feet (based on the reach of unloading equipment). Choose a site with good drainage, preferably on a concrete or asphalt pad. Build the stack using the progressive wedge technique (Figure 7), and pack by driving over the pile from front to back and side to side. Plan a feeding face to limit the exposed surface, and consider a removal rate higher than that used for traditional bunker silos.

Managing balage. Since balage is made from long, unchopped forage, it is less dense at a given moisture content than silage, which means that the fermentation acids and pH produced in balage are different from other silage. Fermentation is most affected by the moisture content at wrapping, not at baling. Bales should be wrapped at 50 to 60 percent moisture, preferably within 2 hours of baling. Any delay between baling and wrapping increases the exposure to oxygen and the risk of unfavorable fermentation.

In addition, moisture levels in bales change throughout the day; bales made early in the day likely contain more moisture than those made at the end of the day. Keep in mind that crop variation exists within the field, and in balage that variation may be concentrated into individual bales. Finally, the maturity and quality of the crop to be ensiled greatly affect balage quality. Making balage from rained-on forage originally intended for hay will not produce high-quality silage.

Secure bales with plastic twine or net wrap, rather than sisal twine, which contains an oil-based preservative that degrades plastic wrap. Plastic used for wrapping should be a high-quality film with low oxygen permeability and should contain ultraviolet inhibitors and an effective tackiness agent. White plastic is preferred over black because it will reflect, rather than absorb, light and heat. Bales should be wrapped tightly with 6 layers of plastic, stretched 55 to 70 percent and overlapped by 50 percent. Once wrapped, bales can be stored on end and stacked up to three layers high to increase density (very wet bales should not be stacked).

Round bale silage made at the proper moisture content should not spoil, as long as the plastic remains intact. However, the quality of round bale silage is best if fed within a few months, and the risk of damaging the plastic is proportional to the length of time round bale silage is stored. Wrapped bales

should be stored in a well-drained site that is free of stubble and sharp objects. A clean site also reduces the potential for rodent damage to the bags. All bagged bales should be inspected regularly, and any holes in the plastic should be patched.

Changes in dry matter from bale to bale can be extreme, which can make feeding a balanced ration difficult. A survey of 449 Pennsylvania balage samples showed wide variation between bales (Table 12). Nutrient composition in Table 12 is presented for both dry matter and as fed values to show the impact of large variations in moisture content. Daily changes in forage dry matter content and acid profile disrupt the rumen microbial population and depress intake and digestibility. Using balage that has different dry matter and nutrient content in each bale is most problematic when feeding high-producing cows, yet this feed may be sufficient for older heifers or animals requiring maintenance-level nutrition.

To limit inconsistencies in dry matter, nutrient composition, and fermentation of balage, mow, harvest, and wrap strategically. Mow only as much as can be baled and wrapped in a timely manner. Number and date bales and monitor dry matter changes daily during feedout. Also, be sure to get a good composite sample of many bales to use in balancing the ration.

Table 12. Average composition of 449 balage samples from five farms in Pennsylvania.

	Average	Minimum	Maximum
Dry matter, %	46.6	23.2	85.5
Crude protein, % DM	14.6	10.8	21.5
NDF, % DM	58.6	44.1	69.5
NE _L , Mcal/lb DM	0.63	0.52	0.75
Crude protein, % as fed	6.3	2.6	10.5
NDF, % as fed	25.0	13.2	52.2
NE _L , Mcal/lb as fed	0.27	0.12	0.49

Source: Place and Heinrichs. 1997. *Silage: Field to Feedbunk*. NRAES-99.

Harvest concerns specific to crop type

Corn. Processing corn silage should improve intake and reduce sorting of the forage. Processing also improves packing ability while allowing a longer TLC. Research trials have reported increased starch digestibility, especially in dry silage, which can lead to better nutrient utilization and milk production from processed silage. In average maturity or immature silages, no improvement in crop digestibility should be expected.

Processed corn should be harvested at 65 percent moisture, the same as unprocessed corn, but the TLC can be increased to $\frac{3}{4}$ of an inch. Roller clearance should be set at 1 to 3 millimeters, following manufacturer's recommendations. It is important to check the effectiveness of the processor; proper adjustment should crush or crack 90 to 95 percent of kernels and leave cob pieces no bigger than $\frac{1}{8}$ of an inch.

Brown mid rib (BMR) corn can be cut quite long (a TLC of 1 to 1.5 inch) if it will be processed. BMR corn should be processed with roller clearance set at 5 to 8 millimeters. Monitor the processing effectiveness; for BMR corn, all cobs should be broken into quarters. Processing is not recommended for BMR corn cut at a TLC less than $\frac{3}{4}$ of an inch.

Particle size of the final crop must be within the ranges presented in Table 10, regardless of whether silage is processed.

Normal cutting height for corn silage is 4 to 6 inches, but some studies have experimented with high cutting at 10 to 20 inches. This practice reduces fiber, especially lignin, and increases starch and energy of the forage. However, silage yields are reduced five to ten percent. For producers who desire a higher energy, drier silage (or earlier harvest), higher chopping height may be an option if excess forage dry matter is available. However, this practice will increase the cost per acre of the final product. To balance this trade-off between quality and yield, the decision should be based on milk per ton or milk per acre of forage. Higher cutting heights may reduce silage nitrate levels.

Perennial hay crops. Cut hay crops in late morning to maximize drying time. Although plants accumulate more sugar later in the day, cutting at this time is not recommended because the extra sugar is wasted as respiration continues overnight. The recommended cutting height for a healthy alfalfa stand is about 1 inch, which should be determined by yield and stand life. Higher cutting heights (3 to 4 inches)

improve the crop's nutritive value, but reduce yield. The final cutting of the season should be at 4 inches to help the stand survive winter conditions.

Grasses extract soil potassium more efficiently than alfalfa when grown on land with similar potassium levels and harvested at similar maturity. Potassium declines as forage matures, so more mature crops can be harvested to provide low-potassium forage for dry cows. Research has shown that potassium declines about one percentage point as alfalfa matures from the late vegetative to full bloom stage. For grasses, the change is about one-half of the levels found in immature forage. Leaching, caused by rain falling on mown grass, significantly reduces potassium levels, as well as many other nutrients.

Harvest concerns related to weather

Cool, wet growing season. Wet weather tends to increase fiber levels and decrease protein content in alfalfa. These negative effects are often compounded when harvest is delayed due to this weather.

Corn silage typically is planted late during cool, wet seasons, and often is harvested immature, which results in low grain production, increased fiber, slightly lower energy content, and slightly higher protein levels. In very immature corn, fiber digestibility is reduced, but in most cases, slight immaturity improves fiber digestibility. Instead of being transferred to the grain, plant carbohydrates remain in the leaves and stalk, which increases their availability. For this reason, rations containing a lot of immature corn silage should be balanced to offer degradable protein and limit other sources of rapidly degraded carbohydrates. In extremely wet seasons, flooding increases the number of yeasts, molds, and aerobic bacteria in the crop.

Frost. Corn planted for silage can become frost-damaged whether it is immature or mature. Frosted immature plants appear drier than unaffected corn of the same moisture content. Even though leaves may brown off along the edges and dry rapidly after a few sunny days, the green stalk and ears do not. The crop will continue to accumulate dry matter and should be left in the field until it reaches the appropriate moisture content. Plants that are killed and still immature will likely contain too much moisture for immediate ensiling. These plants will dry slowly and dry matter losses will increase as the dead plants drop their leaves. The best option is to leave the crop in the field to dry to an acceptable level, unless dry matter losses appear too high or if

harvesting losses will increase dramatically. Immature corn typically has low yields and test weight (pounds of grain per bushel) due to low starch fill in the grain. Energy levels typically are within 10 to 20 percent of normal values. However, immature kernels are more digestible and plant sugars remain in the stover and leaves, increasing stover digestibility.

When frost kills a plant at full maturity, the whole-plant moisture content falls rapidly. The corn should be ensiled before the moisture drops below 60 percent. Sorghum should be harvested four days after a killing frost to avoid prussic acid poisoning.

Drought. Drought-stressed corn may have few, if any, ears (decreased yield), and usually will have an energy value 85 to 100 percent of normal corn silage. Drought-damaged corn silage typically has higher protein content than normal silage. However, most of this protein is found in the plant rather than in the grain, making it more degradable in the rumen. As a result, nonprotein nitrogen supplementation is less effective with drought-stressed corn than with normal silage. It is important to supplement drought-stressed corn with a natural protein source for heifers up 700 pounds and high-producing dairy cows in early to mid-lactation.

The dry matter content of drought-stressed silage must be in the normal range to allow adequate packing and oxygen removal. If the corn did not set ears and is green, or if the ears are brown and the stalk is green, the moisture content often will be too high. On the other hand, hot, dry weather can rapidly decrease crop moisture content. Carefully observe changes in moisture content to determine when to harvest.

Drought reduces alfalfa yield, but tends to increase quality because the lack of moisture stunts stem growth, resulting in leafier plants with finer stems. Drought-stressed alfalfa often contains less, but more digestible, fiber and more protein because there are more leaves relative to stems.

Drought or frost can create another problem in sorghum and sudangrass. Following severe stress, these forages resume growing, and the young regrowth contains high concentrations of hydrogen cyanide, commonly called prussic acid. Risk of prussic acid poisoning may be reduced if sorghum-sudangrass is at least 30 inches high before harvesting and Piper sudangrass is at least 18 inches high. If sorghum forage is stunted by frost, delay harvest until 4 days after a killing frost or ensile the material. Ensiling generally reduces the risk of prussic acid poisoning after about 4 weeks. The same precautions

discussed below to reduce nitrate toxicity can be followed for prussic acid poisoning.

Nitrate toxicity. Although nitrate levels in drought-stricken forages (corn, small grains, and sorghum) may be high, ensiling will change more than half of the nitrates into ammonia, which can be utilized by rumen bacteria. For this reason, nitrate toxicity rarely occurs when feeding ensiled, drought-stressed forage. Although high levels of nitrates can be accumulated during extreme drought or when high levels of nitrogen are applied to the soil, the concentrations typically found in silage can be managed.

To reduce nitrate levels in drought-stressed plants, harvest crops in the afternoon on a warm, sunny day; be sure to wait 3 to 5 days after an appreciable rain or long cloudy spell. Since nitrates often accumulate in stalks, the crop may be cut somewhat higher above the ground than usual; for corn, leave 10 to 12 inches in the field. In addition, harvest as close to normal maturity as possible.

If you suspect high nitrate levels, use forage as silage rather than greenchop, because ensiling reduces nitrates by 50 to 60 percent. Wait 3 to 4 weeks before feeding to allow fermentation to complete. Test any silage with potentially high nitrate levels, preferably before feeding it to animals.

The most critical factor influencing possible toxicity is rate of nitrogen intake, which is affected by forage dry matter intake over a given period and the nitrate content of the forage. Therefore, feeding practices that regulate dry matter intake can be used to manage high nitrate forages.

Forages containing less than 1,000 parts per million (ppm) nitrate nitrogen ($\text{NO}_3\text{-N}$) on a dry matter basis may be fed free-choice, with no restriction on meal size, provided total intake of $\text{NO}_3\text{-N}$, including that from water, is kept at a safe or low-risk level. When stored forages contain more than 1,000 ppm $\text{NO}_3\text{-N}$, intake generally must be managed to avoid elevated methemoglobin levels in the blood and other toxic effects (Table 13).

Table 13. Guidelines for feeding forages with high nitrate levels to dairy cattle.

Nitrate ion (NO ₃) (% DM)	Nitrate nitrogen (NO ₃ -N) (ppm)	Recommendations
< 0.44	< 1,000	Safe to feed under most conditions.
0.45–0.75 ¹	1,000–1,700 ¹	Gradually introduce to ration. Feed some concentrate. Test all feeds and water. Dilute to 0.40% NO ₃ or 900 ppm NO ₃ -N in total ration dry matter. Restrict single meal size.
0.76–1.00	1,700–2,300	Possible acute toxicity. Feed in a balanced ration with concentrate included. Dilute to 0.40% NO ₃ or 900 ppm NO ₃ -N in total ration dry matter. Restrict single meal size.

Source: Adams, et al. 1992. *Prevention and Control of Nitrate Toxicity in Cattle*. Penn State Extension Fact Sheet.

¹If one forage contains over 0.44% NO₃ or 1,000 ppm NO₃-N, test all forages, water, and possibly concentrates. Include nitrate intake from all sources in total dietary intake.

Table 14. Maximum single meal dry matter intake of forages containing various levels of nitrate-nitrogen (NO₃-N).¹

Forage NO ₃ -N (ppm)	Single meal forage DMI ² (lb/100 lb BW)
1,100	1.15
1,700	0.67
2,300	0.41
2,800	0.31
3,400	0.24

Source: Adams, et al. 1992. *Prevention and Control of Nitrate Toxicity in Cattle*. Penn State Extension Fact Sheet.

¹Table values were designed to limit blood methemoglobin at 3% or lower.

²A single meal refers to the amount of forage dry matter consumed during one episode of eating.

Feeding strategies for high-nitrate forage include:

- Gradually introduce high-nitrate forage into the ration over 1 to 2 weeks.
- Feed forages and total mixed rations more frequently to reduce meal size.
- Limit intake per single meal (Table 14).
- Allow a delay of 2 to 3 hours after completion of a meal before feeding again.
- Adjust feeding sequence to provide low-nitrate forage first.
- Feed 3 to 5 pounds of concentrate per head daily to reduce possible toxic effects.
- Consider blending high-nitrate forage with forages containing lower amounts before feeding to provide less than 1,000 ppm NO₃-N in the total dry matter and enable free-choice feeding.
- Restrict the NO₃-N content of the total ration dry matter, including contributions from water, to 400 to 900 ppm.

Due to large variations in forage nitrate levels, it is important to retest forage periodically. In addition, if one stored forage contains over 1,000 ppm NO₃-N, all forage and water sources should be tested to determine total NO₃-N intake.

Finally, when feeding high-nitrate forages, observe animals closely for symptoms of toxicity, which can be seen within 2 hours after cows begin eating. The earliest sign of possible toxicity is discoloration of mucous membranes in the vagina, mouth, or eyes. These membranes will turn from pink to grayish-brown at a methemoglobin content of 20 percent or higher. Acute symptoms include rapid breathing, incoordination or staggering, and signs of suffocation.

Mold and mycotoxins. Molds can grow on forages or concentrates at any point in the crop production cycle if conditions are right. For mold growth to occur, spores and substrate must be present and the environmental conditions must be favorable. Mold prefers moisture levels greater than 12 percent, temperatures above 23°F, at least 0.5 percent oxygen, and moderate pH. Ensiled forage usually meets those temperature and moisture requirements; therefore, eliminating oxygen is the key to restricting mold growth in silage.

Conditions that encourage mold growth increase the risk of mycotoxin problems; these include wet weather during corn silking, insect damage to silks,

and harvest following frost (forage is drier and harder to pack).

As mold grows, forage nutrients are depleted and converted into carbon dioxide and fungal metabolites. Many common spoilage molds do not produce mycotoxins. However, some molds produce mycotoxins to gain a competitive advantage relative to other fungi or to increase their virulence as a plant pathogen by decreasing the plants' ability to resist infection. The presence of visible mold does not mean mycotoxins are present, and mycotoxins may exist when mold is not visible. Furthermore, the color of mold does not distinguish toxic silage from nontoxic.

Proper agronomic practices and fermentation in the silo can prevent mycotoxin production. The primary control method is to reduce fungal infections in crops. Balance soil fertility to reduce the risk of stalk rot, and select crop varieties that are resistant to fungal infections of the leaves, ears, and stalk. Rotating crops to reduce the risk of carryover from one year to the next also helps limit infections. Once the crop is harvested, eliminate oxygen quickly and completely. Match silo sizes to feeding rates that keep the silage surface fresh, feed silage immediately after removing it from storage, and clean uneaten feed out of bunks each day. Silage additives do not affect mycotoxins, but using additives that reduce mold growth should limit the risk of increasing mycotoxin production after harvest. Finally, discard all spoiled or moldy feeds.

Poor weight gain, reproductive problems, reduced feed intake, lowered milk production, and suppression of the immune system are common symptoms exhibited by cattle eating feed contaminated by mycotoxins. Unfortunately, these symptoms could be caused by a variety of problems other than mycotoxins, which makes them difficult to diagnose or treat. Mycotoxin poisoning is less of a concern in dairy cattle than in monogastric animals, because toxins are partially degraded in the rumen. The amount of mycotoxin consumed, the specific toxins present, and each animal's level of tolerance influence the severity of toxic effects. Field observations have shown toxic effects greater than controlled lab research with pure toxins, which is most likely due to real-world interactions between multiple toxins and other stressors (production, nutrient deficiencies, disease, or environment). Dairy animals that are most at risk from mycotoxins are young calves up to several months of age, close-up cows, and early lactation cows. Common mycotoxins that affect dairy cattle are listed in Table 15.

If you suspect mycotoxin poisoning, test all feed ingredients, including concentrates. When testing forages for mycotoxin levels, be sure to sample feed from several locations in the silo—pockets of spoilage create large variation throughout the silo. Adding a binder ingredient (adsorbent) to the ration to inactivate the mycotoxins can also allow continued use of contaminated feeds. In some research trials, clay products, such as calcium or sodium bentonite, and zeolites have been shown to prevent mycotoxins in feed from being absorbed into the body, to a limited extent. Other ration ingredients with some research trial support, which may be used to minimize the effects of mycotoxins, include charcoal, fiber, aluminosilicates, and yeast cell components (mannanoligosaccharide). Research has shown variable effects and a degree of specificity that is not completely understood. Some products appear to have an effect on some toxins and not others, yet these effects are not consistent between studies.

Adsorbent products are not approved by FDA and cannot be marketed for purposes of mycotoxin binding, because these products have very mixed results in field testing (positive and no effects). Consult your dairy nutritionist when you suspect problems related to mycotoxins. Your nutritionist can guide you in testing forages and feeds for such compounds and in alleviating the problem using solutions that appear to provide the best results in your particular area. They are your best resource because they are aware of the problems and solutions that are available in a given year and location.

Table 15. Mycotoxins of concern in dairy production.

<i>Mold species</i>		
Mycotoxin	Effects	Levels¹
<i>Aspergillus</i>		
Aflatoxin	Reduces milk production Abortion, reproductive failure, small calves Increases morbidity Diarrhea, hemorrhage Hair loss Fatty liver, liver cell death Low vitamin A levels Human carcinogen	Milk residues regulated by FDA: < 0.5 ppb Safe level in rations: 30 ppb (25–50 ppb) Toxic level: 300–700 ppb When combined with other stressors or over a long period, exposure to 100 ppb can be toxic
<i>Fusarium</i>		
Deoxynivalenol (DON, vomitoxin)	Reduces milk production and feed intake Marker for other, more toxic mycotoxins	Indicator level: 300–500 ppb (DON not toxic, but may indicate that other substances are present)
Zearalenone (F-2)	Estrogenic response produces abortions, reproductive failure, reproductive tract infections, poor conception, and mammary gland enlargement in heifers Reduces feed intake and milk production May be a marker for other toxins	Toxic level: 200–300 ppb (data limited, based on field observations)
T-2 toxin	Reduces feed intake and milk production Infections of GI tract, intestinal hemorrhage Death	Warning level: 100 ppb (data insufficient to define toxic level)
Fumonisin (B-1)	Carcinogenic	Less toxic than others for dairy cattle
<i>Penicillium</i>		
Ochratoxin	Kidney damage	Rapidly degraded in rumen, more of a problem for preruminant calves

Source: Whitlow and Hagler. 1997. *Silage: Field to Feedbunk*. NRAES-99.

¹Safe levels were set conservatively low due to non-uniform distribution, difficulty in testing, potential for interactions, and dose-related effects; ppb=parts per billion.

SILAGE ADDITIVES

Silage additives encourage desirable fermentation, limit undesirable fermentation, or improve the nutritional quality of silage. Considerable research has been conducted on the use of silage additives; however, due to the dynamic nature of silage fermentation, the results have been variable. The actual chemical and physical characteristics of the plant material at harvest determine the outcome of using silage additives.

For an additive to be worthwhile, it must decrease dry matter loss during fermentation and storage, improve the nutritional value of silage to the animal, or enhance stability of the silage in storage or in the feed bunk. Additives must be carefully evaluated, and producers should request peer-reviewed research as proof of performance claims. Considering both cost and effectiveness will lead to better results than either of these factors alone.

Fermentation stimulants

Microbial inoculants. Microbial inoculants are dried, live, but inactive, organisms that become active when they are re-hydrated. Often, the organisms in silage additive products have been selected for their ability to dominate fermentation.

The most common microbial inoculants are lactic acid bacteria—*Lactobacillus*, *Pediococcus*, and *Enterococcus* species. Theoretically, these bacteria enhance the production of lactic acid, which helps to quickly lower silage pH and results in more efficient fermentation. The increased acidity also helps to limit the growth of undesirable organisms as silage ferments. In addition, organisms selected for microbial inoculation typically produce only lactic acid (homolactic or homofermentative bacteria).

Using homolactic bacteria should result in less dry matter loss than fermentation by naturally occurring bacteria that produce a combination of lactic acid, acetic acid, ethanol, mannitol, and carbon

dioxide. Compared to untreated silage, inoculated silage should contain less acetic acid, butyric acid, and ammonia-nitrogen. It also should have higher lactic acid levels and a lower pH.

Microbial inoculants are most effective when the population of naturally occurring bacteria is less than 10,000 organisms per gram of fresh forage. High levels of naturally occurring bacteria in silage make it difficult for inoculated bacteria to gain a competitive edge. Corn silage tends to have large populations of naturally occurring bacteria, which explains why inoculants are less successful with corn than hay crops. Harvest conditions such as low air temperature and short wilting time can limit natural bacterial populations on the plant.

Another factor in the success of microbial inoculants is plant sugar content. Since sugars are the primary food for lactic acid bacteria, low sugar levels can limit bacterial activity and reduce the effectiveness of the inoculant. For most crops, sugar content is not a concern if the forage is ensiled at the proper moisture level. However, proper fermentation of legume silage is more difficult due to its low sugar content and high buffering capacity. Extended wilting time and rain damage reduce plant sugar content.

In addition, the strains of organisms used in inoculant products tend to be highly specific based on crop type. Select a product labeled specifically for the crop to be ensiled, or a closely related crop. For small grains, use a corn silage or grass product. For soybeans or peas (legumes), use an alfalfa product.

A review of research trials published from 1990 to 1995, found that alfalfa, grasses, and clover inoculated with lactic acid bacteria had lower silage pH than untreated silage in about 60 percent of the trials. Silage pH was reduced in 44 percent of the trials using small grains and in 31 percent of trials with corn silage. Dry matter losses were reduced in about 50 percent of all trials. A companion review of the effects of microbial inoculation on animal performance found that milk production improved in 47 percent of the trials, but dry matter intake increased in only 28 percent. Not all lactic acid bacteria inoculants are created equally; the number, strain, and viability of organisms vary considerably between products.

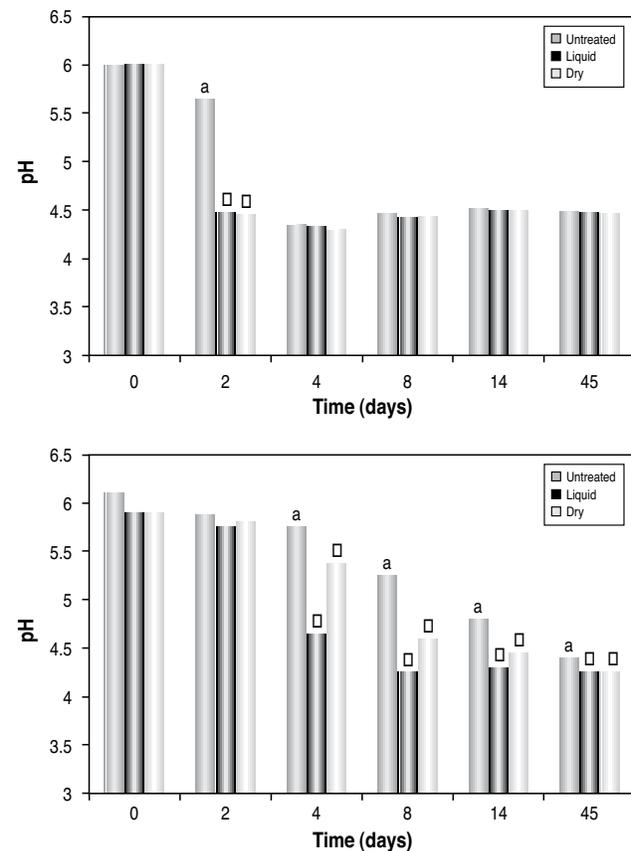
Silage is often inoculated at a rate of 100,000 (or 1×10^5) colony forming units (cfu) per gram of wet forage. This rate will provide enough organisms to dominate fermentation; application of greater amounts is probably not cost effective.

Microbial inoculants are available in both dry and liquid forms. When silage moisture content is

about 70 percent, the two forms are equally effective (Figure 9). However, drier silage may benefit from liquid application. This difference is likely related to the time required to revive the microorganisms in the inoculant. Liquid application revives microbes before they reach the forage, minimizing the lag time before they become active and maximizing their fermentation time. Dry application relies on moisture in the forage to revive the organisms and may slow the initial rate of fermentation. Liquid products are also easier to apply uniformly. Products must be applied according to the manufacturer's recommendations; those intended for dry application should not be mixed with water. Chlorinated water may reduce the effectiveness of microbial inoculation, particularly when chlorine levels exceed 1.5 parts per million.

Figure 9. The effect of inoculating alfalfa silage with *Lactobacillus plantarum* MTD1 in liquid or dry form on pH. Top graph shows results with alfalfa harvested at 70% moisture; bottom graph shows 46% moisture. Bars within a day with different superscripts are statistically different ($P < 0.05$).

Source: Whiter and Kung. 2001. *Journal of Dairy Science*. 84:2195–2202.



The site of inoculant application also affects the fermentation potential of organisms. Organisms in inoculant products cannot move around freely; they will work at the site they are applied, but will not disperse throughout the silage. For this reason, inoculants applied at the chopper tend to be more evenly distributed than those applied in a wagon or directly in the silo. In addition, application at the chopper maximizes contact between bacteria and fermentable substrates in the forage. When storing silage in upright silos or bags, inoculation at the blower or bagger is also acceptable. However, if the time between chopping and ensiling exceeds 2 to 3 hours, inoculants should be added at the chopper. Addition of inoculants should be monitored by flow meters or pressure regulators to ensure the correct application rate.

Proper storage of microbial inoculants is essential to maintain their effectiveness. Follow the manufacturer's recommendations for refrigeration or freezing. All inoculants should be stored in cool, dry areas out of direct sunlight. Opened bags should be used as quickly as possible and within one season. Liquid products that must be mixed on the farm should be used within 24 to 48 hours, before bacterial populations decline.

When selecting a microbial inoculant product, look for one or more of these lactic acid bacteria: *Lactobacillus plantarum* (or other *Lactobacillus* species), *Pediococcus* species, or *Enterococcus* (*Streptococcus*) species. *Propionibacterium* species are not recommended. Although these bacteria do produce propionic acid and may improve bunk life, they do not survive in highly acidic silage.

One recently developed type of microbial inoculant operates quite differently than the more conventional homolactic products. This new formulation contains certain strains of *Lactobacillus buchneri* bacteria that convert lactic acid to acetic acid and have been shown to increase the aerobic stability of alfalfa, corn, barley, ryegrass, and wheat silages. In research trials, *L. buchneri* has increased bunk life and milk production. Since this bacteria increases production of acetic acid, expect lower feed energy values and slightly higher acetic acid values in fermentation analysis. The higher acetic acid levels have not depressed feed intake in current published research. If your silage typically has good bunk stability, *L. buchneri* may actually reduce bunk life due to the production of acetic acid.

Enzymes. Enzymes that digest complex plant carbohydrates (cellulase, hemicellulase, xylanase, amy-

lase, or pectinase) may also be added to stimulate fermentation. Single enzymes or enzyme complexes are typically combined with microbial inoculants to formulate a silage additive. Enzymes digest fiber to provide soluble sugars that lactic acid bacteria can utilize.

The goal of adding enzymes is to accelerate the rate and extent of the initial pH decline, which should increase lactic acid production, improve the lactic acid to acetic acid ratio, and reduce dry matter losses. In addition, fiber-digesting enzymes can partially consume cell walls to improve silage digestibility. Generally, these enzymes are effective on grass and alfalfa at about 60 to 70 percent moisture and are most effective for immature grass.

Research results indicate that enzyme additives stimulate acid production, lower pH, and reduce ammonia-nitrogen levels, but their effects on digestibility are often negative. These enzymes may digest readily available fiber but avoid highly indigestible fiber, which actually decreases forage digestibility. Overall, enzyme additives are less effective than microbial inoculants in stimulating fermentation. Enzyme additives are not recommended for corn due to its high sugar content—the sugar is converted to alcohol, which increases silage dry matter losses.

There is some interest in applying fiber-digesting enzymes to forages or whole diets immediately prior to feeding. Research results have been variable, although spraying a liquid enzyme solution on feed has been more effective than topdressing a dry, granular product.

Fermentable substrates. Adding molasses may provide a readily fermentable carbohydrate that promotes lactic acid fermentation. When applied at 40 to 80 pounds per ton of fresh forage, molasses reduces silage pH, discourages clostridial fermentation and proteolysis, and decreases organic matter losses. It is most beneficial in forages that contain fewer fermentable carbohydrates, such as alfalfa. A review of molasses research concluded that it improved silage preservation and dry matter intake, but did not alter forage digestibility or animal performance. In addition, molasses is difficult to distribute evenly and results in a large amount of residual sugars, which could decrease aerobic stability by providing substrate for yeast and mold growth.

Water. Adding water to dry forage can help to stimulate fermentation, but the quantity needed is very high and often impractical. For example, reducing the dry matter content of 1 ton of forage from 50 percent to 44 percent requires 300 pounds of water.

Further reduction, from 44 to 40 percent, requires another 495 pounds. In addition, water is often not absorbed into the plant material and runs off, taking valuable water-soluble nutrients with it. Adding a liquid inoculant to enhance the population of lactic acid bacteria is a better option for dry forages.

Fermentation inhibitors

Preservative products can inhibit undesirable fermentation. These products usually contain a combination of acids, including benzoic, sorbic, acetic, or citric acids, but propionic acid typically is the primary ingredient due to its excellent ability to inhibit the growth of yeast and molds. This inhibitory activity increases as pH declines, making propionic acid an ideal preservative for very acidic silages.

Due to the corrosive nature of propionic acid, it is often sold in buffered form, as a propionic salt. However, the effectiveness of this product is related strongly to its water solubility; greater solubility better inhibits yeast and mold growth. Typical water solubility values for the common salts are: ammonium propionate, 90 percent; sodium propionate, 25 percent, and calcium propionate, 5 percent.

The proper application rate for propionic acid depends on silage moisture content, storage period, and product formulation with other preservatives. Limited studies indicate that the use of organic acids, such as propionic or acetic-propionic mixtures, may reduce silage quality problems and storage losses when they are added at the rate of 10 to 20 pounds per ton of wilted forage. However, propionic acid is expensive and its effect on silage fermentation is inconsistent. Use of this acid at high rates to affect silage fermentation is not recommended.

Instead, apply propionic acid at 2 to 4 pounds per ton of fresh forage. At this level, propionic acid does not affect fermentation; however, it may improve bunk life by limiting mold and yeast growth. Propionic acid may be added to silage at the feed bunk, but application at ensiling is more effective at extending bunk life.

Propionic acid can be applied to forage at the chopper or the blower. Rates of application should be monitored by flow meters or pressure regulators to add the product according to the dry matter content of the silage.

Nutrient additives

Non-protein nitrogen (NPN) additives may be used to increase the crude protein content of corn silage. Examples of NPN additives are provided in Table 16. NPN should be added at a rate that can increase crude protein from about 8.5 to 13 percent on a dry matter basis. Adding higher levels of NPN may interfere with normal fermentation, raise pH, and adversely affect intake or performance. Additives containing NPN should be used only on corn silage with 63 to 68 percent moisture; do not add anhydrous ammonia to silage with high dry matter (40 to 42 percent) because fermentation is already restricted by the lack of moisture. Water or molasses mixed with ammonia could be used for dry forage. NPN produces the best results in corn silage or small grains; it is not recommended for alfalfa or grasses due to their high levels of degradable protein and low sugar content.

Table 16. Commonly used non-protein nitrogen additives for corn silage.

	N (%)	Urea equivalent ¹ (lb)
Anhydrous ammonia	82	0.55
Aqueous ammonia	21	2.14
Urea, 42% N	42	1.07
Urea, 45% N	45	1.00
Urea, 46% N	46	0.98
Urea, 47% N	47	0.96

¹The amount of each source given will provide non-protein nitrogen (NPN) equivalent to 1 pound of 45% N urea.

NPN compounds or additives should be added to provide 0.15 pound of actual nitrogen (N) for each percentage of silage dry matter content. The application rate per ton is computed in two steps. First, calculate the amount of N needed per ton by multiplying 0.15 by the silage dry matter content as a whole number. Then calculate the amount of NPN needed per ton by dividing the number from the first step by the N content of the additive (% N in decimal form). For example, if corn silage is ensiled at 30 percent dry matter and the urea additive contains 45 percent N, the application rate should be 10 pounds of urea per ton of silage, which is computed below:

$$\begin{aligned} \text{Step 1: Nitrogen needed per ton} \\ &= 0.15 \times 30 = 4.5 \text{ lb N/ton} \end{aligned}$$

$$\begin{aligned} \text{Step 2: Urea needed per ton} \\ &= 4.5 \text{ lb N/ton} \div 0.45 = 10 \text{ lb urea/ton} \end{aligned}$$

When the nitrogen content of an NPN ingredient or commercial additive is not listed, it can be computed from the crude protein guarantee by dividing this value by 6.25. Thus, the nitrogen content of an additive containing 85 percent crude protein is 13.6 percent ($85 \div 6.25$). Protein analysis of corn silage treated with NPN should be conducted on fresh silage samples for accurate determinations, because oven drying drives off the ammonia.

Ammonia treatment of corn silage is an effective and economical means of preserving corn silage while supplementing its crude protein value. Anhydrous ammonia is often the most economical source of ammonia or NPN. Adding ammonia to corn silage has the following beneficial effects:

1. Raises the crude protein level of corn silage on a dry matter basis from 8 to 9 percent to 13 to 14 percent, depending on the rate of application. Anhydrous ammonia applied at 6 to 7 pounds of N per 700 tons of forage dry matter typically increases crude protein from 8 to 12.5 percent (dry matter basis).
2. Reduces silage dry matter losses from 4 to 6 percent and reduces energy losses from 6 to 10 percent compared to untreated silage.
3. Protects the corn plant from degradation during the ensiling process. In untreated corn silage, roughly half of the protein is degraded to NPN compounds during fermentation. Ammonia can decrease this protein degradation by 20 to 40 percent.
4. Increases lactic acid content of treated silage 20 to 30 percent over untreated silage. During the ensiling process, sugars that are more soluble are converted to lactic acid. In this case, the ammonia acts as a buffer and allows more of the acids to build up in the silage.
5. Increases bunk life of treated silage, because the ammonia inhibits mold and yeast growth and heating of silage after it has been exposed to the air. Ammonia also is not corrosive to most metal equipment.

Certain guidelines must be followed when feeding ammonia-treated corn silage to dairy cows. The first is to check the moisture level of the silage; apply ammonia only to corn silage in the 63 to 68 percent moisture range and adjust the application rate to the actual dry matter percentage of the silage. Apply 7 pounds per ton on a 35 percent dry matter basis. To assure uniform application of the ammonia, check the silage protein level periodically.

Recommended application sites for ammonia are at the blower for uprights, at the bagger for bag silos, and at the chopper for horizontal silos. Application rates should be regulated, most commonly with a cold-flow applicator that super-cools ammonia gas, converting 80 to 85 percent of the gas to liquid form. Adding ammonia does not affect nitrate levels in drought-stressed forage.

When using ammonia-treated silages, feed only grains containing natural protein sources. Dry cows and heifers (more than 4 months of age) can also utilize ammonia-treated corn silage.

Handle anhydrous ammonia safely. Goggles and rubber gloves are needed to provide eye and skin protection when connecting ammonia hoses and fittings. A water supply should be readily available for immediate first aid treatment in case of ammonia burns. Noticeable ammonia odors occur with atmospheric concentration as low as five parts per million, which is well below the toxic level but often serves as a safety warning. Storing ammoniated silage in zinc-coated steel silos is not recommended because ammonia is highly corrosive to zinc, copper, and brass.

If silage dry matter is above 35 percent, liquid NPN products may have greater retention than anhydrous, and they allow the simultaneous addition of molasses or minerals. Liquid products are less effective than ammonia, but more effective than urea at reducing aerobic spoilage. Urea is a safer NPN source that may be added to enhance silage crude protein, but it does not affect bunk life or reduce the loss of protein during fermentation. Urea is also more expensive than anhydrous, and more difficult to apply uniformly. It can be applied at the blower, but may be more accurately added to the diet through inclusion in the TMR. Adding urea to the TMR allows better mixing and more flexibility in the feeding rate. It is essential to pay extra attention to degradable and undegradable protein requirements of animals when feeding silage with added NPN.

Recommendations for additive use

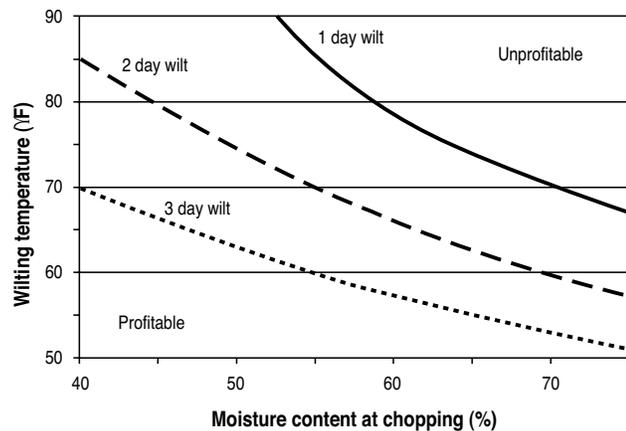
Wilted silage. If field conditions allow for adequate bacteria numbers on plant material, no additives are necessary when forage is wilted to recommended moisture levels. The purpose of wilting is to increase soluble carbohydrate content to a level which will enhance fermentation and preservation.

Consider adding bacterial inoculants when ensiling silage too wet (greater than 50 percent

moisture) or too dry (less than 30 percent moisture), field curing time is 1 day or less, and average curing temperature is low. Figure 10 was developed from alfalfa silage inoculation trials in Wisconsin and New York. The break-even curves in Figure 10 can be used to determine when an inoculant will improve silage quality enough to offset the costs of purchasing and applying the product. Inoculation with *Lactobacillus buchneri* may be considered where bunk life has consistently been a problem. Preservatives may be useful where forages have short bunk life or when the crop is ensiled at less than 60 percent moisture.

Figure 10. Break-even curves for using bacterial inoculants in alfalfa silage wilted from 1 to 3 days, assuming inoculant costs \$1/ton as fed and will result in a return of \$3/ton.

Source: Muck, 1996. *Silage Inoculation*. U.S. Dairy Forage Research Center.



Direct-cut silage. Wet crop material typically contains low levels of carbohydrate. Therefore, when material with over 70 percent moisture is ensiled in an upright silo, 100 to 200 pounds per ton of forage of a suitable feed ingredient with relatively high carbohydrate content should be added. Ground grains, dried beet or citrus pulp, soy hulls, hominy, and dried brewer's grains may be used for this purpose. In addition to providing small amounts of sugar that will enhance fermentation, the use of a feed ingredient at these levels will help reduce seepage. Storage dry matter losses may be held to 13 to 18 percent with the addition of feed ingredients to direct-cut forage.

If high-moisture forage made from hay-crop or annuals other than corn is placed in a horizontal silo, chemical preservatives may be considered as an alternative to adding a feed ingredient. Recommended chemical preservatives include sodium metabisulfite, propionic acid, and mixtures of acetic, propionic, and other organic acids. Apply them according to the directions of the manufacturer. Covering

horizontal silos will help to take full advantage of chemical preservatives.

Corn silage. Since corn silage typically contains ten times more naturally occurring lactic acid bacteria than alfalfa, no additives or preservatives are recommended when whole-plant corn silage is made at the proper moisture level. In addition, reviews of inoculated silage research do not show a consistent economic benefit to corn silage additives. Microbial inoculants may be more effective when corn is immature, overly dry, stressed by drought, or killed by frost.

When corn for silage contains more than 70 percent moisture, delay harvest until frosting, freezing, or advancing maturity lowers its moisture content. If corn must be ensiled wet, a microbial inoculant labeled for corn may be beneficial. Since corn silage tends to be less stable than hay crops when exposed to oxygen, *Lactobacillus buchneri* may be considered to increase bunk life.

If whole-plant corn contains less than 63 percent moisture, water may be added generously; however, remember that adding water has limited benefits. Alternatively, organic acids may be used at the rate of 10 to 20 pounds per ton to aid in preservation.

NPN additives may be used for both beef and dairy cattle to increase the crude protein content of corn silage and improve aerobic stability. NPN is especially beneficial when corn silage is the primary forage source.

Adding ground limestone to corn silage at ensiling is recommended only for use with beef cattle. Ground limestone may be applied at a rate of 20 pounds per ton of whole corn plant material ensiled, which helps to offset the low calcium content of corn silage and increase the lactic acid level in the silage. High lactic acid content may improve the feeding value for fattening animals, but not for milking animals. A combination of 10 pounds of urea and 10 pounds of ground limestone also has given satisfactory results in studies with beef cattle.

Drought stress. Microbial inoculants may benefit drought-stressed forages because normal bacteria populations tend to be low; these are best used when moisture content is normal or high. Propionic acid may be added when moisture content is lower than 60 to 62 percent. Adding fermentable substrates or sugars is unnecessary because drought stress concentrates the plants' fermentable sugars.

Conclusions

Forage additives should be used as tools to improve silage management, not as a substitute for poor management. A history of consistently poor quality silage will not be corrected with an additive. Instead, focus on improving silage harvest and storage practices.

The most critical aspect of silage management is harvesting it at the proper dry matter, which allows for adequate carbohydrate levels in the plant material and improves the probability of proper fermentation. Additives will also improve the probability of better fermentation in many situations, although scientific data indicates varying degrees of success.

The most important consideration when deciding to use silage additives is whether the improved quantity and quality of forage will offset the cost of the product and its application.

Table 17. Summary of silage additives for various forages.

Additive	Useful when:	Precautions	Application rate	Reported results ¹
Lactic acid bacteria (homolactic)	<p>Natural population is lower or less competitive than inoculant bacteria</p> <p>Forage is too wet</p> <p>Alfalfa, > 50% moisture</p> <p>Corn silage, > 70% moisture</p> <p>Forage is too dry, < 30% moisture</p> <p>Corn harvested immature or the day after a killing frost</p> <p>Alfalfa wilted for one day or less or wilted at a low temperature, < 60°F</p>	<p>May reduce aerobic stability</p> <p>Use crop-specific products</p>	<p>100,000 cfu/g fresh forage</p> <p>Liquid application preferred, especially with dry forage</p>	<p>Improved alfalfa fermentation in 60% of cases</p> <p>Improved corn silage fermentation in 31% of cases</p> <p>Reduced dry matter losses in 50% of cases</p> <p>Improved milk production in 47% of cases</p>
<i>Lactobacillus buchneri</i>	<p>Potential exists for aerobic spoilage</p> <p>Can be used on legume, grass, corn, or small grains</p>	<p>Do not use if silage is historically stable at feed out</p>	<p>100,000–400,000 cfu/g fresh forage</p>	<p>Increased aerobic stability (less heat, yeast) in 60% of cases²</p> <p>Improved dry matter recovery</p>
Enzymes	<p>Soluble sugars are limiting</p> <p>Immature grass is harvested</p>	<p>Usually too expensive and not needed</p> <p>Not recommended for corn</p>	<p>Depends on specific product</p>	<p>Reduced dry matter losses in less than 30% of cases</p> <p>Improved dry matter digestibility in 9% of cases</p> <p>Increased milk production in 33% of cases</p>
Fermentable carbohydrates	<p>Soluble sugars are limiting</p> <p>Hay crop is too wet, > 75% moisture</p>	<p>Not necessary for corn due to high starch content</p>	<p>Molasses: 40–80 lb/ton fresh forage</p>	<p>Improved fermentation</p> <p>Increased dry matter intake</p>
Propionic acid	<p>Forage is too dry, < 60% moisture</p>	<p>Often very expensive</p>	<p>2–4 lb/ton fresh forage</p>	<p>Increased aerobic stability of face and feed out in 50% of cases²</p> <p>Reduced yeast and mold growth</p>
Anhydrous ammonia	<p>Corn silage is at proper moisture level, 63–68%</p> <p>Corn silage is the primary forage in diet</p>	<p>Avoid adding to dry (< 60% moisture) or wet (> 70% moisture) silage</p> <p>Use for corn only</p> <p>Dangerous to handle</p>	<p>6–7 lb/ton forage (at 65% moisture)</p>	<p>Increased aerobic stability of face and feed out</p> <p>Increased silage protein content</p> <p>Reduced yeast and mold growth</p> <p>Improved dry matter recovery</p> <p>Increased dry matter digestibility</p>

¹Muck and Kung and Kung and Muck. 1997. *Silage: Field to Feedbunk*. NRAES-99.

²Survey of research published in the United States from 1996 through July 2003.

FEEDING MANAGEMENT

Aerobic spoilage

Remember that silage is part of a dynamic biosystem, where fermentation is delicately balanced based on exclusion of oxygen, the amount of residual water-soluble carbohydrates, the acid profile of the crop mass, the microbial and fungal populations present on the crop, and environmental conditions. Any of these factors can change silage nutritional value quickly when the storage structure is exposed to oxygen.

Bunk life. Anaerobic (no oxygen) conditions and low pH limit the activity and growth of spoilage organisms. However, exposure to even a small amount of oxygen allows yeast to grow. Yeast convert organic acids and residual plant sugars to carbon dioxide, water, and heat. As a result, silage pH increases, allowing bacteria, yeasts, and molds that had been inhibited by the acidic environment to grow. These organisms also consume digestible nutrients and produce heat. Aerobic spoilage reduces the quantity and nutritional quality of silage; temperature, pH, and fiber contents are increased and digestible nutrients and energy are lost.

Since all exposed surfaces of the silage mass allow oxygen to enter, spoilage happens during both storage and feedout. Losses during storage can be limited by properly packing and sealing the storage structure. However, once the silo is opened, the exposed face must be managed to limit the time silage is exposed to oxygen. The aerobic stability of silage that has been removed from the silo is commonly called bunk life. Aerobic stability refers to the resistance of silage to heating and spoilage after exposure to air. Bunk life is defined as the length of time silage remains at normal temperatures once it is exposed to air.

Factors affecting bunk life:

- Oxygen: Levels greater than 5 percent allow aerobic bacteria to grow. Infiltration of oxygen is caused by poor compaction and/or sealing of the silo.
- Carbon dioxide: Levels greater than 20 percent prevent aerobic bacteria from growing.
- Spoilage organism population: A poor seal lets yeast, mold, and aerobic bacteria grow during storage, which greatly shortens bunk life.

Mold and yeast can live in the silo from one year to the next, and crops may be inoculated with mold spores or yeast by manure or soil contamination, manure fertilization close to harvest, or soil splashing onto plants.

- Temperature: Ensiling, storage, and/or unloading at temperatures greater than 40°F encourages microbial growth. Aerobes do not grow above 110 to 140°F.
- Incomplete or inadequate fermentation: A high concentration of organic acids lowers silage pH and inhibits the growth of aerobic organisms. Also, any unfermented water-soluble carbohydrate (residual sugar) provides a food source for spoilage organisms.
- Forage dry matter: Dry silage often has a short bunk life because it is hard to pack, has lower acid levels, and heats quickly. Environmental stresses such as drought, insect damage, or hail can influence forage dry matter.
- Forage species: Complete fermentation of legumes produces more organic acids and less residual sugar than complete fermentation of corn or grass silage, making legume silage more stable. However, incomplete fermentation of legumes may lead to unstable silage due to low acid production, which results in a high pH. Corn silage and small grains also have higher natural yeast populations and more available sugars than legumes.

Controlling spoilage at the exposed face. The best way to limit aerobic spoilage is to promote rapid, complete fermentation by harvesting at the proper moisture level and TLC, packing and sealing silos, and using appropriate silage additives as needed to stimulate fermentation or prevent spoilage.

However, the silo face is constantly exposed to oxygen, so the daily removal rate must be enough to keep ahead of aerobic spoilage. This is accomplished by correctly sizing storage structures to match forage needs. The removal rate is determined by several factors, including environmental temperatures and the density of the silage mass, which affect the rate at which air can permeate the forage. Oxygen can penetrate several yards into a loosely packed silage mass, but dense forage limits the rate of oxygen infiltration. Recommended removal rates are presented in Table 18.

Management of the silage face is also extremely important, because this surface is exposed from the time the silo is opened until it is emptied. Minimize the exposed surface area by removing silage evenly

Table 18. Recommended minimum removal rate (inches per day) by storage type.

Storage type	Daily high ≤ 40°F	Daily high > 40°F
Unsealed upright	3	4
Sealed upright	3	3
Horizontal ¹	4	6
Silo bag ¹	4	6
Stack or pile ¹	4	6

¹Increase these rates for silage with dry matter density less than 14 lb/ft³ (bulk density less than 40 lb/ft³).

from the entire face to form a smooth, vertical surface that is perpendicular to the silo sides and floor.

Recommended methods of removing material from bunker silos or piles with a front-end loader include scraping from the top down, or, if space permits, shearing from side to side. It is also possible to scoop one load from the bottom, and chip down from the top into that opening. Always avoid lifting from the bottom of the silage mass, which creates cracks that allow air to penetrate deep into the silage.

Another method gaining popularity is the silage facer, usually a rotating drum covered with blades. Facers are designed to remove a thin layer of silage and maintain a smooth bunk face. Wisconsin research showed that facers did not reduce forage particle size compared to unloading silage with a bucket or by hand; however, operating techniques should be monitored closely to prevent particle size reduction.

Finally, regardless of silo type, remove only enough silage for the current feeding, clean up all loosened feed, and do not leave piles of silage around storage areas. If possible, design silos to shelter the open face from prevailing winds and hot afternoon sun.

Controlling spoilage at the feed bunk. To keep silage fresh in the feed bunk, remove uneaten feed, clean the bunk daily, and keep water out. Tips useful in hot weather include: feed multiple times per day, limit wet ingredients in the ration, mix TMR for one feeding (do not mix ahead), and add a buffered propionic acid product or other mold inhibitor to the TMR where spoilage is a problem.

Other concerns

Over mixing. Particle size may be reduced during all phases of forage handling, from harvesting and storing to mixing and feeding. Mixing a TMR reduces the particle size of all feeds, and the length of time the

Table 19. Percentage reduction in the mass of large TMR particles in a Pennsylvania field study.¹

Mixer type	# Batches	Percent reduced by mixing	
		Particles > 1 inch	Particles > 0.71 inch
Auger	4	56	37
Chain and slat	7	40	2
Reel	2	70	35
Tumble	3	54	22
Overall	16	50	19

Source: Heinrichs, et al. 1999. *Journal of Animal Science*. 77:180–186.

¹TMR were mixed according to normal farm procedures and contained no long hay.

Table 20. Effect of feeding spoiled corn silage on intake and nutrient digestibility in steers.

Item	Percent spoiled silage in ration			
	0	25	50	75
Dry matter intake, lb/day	17.5 ^a	16.2 ^b	15.3 ^{bc}	14.7 ^c
Digestibility, %				
Dry matter	74.4 ^a	68.9 ^b	67.2 ^b	66.0 ^b
Crude protein	74.6 ^a	70.5 ^b	68.0 ^{bc}	62.8 ^c
Starch	94.6	95.0	93.3	95.3
NDF	63.2 ^x	56.0 ^y	52.5 ^y	52.8 ^y
ADF	56.1 ^a	43.2 ^b	41.3 ^b	40.5 ^b

Source: Whitlock, et al. 2000. Kansas Ag. Exp. Stn. Progress Rpt. 850.

^{abc}Means in a row with different superscripts differ ($P < 0.05$).

^{xy}Means in a row with different superscripts differ ($P < 0.10$).

ration is mixed can greatly influence particle size. A field study of rations mixed on Pennsylvania farms showed that feed particles longer than 1 inch may be shortened by 50 percent due to mixing (Table 19).

The order ingredients are added to a TMR mixer also influences particle size. In general, load ingredients without running the mixer and add the less bulky, non-forage ingredients first. If the mixer must operate while loading, add forages last. After all ingredients are added, the ration should be mixed for 3 to 6 minutes and unloaded, running the mixer only as needed. Individual machines may differ from these general recommendations, so be sure to follow the order and times described by the manufacturer.

Another consideration is batch size. In most cases, mixer capacity is 60 to 75 percent of the “struck full level.” Exceeding this limit reduces the mixer’s ability to evenly distribute the ingredients and increases the risk of over mixing.

Feeding spoiled silage. Discard all spoiled, moldy,

wet, or warm silage. Spoiled feed has much lower nutritional value and palatability than normal silage. This feed is also more likely to contain toxins that could harm animal health. The negative impacts of feeding spoiled silage are demonstrated in the results of a Kansas research trial (Table 20). Steers in this study were fed rations containing various amounts of spoiled silage. As the amount of spoiled silage in the diet increased, intake and nutrient digestibility decreased.

Monitor shrink. Develop a system to account for silage losses during storage and feeding. This practice is essential to find and fix weak links in silage handling and helps calculate the real costs associated with producing forage. Often, losses associated with silage management are underestimated because they are indirect or invisible.

DIAGNOSING SILAGE PROBLEMS

Odor and color are often enough to identify poor quality silage, but evaluating the pH, dry matter, and fermentation acid profile may be useful when determining the extent of adverse fermentation. Although information about silage fermentation is not needed to balance rations, it may be analyzed to evaluate the ensiling process and aid in troubleshooting intake or milk production problems.

Silage odor and appearance

Normal. Silage that has undergone normal fermentation has a light green to green-brown color and the slightly sweet odor of lactic acid.

Abnormal. Silage with a rancid, fishy, or putrid odor, yellow-green or brown color, and slimy texture may result from clostridial fermentation. This silage probably contains high levels of bound protein and might reduce dry matter intake. Foul-smelling silage usually contains high levels of butyric acid, but a variety of other compounds add to this odor.

Clostridial fermentation involves a number of species, and each converts lactic acid and excess plant sugars into a variety of compounds including butyric acid, carbon dioxide, hydrogen gas, acetic acid, and ammonia. In addition, other non-protein nitrogen compounds (NPN) are created from plant proteins, and some, such as putrescine and cadaverine, have particularly unpleasant odors. The combination of odors from these various NPN compounds and butyric acid leads to intake depression. In some cases, by-products of clostridial fermentation also affect the normal rumen microbial population and create additional feed intake depression due to reduced feed digestibility.

A caramelized or cooked odor, similar to tobacco or burnt sugar, is also abnormal. This odor is usually associated with dark black silage that has heated excessively (over 120°F). This silage typically has reduced energy and protein content, and it results from excess oxygen in the forage mass, which allows extended respiration. Slow fill rates, poor compaction, overly mature or dry forage, and excessively long chop length are potential causes of this problem.

Other abnormal odors include alcohol, vinegar, and acetone. Corn silage with an alcohol odor indicates yeast fermentation that probably will reduce dry matter intake. A vinegar odor indicates exten-

sive acetic acid fermentation, which is promoted by wet silage, inadequate lactic acid bacteria populations, and low levels of crop sugars. An acetone odor results when yeast produce methyl- and ethyl-acetates.

Fermentation end product analysis

Moisture content of the forage plays an important role in the extent of fermentation, due to variation in bacterial populations and the buffering capacity of water. Greater moisture content will dilute acid production, which allows lactic acid bacteria to grow for a longer time and produce more acid. In addition, crop species greatly influences the buffering capacity and carbohydrate level of plants before ensiling. Legume forages have greater buffering capacity than corn silage due to their high protein and mineral content, which means it takes more acid to lower the pH of legume silage.

Silage pH. The most common measurement of silage fermentation is pH, and when combined with dry matter, pH can adequately indicate the overall effectiveness of fermentation. The pH can be measured in fresh silage samples on the farm, or samples can be shipped to a lab for analysis. If silage has undergone proper fermentation, the expected pH will range from 3.5 to 4.5 for corn silage and 4.0 to 5.5 for haylage, depending on forage moisture content.

In general, low pH indicates greater acid production. High pH (greater than 5.5) may result from several causes, including high dry matter at ensiling. High levels are often found in legume haylage because it contains more protein (greater buffering capacity) than corn silage. Silage with incomplete fermentation due to forage containing too little carbohydrate, cold environmental conditions at harvest, or poor packing often has high pH. Silage exposed to oxygen during storage also may have high pH (7.5 or more).

Sample collection and handling. For all fermentation analyses, prepare and ship the sample properly to prevent additional fermentation, which will change the pH and/or acid profile. The sample should be collected 10 to 12 inches deep in the silage mass to avoid silage that has been exposed to oxygen. Place the sample (at least 0.5 pound) in a plastic bag, squeeze out all air, and seal tightly. Ideally, samples should be refrigerated or frozen and sent to the lab overnight with an ice pack. However, if the sample has normal moisture content and is well-sealed, it can be sent within 2 days. Mail early

in the week to avoid weekend delays. Very dry or aerobically unstable samples may undergo extreme fermentation changes if shipping is delayed.

Fermentation acid profile. The acid profile of silage indicates the type of fermentation that occurred, and the relative concentrations of free acids in silage likely influence intake much more than pH alone. Typical acid profiles for silage are presented in Tables 21, 22, and 23. Note the considerable variation due to crop and dry matter content differences.

Lactic acid should be the most prevalent acid in well-fermented silage, comprising 60 percent of the total acid concentration and 3 to 8 percent of forage dry matter. Acetic acid typically ranges from one to four percent of dry matter in well-preserved silage. If acetic acid predominates, forage intake may be reduced when cows are fed large quantities of this silage. The ratio of lactic to acetic acid also may be calculated; ideally, the ratio should be 2:1 in favor of lactic acid (higher is better).

Propionic acid levels should be less than one-half of a percent; high levels of this acid usually indicate that insufficient sugar was available for fermentation. High levels of propionic acid do not indicate poor packing or excess moisture at harvest.

Properly fermented silage has butyric acid levels near zero. Any appreciable amount of butyric (greater than one-half of a percent) or iso-butyric (greater than one percent) acid indicates clostridial fermentation, which is typically accompanied by reduced energy content, increased fiber, and increased soluble protein, resulting from the high ammonia and amine levels. Since it has progressed through more complete fermentation, silage high in butyric acid is actually more aerobically stable than silage high in lactic acid.

High butyric or iso-butyric acid levels usually result from excessive moisture in the crop at ensiling (as demonstrated in Tables 21, 22, and 23). The increased moisture allows fermentation to continue past the lactic acid phase into the clostridial phase.

The level of ammonia in silage, which is negatively related to intake, may be listed as a percent of crude protein or percent of total nitrogen. Ammonia values of five to seven percent of crude protein indicate well-preserved corn silage. However, it may be difficult to achieve these levels in legume forages due to their high protein content; 10 to 15 percent is considered normal. Silage harvested very wet may contain high ammonia concentrations because of clostridial fermentation. Silage that was very dry at harvest also may contain high ammonia concentrations due to excessive heating.

Table 21. Typical fermentation profile of corn silage at various dry matter contents.

	< 30% Dry Matter		30–35% Dry Matter		> 35% Dry Matter	
	n ¹	Range ²	n ¹	Range ²	n ¹	Range ²
Dry Matter, %	483	25.7–29.4	570	31.9–34.2	669	35.1–43.2
pH	477	3.5–4.4	551	3.5–4.5	603	3.7–4.8
Lactic, % DM	383	2.9–8.0	351	2.7–7.0	314	2.1–5.9
Acetic, % DM	386	1.6–6.0	351	0.9–4.1	315	0.4–2.9
Propionic, % DM	310	0.1–1.0	252	0.1–0.7	200	0.0–0.6
Iso-butyric, % DM	127	0.0–1.3	116	0.1–0.9	112	0.2–0.7
Butyric, % DM	106	0.0–0.8	78	0.1–0.7	91	0.1–0.6
Ammonia, CP Equiv., % DM	386	0.0–1.6	352	0.0–1.8	315	0.0–1.8
NH ₃ -N, % Total N	290	1.0–9.6	282	0.0–9.0	237	0.0–7.7

Source: Cumberland Valley Analytical Services, Inc.

¹Number of samples.

²Range was calculated by subtracting or adding one standard deviation to the average obtained for all samples.

Table 22. Typical fermentation profile of mixed, mostly legume, silage at various dry matter contents.

	< 30% Dry Matter		30–35% Dry Matter		> 35% Dry Matter	
	n ¹	Range ²	n ¹	Range ²	n ¹	Range ²
Dry Matter, %	65	24.0–29.2	45	32.0–34.3	122	36.0–54.4
pH	65	4.0–5.8	41	4.2–4.9	99	4.2–5.4
Lactic, % DM	47	0.3–6.8	29	3.0–7.6	46	1.6–5.5
Acetic, % DM	47	1.6–5.1	29	0.9–3.3	46	0.4–2.6
Propionic, % DM	43	0.2–0.9	21	0.1–0.5	29	0.1–0.5
Iso-butyric, % DM	30	0.1–0.5	13	0.1–0.6	18	0.1–0.6
Butyric, % DM	32	0.2–3.3	12	0.2–0.9	19	0.0–1.0
Ammonia, CP Equiv., % DM	47	0.4–5.3	29	0.6–1.8	46	0.5–2.1
NH ₃ -N, % total N	37	0.7–19.6	28	2.3–5.6	42	1.4–5.0

Source: Cumberland Valley Analytical Services, Inc.

¹Number of samples.

²Range was calculated by subtracting or adding one standard deviation to the average obtained for all samples.

Table 23. Typical fermentation profile of, mixed mostly grass, silage at various dry matter contents.

	< 30% Dry Matter		30–35% Dry Matter		> 35% Dry Matter	
	n ¹	Range ²	n ¹	Range ²	n ¹	Range ²
Dry Matter, %	145	25.1–29.2	144	32.0–34.1	570	37.4–51.9
pH	143	4.4–6.0	135	4.3–5.5	519	4.4–5.6
Lactic, % DM	126	1.1–7.9	89	2.3–8.2	228	2.0–6.9
Acetic, % DM	126	2.0–5.6	88	1.5–4.3	228	0.6–2.7
Propionic, % DM	106	0.2–1.0	74	0.1–0.7	118	0.1–0.6
Iso-butyric, % DM	65	0.0–0.8	36	0.0–0.8	58	0.1–0.6
Butyric, % DM	76	0.1–4.8	41	0.0–3.0	70	0.0–1.8
Ammonia, CP Equiv., % DM	126	1.2–7.3	89	1.2–4.4	228	0.7–3.3
NH ₃ -N, % total N	77	3.6–20.7	62	2.2–10.6	140	1.5–6.6

Source: Cumberland Valley Analytical Services, Inc.

¹Number of samples.

²Range was calculated by subtracting or adding one standard deviation to the average obtained for all samples.

Ethanol may be present in silages that have undergone extensive fermentation by yeasts. This silage will have greater nutrient losses and tends to heat rapidly in the feed bunk.

Careful management of the ensiling process can alter and improve silage fermentation profiles to reduce dry matter and energy losses and enhance dry matter intake and cow performance. Typically, once

silage has fermented poorly, the only option is to dilute it by mixing it with other forages. Therefore, the primary goal of fermentation profile analysis is creating an awareness of the factors that can be controlled during harvest and storage to prevent future problems.

Table 24. Summary of common silage problems and possible causes.

Physical characteristics	Chemical or microbial characteristics	Possible causes
Vinegar odor	Acetic acid > lactic	Low population of lactic acid bacteria, low sugar levels in crop, wet forage
Rancid, fishy, or putrid odor Yellow-green color Slimy texture	Butyric acid > 0.5%	Clostridial fermentation, wet forage, low sugar levels in crop
Alcohol odor	Ethanol > 1% for legume or grass silage or > 3% for corn silage Yeast populations > 100,000 cfu/g fresh forage	Oxygen exposure, resulting in yeast growth and fermentation
No odor detected	Propionic acid > 0.5%	Low sugar levels in crop
Caramelized or cooked odor Dark brown or black color	Energy and protein reduced	Heating due to oxygen exposure Slow fill rate, poor packing, dry forage
Musty odor, hot	Mold populations > 100,000 cfu/g fresh forage	Oxygen exposure, pH > 4.5
	Ammonia nitrogen Corn silage > 10% of total nitrogen or > 7% of crude protein Alfalfa > 5% of total nitrogen or > 10% of crude protein	Excessive protein breakdown, could be clostridial fermentation
	pH > 4.5	Dry forage, poor packing, low sugar levels in crop, low temperatures at harvest pH > 5 indicates clostridial fermentation pH > 7.5 indicates oxygen exposure

APPENDIX 1:

DETERMINING FORAGE DRY MATTER USING A MICROWAVE

Tips to ensure accurate measurements

1. Use the full power setting.
2. Limit the sample size to less than 50 grams.
3. Use short heating intervals when drying to prevent the sample from burning.
4. Keep the sample spread out thinly to promote uniform heating.
5. Samples do not have to cool before weighing.
6. Puncture grain kernels in corn silage and high moisture grains to ensure more complete drying.
7. Do not place a glass of water in the microwave with the sample; it will add moisture to the sample as it boils.
8. Use a scale that reads to one-tenth of a gram (0.1).

The procedure

1. Weigh a paper plate; tare the scale with its weight.
2. Collect a small sample of forage and place it on the plate.
3. Weigh the sample on the plate.
4. Record this weight as the "Initial Weight."
5. Dry the sample using the guidelines in the table to the right. Feel the sample after each drying period; it should get more brittle after each drying.
6. After the fourth drying, weigh the sample and record this amount.
7. Place the sample in the microwave for another 10 to 20 seconds.
8. Weigh the sample again.
9. Repeat steps 7 and 8 until the sample weight does not change.
10. Record this weight as the "Final Weight."
11. Calculate dry matter by dividing the initial weight into the final weight and multiplying this result by 100.

$$\% \text{ Dry matter} = (\text{Final Weight} \div \text{Initial Weight}) \times 100$$

Suggested guidelines for drying time

	Corn silage < 40% DM	Hay-crop silage < 40% DM > 40% DM	
Initial drying	1:30 min	1:00 min	0:50 sec
2nd drying	0:45 sec	0:35 sec	0:40 sec
3rd drying	0:35 sec	0:25 sec	0:25 sec
4th drying	0:30 sec	0:15 sec	0:15 sec

After the fourth time, weigh sample, then dry at 10 to 20 second intervals.

Weigh after each drying until the sample weight stops changing.

APPENDIX 2:

ABBREVIATIONS USED THROUGHOUT THIS PUBLICATION

ADF—Acid detergent fiber

CFU—Colony forming unit

CP—Crude protein

DM—Dry matter

DMI—Dry matter intake

NDF—Neutral detergent fiber

NE_L—Net energy for lactation

NPN—Non-protein nitrogen

TLC—Theoretical length of cut

TMR—Total mixed ration

Recommended Practices for Harvesting and Utilizing Silage

Recommended Practice	Rationale
Seal silo walls and doors as necessary	Eliminates oxygen and water infiltration
Harvest forage at suitable maturity stage and moisture content (see table below)	Optimizes nutrient content Aids in packing and eliminates oxygen Minimizes heating Minimizes seepage Limits clostridial fermentation
Chop at correct cut length	Aids in packing and eliminates oxygen Promotes cud chewing and rumen health
Harvest, fill, and seal quickly	Reduces respiration losses Eliminates oxygen Minimizes heating Increases rate of pH decline
Pack and seal tightly	Eliminates oxygen Reduces respiration losses Prevents water from entering silage mass Minimizes heating Increases rate of pH decline
Test moisture content of forage	Ensures that moisture content at harvest is correct Enables the calculation of additive required, if necessary
Evaluate forage particle size	Monitors the accuracy of harvester settings Allows adjustment of cut length during harvest
Ensilage forage 2 to 3 weeks before feeding	Allows fermentation to stabilize
Maintain a smooth feed out face	Limits oxygen penetration and aerobic spoilage
Remove 4 to 6 inches per day from each open silo	Limits aerobic spoilage at the exposed face
Discard spoiled feed	Prevents possible illness from toxins Improves silage palatability and intake

Maturity and Moisture Guidelines for Silage Harvest and Storage

	Alfalfa	Grass	Corn silage	Small grains
Stage of maturity	Mid bud to 1/10 bloom	Boot	1/2–2/3 milk line	Boot or soft dough
Theoretical cut length (inch)	3/8–1/2		Unprocessed: 3/8 Processed: 3/4	
Moisture by storage structure				
Horizontal silo	65–70%	65–70%	65–70%	60–70%
Conventional upright	60–65%	60–65%	63–68%	63–68%
Oxygen-limiting upright	40–55%	40–55%	55–60%	55–60%
Bag	60–70%	60–70%	60–70%	60–70%
Balage	50–60%	50–60%	—	—
Pile or stack	65–70%	65–70%	65–70%	60–70%

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