THE ART AND SCIENCE OF MAKING SILAGE

Richard E. Muck[1]

ABSTRACT

In ensiling, a moist crop is preserved by a combination of an anaerobic environment, the lactic and acetic acids produced by lactic acid bacteria fermenting sugars, and a low pH resulting from that acid production. Fermentation causes some dry matter loss, but most loss is caused by aerobic spoilage microorganisms that need oxygen entering the silo to grow and consume the digestible portions of the crop. As a consequence, the keys to delivering a silage to livestock of similar quality as that harvested center on minimizing the exposure of silage to oxygen. These keys include: designing a silo/pile so that feed out rate is high; packing the crop to achieve a low porosity; using a high quality film to cover a silo, securing it tightly to the crop, monitoring it regularly and patching as needed; and removing only the silage needed for that day, leaving a smooth face.

Key Words: silage, fermentation, porosity, feed out rate, covers

INTRODUCTION

The goal in storing any crop is to keep its quality as close as possible to that of the crop at harvest and minimize losses of dry matter. In making hay, the crop is dried to a low moisture content so that spoilage microorganisms cannot grow. Losses are low if bales are kept at low moisture content. In making silage, the crop is stored at a moisture content where many kinds of microorganisms and plant enzymes can reduce crop quality and cause significant dry matter losses. However, good silage management can result in low losses and silages with similar nutritive values to original crops. To make high quality silage it is essential to understand how crops are preserved in the silo. Then the recommendations for making silage will make sense. This paper will focus both on preservation in the silo and how various silage management factors influence preservation.

SILAGE PRESERVATION

Silage can be made in many ways: tower silos, bunker silos, bags, covered piles or a wrapped bales. However, the mechanisms that preserve the crop are the same across all silo types. The crop is placed in an environment where oxygen is excluded, i.e., anaerobic conditions. Under anaerobic conditions, lactic acid bacteria ferment sugars in the crop primarily to lactic acid, which lowers the pH of the crop.

I like to think of silage preservation being a three-legged stool. Preservation in the silo depends upon the fermentation products, low pH and anaerobic conditions. When one leg of a three-

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[1] R.E. Muck (richard.muck@ars.usda.gov), Agricultural Engineer, US Dairy Forage Research Center, USDA, Agricultural Research Service, 1925 Linden Drive, Madison, WI 53711; **<u>In</u>**: Proceedings, 2011 Western Alfalfa & Forage Conference, Las Vegas, NV, 11-13 December, 2011. UC Cooperative Extension, Plant Sciences Department, University of California, Davis, CA 95616. (See http://alfalfa.ucdavis.edu for this and other alfalfa symposium Proceedings.)

legged stool breaks, you will be sitting on the ground. In the same way, the preservation of silage suffers when you do not have all three factors.

Fermentation Products. Lactic acid bacteria ferment sugars, producing a variety of products. Table 1 shows typical fermentation products from lactic acid bacteria. The products vary with the type of lactic acid bacteria. Homofermentative species such as *Lactobacillus plantarum* will generally produce only lactic acid when growing on glucose. Heterfermentative species such as *Lactobacillus buchneri* will produce lactic acid and carbon dioxide (CO_2) plus either acetic acid or ethanol when growing on a glucose. *Lactobacillus buchneri* may also ferment lactic acid to acetic acid and CO_2. Fermentation products will also vary by the type of sugar fermented. In any case, the main products from fermentation by lactic acid bacteria are lactic acid, acetic acid, ethanol and CO_2.

Table 1. Fermentation products from lactic acid bacteria.

Type of Lactic Acid Bacteria	Substrate	Products
Homofermentative	Glucose	Lactic Acid
Heterofermentative	Glucose	Lactic Acid, Acetic Acid, CO_2
	Glucose	Lactic Acid, Ethanol, CO_2
	Lactic Acid	Acetic Acid, CO_2

Of these products, lactic and acetic acids inhibit various microorganisms. Lactic acid inhibits two detrimental groups of bacteria in silage – acetic acid bacteria and listeria. Acetic acid bacteria can begin heating and spoilage in corn silage. Listeria are disease bacteria that can affect cattle health and cause listeriosis in humans. Both groups are held in check when lactic acid is present at high levels, particularly greater than 5% of dry matter. Unfortunately lactic acid is very limited in inhibiting yeasts and molds. Yeasts are the group of microorganisms that normally begin the spoilage process in silage, and so are particularly important to control.

Acetic acid is an effective yeast and mold inhibitor. Acetic acid is often in chemical additives for reducing mold in hay or high moisture corn. Salts of acetic acid, acetates, are commonly added to human foods to keep them from getting moldy. Unfortunately, acetic acid concentrations are rarely high enough alone to prevent yeasts and molds from growing.

Low pH. Lactic acid is a strong acid compared to acetic acid. When lactic acid is essentially the only fermentation product, a silage pH of 3.5 is possible. With acetic acid alone, it would be difficult for silage pH to be below 4.5.

A sufficiently low pH can prevent many detrimental microorganisms from growing. These include listeria, enterobacteria, bacilli and clostridia. Enterobacteria produce silo gas (nitrogen oxides) and may cause high acetic acid silages. Bacilli are spoilage bacteria that grow fast and produce high silage temperatures. These two groups of bacteria plus listeria cannot grow if pH is below 4.5 to 5.0. Clostridia are anaerobic bacteria that produce butyric acid and amines, making the silage unpalatable. The butyric acid may also contribute to cases of ketosis in cows in transition. The critical pH to stop their growth is affected by crop and dry matter content (Fig. 1).

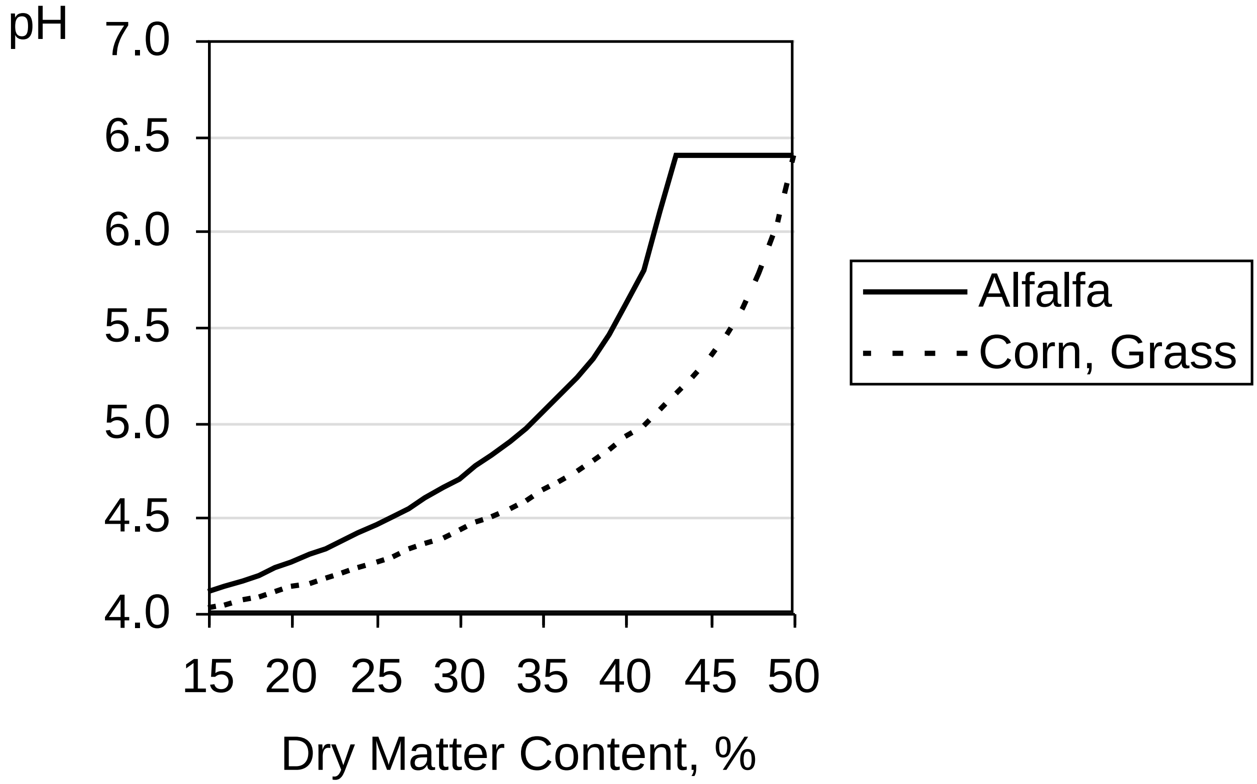

Figure 1. Critical pH below which clostridia will not grow as affect by silage dry matter content and crop ensiled, based on Leibensperger and Pitt (1987).

Low pH reduces plant enzyme activity. The breakdown of crop protein to soluble nonprotein nitrogen is caused by plant enzymes, and the only way to slow this process is a rapid drop in pH.

Low pH also makes lactic and acetic acids more inhibitory to yeasts and molds. However, the combination of low pH and normal levels of lactic and acetic acids will not stop all yeasts and molds.

Anaerobic Environment. Spoilage of silage by yeasts, molds and aerobic bacteria depends on a supply of oxygen. Fermentation alone is rarely able to stop the yeasts that initiate the spoilage of silage or the molds that finish off the spoilage process, but keeping oxygen out will. We do have fermentative yeasts that grow with essentially no oxygen. (That's how we make beer and wine, ethanol for our cars, etc.) However, these fermentative yeasts vary considerably in their ability to cause spoilage. Keeping oxygen out also keeps acetic acid bacteria from growing. So the two primarily initiators of spoilage (yeasts and acetic acid bacteria) can be stopped by keeping oxygen out regardless of the fermentation.

Losses. Losses from silage come as a result of various processes (Table 2). During filling, plant respiration uses sugars and oxygen and produces heat. This process causes the silo to become anaerobic, which is good, but slow filling allows excessive loss of sugars. Fermentation losses are primarily the CO_2 produced by lactic acid bacteria and are usually less than 4%. It can be greater if clostridia or fermentative yeasts are active and less if you use a homofermentative inoculant. Effluent or seepage is the result of ensiling too wet and should be avoided because it can cause environmental damage if it reaches surface or ground waters. The rest of the losses during storage and feed out are losses from respiration by spoilage microorganisms. These are all the result of oxygen entering the silo and are the most variable, depending on silo management. Because most of the losses are from spoilage microorganisms and because fermentation only slows down the spoilage process, the key to minimizing losses in the silo is reducing the exposure of the silage to oxygen both during storage and at feed out.

Table 2. Typical dry matter losses from silages by storage phase.

Phase	Loss Range
Filling	1-2%
Active fermentation	1-4%
Effluent	0-2%
Storage after fermentation	1-10%
Feed out	1-10%

FACTORS AT FEED OUT

Discussions of silage management usually start at filling, proceed to covering and finish with feed out management. However, if you are serious about reducing silage losses, the best place to start is in creating a good plan of what feed out will look like before the first load reaches the pad or bunker. Why? Much of the variability in feed out losses comes from silo/pile design and filling practices, not what we do when we are feeding are livestock.

If our silages are cool and the ration does not heat in the feed bunk, we tend to think that there is not much loss occurring at the silo face during emptying. Unfortunately, that is not true. We have measured oxygen more than 3 feet back from the faces of well-packed bunker silos. That means that the silages were exposed to oxygen for 6 days if we were using a typical recommendation of removing 6 in./day from the whole face. That is plenty of time for slow losses to occur that are not sufficient to cause appreciable increases in temperature or show signs of mold.

Feed Out Rate and Porosity. Losses at the face should be related to how porous the face is and the rate of removal. Figure 2 shows how dry matter losses during feed out are a function of dry matter content, dry matter density and feed out rate. At a given dry matter density and feed out rate, losses increase the drier the crop. Why? Less volume in the silo is filled with water and more volume is filled with gases, allowing a faster movement of oxygen into the silage. Consequently, you see that losses at a given feed out rate are proportional to porosity – the fraction of volume that is gas.

With hay crop silage, it is much more difficult to control dry matter content in the harvested crop. If your feed out rate is low (e.g., 3 in./day) and you pack to the same dry matter density, losses will increase substantially in the dry silage (Fig. 2). If your feed rate is high (e.g., 9 in./day), there are only modest increases in losses when the silage is dry. This then becomes the reason for the first principle in making high quality silage: *1) Design your silo/pile so that your feed out rate is high.*

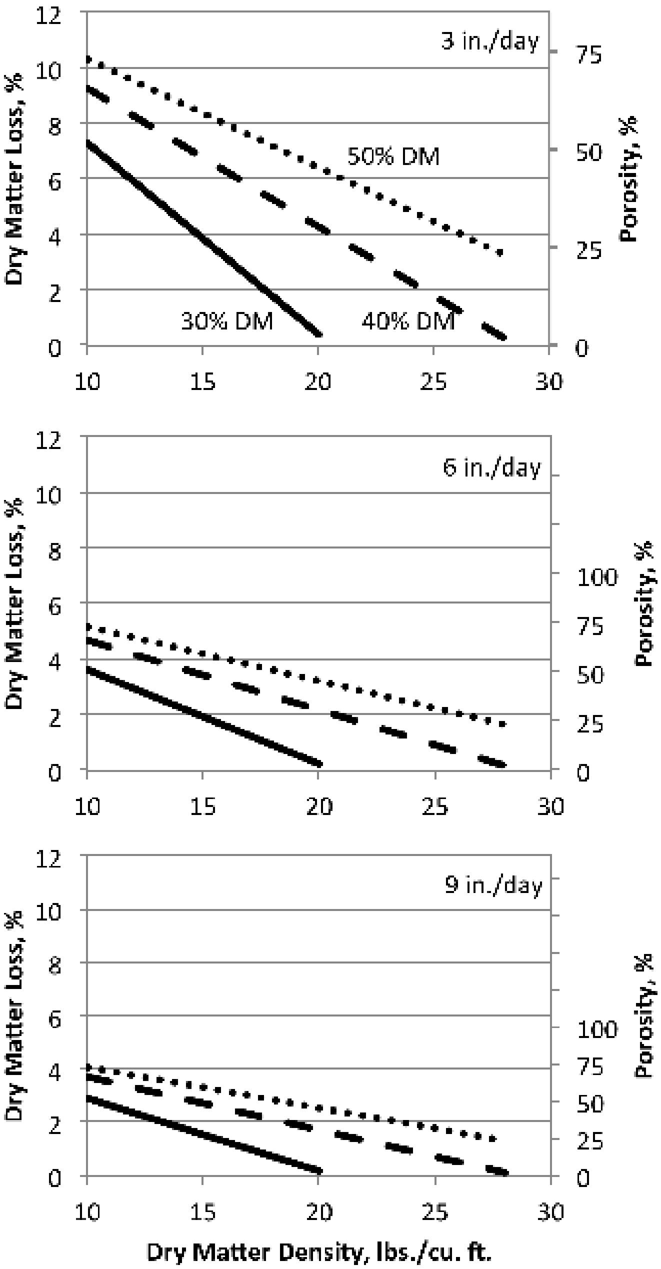

Figure 2. Dry matter losses during silage feed out as a function of dry matter density, feed out rate and dry matter content of the crop.

Bunker and pile silos should be sized to remove 12 in./day from the full face. Bag silos should be sized to remove 24 in./day from the face. If you already have a bunker with too big a face, split the width with one or more walls to increase feed out rate. Another option is to only partly fill a bunker. Why should you design for a high feed out rate? The number of animals that you intend to feed from a silo may vary from your plans. A silage may need to be fed out at a lower rate than you originally anticipated because of poor quality, unexpected changes in ration, etc. If you plan for a high feed out rate, you can help get low losses even when your plans change.

How do you design for a high feed out rate? Spreadsheets are available on the University of Wisconsin Team Forage website for sizing bunker and pile silos and selecting the right bag (http://www.uwex.edu/ces/crops/uwforage/storage.htm). These spreadsheets help you calculate your silage requirements and then help you size your storages accordingly.

Minimizing Porosity. From Figure 2, increasing density is important for reducing losses during feed out. However, losses at a given dry matter density increase with increasing dry matter content of the silage because of the increased porosity of the drier silage. If we want the same dry matter loss in a drier crop that we have when ensiling at normal dry matter contents, we need to pack to a higher dry matter density so that we reach the same porosity as in the wetter silage. Thus the second principle for making high quality silage is: *2) Pack the crop to achieve a low porosity*.

From a practical perspective, it would be difficult to keep track of the dry matter content as you chop from field to field during the course of a day, particularly in making hay crop silages, and then adjust your packing process to account for the changes. We are beginning to see moisture measurements being made on-the-go on forage harvesters, but that information would need to be transmitted to the guys on the packing tractors. Fortunately there is an easier way – bulk density. As shown in Figure 3, porosity is relatively constant for a given bulk density across a wide range of dry matter contents.

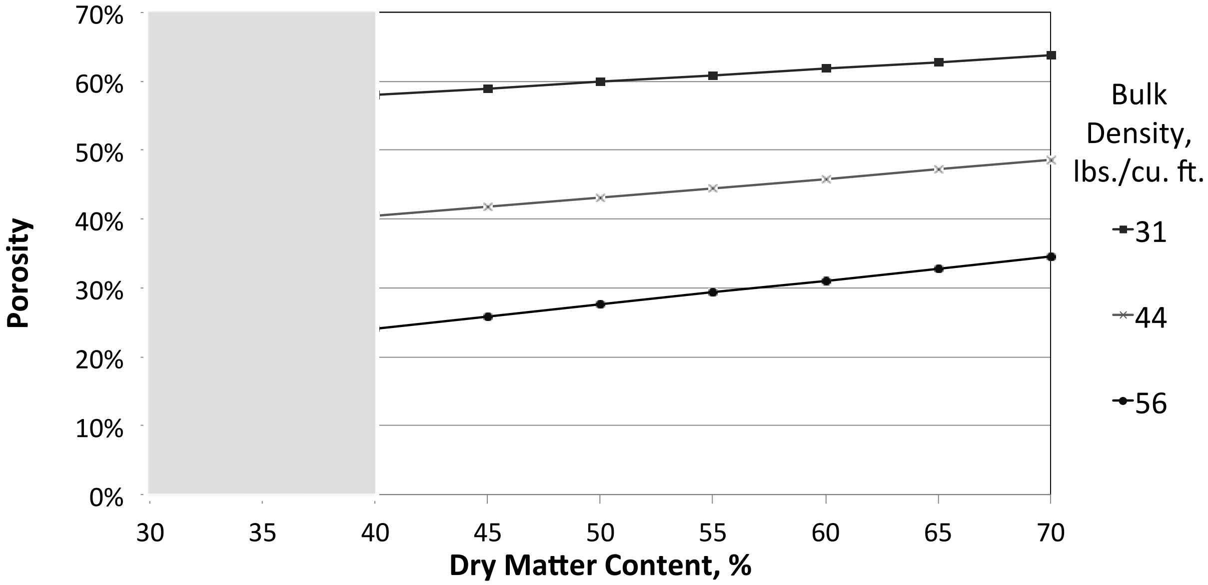

Figure 3. Porosity in silage as a function of dry matter content and bulk density. Shaded area is the recommended dry matter content for ensiling in bunkers, piles and bags.

An achievable minimum bulk density is 44 lbs./ft^3. This results in a porosity of 40% in our normal ensiling range of 30 to 40% dry matter. If you are weighing loads as they come to the silo, all you have to do is sum the weights and divide by the rough volume filled to give you an approximate density as you are filling the bunker or pile. That will allow you to estimate on-the-go how you are doing. When harvesting drier crops, you will notice that the weights of loads go down and that will indicate that you need to do more packing to achieve a good density.

A high bulk density is achieved similarly to a high dry matter density. Heavy packing tractors and time per ton are the most important factors. Other factors include how thinly loads are spread in the silo, dry matter content, particle size and depth of the silage. If you want to improve your silage densities in bunkers or piles, spreadsheets (Bunker Silo Density Calculator and Silage Pile Density Calculator) are available on the Team Forage website listed above that allow you to estimate how changes in your packing practices will improve density. As you work with the calculator, you will note that it is much easier to achieve 44 lbs./ft^3 bulk density if you put up silage at recommended dry matter contents (30 to 40%).

A final factor that affects density but is not in the spreadsheet is slope. The slopes front and back in bunkers and the slopes on all four sides of a pile should be lower than 1 vertical:3 horizontal. Beyond ensuring good density, a low slope reduces the risk of a packing tractor tipping over, allows piles to be packed safely side to side as well as front to back, and helps in securing the cover.

Smooth Face. The third factor affecting losses during feed out is the smoothness of the face. The majority of silos are unloaded with a bucket on a skid-steer, tractor or payloader. On piles, it is much easier to make a smooth cut by driving parallel to the face and loosening silage using the side of the bucket. Even so, it is difficult to provide as smooth a face as can be achieved with various defacers.

What is the value of a smooth face? Figure 4 shows the difference in dry matter losses between a smooth face and a very good job using a bucket. The smooth face reduces oxygen penetration into the silage face and thus gives you better dry matter recovery. The difference in losses between the two removal methods decreases at higher densities and feed out rates. Nevertheless, there is still approximately a 1% improvement in dry matter recovery even with high density and good feed out rates. Even with such modest improvements, it does not take long to pay for either attachments to buckets or dedicated defacers, especially on larger farms.

Finally, remove only what you need for the day from the face. Loose silage at the bottom of the face is much more likely to heat either there or in the feed bunk. So the third principle of making high quality silage is: *3) Remove only the silage that you will feed that day, leaving a smooth face*.

COVERING

The preceding factors deal with the highly variable losses during feed out, but losses prior to opening can be variable too. Aerobic losses during storage are controlled by one factor – how well the silo is sealed. For bunkers and piles, that means the plastic that is used to keep oxygen out and how it is held in place.

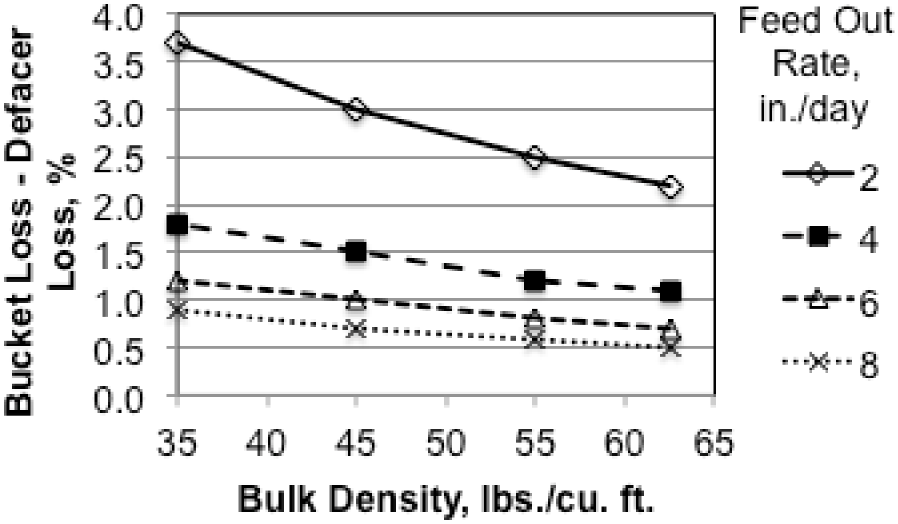

Figure 4. Difference in feed out dry matter losses between using a bucket and a defacer as a function of bulk density and feed out rate. Based on Muck and Rotz, 1996.

Type of Plastic. The thickness and type of plastic film that you use can make a difference in storage losses. Research at the US Dairy Forage Research Center has looked at various films for covering bunkers. Our farm had traditionally used a 6 mil black polyethylene film. We compared it for two years with an 8.5 mil white polyethylene (black underside) and found the white film improved dry matter recovery 5 percentage points in the top 6 in. of silage. The farm crew liked the white film because it behaved better when covering on a breezy day and stretched less under foot on warm days. Later we compared the white film with the black side up vs. the white side up. Losses were not affected by which side was up, but there was greater browning of the silage at the top when the exposed surface was black.

Over the past 5 years, we have been comparing several oxygen barrier films with 8 mil white polyethylene. Under the middle of the sheets, the quality of the silage has always been higher under the oxygen barrier film (i.e., higher lactic acid, lower acetic acid) even when there has been no significant difference in dry matter losses. The bottom line is that the quality of a film does affect oxygen transmission.

Securing the Plastic. The best film cannot prevent spoilage losses if it is not secured tightly to the crop. Overlap sheets by at least 3 to 4 feet. The edges of sheets on bunkers should be sealed with tires or gravel bags butted against one another to form a continuous seal. The film on the edges of piles can be sealed with soil or sand in place of tires or gravel bags.

Away from the edges, you want to keep the film from billowing in the wind, which can act like a bellows to draw air under the cover. Securing the film most commonly is done with tires or tire sidewalls. Ideally the whole surface should be covered with tires touching tires. Tire sidewalls are much easier to handle, don’t collect water and can be effective. However, their effectiveness depends on typical wind velocities in your area. At our research farm, our bunker films are usually covered with tires on the edges, at seams and down the middle of sheets while sidewalls are used in between. This seems to work well in our case, but our bunkers are built into a hill that protects them from prevailing winds. If you are using a lot of sidewalls and see spoilage under a high quality film, then you may need to increase the number of tires or you may have side slopes that are too steep for sidewalls to work effectively.

With oxygen barrier films, we have used woven tarps and gravel bags to protect and secure the films. These have worked well and seem to go on faster than distributing tires. The down side is that the tarp has to be used multiple years to be cost-effective. That may not be an issue in the Southwest, but in Wisconsin that means shoveling snow off the tarp during winter rather than quickly cutting the film with a utility knife.

A final issue related to securing the film is the shoulder of bunkers. For years at our research farm, we cut the sheet for the top of our bunkers a little bit wider than the bunker so that the plastic could ride up the wall and form a trough that would minimize the rain that would run off the top and down the walls of the bunker. Unfortunately we would still get spoilage at the shoulder because the tires would not provide a perfect seal. When we began working with one of the oxygen barrier films, they wanted us to use their system, which included putting film down the walls, lapping those sheets onto the top at least 3 feet and then securing the top sheet. This eliminated visible spoilage at the shoulders and reduced losses by 18 percentage points in the top 6 in. of the bunker shoulders. Since those experiments, our farm manager has continued to use film down the bunker walls. The farm crew is not really keen about putting the film on the walls prior to filling, but no one is sad about not having spoiled silage to remove at feed out. On top of that, having no spoiled silage at the top keeps us from having to choose between two bad alternatives – feeding spoiled silage to livestock or risking workers' safety to pitch the spoiled silage.

Monitoring the Plastic. The last issue on covering is monitoring. No matter how well you secure the film, it is vulnerable to punctures from birds, rodents, raccoons and other wildlife as well as hail. This can lead to substantial losses over the course of months of storage. You should develop a routine to weekly survey your silo storages and patch holes with tape that is specifically designed for the plastic. This is not a job for duct tape. A weekly survey is particularly important for bag silos because of the high surface-to-volume ratio and the lower densities typically in bags.

The fourth principle for making high quality silage thus is: *Use a high quality film to cover your silo, securing it tightly to the crop, monitoring it regularly and patching as needed*.

ADDITIONAL FACTORS

The four principles above are the most important for reducing spoilage losses and their negative effects on silage quality. There are several other factors that influence silage quality.

Crop Quality at Harvest. The quality of a silage starts with the quality of the crop at harvest. If the crop is too mature at harvest, it will also result in a silage of lower nutritional value. Conversely, a silage of high nutritional value starts with a high quality crop. However, more than nutritional value is important. The crop needs a sufficient sugar content and proper dry matter content to ensile well. Ensiling below 30% dry matter increases the chance for a butyric acid (clostridial) silage, particularly in alfalfa silage. Even in corn silage, it is possible to have a funky (although not clostridial) fermentation when ensiled too wet. If alfalfa gets rained on during wilting, leaching of sugars can make a clostridial silage more likely. In such cases wilting to 40% dry matter may be necessary to avoid a clostridial fermentation.

Speed of Ensiling. Speed of filling was an issue 20 to 30 years ago when many farmers were taking a week or more to fill a silo. While the silo is open and being filled, plant respiration is using up oxygen that enters the crop in the silo. Most of that oxygen is used up in the first foot or two below the surface. So with slow filling, heating and losses of sugars from plant respiration were significant. With today's larger harvesting equipment and the increased use of contract harvesting, filling losses are less a problem. In fact often we would like to slow down the contractor so that we can do a better job of packing.

Additives. Additives can modify silage quality. Lactic acid bacterial inoculants supplement the natural lactic bacteria on the crop to help ensure a good fermentation. Homofermentative inoculants such as *Lactobacillus plantarum* shift fermentation toward lactic acid, decreasing pH rapidly and improving dry matter recovery. Various homofermentative inoculants have also been shown to increase milk production and improve gain in growing livestock. *Lactobacillus buchneri* is a heterofermentative lactic acid bacteria that improves the aerobic stability of silages (i.e., resistance to heating and spoilage) by increasing acetic acid content. Propionic acid or propionic/acetic additives also increase aerobic stability by inhibiting yeasts and molds. Anhydrous ammonia is sometimes added to corn silage for increasing the crude protein content of the silage as well as increasing aerobic stability.

SUMMARY

Silage preservation depends on the establishment and maintenance of an anaerobic environment as well as the fermentation of sugars by lactic acid bacteria. The losses of CO_2 from fermentation are generally small. So the biggest source of losses is respiration by spoilage microorganisms caused by oxygen entering the silage during storage and feed out. To minimize these losses, the keys are:

- Designing a silo/pile so that feed out rate is high
- Packing the crop to achieve a low porosity
- Using a high quality film to cover a silo, securing it tightly to the crop, monitoring it regularly and patching as needed
- Removing only the silage needed for that day, leaving a smooth face.

If you do these four things along with harvesting the crop at the proper maturity and dry matter content, you will be able to produce consistently high quality silage.