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SIZING AND MANAGING SILAGE STORAGE TO MAXIMIZE PROFITABILITY

Brian J. Holmes
Biological Systems Engineering Department
College of Agricultural and Life Sciences
University of Wisconsin-Madison

The Ensiling Process

Silage is made by anaerobic (absence of oxygen) fermentation of readily available sugars into organic acids by a variety of bacteria. Lactic acid is the preferred fermentation end product since it provides the best preservation. For this process to be most effective, Pitt [1990] states the following conditions must be met.

-Sufficient plant sugars;
-Lactic acid bacteria present in the forage;
-Anaerobic conditions;
-Proper dry matter content (30-50% DM).

Care must be taken to harvest at optimal times and minimize the loss of sugars during harvest so they will be available for good fermentation. Overly mature forage will be naturally low in sugars. During the wilting stage, the plant respires, using sugars as an energy source. Leaf loss and precipitation can remove valuable sugars before the forage is delivered to storage. By wilting to no less than 50% DM, dry matter losses at harvest can be kept below 8%. Practices which promote rapid field drying reduce respiration time and exposure to precipitation.

Warm, moist environments encourage lactic acid forming bacteria to grow quickly. Handling the crop increases the number of bacteria which are added to the vegetative material. When conditions do not support large numbers of lactic acid forming bacteria, inoculation with a commercial source can be beneficial to obtaining a good fermentation.

Anaerobic conditions are achieved during fermentation by expelling as much air (oxygen) as possible from the silage mass during silo filling and by precluding oxygen movement into the silage mass during fermentation. Achieving a 3/8-inch theoretical length of cut (TLC) for hay silage and a 1/4-inch TLC for corn silage with the forage harvester, providing uniform particle size distribution (avoiding separation), and dense packing in the storage are the important management steps needed to expel oxygen during the silo filling process. Oxygen exclusion during fermentation is accomplished by rapid filling of the silo, using a structure with low oxygen permeability, and covering the exposed surface with a low permeability material. These objectives are accomplished with different practices, depending on the storage method used. Chopper knives should be sharpened and adjusted frequently to maintain proper particle size and distribution. Cracks and holes in tower and bunker silo walls and doors should be sealed before filling. Tower silos should have a distributor to improve particle distribution. Bunker silos should be filled by pushing feed with a blade. Using a blower to fill a bunker silo causes excessive particle separation. A bunker packing tractor should be heavy with single wheels to promote compaction. The silage should be spread in 6-inch layers before packing. Driving on the silage should be done throughout the filling process. Harvest, transport and packing equipment must be matched to allow enough packing time for the bunker. Achieving a 14-15 lbs DM/ft^3 density in a bunker is a reasonable goal. The silo bagging machine should be adjusted for maximum compaction. Sizing harvesting and storage to complete filling in three days or less reduces exposure to oxygen during the filling phase. If one uses an 8-hour harvest day, the harvest rate needed to deliver 109 TDM into one of the 19 ft × 9 ft × 90 ft bunker silos in a 3-day period requires a 4.54 TDM/hr (13 TAF/hr) harvesting capacity. (See "Sizing a Silo Storage" later in this article.) Based on the work of Ruppel [1992], Holmes [1995c] recommends a tractor of at least 8300 lbs (65 HP) operating over this harvest period to distribute and pack the silage to 14 lbs DM/ft^3 (40 lbs AF/ft^3) at 65% moisture. A more rapid harvest rate would require a heavier tractor.

Once filling is complete, immediate covering with an air-excluding material is required. Plastic films have proven effective sealers when properly installed. Weighting the plastic film with soil, silage or tires (touching each other) has been effective at limiting air movement under the bunker silo plastic. Plastic bag ends must be tightly sealed. Any holes in plastic covers or bags should be repaired immediately after they occur. Cover the top of a tower silo with plastic and blow silage on top to weight it. Trenching the plastic edges improves the seal on tower silos.

Minson and Lancaster [1965] studied the effects of different methods of covering silage in 3.5-ft deep bunker silos filled with direct cut grass forage. The silos experienced about 20 inches of rain during the 167- to 224-day storage/feedout period. Visible waste was discarded from the surface and weighed. Effluent or seepage was collected from all but one silo. Dry matter loss was measured in the effluent. Gaseous losses were obtained by subtracting visible waste and effluent from total dry matter loss. The results of the study are shown in Table 1.

Table 1. Effects of Cover Type on Dry Matter Loss
from a 3.5-ft Deep Bunker silo [Minson and Lancaster, 1965]

Cover Type	**None**	**Roof**	**Sawdust**	**Soil†**	**Limestone**	**Plastic**
Visible Waste (in)	3.0	4.0	3.0	2.0	2.0	0.0
Cause of Loss	**Two-year Average Loss (% DM)**					
Visible Waste	5.6	10.0	4.2	6.3	5.8	0.8
Effluent	7.5	3.0	6.5	5.0	‡	2.5
Gaseous	21.1	19.6	19.3	13.8	- - -	8.6
Total	**34.2**	**32.6**	**30.0**	**25.1**	**23.6**	**11.9**
Moisture Content at Recovery (%)	82.0	78.6	81.6	79.4	80.4	78.6

† Vegetation grew last 60 days.
‡ Leak caused effluent not to be collected.

No system of covering compared to preservation characteristics of plastic covered with soil. Deducting the 2.5-3% effluent loss that occurred due to juicing (plastic, roof) yields an effluent loss of 2.5-5% caused by rainfall percolating through the more porous covers.

Harvesting at the proper dry matter content is important to obtain good fermentation and to avoid seepage (effluent) losses from the silage. Effluent losses remove soluble sugars, soluble protein, organic acids and minerals. These nutrients are not available to the animals and can limit the fermentation process. The discharged effluents can have detrimental effects on surface and groundwater quality. Harvesting at 30% DM usually avoids seepage from most bunker silos. The denser compaction of tower silos requires a dry matter content of 35-45%, depending on height and diameter, to avoid effluent [Pitt, 1990]. High moisture conditions encourage clostridia bacteria to grow even if the silage acidity is low (4.5 pH). Clostridial fermentation causes odorous silage and can support disease-producing organisms. Dry matter loss will be higher with clostridial fermentation than with lactic acid bacteria fermentation.

Storage/Feeding Period

The fermentation process requires about two weeks. The storage/feeding process can last 50 weeks or longer. During the storage/feeding period, the opportunity for feed value loss can be great. Loss of dry matter occurs primarily as aerobic (presence of oxygen) microbial deterioration of silage. If oxygen is allowed to contact the silage, the microbes use the oxygen and the silage (energy source) to grow and multiply. Oxygen can penetrate sound concrete but moves through cracks much more quickly. Sealing concrete with an epoxy or plastic sheets helps to reduce the amount of oxygen entering the silage through silo walls. Holes in plastic covers and bags should also be repaired to exclude air. If the cover on a silo does not preclude water, rainfall and runoff carry dissolved oxygen into the silage mass. This oxygen is also available to microbes for aerobic silage deterioration. Percolating water washes away organic acids resulting in an elevated pH. Along with the dissolved oxygen, this provides a good environment for the microbial population to grow, especially in warmer weather. The gaseous losses of Table 1 are largely due to aerobic deterioration.

Percolating water exiting the silo as effluent carries nutrients meant for the animals, thus increasing dry matter loss. This is another potential source of water quality degradation. Thus any cover used on a silage surface should be placed in such a way that water sheds away from the silage rather than onto or through it. Percolation contributed to the effluent loss shown in Table 1. The 1.8-3.4% higher moisture content found at recovery (none, sawdust, soil, limestone covers) is an indication of how much precipitation has seeped into the silage.

Oxygen diffuses into silage at the silage removal face. Oxygen again encourages aerobic deterioration at this "face." Keeping a smooth face surface on the silage minimizes the depth of oxygen penetration. Oxygen penetrates this face more quickly if the silage was packed to low density (i.e., top vs. bottom of tower silo or inadequate bunker or bagger packing). This re-emphasizes the value of proper packing during filling. Sizing the storage for adequate face removal thickness (2 in/day tower silo, 6 in/day bunker/bag silo) helps to minimize spoilage at the removal face. This type of spoilage is seldom visibly evident but can be detected as forage that is warmed due to energy released during deterioration.

Care should be taken to operate equipment in such a way as to leave a smooth, tight silage face after removing silage. This is be done by scraping silage down the face with the edge of the front end loader bucket. Silage deposited on the floor is then picked up with the bucket without digging into the silage face.

In the case of bunkers and bags, the plastic covering is removed to expose only a 2- to 3- day supply of feed. This keeps a good seal on the remaining silage during most of the feedout period.

With good harvest, storage and feeding practices, dry matter losses can be kept to the 15-20% range. However, with poor management, 50% or more dry matter losses can occur. If good quality hay is valued at $100/TDM, a loss of 10% DM is a loss of $10/ TDM in the field. This doesn't even account for the fact that the dry matter lost is primarily the digestible nutrients (energy and protein) which have a much higher value than the undigestible portion of the feed. To optimize profits, these losses must be minimized.

Sizing a Silage Storage

Many factors influence the size of a silage storage system. The following storage criteria should be considered:

1. Has the capacity to store the quantity and quality of forage harvested;
2. Will store for the length of the feeding period;
3. Can be filled quickly and be covered just after filling without extended delays;
4. Has smooth face removal with adequate removal rate;
5. Has adequate width for packing bunker silo;
6. Has flexibility to store other feeds or quantities of feed;
7. Allows for rapid unloading.

The face area of a silo is determined by the minimum removal thickness, silage dry matter density, and the quantity of dry matter from that silo which must be fed to the herd each day. Several publications [Chastain et al., 1995; Holmes, 1992; Huhnke, undated] and computer software [Holmes, 1987] are available to show how to size horizontal silos. As an example, let's size a bunker and a tower silo to store hay silage for a 200-cow herd with replacements. The storage holds half the hay silage in the ration, and hay silage represents 67% of the forage in the ration. Thus the new storage will contain one third of all the forage. Other storages are used for the remaining hay and corn silage. Let's assume each cow consumes 25 lbs dry matter as forage daily, and each heifer consumes 12.5 lbs MD daily. The silage coming from the new unit represents:

lbs hay silage DM/day =

$$\left[\left(200\ cows \times 25\ \frac{lbs\ DM}{cow\text{-}day}\right) + \left(180\ heifers \times \frac{12.5\ lbs\ DM}{heifer\text{-}day}\right)\right] \times \frac{1\ lb\ hay\ DM}{3\ lbs\ forage\ DM}$$

The density of silage in the bottom of a tower silo is about 25 lbs DM/ft^3 and that in a bunker silo is about 14 lbs DM/ft^3. In the case of a bunker silo, use a 6-inch removal rate and calculate the face removal area as:

$$2417\ lbs\ DM\ fed/day \times \frac{ft^3}{14\ lbs\ DM} \times \frac{12\ in/ft}{6\ in/day} = 345\ ft^2$$

Using an average depth of 9 ft, the average width of a bunker must be 38 ft. Using a storage period of 270 days, the quantity to be stored is 326 TDM. Selecting a 12-inch removal rate for the bunker silo design yields a 19-ft wide bunker (38 ft ÷ 2). Since this width is greater than 16 ft, an 8-ft wide tractor can pack all the way across the silage surface to obtain uniform packing. The 1-ft removal rate requires 270 ft of bunker length for a 270-day feeding period. One bunker of this length is difficult to fill quickly, keep covered during filling, and empty efficiently. Selecting three bunkers (90-ft length) allows rapid filling/covering of each with a shorter average drive distance to empty. One bunker can be open for feeding while another is being filled and fermented.

If we use a 2-inch removal rate in the tower silo, the area of the silage surface must be:

$$2417\ lbs\ DM\ fed/day \times \frac{ft^3}{25\ lbs\ DM} \times \frac{12\ in/ft}{2\ in/day} = 580\ ft^2$$

A 27-ft diameter silo will satisfy this need. Selecting a tower silo with a 26-ft diameter from a silo table [Bickert, 1995], the silo height must be 68 ft (allows 5 ft for settling and unloader) to hold this much material.

Storage Costs Must Include Annual Cost

Silage storage costs include capital investments and many annual costs which can be large or small, depending on type of storage and management of the selected system. The relative advantage of one storage system over another will be influenced by initial capital outlay and the sum of all annual costs [Holmes, 1995a; Holmes, 1995b].

In an attempt to obtain a realistic understanding of the economics of silage storage, an analysis was developed. This analysis considered the capital and annual costs for hay silage stored in glass lined steel, cast-in-place concrete and concrete stave tower silos, as well as concrete above-ground bunker silos, drive-over piles, silo bags and wrapped silage bales. Capital costs were for structures and equipment used in the operations of filling, storing and emptying the hay silage. Since the analysis was for silage storage, costs of harvest, transport to storage, and moving feed to animals were not considered. Silos and gravel pads for placing bags, piles and bales were considered structures with a 20-year life expectancy. Equipment was assumed to have a 10-year life. An attempt was made to include all costs. Annual costs included annualized capital costs (depreciation, interest, repairs, taxes and insurance), labor, plastic coverings, fuel/lubrication, and dry matter lost during storage. Hay was assumed to have a value of $85/TDM. Tractors were assumed to have other duties on the farm, so their costs, allocated to storage, were based on a proportion of time used with hay silage storage.

Four quantities of feed were selected for storage as a major variable changed. This change affects most of the other variables. Capital and annual cost variables were increased as the volume stored increased. The capital cost and annual cost per ton of dry matter stored are presented in Tables 2 through 5. From Tables 2 and 3, it becomes apparent that:

1. Capital costs/ton of new steel oxygen-limiting silos are appreciably higher than those of the other systems. Capital costs for reconditioned steel silos are competitive with cast-in-place oxygen-limiting silos.
2. Capital costs of silo bags, silage piles and wrapped bales are lowest and quite similar.
3. Capital costs for bunker silos and stave tower silos are in a similar range, with the bunker silo having an advantage.
4. Significant economies of scale exist up to 768 TDM stored with smaller economies above 768 TDM.

When total annual costs are considered (Tables 4 and 5), one might conclude:

1. The annual cost of new steel oxygen-limiting silos are the highest of all systems considered.
2. The annual cost of reconditioned steel and cast-in-place concrete oxygen-limiting silos are competitive with each other but still slightly more expensive than the other systems.
3. The annual costs for top unloading concrete stave silos and bunker silos are cost competitive and in the middle of the range of annual costs for all systems considered.
4. The packed silage pile, silo bag and wrapped bales have similar annual costs and are the lowest annual cost systems.
5. Economies of scale are present up to about 768 TDM stored.
6. When less than good management is used with any silo, the dry matter loss will be higher than those used in this analysis. For example, a 13% DM loss was assumed for bunker silos using good management. Using 18% and 25% DM losses, the annual cost of bunker silos may equal or exceed those of oxygen-limiting cast-in-place or reconditioned glass lined steel tower silos.

Based on this analysis, several other conclusions can be drawn.

1. Even though stave tower and bunker silos have higher capital costs than some of the other systems, their annual costs are quite competitive with some of the other systems.
2. Costs of a silage handling system should include costs for harvest, transport, storage and delivery to the animals. Since it appears that seven of the eight systems have similar annual storage costs, the harvest and handling system costs may be more influential in determining which systems have the lowest total annual costs.
3. All tower silo costs are not the same. Top unloading tower silos can compete on an annual cost basis with many of the other storages. However, oxygen-limiting silos are at an economic disadvantage when purchased new at high capital cost. Reconditioned

steel OL and cast-in-place OL silos could compete with other systems if factors other than those used in this analysis are considered. Selecting fewer, larger-diameter silos for large volumes stored and using multiple additions of silage would reduce capital and annual costs.

Table 2. Total Capital Cost for Four Quantities Stored.

	Quantity Stored			
	384 TDM	**768 TDM**	**1,536 TDM**	**3,072 TDM**
Storage Type	**Total Capital Cost ($)**			
Steel/Glass OL Tower, new	163,825	230,825	452,025	894,425
Steel/Glass OL Tower, reconditioned	102,825	143,625	277,625	545,625
Cast-in-Place OL Tower	109,625	143,225	276,825	544,025
Concrete Stave Tower	73,825	105,985	202,345	395,065
Above Ground Bunker	58,525	78,945	135,603	233,175
Packed Silage Piles	24,165	31,125	42,975	71,775
Bagger	33,895	40,715	54,355	81,635
Wrapped Bales	24,603	29,425	39,505	58,205

Table 3. Total Capital Cost/Ton Dry Matter for Four Quantities Stored.

	Quantity Stored			
	384 TDM	**768 TDM**	**1,536 TDM**	**3,072 TDM**
Storage Type	**Total Capital Cost/TDM ($/TDM)**			
Steel/Glass OL Tower, new	427	301	294	291
Steel/Glass OL Tower, reconditioned	268	187	181	178
Cast-in-Place OL Tower	285	186	180	177
Concrete Stave Tower	192	138	132	129
Above Ground Bunker	152	103	88	76
Packed Silage Piles	63	41	28	23
Bagger	88	53	35	27
Wrapped Bales	64	38	26	19

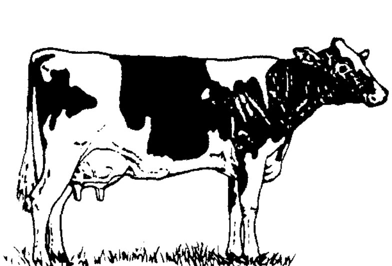
Table 4. Total Annual Cost for Four Quantities Stored.

	Quantity Stored			
	384 TDM	**768 TDM**	**1,536 TDM**	**3,072 TDM**
Storage Type	**Total Annual Cost ($/yr)**			
Steel/Glass OL Tower, new	31,428	45,986	90,165	178,523
Steel/Glass OL Tower, reconditioned	21,151	31,602	61,396	120,985
Cast-in-Place OL Tower	22,349	31,829	61,851	121,896
Concrete Stave Tower	17,502	27,755	53,702	105,598
Above Ground Bunker				
13% DM loss	17,290	28,219	53,027	99,636
18% DM loss	18,922	31,483	59,555	112,692
25% DM loss	21,207	36,052	68,694	130,970
Packed Silage Piles	14,051	24,670	45,688	88,715
Bagger	14,703	24,322	43,562	82,040
Wrapped Bales	14,005	24,351	45,102	86,402

Table 5. Total Annual Cost/Ton Dry Matter for Four Quantities Stored.

	Quantity Stored			
	384 TDM	**768 TDM**	**1,536 TDM**	**3,072 TDM**
Storage Type	**Total Annual Cost/TDM ($/yr-TDM)**			
Steel/Glass OL Tower, new	82	60	59	58
Steel/Glass OL Tower, reconditioned	55	41	40	39
Cast-in-Place OL Tower	58	41	40	40
Concrete Stave Tower	46	36	35	34
Above Ground Bunker				
13% DM loss	45	37	35	32
18% DM loss	49	41	39	37
25% DM loss	55	47	45	43
Packed Silage Piles	37	32	30	29
Bagger	38	32	28	27
Wrapped Bales	36	32	29	28

NOTES



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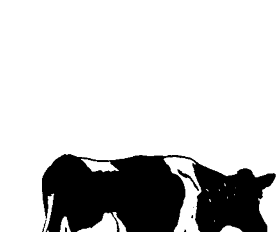

The results of this analysis are a function of the assumptions used to develop the values. One should not make financial decisions based on this analysis but should use a similar method of accounting for all of the costs for the operation. Some factors which could be adjusted to lower capital costs and annual costs include:

1. Increase tower silo, bunker silo and bag silo size, and reduce number of silos used as volume of feed increases.
2. Increase the slope on silage piles to reduce storage pad size. A 3:1 side slope was used.
3. Increase utilization rate and reduce size for tower and bunker silos. A 1x utilization rate was used. A 1.5x utilization rate can be used for oxygen-limiting silos. With two silos, a 1.2x utilization rate is achievable for top unloading towers and bunkers. With four or more silos, a 1.5x utilization rate could probably be attained for top unloading and bunker silos.
4. Reduce the proportion of time a tractor is allocated to a specific feed storage task.
5. Reduce the dry matter loss assumptions for any and all storages.

Conclusions

Understanding how silage is made through the fermentation phase and how silage exposed to oxygen deteriorates during the fermentation and storage/feedout process is critical to the motivation of applying recommended practices to the silage making process. These issues have been discussed as they relate to sizing and managing bunker and tower silos. A discussion of the capital and annual cost of several types of silage storage systems was also presented. One conclusion from this analysis is that how a storage is managed will influence the total annual cost of that system. With less than good management, the annual cost of a lower capital cost system can be driven up to be more costly than a higher capital cost system requiring less management/labor time.

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