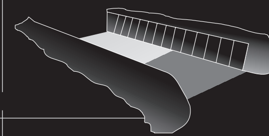
Managing and Designing Bunker and Trench Silos



Agricultural Engineers Digest AED 43

Published by MidWest Plan Service

2nd edition, February 2004

Authors

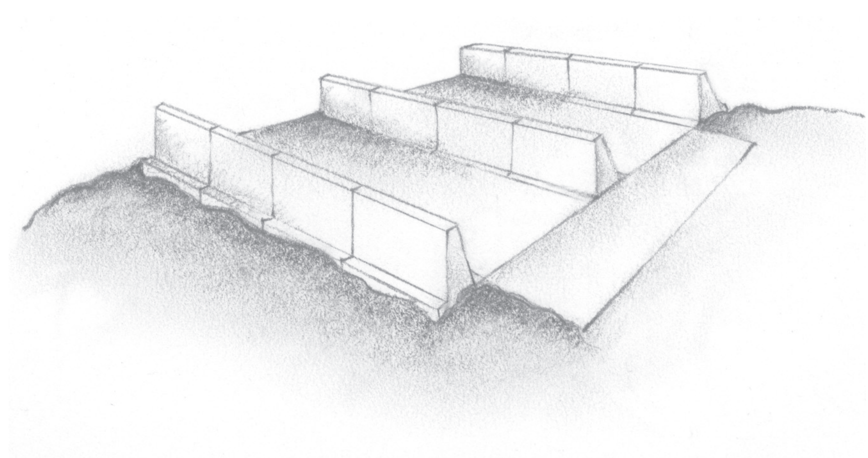
Brian J. Holmes
Extension Agricultural Engineer
University of Wisconsin-Madison

Richard Muck
Agricultural Engineer, U.S. Dairy Forage Research Center, USDA, ARS

This publication reviews some of the general concepts involved in choosing and using bunker and trench silos, collectively called horizontal silos. It discusses the management techniques and design principles that can help a producer use a horizontal silo to its maximum potential. An example worksheet provides a step-by-step procedure for calculating the dimensions for a horizontal silo.

For producers milking more than 100 head or feeding more than 100 head of beef cattle, the horizontal silo may be a viable option. Horizontal silos can have higher storage losses than tower silos. If, however, horizontal silos are well managed, losses can be kept in the 13-17% range. Producers who are using horizontal silos for the first time will need to learn new management skills.

Horizontal silos are particularly well suited for storing corn silage. Management of hay crop silages in horizontal silos is more difficult because of several-times-per-year harvesting and increased spoilage rates caused by higher pH and dryer forage. Ground or rolled high moisture corn or grain sorghum can be stored in horizontal silos. A horizontal silo is not a good choice for storing whole-kernel, high moisture corn without some processing.



Contents

Types of Horizontal Silos

Horizontal silos are of two types:

- **Bunker.** Bunker silos (see Figure 1a, 1b) generally have a grade level floor and above ground walls. Reinforced concrete panel sidewalls are self supporting or supported by concrete buttresses. The walls can be purchased as precast panels, tilted into position, or cast-in-place. Soil also can be used to form sidewalls; however, spoilage may be higher, and some soil will be scraped into feed. Place plastic on soil to limit spoilage.
- **Trench.** Trench silos (see Figure 1c) are built into the ground. Sidewalls may be soil or concrete. Trench silos are considered safer than bunker silos because of the reduced risk of driving over the edge as the silo is filled and packed.

A concrete or asphalt floor is required in nearly all instances to ensure all-weather access to feed. Additionally, most horizontal silos require an apron in front of the silo. Concrete is prone to deterioration due to silage acids, and asphalt is more prone to damage resulting from turning of loading and transport equipment.

Recommendations on concrete floors, wall panels, and construction practices are in the “Construction” section beginning on page 13. More complete information is available in the *Farm and Home Concrete Handbook*, MWPS-35.

Advantages and Disadvantages

Horizontal silos have the following advantages:

- Moderate construction costs.
- Low maintenance.
- Fast filling and feed removal.
- Longer forage material cut length than tower silos.

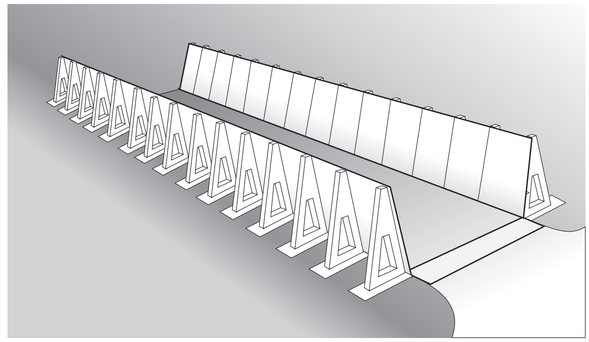


Figure 1a. Bunker silo. Tilt-up construction.

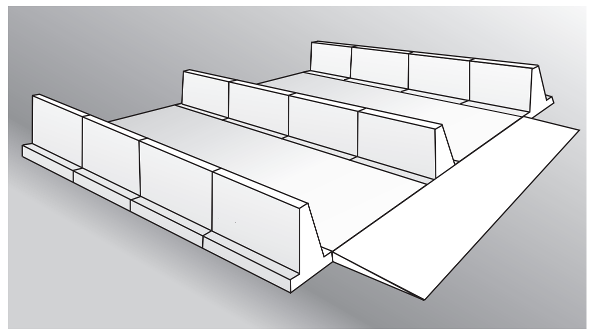


Figure 1b. Bunker silo. Free-standing panels.

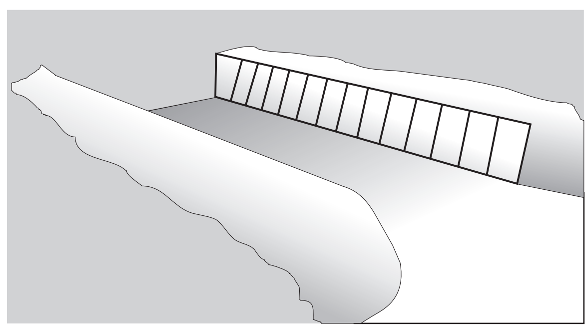


Figure 1c. Trench silo. Tilt-up construction.

Figure 1. Horizontal silos.

The last advantage is significant. Cut length has a profound impact on the metabolic function of a cow’s rumen and is especially critical with hay crop forage. A longer length of cut helps ensure high quality fiber to maintain better rumen function, reduce risk of acidosis, and bolster butterfat production. Tower silos cannot accommodate longer cut lengths very well. Longer cut lengths do not severely affect the front-end loader or face cutter methods used to remove silage from a horizontal silo. A dairy nutritionist should be consulted to determine the optimum cut length for your feeding program.

Among the disadvantages of horizontal silos are:

- Low filling flexibility.
- Filling labor.
- Heavy filling tractors.
- A need for a weighted cover.
- Typically higher storage losses compared to tower silos.
- Exposure of silage and operator to all kinds of weather during unloading.

Good design and construction combined with proper filling and removal practices minimize these disadvantages.

Minimizing Losses

Producers should be concerned with three types of losses:

- Handling losses incurred while moving silage from the field to storage.
- Spoilage losses in storage.
- Handling losses incurred while moving silage from storage to feeding.

Handling Losses

Handling losses can be difficult to control. They occur as forage is being raked, picked up by the chopper, and blown into a transport vehicle or when a vehicle sways and spills material over the sides. Even when the best care is taken to reduce handling losses, a manager will have difficulty obtaining handling losses less than 6-9% from field to storage, or 10% from storage to feed consumption. The best ways to minimize handling losses are to harvest at higher moisture content within the acceptable range for the crop and train personnel to operate equipment with care and to avoid overfilling transport vehicles.

Storage Losses

When a forage or feed material of sufficient moisture is placed and packed in a horizontal silo in the absence of air, fermentation occurs. This process is called *ensiling,* and the resulting material is called *silage*. The key components in the ensiling process are moisture content, the absence of air, and bacterial fermentation. The entire ensiling process takes 2-3 weeks.

Spoilage of stored silage can be a major problem, but silage can be managed to minimize storage losses. The most common storage losses are from effluent flow and growth of spoilage microorganisms (see Figure 2). Because most producers calculate silage needs based on the dry matter content of the feed products, understanding dry matter losses can help producers estimate their silage storage needs. Among the factors that can affect the amount of dry matter lost in a horizontal silo are these:

- Moisture content.
- Cut length.
- Time required to fill the silo.
- Length of time the surface of the silage is exposed to air and rain.
- The method and thoroughness of silage packing.
- The condition of the silo's walls and floor.
- The effectiveness of the cover at excluding rain fall and runoff.
- The effectiveness of the cover in excluding oxygen and avoiding air spaces between the cover and the silage surface.
- The method used to remove silage.

Horizontal silos are particularly well suited for storing corn silage because of the once-per-year filling and all-at-once nature of the harvesting operation. Smaller particle size, higher moisture content, and low buffering capacity allow corn silage to pack and ferment well.

Management of hay crop silages in horizontal silos is more difficult because of several-times-per-year harvesting methods and greater spoilage rates for hay silage than for corn silage. Spoilage can be reduced by harvesting with shorter particle lengths and at higher moisture content to facilitate packing (see Figure 2). Harvesting at higher moisture levels (60-65%, hay crop) also reduces field losses, compared to haylage or low moisture silage (40-60% moisture), because of lower leaf loss.

In horizontal silos, corn silage is stored at about 67% and haylage at about 63% moisture content. By contrast, corn silage usually is stored at about 60% moisture content and haylage at about 55-60% moisture content in upright silos.

A horizontal silo generally is not a good choice for storing whole-kernel, high-moisture corn. Whole-kernel, high-moisture corn in the 28-32% moisture range poses a special challenge when stored in a horizontal

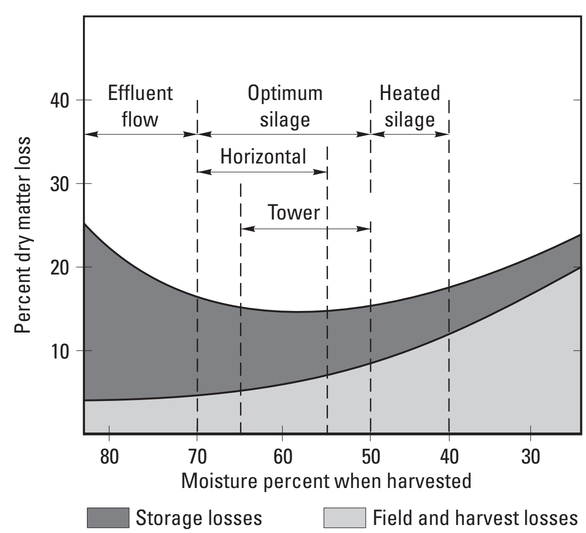


Figure 2. Estimated total field, harvest, and storage loss for grass and legume forages.

silo because of the large pore space between kernels. Air can move freely, thereby allowing the grain to spoil more easily. Whole-kernel, high-moisture corn should be ground before being put into storage. Grinding the corn significantly reduces pore space, thereby reducing the rate of spoilage.

To minimize storage losses, use the following techniques:

- Ensile forage at the proper moisture content (55-70%).
- Fill the silo rapidly.
- Exclude oxygen by packing the forage well and then covering it.
- Cover in such a way as to exclude rainfall and runoff.
- Keep the silo sealed for **at least** two weeks to allow time for fermentation. Four weeks or more is preferred to make a stable silage that does not heat in the feedbunk.
- Limit exposure of the silage to oxygen by maintaining a smooth face and by rolling back the plastic cover to uncover less than three days' supply of feed.

Silage Effluent

Properly ensiled silage will not produce high levels of leachate. However, even small amounts of leachate can accumulate and result in significant amounts of effluent flowing from large silos. Forages harvested at high moisture content are most susceptible to leaching or *effluent flow* (see Figure 2). The most important characteristics of silage effluent are these:

- Loss of feed value.
- Corrosive effects.
- High polluting strength.
- The ability to form poisonous gas.

Silage effluent has a high biochemical oxygen demand (BOD). If allowed to enter a water supply, silage effluent removes a large portion of the available oxygen from the water, causing a possible toxic condition and fish kills. The potency of uncontrolled effluent not only severely pollutes water, it will also burn or kill vegetation if applied at full strength or allowed to run directly onto crops from a leaching silo.

Include silage leachate collection and disposal with the overall waste management planning for the farmstead. Common disposal practices include:

- Diverting to an open-top liquid manure storage.
- Diluting leachate with equal parts of milking center wastewater or barnyard runoff before using it for irrigation.

DO NOT add effluent to storage tanks, reception pits or sumps located inside livestock buildings, other enclosed spaces, or any covered underground manure storage. Silage effluent, especially when mixed with manure, can produce poisonous gases that result in almost instant death to humans and/or animals. Whatever the effluent control system, it must also have a regular maintenance schedule to ensure it will continue to function correctly. Contact the local county conservation district or the Natural Resource Conservation Service (NRCS) for design information and assistance to properly handle silage effluent. See also "Construction" page 13.

Spoilage Microorganisms

For crops ensiled sufficiently dry to prevent effluent losses, the vast majority of storage losses come from the growth of spoilage microorganisms. These include various yeasts, molds, and bacteria. These spoilage microorganisms require oxygen to grow. Under the best management conditions, they are active only at filling and feed out. However, substantial activity can occur during storage if the forage is not covered or if the cover is not well maintained.

Spoilage microorganisms consume the most digestible parts of the crop (sugars, other carbohydrates, fermentation products, and proteins) and produce carbon dioxide, water, and heat. This causes serious losses of dry matter and energy and leaves a silage of lower nutritional value. If the lactic and acetic acids produced by fermentation are eaten by some of the spoilage microorganisms, silage pH will rise, and an even wider group of microorganisms will be able to grow and spoil the silage. The heat produced by the spoilage microorganisms can also have a detrimental effect on the quality of the remaining silage, particularly if the crop has been ensiled too dry.

Heated Silage

Dryer silage has a higher porosity than wetter silage. If the silage is not well packed, more air is entrapped in the silage. The entrapped air will support more aerobic activity and result in increased silage temperatures. Because dryer silages have less thermal mass than wetter silages, the temperature rise in dryer silages will be higher than in wetter silages. This condition is called *heated silage* (see Figure 2). The silage that has heated will very gradually cool down, but if a continuous supply of air is available, a silo fire could result.

When silage heats, the high temperatures result in a denaturing of some of the proteins in the silage. These denatured proteins are indigestible or less well digested and reduce the feed value even further.

The best way to avoid heated silage is to harvest forages at the proper moisture content and to pack the forage properly. Cover the forage with oxygen-limiting plastic as quickly as possible. Contact a feed nutritionist to determine the proper time to harvest the crop being stored.

Compensating for Handling and Storage Losses

The goal in feeding is to have the proper amount of quality silage consumed by the animal. To compensate for the inevitable handling and storage losses, one needs to know what amount of handling and storage losses to expect. Table 1 lists some typical handling and storage losses.

Losses during each stage in Table 1 are based on the amount of material lost from the beginning of that stage. Stage and cumulative multipliers are also included in the table. The multipliers are used to determine the amount of silage needed to produce the desired amount of material at the end of the stage or multiple stages. The last two columns of the table show how much silage is needed, before losses, for the animals to consume 1,000 pounds of dry matter.

Example 1: *Amount of dry matter loss during storage.*

A producer fills a horizontal silo with 360,000 pounds of dry matter. How much silage dry matter loss should be expected during the storage period?

Solution:

From Table 1 we can expect about 15% dry matter loss during storage. The amount of loss can be calculated by:

0.15 x 360,000 lbs dry matter = 54,000 lbs of dry matter loss during storage

The silage remaining after storage is:
(1 – 0.15) x 360,000 lbs DM = 306,000 lbs DM

Example 2: *Amount of forage needed to be put into the feed bunk for animals to consume a desired amount.*

A producer has calculated that a herd needs to consume 1,000 pounds of silage dry matter per day. How much silage dry matter should be removed from the bunker silo?

Solution:

To calculate the amount that should be removed from the bunker silo, multiply the amount the animals need by 1.11 (stage multiplier from Table 1).

1.11 x 1,000 lbs of dry matter consumed = 1,110 lbs DM per day from storage

Example 3: *Amount of dry matter needed for the animals, considering all losses from the beginning of storage.*

A herd needs 1,000 pounds of silage dry matter per day. How much forage should be delivered to storage for each 1,000 pounds of dry matter consumed?

Solution:

Table 1 shows the cumulative multiplier for the two stages of storage and storage to feed consumption to be 1.31. The amount of silage needed to be loaded into storage for each 1,000 pounds consumed is:

1.31 x 1,000 lbs of dry matter consumed per day = 1,310 lbs dry matter per day placed into storage

Managing Horizontal Silos

To minimize losses, producers need to give careful attention to the following tasks:

- Organizing and managing the silo area.

Table 1. Typical silage handling and storage losses.

Stage	Loss During Stage	Stage Multiplier	Cumulative Multiplier	Forage Needed for animals to consume 1,000 lbs of Dry Matter	
				Start of Stage	End of Stage
Field to Storage	7%	1.08	1.41	1,410 lbs DM	1,310 lbs DM
Storage	15%	1.18	1.31	1,310 lbs DM	1,110 lbs DM
Storage to Feed Consumption	10%	1.11	1.11	1,110 lbs DM	1,000 lbs DM

DM = Dry Matter

Note: Values in the table are average, or typical numbers. If a producer has kept good records on losses, then those numbers should be used in sizing.

- Filling the silo; packing and covering the silage.
- Unloading the silo.

One way to minimize spoilage and increase flexibility is by using multiple horizontal silos. Using multiple horizontal silos can let a producer:

- Shorten silo lengths.
- Share a common wall between adjacent silos.
- Incorporate different feeding rates.
- Allow crops to be harvested at different times.
- Allow for storage of multiple types of crops.
- Fill one or more silos twice in a season.

Organizing and Managing the Silo Area

A recommended practice is to use separate and smaller silos for feeding hay silage and high moisture corn during the summer months. A smaller silo that is shallower and narrower allows a faster feed removal rate and keeps day-to-day deterioration at an acceptable level. Alternatively, some producers simply discontinue feeding high moisture corn during the summer. The quality of the feed deteriorates more quickly after it is delivered to the bunk during warm weather, so more frequent feeding is desirable regardless of the storage system used.

With smaller silos, each can be filled and covered more quickly. This helps to reduce the time the silage is exposed to air and precipitation, thus reducing the risk of dry matter loss. When a smaller silo has been emptied, it is available for refilling; a larger silo is available for refilling less frequently.

When the silo is empty, place evenly spaced marks at 1- or 2-foot intervals on the sidewalls as shown in Figure 11. These marks will aid in determining the feeding rate during the unloading period. Numbers below the marks also can be helpful in determining the amount of silage remaining in the bunker. The section on “Knowing and Managing the Feeding Rate” on page 10, explains in more detail how to use the information gathered using these marks.

As part of the strategy for organizing and managing the silo area, fence the storage area to reduce the risk of deer, livestock, or other stray animals walking across the surface of the silo. Some producers have used an electrically charged wire 4-6 inches above the ground to discourage raccoons and similar animals from entering the area.

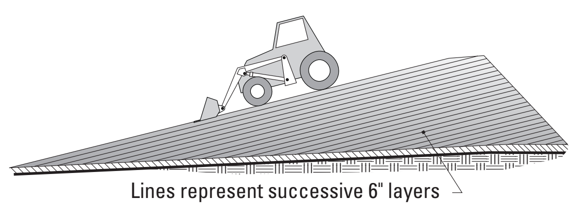
Implement a control program to limit the rodent population on the farm. Keep grass and weeds in the area near the silo well trimmed to help control rodents, and store tires used to weight down the silo cover in a manner that does not provide cover for rodents. Once rodents discover corn in a silo, control becomes more difficult.

Filling, Packing, and Covering

Stage of crop maturity, length of cut, moisture content, filling practices, packing methods, and the quality of the cover all influence the storability of forages. Packing is often overlooked or found to be inadequate. The importance of packing cannot be overemphasized. The goal in packing is to reduce the amount of oxygen that is initially in the forage and to prevent air from infiltrating the silage after packing. Minimizing oxygen in the silage reduces the amount of spoilage.

Once filling of the horizontal silo begins, packing should be continuous. Pack silage in layers not exceeding 12 inches thick. If filling can be completed in one day, use 6-inch horizontal layers. Packing in 6-inch layers using the progressive wedge technique is preferred when several days are needed to fill the storage (see Figure 3). During filling, minimize the amount of exposed silage surface.

Operate the packing tractor at a slow speed to give time for forage particles to be pressed together



3a. Side view of a horizontal silo during filling.

3b. Pictoral view of a horizontal silo during filling.

Figure 3. Filling of horizontal silos.
A tractor may rollover during the packing operation, causing severe injury and possibly death. Use rollover protection with seat belts and a limit on the side slope of 1:4.

and interlocked. Driving the tractor over the forage is commonly called rolling. Rolling the forage in two different directions enhances packing, but do not drive tractors perpendicular to slopes greater than 1:4 (see Figure 4a, d). Roll each layer of silage at least twice before placing the next layer. In addition to rolling between placing of layers, roll the entire silo at least one hour at the beginning and end of each day.

Use a weighted-wheel tractor with well-lugged tires, rollover protection, and seat belts. Silage density is highest when using the heaviest packing tractor available. In cases where forage is delivered to the storage rapidly (self-propelled forage harvester), more than one packing tractor may be needed. Use the "Bunker Silo Packing Density Spreadsheet" to determine packing management to achieve at least 15 lbs DM/ft^3. The spreadsheet can be found at URL http://www.uwex.edu/ces/crops/uwforage/storage.htm. Four-wheel drive tractors give better control than do rear-wheel drive tractors. Track-mounted equipment is fine for pushing and leveling silage but should not be relied upon for packing due to lower contact pressures and a general inability to identify low and soft spots.

Managing rainwater runoff to keep it away from silage is critical for preserving silage quality. As filling is completed, keep the top surface slightly rounded to ensure good drainage of precipitation. Allowing water to pool along the edges increases the risk of seepage into the silage mass with increased spoilage. Runoff water should be directed down the inside of the wall with a plastic liner protecting the silage (Figure 4a), toward drainage channels (Figure 4b), toward the end of the silo to the ground, (Figure 4c), or as a last resort next to the wall with plastic lapped up the wall (Figure 4d).

Cover the bunker immediately after filling. Silos requiring several days to fill should have the exposed silage covered with a weighted plastic cover at the end of each day's packing. A study showed that waiting even 7 days will result in significant dry matter loss in the top 13 inches. However, installing a cover late is better than not installing one at all. In the same study, once the cover was installed after 7 days, further dry matter loss was similar to that experienced in silos where covers had been installed immediately.

Black or white plastic is most commonly used to cover the silage. A 6-mil thickness is minimum. Generally the thicker the plastic, the better the oxygen exclusion.

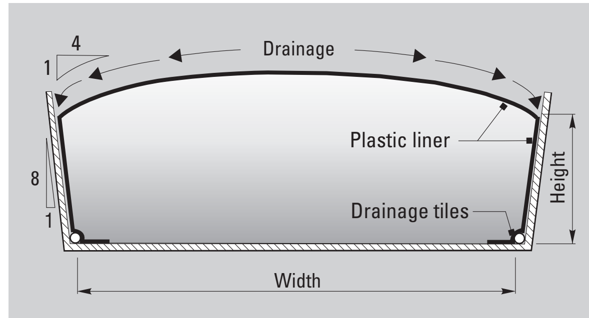


Figure 4a. Water draining between wall and interior plastic liner.

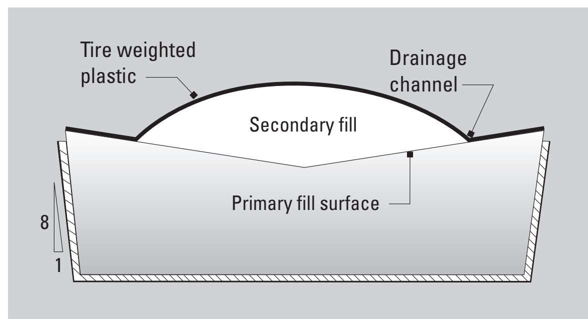


Figure 4b. Packing to create an interior drainage channel.

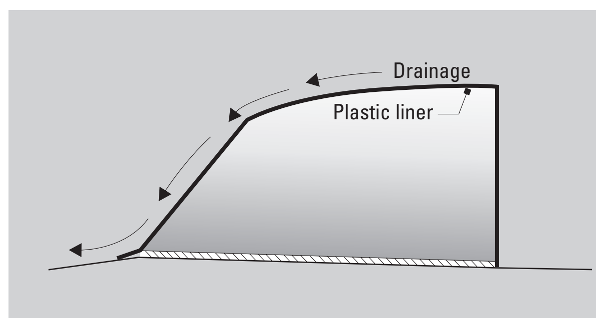


Figure 4c. Water draining off the end, side view.

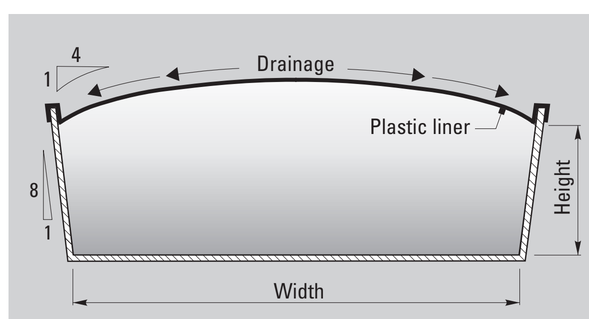


Figure 4d. Shaping horizontal silos to shed water, cross-section.

Figure 4. Directing runoff water.
Note: Tires left off all figures so drainage patterns could be better demonstrated. Silo floors are sloped from back to front.

The cover should be solidly weighted to reduce billowing and pumping of air during windy conditions. Used car tires are the most common means of holding down the plastic cover. Install tires on the cover so they are touching each other (Figure 5). Plastic bags filled with sand, limestone, or other heavy material also can be used. Other products used successfully for weighting the plastic include sawdust and ground limestone. A material such as limestone should be applied to the perimeter to hold the cover down even if tires are used.

One problem with using tires to weight down the cover is that they can become a breeding ground for mosquitoes when water collects in them. To minimize this problem, cut holes in the low side of each tire to prevent water accumulation. An alternative is to split tires so each sidewall with a section of tread is laid down separately. When using this method, cut holes into the sidewall to reduce entrapment and water ponding (Figure 6). Place tires with the cut side up so that the steel belting does not cut into the plastic. Split tires are much lighter than whole tires and are susceptible to blowing off on windy sites. Use several layers of split tires on these sites.

Figure 5. Tires used to hold down the plastic cover.
Install tires on the cover at a rate of 15 to 20 per 100 square feet.

Figure 6. Split tire with sections of sidewall removed.

Unloading Silage

The operator who unloads the silo can play an important role in minimizing dry matter loss. The operator should be experienced and dedicated to doing a good job. In the unloading process:

- Keep a smooth vertical silage face.
- Avoid leaving fissures or cracks in the silage.
- Clean up all the fallen silage left at the base of the face.

Silage should be removed from the silo in a manner that preserves a smooth face. Studies have indicated that significant loss of silage quality occurs to the silage face within just 6 hours after silage is removed. Therefore, a smoother face minimizes the amount of exposed silage leading to less spoilage.

Horizontal silos adapt readily to feed wagon distribution. Bucket loaders are the most common method of unloading (Figure 7). Bucket loaders can be part of a tractor front-end, skid steer, or industrial loader. Many producers use a bucket loader for other farm applications.

Another method of removing silage is with mechanical face cutters. Face cutters will produce a smoother face than bucket loaders and reduce the amount of dry matter decomposition.

Figure 7. Bucket loader removing silage.

Removing Silage

Face removal rates should never go below 6 inches per day during the summer and 4 inches per day during the winter. Minimum removal rates are most critical with corn silage and high-moisture corn, becoming more important as moisture content decreases.

The preferred method of removing silage is by slicing the silage from the top and allowing it to fall down (Figure 8a). In silos with very high sidewalls, the slicing method of unloading may not be practical.

One successful technique is to first remove silage from the base of the mass at the floor, creating a cavity. Then silage is chipped away from the face with a downward motion of the bucket with the force being applied just above the cavity (Figure 8b). Another method is gouging the front end loader into the stack and dislodging silage by lifting the bucket. Gouging into silage can create cracks or crevices that allow air to penetrate deep into the silage stack leading to increased spoilage and should not be used.

In wider silos, an operator may be able to shear the silage horizontally (Figure 9). This method enables the operator to estimate more easily the thickness of the slice of silage being removed. The size of the tractor and bucket loader will dictate whether this method can be used. Usually a minimum of a 40-foot wide silo is needed for horizontal shearing.

Do not create an overhang when unloading from silos with high sidewalls (Figure 10). Silage overhangs are caused in part by spoiled silage that has formed a crust. They may look safe to walk on or under but may be very dangerous and possibly deadly. Someone walking on top of an overhang could suffer serous injury if it collapses and the person falls to the concrete floor. Similarly, serious injury can occur if an overhang collapses onto someone. Silage avalanches can occur, even with vertical faces. Avoid the silage removal face to minimize the hazard. Collect silage samples from the bucket after moving away from the face.

Figure 8a. Silage being removed by face cutter.

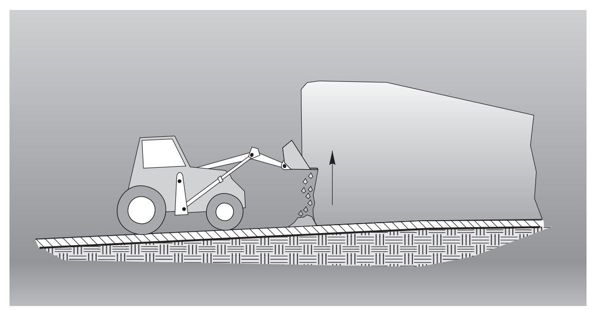


Figure 8b. Silage being removed as undermining cavity.

Figure 8. Removing silage by vertical slices.

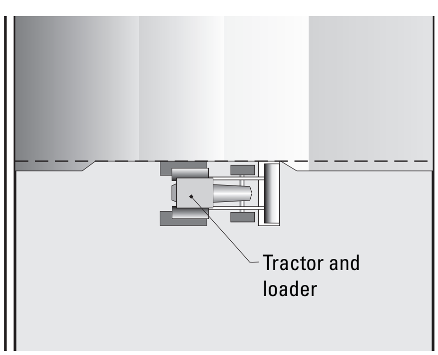


Figure 9a. Remove a uniform slice when cutting.

Figure 9b. Removing a uniform slice with a bucket.

Figure 9. Horizontal shearing or face cutting of silage.

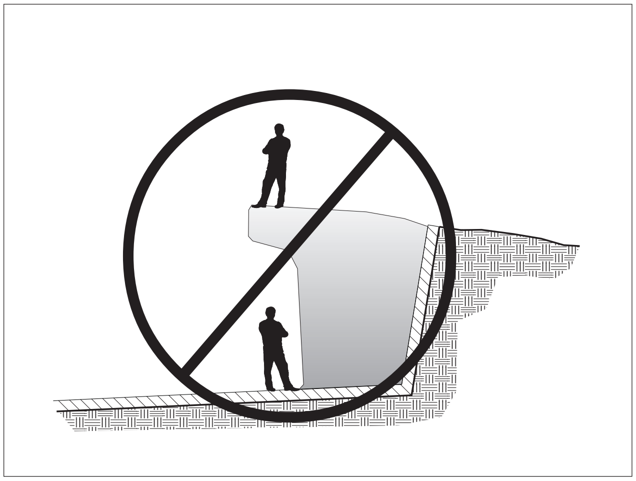


Figure 10. Silage overhangs create dangerous situations.

Knowing and Managing the Feeding Rate

Because silage is typically removed using a bucket loader, estimating the thickness of the slice of silage being removed may be difficult, especially if only a 4- to 6-inch slice is removed. Usually the amount of silage dry matter fed is estimated based on the weight of the silage added to the feed wagon. Moisture content of the silage is needed to determine dry matter. Producers should have their silage tested to determine its moisture content and make feeding adjustments when moisture content changes.

The following simple technique allows producers to calculate the rate of silage use and helps to control spoilage. Use the marks painted at 1- to 2-foot intervals on the silo's sidewalls before the silo was filled to help determine the rate of silage removal (Figure 11). To determine the feeding rate, divide the distance the face has moved by the number of days needed to go between marks or multiple marks. For example, if the face has moved 4 feet in 4 days, the approximate feeding rate is 48 inches divided by 4 days, i.e., 12 inches per day. The ideal feeding rate is the rate for which the silo has been designed, but the feeding rate should not fall below 6 inches per day for summer feeding or 4 inches per day for winter feeding.

These marks also can be useful for determining silage density. When the silage face is at a mark, start recording the daily silage weight added to the TMR wagon. After a few days when the silage face has reached another mark, measure the distance between marks and add up the total weight of the silage fed during that period. The density of the silage is equal to the weight of the silage divided by the volume. Silage volume is calculated by:

Silage Volume, cubic feet =
(Average Silo Width, feet) x (Distance Between Marks, feet) x (Average Silage Height, feet)

Where:
Average Silage Height, feet =

$$\frac{(\text{Height of Silage at Wall, feet}) + (\text{Max Silage Height, feet})}{2}$$

Example 4: *Silage Density Calculation.*

What is the silage density for a bunker with average silo width of 40 feet, an average silage height of 11 feet and a 4-foot slice of silage removed? The total weight of the removed silage is 62,000 pounds.

Solution:

$$\text{Silage Density} = \frac{62{,}000 \text{ lbs}}{(40 \text{ ft}) \times (4 \text{ ft}) \times (11 \text{ ft})}$$

Silage Density = 35.2 pounds as fed per cubic foot

Removing the plastic cover can affect silage moisture content. Exposure to the sun will dry the silage, while heavy rains will increase the moisture content. To minimize the effects of the weather, the plastic covering should be removed to expose no more than 3 days' worth of silage (Figure 12).

When moving back the plastic cover, cut off the excess plastic. This will minimize the area that rodents have to hide. As tires are removed during the emptying process, store them in a manner that reduces water entrapment and ponding and that minimizes hiding places for rodents. Store whole used tires in racks with the drain hole down. Consider stacking split tires on stakes with the inside of the tire facing down, as illustrated in Figure 13. Storing tires on a concrete surface further reduces problems with rodents and weeds. Storing tires on pallets facilitates moving tires with forks on a loader tractor.

Sizing

Proper horizontal silo sizing enhances manageability and reduces losses. Crop moisture is an important consideration when calculating space for silage, but silos should be sized using a dry matter basis for each type of forage desired. Two or more silos will increase

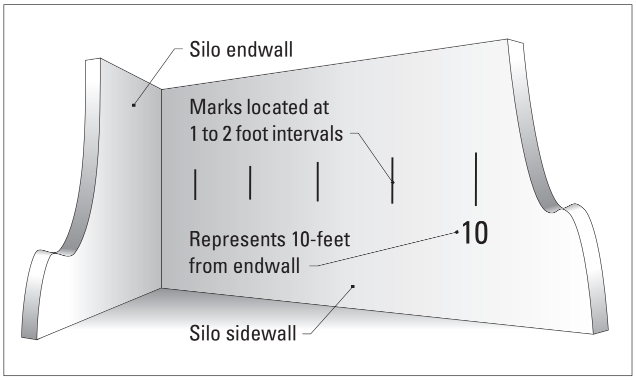


Figure 11. Marks painted on the sidewall aid in determining feeding rates and remaining capacity.
Marks on this sidewall are located at 1- to 2-foot intervals. Note the number 10 located under the fifth mark from the endwall. This informs the manager that 10-feet of silage remain at that location. Paint marks and numbers at intervals that will aid in determining feeding rates and remaining capacity.

Figure 12. Do not uncover more than 3 day's worth of silage.

Figure 13. Split tires stacked vertically for easy access and to minimize problems with rodents.
Cupped side down to prevent water accumulation.

handling and management flexibility. Silos do not need to be the same length unless a common wall is used between them.

When sizing silos, consider long term plans. Locating silos in an area where more silos can be added or existing silos can be lengthened will help facilitate future expansion.

The types of silage, the quality of silage, the frequency of harvest, and the degree of silo reuse determine the number of silos needed for an operation. Annual silage needs should be based on dry matter intake. When sizing a storage, assume a storage loss of 15%.

Handling losses from storage to feeding are another consideration when calculating silo size. These losses usually are in the 10% range. The design procedure in this publication assumes a silo with vertical sidewalls and a level top. The extra silage in the crowned top and along the sidewalls, when they are built at an 8:1 slope rather than at vertical (see Figure 4), will compensate for the 10% handling loss from storage to feed consumption. On this basis, the design examples ignore the handling loss from storage to feed consumption. If plans call for a silo with vertical walls that is to be filled so it has a level top rather than a crowned top, the length of the silo needs to be increased 10%.

Horizontal silo capacity depends on width, height and length, and silage density. Provide enough width to accommodate equipment during packing and removal, but minimize the width to reduce spoilage on the face and top. Packed silage usually will have a density of 30-50 pounds per cubic foot wet basis. If silage is well packed, silage density should be 40-50 pounds per cubic foot. See "Filling, Packing, and Covering" on page 6.

To determine silage needs and to calculate horizontal silo size, base calculations on these factors:

- Daily silage needs.
- Face removal rate.
- Average sidewall depth.
- Average width.
- Storage period.

Daily Silage Needs

Consult a dairy nutritionist or feed specialist to help calculate average daily dry matter needs for each forage crop you will use. Add at least an additional 15% to your calculations to compensate for dry matter lost in storage.

Removal Rate

For design purposes, use a silage face removal rate of at least 12 inches per day (Table 2). This will provide some leeway if feeding needs change over the years because of a change in the number or size of animals fed, feed quality, or ration fed.

Sidewall Depth and Silo Width

Sidewall depths of 8-12 feet are considered most practical. These depths match sizes of commonly available precast panels. Silo depths less than 6 feet may not be practical. Consider using a silage stack (i.e., a horizontal silo without sidewalls) if it is not practical to use horizontal silos with sidewalls 6 feet or higher. Other options include silo bags or tower silos.

Typically, sidewalls have an 8:1 slope (see Figure 4), and the silage is packed with a rounded top. Because of variations in packing, horizontal silos usually are sized by assuming vertical sides and a flat top.

A width of at least 16 feet is needed to facilitate packing. Silos that have a bottom width of 30 feet or greater are more labor-efficient than narrower silos. This helps to position the transport vehicle near the silage pack and to minimize loader turn around and travel time, which is especially important when the silo length exceeds 75 feet. To maintain proper silage packing in smaller operations, it may be important to reduce the sidewall depth or reduce the feeding rate to keep the silo width at least 16 feet. When deciding on silo width, remember feed quality is more important than labor efficiency.

Another consideration when deciding on silo width is the width of a roll of plastic used to cover the silage. Check with local suppliers on the type and width of plastic rolls. Typically black rolls are 40 feet wide, while white rolls are 50 feet wide. When sizing the silo width based on plastic roll width, be sure to compensate for sidewall slope and the crowned top (see Figure 4).

Table 2. Face removal rate.

Condition	Removal Rate, inches per day
Forage Design (recommended)	12
Winter Forage (minimum)	4
Summer Forage (minimum)	6
High-moisture Corn Design	24

Example 5: *Calculating the top and bottom widths for a bunker with sloped walls.*

A bunker silo has an average width of 40 feet and a wall height of 12 feet. The wall slope is 8:1.

The width at the bottom is:

w_B = 40 feet – (6 feet/wall x 1/8) x 2 walls
= 38.5 feet

The width at the top is:

w_T = 40 feet + (6 feet/wall x 1/8) x 2 walls
= 41.5 feet

Example 6: *Calculating the minimum width of plastic needed for the top of the silo.*

If the silage is mounded to a height of 5 feet above the wall (4:1 slope) in Example 5, the distance from wall to wall measured over the top surface of silage can be approximated as:

$$D_T = 2 \times [5^2 + (41.5 / 2)^2]^{0.5} = 42.7 \text{ feet}$$

A 50-foot wide cover will work with some material available at each wall to manage runoff. A 40-foot wide plastic tarp would not cover the full surface.

Silo Length and Storage Period

The silo length is determined by multiplying the design face removal rate (see Table 2) by the storage period. Removal rate has a significant impact on silo length. The higher the removal rate from the face, the longer the silo. This means for silos of the same depth with equal daily amounts of dry matter removed, a removal rate of 12 inches per day will result in a silo length 100% longer than one using the minimum summer removal rate of 6 inches per day (see Figure 14). Comparing silos with the same sidewall height and with equal daily amounts of dry matter removed, the silo using a removal rate of 6 inches per day will be 100% wider than the silo using the removal rate of 12 inches per day. The benefits of silage quality and future flexibility when using the 12-inch per day removal rate usually outweigh the negatives of a longer and narrower silo.

If calculated lengths are much over 150 feet, using multiple horizontal silos will increase labor efficiency. Use of multiple horizontal silos may be limited because of the layout of the site. Constructing two horizontal silos that share a common wall may cost less than having one long silo.

Construction

Locate silos for easy year-round access. A north-south orientation results in the fewest problems with snow accumulation.

Slope the floor 0.5 to 1.0% (6 to 12 inches per 100 feet) toward from which silage will be removed. This slope is sufficient to drain off precipitation and melted snow and still allow safe operation of loading equipment across the slope. As part of the design process, plan for a drainage system to carry water away from the silos. Complete site preparation before placing the floor. Some sites may require extra effort to manage drainage to protect water quality. Contaminated seepage passing through the silo walls and floor cracks should be captured to protect surface and ground water quality. Drain tiles placed in trenches below the geotextile/Macadam base in front of the silo can be used to intercept the seepage. Direct the seepage to an environmentally sound storage from which it can be distributed to farm fields.

Except in rare instances, a concrete floor is a must. The concrete should have the following characteristics:

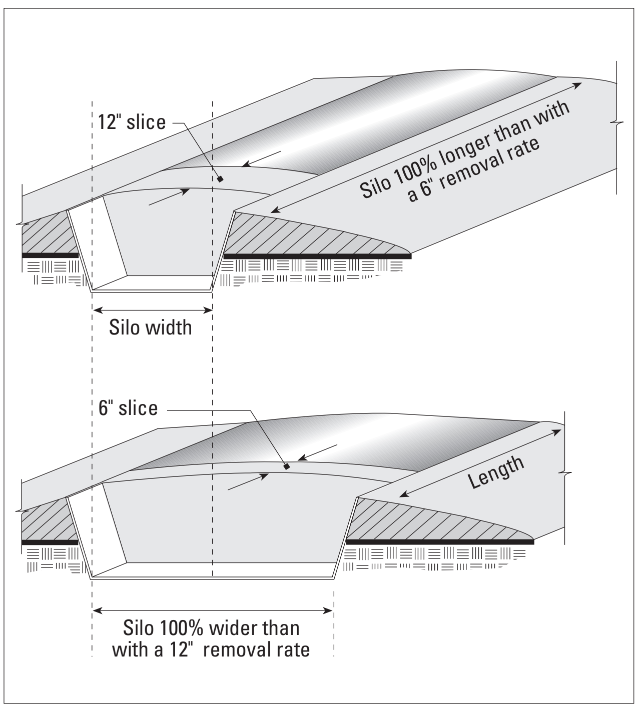


Figure 14. Feeding rates affect silo size.

- Be made with air-entraining cement, gravel (not limestone) aggregate.
- Be formulated for a minimum compressive strength of 4,500 psi.
- Have a minimum thickness of 6 inches.

Place the concrete on a solid, well-drained base. See *Using All-Weather Geotextile Lanes and Pads* (AED-45) for information on developing a good base for a concrete or asphalt bunker silo floor; see *Farm and Home Concrete Handbook* (MWPS-35) for good information on concrete floors. Keep the concrete cool during curing. Keep the concrete damp for at least 7 days. Do not load the floor with silage until 28 days after placing the concrete.

Place the floor in 10- to 12-foot wide sections. Add welded wire mesh to further control random crack development. During finishing, trowel the concrete to consolidate the top surface and then give it a medium broom finish (like medium to coarse sandpaper) for added traction.

Locate a concrete slab (apron) in front of the silo. The slab should cover the width of the silo and should extend a minimum of 20 feet, with 40 feet preferred, in front of the silo. It should meet the same criteria as the concrete in the silo floor. This apron can be used to store overflow feed and as a maneuvering area for equipment filling and emptying the silo.

Make the sidewalls smooth and as nearly air tight as feasible. Tilt them outward with an 8:1 slope (8 feet vertical per 1 foot horizontal). Vertical walls are easier to construct but reduce lateral compression during packing and generally increase spoilage.

The preferred material for silo sidewalls is concrete. Concrete sidewall panels must contain the proper amount of steel reinforcing and be of sufficient thickness for the designed panel height, spacing of supports, depth of soil backfill, etc. For trench silos in heavy soils, place a perforated tile with an overlying gravel layer at the base of the wall to reduce water seepage and hydrostatic pressures against the wall panels.

Because of contamination concerns, do not use pressure preservative treated wood for feed storages. Bales of hay, straw, or similar products are unacceptable as a sidewall because they lead to higher rates of spoilage. When emergency storage is needed, use a well packed silage pile properly covered with plastic and tires.

Sizing Example

The following is a hypothetical example based on a producer with 120 lactating cows. The producer has met with a dairy nutritionist, and the producer and nutritionist have developed the nutritional requirements shown in Table 3.

The worksheets accompanying this example show how to design a horizontal silo to accommodate one year's storage for corn silage. While this example will show calculations only for the corn silage, the calculations for alfalfa silage are similar.

Step 1. Recording Silage Characteristics: The first step is to record basic information about the silage characteristics in blanks A and B of the worksheet (Page 15). If silage has been tested in the past and is consistent from year-to-year, put these values in the blanks. Otherwise, the suggested values of 40 pounds per cubic foot and 65% (wet basis) are good estimates.

Step 2. Calculating Daily Silage Crop Needs: Next, calculate the amount of silage to store, taking into account silage lost in storage, to meet daily needs.

Put the Total Daily Dry Matter Intake of corn silage of 4,066 pounds dry matter from Table 3 in blank C. Put the estimated storage loss in blank D. In most cases, use the values from Table 1 because it is difficult to measure actual storage losses. The example uses 15% (blank D). The effects of storage losses due to poor management may be additive. If no plastic is used, add 10% dry matter loss. If limited packing is used, add 10% dry matter loss. If silage is packed poorly and no cover is used, the storage dry matter loss to record on line D is 35% (15% + 10% + 10%).

Insert the information from blanks C and D into the equation. The result is 4,783.5 pounds of dry matter per day. Round the number to 4,784 pounds of dry matter per day, and record it in blank E.

Step 3. Selecting a Silage Removal Rate: Now, select a silage removal rate. The example uses a removal rate of 12 inches per day. This removal rate allows some flexibility in the future, if or when feeding needs change. This decision is entered in blank F.

Step 4. Selecting Silo Depth and Width: The process of selecting a sidewall height and calculating the silo width may require some trial and error. First, select a sidewall height and calculate the width. If the resulting width is unsuitable, repeat the process with another height.

Select a sidewall height and enter for silo width value in blank G (page 16). The equation for silo width in the worksheet uses information from blanks A, B, E, F, and G.

Choosing a sidewall height of 12 feet yields a result of 28.5 feet, or a 29-foot average width silo, which is recorded in blank H.

Step 5. Calculating Silo Length: The next step is to select a desired storage time and a handling loss from storage to feeding, then calculate the silo length and the number of silos needed for the operation.

In this example, the producer wants to feed corn silage all year long or 365 days. Put this decision in blank I.

The first calculation in Section i determines the silo length if one long silo is used. This calculation uses the information in blanks F, and I. The calculation shows a silo length of 365 feet is needed to store the entire volume of silage needed for one year.

Because 365 feet is very long for a silo, the second calculation determines the number of silos needed based on 150 feet being the longest practical length . The calculation gives a result of 2.4. Rounding up to the nearest whole number determines three silos are needed. This result is entered in blank J.

The third calculation determines the length of the three silos. Using the information in Section i and Blank J, gives a result of 121.7. Rounding up to the nearest whole number indicates that three 122-foot long silos are needed for corn silage.

Step 6. Final Design: The final step is to put the design information on the diagram.

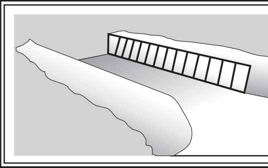
Table 3. Daily dry matter requirements from various feed stuffs.

Animal Group	Number of Animals	Total Dry Matter Intake	Concentrate, lbs DM	Corn Silage, lbs DM	Alfalfa Silage, lbs DM
High Producers	58	3,190	1,595	957	638
First Calf Heifers	58	2,610	1,305	783	522
Low Producers	24	1,152	346	645	161
Dry Cows	20	560	112	358	90
Heifers @ 500 lbs	50	600	120	384	96
Heifers @ 850 lbs	15	270	54	173	43
Heifers @ 1300 lbs	46	1,196	239	766	191
Daily Total		9,578	3,771	4,066	1,741

MWPS
MidWest Plan Service
A Foundation of Knowledge

Design Guide (Example from page 14)

Bunker/Trench Silo Sizing



Silage Characteristics

Estimated Silage Density (A) 40 lbs/ft^3 *(Silage Density)*
(Use 40 lbs/ft^3 if unknown)

Estimated Moisture Content (B) 65 % *(Moisture Content)*
(Use 65% if unknown)

Daily Silage Crop Needs

Note: Consult a Dairy Nutritionist or Feed Specialist to determine the proper amount of dry matter (DM) intake for your needs.
Note: 4066 lbs DM per day is corn silage daily total from Table 3.

Total Daily Dry Matter Intake (C) 4,066 lbs DM/day *(Daily Dry Matter Intake)*

Estimated Storage Losses (D) 15 % *(Storage Losses)*
(Use 15% if unknown; 35% if no cover and poorly packed)

Amount of crop to be ensiled to meet daily silage need

$$= \frac{\text{Total Dry Matter Intake (C)}}{1 - \frac{\text{\% Storage Losses (D)}}{100}}$$

$$= \frac{(\ 4{,}066\ )}{1 - \frac{(\ 15\ )}{100}} =$$

(E) 4,784 lbs DM/day *(Daily Crop Needs)*

Silage Removal Rate

Select Face Removal Rate (F) 12 in/day *(Removal Rate)*

12 inches per day recommended
4 inches per day minimum (winter)
6 inches per day minimum (summer)

Silo Depth and Width

Select Sidewall Depth (8 ft to 12 ft typical) (G) 12 ft
(Silo Depth)

Calculate Width

$$\frac{\text{Daily Crop Needs (E)} \times 12}{\text{Removal Rate (F)} \times \text{Sidewall Depth (G)} \times \text{Silage Density (A)} \times \left(1 - \frac{\text{Moisture Content (B)}}{100}\right)}$$

$$\frac{(\ 4{,}784\ ) \times 12}{(\ 12\ ) \times (\ 12\ ) \times (\ 40\ ) \times \left(1 - \frac{(\ 65\ )}{100}\right)} =$$

(H) 28.5 ft
(Silo Width)

Silo Length

Select a Storage Period (I) 365 days
(Storage Period)

Calculate Length and Number of Silos Needed

i) Single Silo Length $= \frac{\text{Face Removal Rate (F)} \times \text{Storage Period (I)}}{12}$

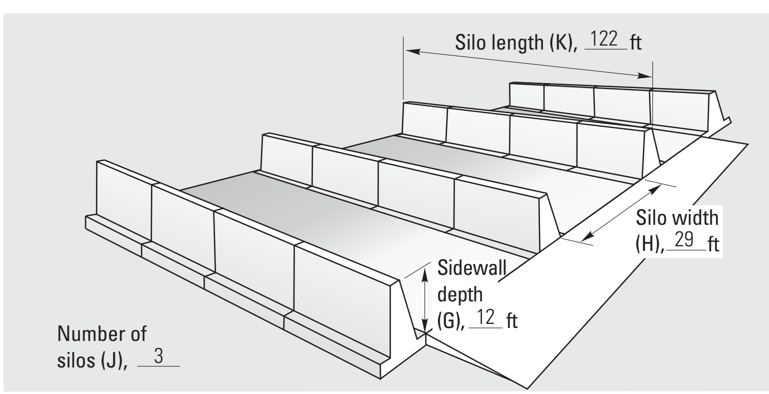
$$= \frac{(\ 12\ ) \times (\ 365\ )}{12} = 365 \text{ ft}$$

(If 150ft or less, enter value in blank (K) and enter "1" in blank (J))

ii) Number of Silos $= \frac{\text{Silo Length (i)}}{150} = \frac{(\ 365\ )}{150} =$ (J) 3
(Number of Silos; Round Up)

iii) Individual Silo Length $= \frac{\text{Silo Length (i)}}{\text{Number of Silos (J)}} = \frac{(\ 365\ )}{(\ 3\ )} =$ (K) 121.7
(Silo Length)

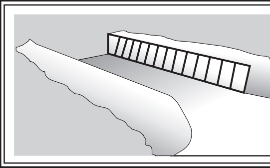
Bunker/Trench Silo



MWPS
MidWest Plan Service
A Foundation of Knowledge

Design Guide

Bunker/Trench Silo Sizing



Silage Characteristics

Estimated Silage Density (A) ______________ lbs/ft^3
(Use 40 lbs/ft^3 if unknown) *(Silage Density)*

Estimated Moisture Content (B) ______________ %
(Use 65% if unknown) *(Moisture Content)*

Daily Silage Needs

Total Daily Dry Matter Intake (C) ______________ lbs DM/day
(Daily Dry Matter Intake)

Estimated Storage Losses (D) ______________ %
(Use 15% if unknown; 35% if no cover and poorly packed) *(Storage Losses)*

$$\text{Amount of silage to meet daily silage need} = \frac{\text{Total Dry Matter Intake (C)}}{1 - \frac{\text{\% Storage Losses (D)}}{100}}$$

$$= \frac{(\qquad\qquad)}{1 - \frac{(\qquad)}{100}} =$$

(E) ______________ lbs DM/day
(Daily Silage Needs)

Silage Removal Rate

Select Face Removal Rate

12 inches per day recommended
4 inches per day minimum (winter)
6 inches per day minimum (summer)

(F) ______________ in/day
(Removal Rate)

Silo Depth and Width

Select Sidewall Depth (8 ft to 12 ft typical) (G) ______________ft
(Silo Depth)

Calculate Width

$$\frac{\text{Daily Silage Needs (E)} \times 12}{\text{Removal Rate (F)} \times \text{Sidewall Depth (G)} \times \text{Silage Density (A)} \times \left(1 - \frac{\text{Moisture Content (B)}}{100}\right)}$$

$$\frac{(\qquad) \times 12}{(\qquad) \times (\qquad) \times (\qquad) \times \left(1 - \frac{(\qquad)}{100}\right)} =$$ (H) ______________ft
(Silo Width)

Silo Length

Select a Storage Period (I) ______________day
(Storage Period)

Calculate Length and Number of Silos Needed

i) Single Silo Length $= \frac{\text{Face Removal Rate (F)} \times \text{Storage Period (I)}}{12}$

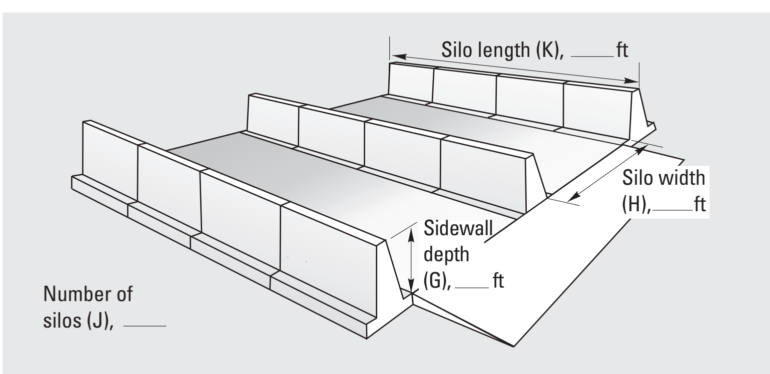
$= \frac{(\qquad) \times (\qquad)}{12} =$ ______________ ft

(If 150ft or less, enter value in blank (K) and enter "1" in blank (J))

ii) Number of Silos $= \frac{\text{Silo Length (i)}}{150} = \frac{(\qquad)}{150} =$ (J) ______________
(Number of Silos; Round Up)

iii) Individual Silo Length $= \frac{\text{Silo Length (i)}}{\text{Number of Silos (J)}} = \frac{(\qquad)}{(\qquad)} =$ (K) ______________
(Silo Length)

Bunker/Trench Silo



References

*Farm and Home Concrete Handbook, MWPS-35. Friday, W.H., et al., MidWest Plan Service, 122 D*avidson Hall, Iowa State University, Ames, IA 50011-3080.

Horizontal Silos, H76. Tyson, J.T., Graves, R.E., and Buckmaster, D.R. The Pennsylvania State University, Agricultural and Biological Engineering Extension, 246 Agricultural Engineering Building, University Park, PA 16802.

Dairy Freestall Housing and Equipment, MWPS-7. Seventh Edition. MidWest Plan Service, 122 Davidson Hall, Iowa State University, Ames, IA 50011-3080.

Dairy Cattle Science. Ensminger, M.E. Interstate Publishers, Inc., 510 North Vermillion Street, P.O.Box 50, Danville, IL 61834-0050.

Sizing and Management of Bunker Silo, AEU-10. Chastain, J.P., Linn, J.G., and Holmes, B.J. University of Minnesota, Department of Biosystems and Agricultural Engineering, 1390 Eckles Avenue, St. Paul, MN 55108-6005.

Sizing and Managing Silage Storage to Maximize Profitability. Holmes, B.J., University of Wisconsin-Madison, Biological Systems Engineering Department, Madison, WI. 53706

Bunker Silo Sizing and Management, F-1011. Huhnke, R.L. Oklahoma State University.

Forages: The Science of Grassland Agriculture, Fourth Edition, Iowa State University Press, 2121 State Avenue, Ames, IA 50014

Silage and Hay Preservation, NRAES-5. Northeast Regional Agricultural Engineering Service, 152 Riley-Robb Hall, Cooperative Extension, Ithaca, New York 14853.

University of Wisconsin Extension Team Forage Harvest and Storage Website, http://www.uwex.edu/ces/crops/uwforage/storage.htm

Using All-Weather Geotextile Lanes and Pads, AED-45. Janni, K., Funk, T. and Holmes, B. MidWest Plan Service, 122 Davidson Hall, Iowa State University, Ames, IA 50011-3080.

MWPS would like to thank Gerald R. Bodman for being an author to the first edition of this publication.

Reviewers, 1st edition

Ted Funk, Assistant Professor and Extension Ag Engineer, University of Illinois.

Joe Harner, Professor and Extension Ag Engineer, Kansas State University.

Kenneth Hellevang, Associate Professor and Extension Ag Engineer, North Dakota State University.

Kevin Janni, Professor and Extension Ag Engineer, University of Minnesota.

Jim Lindley, Associate Professor of Ag Engineering, North Dakota State University, retired.

James Murphy, Professor and Extension Ag Engineer, Kansas State University.

Howard Person, Associate Professor and Extension Ag Engineer, Michigan State University, retired.

Ron Schuler, Professor of Ag Engineering, University of Wisconsin.

Randy Shaver, Professor and Extension Dairy Nutritionist, University of Wisconsin.

LaVerne Stetson, Agricultural Engineer, retired USDA-ARS, University of Nebraska.

Richard Stowell, Assistant Professor and Extension Ag Engineer, University of Nebraska.

William Wilcke, Associate Professor and Extension Ag Engineer, University of Minnesota.

Joe Zulovich, Extension Ag Engineer, University of Missouri.

Richard Muck, Ag Engineer, USDA-Dairy Forage Research Center, University of Wisconsin-Madison

Safety Summary

As with all activities in which large equipment is used, safety cannot be overemphasized. Follow the safety procedures listed below when loading, packing, and unloading horizontal silos:

- Do not allow children to play around the silo.
- Identify routes and areas that will be used to haul and handle forage.
- Turn off equipment when not in use.
- Discuss the loading and packing operation in detail with personnel.
- Know each other's hand signals.
- Have experienced people operating the equipment, especially the packing tractor.
- Always be sure other personnel are visible to the equipment operator.
- Use a weighted-wheel tractor with well-lugged tires and rollover protection, and wear seat belts.
- Use a four-wheel drive or front-wheel assist tractor for better control.
- Operate the packing tractor at a slow speed.
- Pack the silage in 6-inch thick layers.
- Pack layers evenly.
- Pack by backing the tractor up the slope of the forage.
- Do not drive tractors across slopes greater than 1:4.
- Do not create a silage overhang during removal.
- Do not walk on top of silage near the removal face.
- Do not stand behind dumping loads of silage.
- Push silage in front of a blade or bucket.
- Do not carry silage in an elevated bucket.
- To avoid avalanches, do not stand near silage face.
- Avoid walking on wet or snow covered plastic cover.

Printed on
Recycled Paper

MWPS
MidWest Plan Service
A Foundation of Knowledge