Management of Bunker Silos and Silage Piles

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As cow numbers on today's modern dairies continue to increase, methods of storing and dispensing large quantities of forage in a labor efficient manner have developed. Examples include three basic types of horizontal storage structures; piles, bunkers and bags. Large volume, vertical storage systems are beginning to be used on a few farms around the country as well. The topic of this paper addresses the management of bunkers and piles.

Harvest

The economical production of quality forage is dependant upon stage of maturity at harvest, efficient removal of the crop from the field, fast placement into storage, effective preservation and precise, timely distribution to the herd. Recommended harvest time parameters have been monitored in a variety of ways over the years, progressing from 1) the goal of maximum tonnage yield 2) assessment of the quality parameters of full bloom alfalfa 3) bud development 4) scissors clipping using infrared (IR) analysis and 5) Predictive Equations for Alfalfa Quality (PEAQ) measures. PEAQ measures allow immediate, in the field predictions of quality. Research has proven that high producing dairy cows perform at their optimum and feed costs are minimized when forages are harvested to produce Prime quality haylage. Prime quality corresponds to a Relative Feed Value (RFV) greater than 151. Harvesting forages at Prime quality maximizes the yield of digestible dry matter (DDM) while providing adequate fiber to the dairy cow.

For alfalfa, a RFV of 170%, when using either scissors clip or PEAQ measurements, is the point where harvest should commence. Hay crop for silage should be chopped at a 3/8" (0.375") Theoretical Length of Cut (TLC) where more than 15-20 percent of the particles are greater than 1 ½" long on a wet basis. This allows minimum ration forage to be 21 percent Neutral Detergent Fiber (NDF) from forage on a dry matter basis depending on the type, level and TLC of other forages in the ration (Shaver, 1990). Field data collected from 168 Wisconsin bunker silos and piles indicate that the recommended TLC is being achieved by farmers with a range of particle size from 0.27-1.23" with an average of 0.46"(Holmes and Muck, 2000). A typical rule of thumb used on high producing dairy farms is to chop forages, particularly hay crop, as long as possible and still be able to pack to a desired density. This also allows a finer chop of corn silage, if fast dry down conditions dictate, to obtain a good pack.

The recommended corn silage TLC varies based on the maturity of the plant and whether a forage processor is utilized. When corn silage is harvested at the preferred maturity of 1/3 to ½ kernel milk line and a whole plant moisture of 65-70% the recommended TLC is 3/8" (0.375") without a processor or ½-3/4" (0.50-0.75") with a processor. When silage is harvested at the more mature stages of ½ milk line to black layer or moisture levels of <59%, recommended TLC changes to ¼" (0.25") without processing and ½-3/4" (0.25-0.75") with processing (Holmes, 2000). Data collected from the 168 Wisconsin silos (Table 3) document a range of corn silage particle lengths of 0.28-0.68" and an average of 0.43".

Four criteria are considered in recommendations for moisture content of forages going into storage 1) minimizing harvest dry matter (DM) loss, 2) maximizing silage mass density, 3) short and complete fermentation process and, 4) the type of storage structure. The preferred corn silage moisture range for bunkers and piles is 65-70% and for hay silage the preferred moisture is 60-65%. Seepage of forage juice can occur from these structures if forage is harvested at moisture contents above 70%. The juice carries a high concentration of soluble nutrients, which represents a significant loss of valuable feed DM. Clostridial fermentation can be a problem at these levels as well. Conversely, harvesting at 40% moisture or less exposes forage in a horizontal structure to the risk of spontaneous combustion (Tormoehlen et al, 1989).

Storage Design

The first step in forage storage design is to determine the volume of silage to be stored. Quantities should be determined on a DM basis to avoid the weight and volume discrepancies associated with As-Fed (AF) moistures. To make the calculation, you first need to know how much of each forage will be represented in the ration, again on a DM vs. AF basis. A dairy cow plus support stock, including dry cows and raised replacements, known as one dairy cow equivalent (CE), will consume 7 tons of forage dry matter each year. The figure assumes a 6% feeding loss. For example, a 50% hay silage:50% corn silage ration on an as-fed moisture basis with haylage (40% DM) and corn silage (32% DM) is actually a 56:44 DM basis ration. Using these assumptions, a person will need 7 T DM/CE/yr. X 0.56 = 3.92 T hay silage DM per cow equivalent/yr. and 7 T DM/CE/yr. X 0.44 = 3.08 T of corn silage DM per cow equivalent for a year of feeding. This translates into 21.48-lb. DM/day for hay silage and 16.88-lb. DM/day per cow equivalent for corn silage. Using the average packing densities of 14.8 lb. DM/ft^3 for hay silage and 14.5 lb. DM/ft^3 for corn silage, obtained from the Wisconsin field study (Table 3), allows us to determine needed amounts of 1.45 ft^3 (21.48/14.8) of haylage per cow equivalent per day and 1.16 ft^3 (16.88/14.5) of corn silage per cow equivalent for feeding. Therefore, the total annual storage volume for hay silage and corn silage respectively is;

(1.45 ft^3/CE-day) X 365 days/yr. = 529 ft^3 hay silage per CE/yr.

(1.16 ft^3/CE-day) X 365 days/yr. = 423 ft^3 corn silage per CE/yr.

If we assume a 500 cow equivalent herd the annual volume to store becomes:

500 CE/herd X 529 ft^3 hay silage/CE/yr. = 264,500 ft^3 hay silage/herd/yr.

500 CE/herd X 423 ft^3 corn silage/CE/yr. = 211,500 ft^3 corn silage/herd/yr.

Now that volume of storage is known, the second step is to determine silo dimensions. To do so, a daily face removal rate needs to be selected. Face removal should be determined based on the minimum amount required to prevent heating of the face between feedings. A suggested minimal face removal rate of 6" per day for hay silage and 4" per day for corn silage (Bodman and Holmes,

1997) with the larger of the two doubled for design purposes. For this example, 1 foot of removal per day is used. For this amount of storage we will assume a wall height of 12 ft. Because of variations in packing, horizontal silos are usually sized with vertical sides and a flat top.

A width of at least 16 feet is needed to facilitate packing. To increase labor efficiency, design for a bottom width of 30 feet or more. This helps in positioning the transport vehicle close to the silage pack and minimize loader turn around time (Bodman and Holmes, 1997). To calculate the silo width that allows the removal of one foot of silage face per day, we must first determine the total pounds of silage to be fed each day. The pounds of each forage per day may be calculated in the following way;

1.45 ft^3/CE/day x 500 CE x 14.8 lbs. DM/ft^3 = 10,730 lb. DM hay silage/day

1.16 ft^3/CE/day x 500 CE x 14.5 lbs. DM/ft^3 = 8,410 lb. DM corn silage/day.

Next, divide each amount by the feet of silage removed x wall height in ft. x density in lb. = silo width, i.e.

Width = (10,730 lb. DM/day)/ ((1ft. /day) x (12 ft.) x (14.8lb. DM/ft^3))

= 60 ft. for hay silage

Width = (8,410 lb. DM/day)/((1ft. /day) x (12 ft.) x (14.5 lb. DM/ft^3))

= 48 ft. for corn silage.

Silo width may be adjusted by selecting a different wall height. Now that the silo width is known, length can be determined by;

$$\text{Silo Length} = \frac{\text{Face Removal (inches/day)} \times \text{Storage Period (days)}}{12 \text{ (in/ft.)}}$$

$$\text{Silo Length} = \frac{12 \text{ in./day} \times 365 \text{ days}}{12 \text{ in/ft.}}$$

Silo Length = 365 ft

The temptation (to be resisted) is now to layout only two large horizontal structures.

Inventory Management

Prior to selecting the number of structures to build, it is advisable to review aspects of both filling and inventory management. The recommended procedure for filling a bunker silo or silage pile is to spread the silage in thin layers on the sloped filling face and driving over it several times with one or more heavy tractors. This is the “progressive wedge” method of silo filling.

The top of the forage mass is a large area exposed to air and moisture penetration. Migration of air and moisture supports aerobic microorganisms, which cause deterioration throughout the top surface of exposed forage. The progressive wedge technique of filling continually covers previous layers of forage, thus reducing exposure to the elements. Packing the forage to form a high-density mass reduces entrapped air and limits penetration of both air and moisture into the forage. Filling the structure quickly (within three days) limits forage exposure to air and precipitation. Consequently, equipment to harvest, transport and fill the storage as well as labor should be capable of filling rapidly. Each of two smaller bunkers/piles can be filled and covered with less exposure time than one large structure (Holmes and Muck, 2000).

Additionally, management of varying qualities of forages into and out of one long structure is next to impossible. An added concern, documented through the Wisconsin field study, is the ability to achieve an adequate packing density, given the speed of today’s modern custom harvesters.

Multiple smaller silos can be filled more quickly, can contain forage of similar quality, exposes less surface area to the environment and allows the delivery of forage to different silos simultaneously for more efficient and complete packing under custom harvest conditions. When sizing storage, the selection of multiple smaller structures allows many management options over one large silo. One practical approach may be to size one or two silos for corn silage, one or two silos for first crop alfalfa and one silo for both second and third crop alfalfa.

Locate silos for convenient year round access. A north-south orientation results in the fewest problems with snow accumulation (Bodman and Holmes, 1997).

End Wall or Not?

To have an end wall or not to have an end wall, that is yet another question. Advantages of a bunker rear end wall include the ability to construct the storage into a hill so forage delivery can be made from the closed end and sides, along with the ability to drive over the end wall or side walls when filled at that level. Disadvantages include the safety concern of working near the top of walls (tipping into the empty silo) and the convenience of lengthening the silo if desired.

Advantages of no end wall include; the ability to fill and/or unload from each end, allowing maximum flexibility for inventory management within a single structure. If there is a need to remove a specific quality from the rear portion of the silo, the open end allows access. Water accumulation at the feedout face can be a problem with this technique, as the floor slopes toward the feedout face. Where one structure will be filled with a single crop in a short period of time, i.e. corn silage, open ends allow the option of pulling self-unloading wagons through the structure. Open ends allow flexible storage space needs based on fluctuating crop yields by allowing the operator to fill beyond the structure walls. Open ends also allow the convenient lengthening of silo walls. Where available construction space is limited, end walls may be indicated for access or aesthetic reasons. If these issues are of concern a better site should be considered.

Silo Design and Surface Area Exposure

The temptation to build shorter lower cost sidewalls and thus extend the width or length of a horizontal silo should be avoided. The shallower the silage mass, the more top surface is exposed to the elements and the greater the DM loss to hold the same volume of feed. In small silos it may be necessary to reduce the sidewall depth or reduce the feeding rate to keep width at least 16 feet. If design of the silo precludes a silo width of at least 16 feet and wall heights of 8 feet, consider using alternative storage options like silo bags or a well-constructed pile. The importance of minimizing the amount of surface area of exposed silage is demonstrated in Table 1 using top surface DM loss provided by Bolsen in Table 10 (Bolsen et al, 1993).

The information in Table 1 documents an increased loss of $1,720 per year for a silo with 8-foot versus 12-foot walls due to the increased surface area of the top when the feed is valued at $100/T
DM. The initial capital investment savings of eight-foot walls over twelve-foot walls, in this example, are $34,200. Lowering the height of the walls necessitates increasing the width of the silo from 50 feet to 75 feet to maintain storage capacity. The extra initial capital expense of the 25-ft. wider floor totals $13,688 yielding a net saving of $20,512 for the 8 ft. silo.

Table 1. DIFFERENTIAL DRY MATTER LOSS IN TWO BUNKER SILOS

	SILO #1	SILO #2	DIFFERENCE 8 ft. vs 12 ft.	VALUE LOSS DIFFERENCE @ $100/Ton DM	VALUE LOSS NPV 20 YRS @ 9% Interest Rate $100/Ton DM	VALUE LOSS NPV 20 YRS @ 9% Interest Rate $150/TON DM
DIMENSIONS:						
WALL HEIGHT	12’	8’	-4’			
WALL WIDTH	50’	75’	25’			
WALL LENGTH	365’	365’	0			
SILAGE WT. (DM IN TOP 3’)	383T	575T	192T			
DM LOSS (% in Top 3 ft.):	**DM LOSS**	**DM LOSS**				
	Tons	Tons	Tons			
9	(34.5)	(51.7)	17.2	($1720)	$(4155)	$3176
10	(38.3)	(57.5)	19.2	($1920)	$(2450)	$5734
11	(42.1)	(63.3)	21.2	($2120)	$(745)	$8291
12	(46.0)	(69.0)	23.0	($2300)	$789	$10,593
13	(49.8)	(74.8)	25.0	($2500)	$2494	$13,150
14	(53.6)	(80.5)	26.9	($2690)	$4113	$15,580
15	(57.5)	(86.3)	28.8	($2880)	$5734	$18,010

Using the Net Present Value (NPV) function in Microsoft Excel spreadsheet, at an interest rate of 9% for 20 yrs. produces a NPV of ($4,155) in favor of the 8ft. walls. Therefore, if producers can purchase replacement forage for $100/T DM, they are financially better off taking the loss. However, if DM loss exceeds 11% or replacement forage must be purchased at $150/TDM, it is more economical to construct the 12 foot walls.

A variety of wall designs and materials have been used. Typically, sidewalls have a 1:8, one unit of run for each eight units of rise, outward slope. Vertical walls are easier to pour but reduce lateral compression of the silage during packing due to the inability to run the tractor tire near the wall. Make the sidewalls smooth and as air tight as feasible. The preferred material for silo sidewalls is concrete. Because of contamination concerns, do not use pressure treated wood for feed storage. Other materials commonly used for temporary storage walls, including bales of forage or concrete “spoil blocks” should be avoided (unless lined with plastic) because of air penetration leading to higher rates of spoilage (Bodman and Holmes, 1997). Silo bags are used to form walls for bunker silos. Although used with some success, the level of management needs to be high to avoid unnecessary spoilage resulting from bag damage during feedout. When emergency storage is needed, it is recommended to use either silage bags or well packed silage piles.

Silo floors should be sloped 0.5 to 1.0% (6 to 12 inches per 100 feet) towards the open end. This slope is sufficient to drain off precipitation and melted snow and still allow safe operation of equipment across the slope. As part of the design process, plan for a drainage system to carry water away from the storage. Complete site preparation before laying the floor (Bodman and Holmes, 1997).

Except in rare instances, a concrete floor is a must. The concrete should be air-entrained concrete with gravel aggregate, formulated for a minimum compressive strength of 4,500 psi and have a minimum thickness of 6 inches. Place the concrete on a solid, well-drained base, such as macadam. Locate a concrete slab at each open end of the silo. The slab should be at least as wide as the silo and extend a minimum of twenty feet in front of the silo. (Bodman and Holmes, 1997).

Asphalt has been used for silo floors and costs approximately one half to two thirds that of concrete. However, it requires a well-designed base, is more susceptible to heaving and equipment damage and is usually of shorter life than that of good concrete. Recommendations for construction are for an 8-inch base covered with two 2-inch lifts of asphalt. Seal coating the surface at five-year intervals extends the life of an asphalt floor significantly. Caution is advised in the turning of equipment; particularly skid steer loaders, on hot asphalt. The pressures created during turning will cause layers of asphalt to separate. The operation of heavy equipment on asphalt surfaces during hot, summer weather can also cause rutting of the floor’s surface.

Macadam alone can serve as an acceptable silo base (Janni, Funk and Holmes, 1999). Macadam is constructed by excavating topsoil down approximately 12 inches. Stone is then placed in six to eight inch layers, watered and rolled into place beginning with large aggregate (three inch) stone, with progressively smaller stone at each lift to produce a final thickness of 16-18 inches. The use of a geotextile material may replace the first layer of stone when constructing a macadam base (Janni, Funk and Holmes, 1999). Macadam can usually be constructed for about one-third the cost of concrete. On the downside, macadam is particularly susceptible to damage during feedout resulting in gravel in the feed and because of its porosity, can present an environmental concern in areas of high water table or fractured bedrock.

Silage Pile Design

Silage piles should be built so the entire surface can be driven upon to obtain high-density forage throughout. The side slopes of the pile should be sloped at 3 units of run for each unit of rise (3:1) to obtain a surface which can be driven over with minimal risk of tractor roll over.

The design of silage piles is similar to that of bunker structures. The main difference is that in the absence of walls, depth of the silage mass is restricted. At depths beyond 10 ft., area of the base or the number of piles become an issue. Selection of pile shape determines the formula for calculating capacity. Typically, piles are constructed as rectangles, triangles or trapezoids. The approach for calculating capacity and dimensions for a rectangle is the same as for the bunker. Area formulas for the triangle and trapezoid are A=½HB and A=½H(B+b) respectively. Where A= cross sectional area, H= height, B= base width and b= top width of the trapezoid.

Using the data for the example 500-CE herd, the feeding rate of corn silage per day of 8,410 lb./day equates to 580 $ft.^3$/day. For the triangle with a ten-foot height, the equation becomes:

A = 580 ft^3/ 1ft removal rate = 580 ft^2.

B = (580 ft^3 x 2)/10 ft. = 116 ft. wide base.

The number of days in the feeding period, at the feeding rate per day of a one-foot slice, becomes the dimension of the length of the pile.

For the trapezoid, given 3:1 side slopes, a depth of 10 feet equals a horizontal run of 30 ft. for each sloping side of the pile. The bottom base width of the trapezoid is:

B = b + 2 X 30 ft. = b + 60 ft.

Then area equals;

A = 580 ft^2 = ½ [10 ft.((b+60 ft.) +b)]

A = 580 ft^2 = ½ [10 ft.(2b+60 ft)]

80 ft^2 / 5 ft. = 2b + 60 ft.

116 ft. = 2b + 60 ft.

56 ft. = 2b

28 ft. = b = trapezoid top width

B = 28 ft. + 60 ft. = 88 ft. = trapezoid bottom width

Length of the trapezoid shaped pile is the number for feeding days times the one-foot daily removal slice.

The concern of height to surface area and surface area to volume is the same for piles as for bunker silos. Given the depth restrictions of the pile the additional surface area and resulting DM loss is naturally greater than from a bunker for the same volume of feed stored. Constructing the pile as deep as is practical for the available site, ability to maintain 3:1 side slopes and the construction of multiple piles will limit exposed surface area. Additional information on the management of silage piles may be obtained from "Drive-Over Silage Pile Construction" (Roach and Kammel, 1990).

Filling Procedure

There are several procedures used for filling bunker/pile silos that are influenced by wall configuration and storage size. The filling procedure often begins by filling the back end of the storage by pushing forage up a sloped filling face in a progressive wedge technique. In the preferred method of filling, the forage is added in thin (<6-inch) layers to this filling face until the storage is full. This is known as the progressive wedge method. The progressive wedge method allows a plastic cover to be applied to the top surface soon after that area is full. The progressive wedge method can be used with or without a back silo wall.

When a back silo wall is built into an embankment or a ramp is constructed to the top of the back wall, forage can be deposited onto the filling face as the transport vehicle unloads while driving on the forage. Unloading while driving on the forage increases forage distribution efficiency and adds some packing of the forage. A blade/bucket is used to spread the forage in thin layers. Do not lift dump bodies on the forage as differential settling may cause a dump truck to tip over. These trucks are usually emptied on solid surfaces with the forage pushed into the bunker/pile with the tractor.

Where bunker silo side walls are embanked and a 12-ft drive is left between bunkers, some producers use side discharge wagons to deliver forage along the wall by driving past the wall. This technique is most compatible with a horizontal fill procedure.

The horizontal fill procedure places forage in the storage in horizontal layers. The horizontal fill procedure is not recommended for several reasons.

1. A much larger surface is exposed to air and precipitation during filling compared to the progressive wedge method where covering occurs during filling.
2. A storage which is not filled with one type and/or quality of feed will have multiple layers of forage. This eliminates the ability to inventory feed and blend rations according to ration need.
3. The whole cover must be removed to add more forage to fill the storage.

When filling silage piles, thin layers of forage must be placed on the filling face and driven upon to provide good packing and high density. This requires shallow slopes (1 rise: 3 run) so a tractor can safely pack the whole surface. Driving on the forage in perpendicular directions will probably provide a denser mass. It is safer to back up a sloped surface than to drive forward or along the slope. Take care to avoid a tractor overturn. The shallow slope also assures plastic can be held tightly to the surface after covering.

Packing Density

Attaining a high density in a silo is important for two primary reasons. Firstly and most importantly, density and dry matter content determine the porosity of the silage. Porosity, in turn, sets the rate at which air moves into the silo and subsequently the amount of spoilage which occurs during storage and feedout. Ruppel (1992) measured dry matter loss for alfalfa silage and developed an equation to relate the loss to density. Table 2 summarizes those results. Secondly, the higher the density, the greater the capacity of the silo. Thus, higher densities generally reduce the annual cost of storage per ton of crop by both increasing the amount of crop entering the silo and reducing crop losses during storage. The factors affecting density in bunker and pile silos are not well understood. General recommendations have been to spread the crop in 6-inch layers and pack continuously with heavy, single-wheeled tractors. In a survey of alfalfa silage in 25 bunker silos, Ruppel et al. (1995) found tractor weight and packing time (min/T AF or min/ft^2) were the most important factors affecting density. However, both factors only explained a small fraction of the variation observed, and layer thickness was not measured. The objectives in a study conducted by Holmes and Muck (1999b) were to measure density in a wider range of bunker silos and to correlate those densities with filling practices.

TABLE 2. Dry Matter Loss as Influenced by Silage Density (Ruppel, 1992)

Density (lbs DM/ft^3)	**Dry Matter Loss, 180 days** (%)
10	20.2
14	16.8
15	15.9
16	15.1
18	13.4
22	10.0

The range of densities and dry matter contents observed in haycrop and corn silages are shown in Table 3. Ranges of dry matter densities were similar for both haycrop and corn silages. Densities on the low end suggested little packing, whereas the highest densities were in the range observed in tower silos. Average dry matter densities were slightly higher than a recommended minimum density of 14 lbs DM/ft^3.

TABLE 3. Summary of Core Samples Collected from 168 Bunker Silos (Holmes and Muck , 1999b)

Characteristic	**Haycrop Silage** (87 silos)			**Corn Silage** (81 silos)		
	Average	**Range**	**SD***	**Average**	**Range**	**SD***
Dry Matter (%)	42	24-67	9.50	34	25-46	4.80
Wet Density (lbs/ft^3)	37	13-61	10.90	43	23-60	8.30
Dry Density (lbs/ft^3)	14.8	6.6-27.1	3.80	14.5	7.8-23.6	2.90
Avg. Particle Size (in)	0.46	0.27-1.23	0.15	0.43	0.28-0.68	0.08

* SD = standard deviation.

Forage becomes denser in response to the weight of forage piled above it. Consequently, one can expect to have an average density that is higher in a taller bunker/pile silo than one which is shallower, all other factors being equal. Densities were positively correlated with the height of silage above the core, indicating the effect of self-compaction in bunkers. To put densities on a common basis, all densities were adjusted to the median depth below the surface (7.1 ft) using Equation 15 of Pitt (1983) and assuming a compressibility of 2.2×10^{-9}/psi. Adjusted dry matter density was positively correlated with average packing tractor weight, packing time, and dry matter content. Density was inversely correlated with the initial depth of the crop layer when spread in the silo.

The linear regression which explains 18% of the variation of estimated dry matter density (DMD) is expressed as:

$$Est.\ DMD\ (lbs\ DM/ft^3) = (8.5 + PF \times 0.0155) \times (0.818 + 0.0136 \times D)$$

where average depth (D) and packing factor (PF) are calculated as:

$$D = average\ silage\ depth\ (ft) = (height\ at\ wall + height\ at\ center) \div 2.$$

$$PF = \left(\frac{W}{L}\right) \times \sqrt{N \times DM \div C}$$

W = Proportioned average tractor weight (lbs) for all tractors packing silage. Example: Two tractors pack 100% of the filling time; tractor #1 weighs 25,000 lbs and tractor #2 weighs 15,000 lbs. Then the proportioned average tractor weight is 20,000 lbs = (25,000 + 15,000) ÷ 2. If tractor #1 packs 90% of filling time and tractor #2 is used 50% of the time, the proportioned average tractor weight becomes:

$$19{,}286 \text{ lbs} = (25{,}000 \times 0.9 + 15{,}000 \times 0.5) \times [90 \div (90 + 50)].$$

L = Layer thickness (inches) of the spread but unpacked crop in the silo prior to driving over it during the first packing pass.

N = Number of tractor-packing equivalents, where N = 1 when one tractor is packing continuously during the filling process. This value can be fractional, reflecting one or more tractors packing intermittently. For example, if one tractor packs continuously during the filling process and another packs 50% of the filling time, N = 1 + 0.5 = 1.5. If there is only one packing tractor and it packs for 11 hr/day and the silo is filled 10 hr/day, then N = 11/10 = 1.1.

DM = Dry matter content (decimal).
For example, 35% dry matter forage is used as 0.35 in the equation.

C = Crop delivery rate (T AF/hr) to the silo.

Use of rear duals or all duals on packing tractors had little effect on density. Other factors such as tire pressure, crop, and average particle size were not significantly correlated with density. Thus the low r^2 of the regression of dry matter density vs. the 5-parameter packing factor probably reflects variability in accurately estimating parameters such as initial depth of the crop and packing time per ton rather than missing factors important to determining density. Holmes and Muck (1999a) have developed a spreadsheet to simplify the process of solving those equations.

One practical issue raised in the study was packing time relative to crop delivery rate to the silo. Packing time per ton was highest (1 to 4 min/T AF) under low delivery rates (<30 T AF/hr) and generally declined with increasing delivery rate. Packing times were consistently less than 1 min/T AF at delivery rates above 60 T AF/hr in the survey. These results suggest that farmers using contractors to harvest their silage crops probably will need to pay particular attention to spreading the crop in a thin layer and would benefit from using several packing tractors simultaneously.

Rapid forage harvest and delivery to storage requires a corresponding rapid rate of storage filling. A producer selecting a self-propelled forage harvester may see a doubling of forage delivery rate (Table 4) compared to a large pull-behind harvester, provided transportation is also increased. This requires larger and perhaps more push-up/packing tractors at the bunker silo/silage pile.

TABLE 4. Forage Harvester Capacity (Shinners, 1998)

	Capacity (T AF/hr)	
Forage Harvester Type	**Hay**	**Corn**
Pull, 200 HP	25	55
Self-propelled, 400 HP	50	120

The desire to improve feed quality drives the need to have rapid harvest and silo filling. As herd size increases, the quantity of forage harvested also increases. However, the window of harvest opportunity remains the same. Thus another reason to increase the harvest rate on many farms is also forced by an increase in herd size. Any bottlenecks in the harvest/delivery system will cause cost increases due to equipment downtime and/or forage quality losses. Some custom operators using high capacity harvesting equipment offer a complete service of harvesting through silo filling. With an adequate complement of equipment and labor force, bottlenecks found on many farms can be eliminated, and rapid harvest/delivery can be accomplished. This service requires a higher out-of-pocket cost to the producer but will be covered by the preservation of feed quality. This will pay dividends when fed in a well-balanced diet to the herd by maximizing productivity while keeping purchased feed costs to a minimum.

The spreadsheet of Holmes and Muck (1999c) was used to estimate dry matter density for a hypothetical case where a producer increased harvest rate from 50 T AF/hr to 100 T AF/hr. The storage was assumed to average 9 ft tall, the forage dry matter was 35%, the forage layer thickness was 6 inches, and one tractor (30,000 lbs) was being used to distribute/pack the forage. The results of several scenarios are summarized in Table 5.

TABLE 5. Scenarios for Trying to Improve Silage Density When Forage Delivery Rate is Increased to 100 T AF/hr

Variables Changed from the Base Case	Est. Dry Matter Density (lbs DM/ft^3)
Add 20,000-lb tractor for 50% time	12.7
Add 20,000-lb tractor for 100% time	13.1
Add 5,000 lbs weight to 30,000-lb tractor and do not use 20,000-lb tractor	13.0
Add 5,000 lbs weight to both tractors and use both tractors 100% of time	14.1
Reduce layer thickness from 6 inches to 4 inches	14.5
Use both tractors 100% of time and reduce layer thickness to 4 inches.	15.6
Add 5,000 lbs to 30,000-lb tractor and reduce layer thickness to 4 inches	15.5
Add 5,000 lbs to both tractors, use each 100% of time, and reduce layer thickness to 4 inches	17.1

The packing tractor should be as heavy as possible to achieve adequate to high packing density. The manufactured tractor weight can be augmented by adding weight to the tractor. Weight can be increased by adding iron wheel weights, adding liquid to tires, or adding front end and 3-point hitch weight. Dual wheels all around will improve traction and tractor maneuverability on a slippery surface. This added safety factor as well as the ability to add more tractor weight makes this a good choice. Tractor rollover protection (ROPS), the use of a seat belt and selecting an experienced operator helps to improve safety in an inherently unsafe process of packing a bunker/pile. A shuttle shift transmission is very convenient for the operator making frequent changes of direction while packing.

As the harvest rate increases, the need for more than one pushing/packing tractor increases. One 40,000-lb tractor will handle a harvest rate of abut 90 T AF/hr while two or more 33,000-lb tractors may be needed between harvest rates of 90 to 120 T AF/hr. At the harvest rate up to about 90 T AF/hr, one 40,000-lb tractor is more effective than two 28,000-lb tractors. When more than one tractor operates in a bunker/pile silo, the danger of a collision is ever-present. Consider filling two storages simultaneously with a tractor operating in each as a means for avoiding collisions.

In narrow bunker silos, the most logical packing direction is from back-to-front. In wider bunkers and piles, consider packing in both directions to achieve a more uniform packing of the forage. In either case, the packing pattern should allow the wheel patterns in the forage to overlap about half a tire to improve uniformity of packing. When dual wheels are used, try to have a wheel pack the forage left unpacked between the wheels of the previous pass. If packing in both directions between bunker silo walls, remove the drawbar to avoid damage to the bunker walls and/or to the tractor.

Covering

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. Spreading soil on the perimeter edges of plastic covered silage piles helps to seal those edges and to keep the plastic from blowing in the wind. Plastic bag ends must be tightly sealed. Any holes in plastic covers should be repaired immediately after they occur.

SEALED COVERS

In the search for a low-cost and low-labor method of covering bunker silos/piles, producers have tried a vast array of substances and combinations of substances. Some of these include: weighted plastic, lime, earth, a roof, candy, molasses and molasses-based products, small grain, sod, Nutri-Shield, sawdust, chopped straw, composted manure solids and, in all too many cases, no cover.

Vass and Freeman (undated) compared the performance of Cargill Liqui-Seal (lignin sulfonate and molasses) against weighted plastic with corn silage stored in bunker silos. Results of their tests are summarized in Table 6. At first glance, it appears as if Liqui-Seal provides better dry matter preservation than plastic. However, the plastic covered silage was stored for almost twice as long as the Liqui-Seal protected silage. Holmes (1996a) calculated dry matter loss projected to a 180-day storage for each product based on daily average dry matter loss for each. The result of that projection is listed in the last line of Table 6 and shows that plastic does a much better (10%) job than Liqui-Seal.

Brusewitz et al. (1991) studied the preservation qualities of Nutri-Shield (soybean meal based) on corn silage stored in half barrels measuring 17 inches tall. A summary of their results are presented in Table 7. Some of the conclusions these researchers drew are:

"Covering the silage with polyethylene produced silage with minimal spoilage …."
"Compaction at the time of ensiling had a significant positive effect on silage quality."
"… there was no significant different between Nutri-Shield and uncovered silage."

TABLE 6. Cargill Liqui-Seal vs. Plastic (Vass and Freeman)
Corn Silage – 65% Moisture. Top Width = 15 ft, Length = 70 ft, Depth = 7 ft.

	Weighted Plastic	**Liqui-Seal**
Top Spoilage (%)	0.7	9.1
Average Top Spoilage (in)	4.9	11.6
Dry Matter Loss (%)	26.4	23.1
Feed Out Period	271	150
Dry Matter Loss Normalized to 180 Days of Feed Out by B.J. Holmes	17.5	27.7

Many producers will explain how they have heard of someone who has planted a small grain sod on top of a bunker silo and how very little spoilage was observed. Nieto-Ordaz et al. (1984) studied the effect of wheat sown vs. plastic covers on corn silage stored in 40-foot wide by 150-foot long bunkers. A regression equation was developed to describe the dry matter loss in the top 1.5 feet from day 17 to day 121 post filling. Holmes (1996a) has manipulated the Nieto-Ordaz et al. (1984).

TABLE 7. Nutri-Shield Silage Cover vs. Plastic and No Cover Total Depth = 17 in Tall Mini-Silos. Corn Silage of TDN 60%. 75.7% Moisture. Natural and Simulated Rainfall (2 in). Storage Period = 60 Days.

Surface Treat-ment	**Shrink-age** (%)	**Spoiled Layer** (%)	**Depth to 4.5 pH** (inches)	**High Silage Density, Natural Rain TDN** (%)	**High Silage Density, Sim-ulated and Natural Rain TDN** (%)	**Low Silage Density, Natural Rain TDN** (%)	**Low Silage Density, Sim-ulated and Natural Rain TDN** (%)
Plastic	Less	13	3.7	64.2	- - -	61.8	- - -
Nutri-Shield	26	36	7.1	59.6	54.9	49.9	47.4
None	26	29	7.7	- - -	56.4	49.7	48.7

equations to extrapolate the surface loss from 20 to 180 days of storage. To investigate the total dry matter loss in a bunker of 8.5-foot depth, the dry matter loss over the 180-day storage period in the bottom 5.5 feet was assumed as 8%. The silage in the 5.5 to 7 feet above the floor zone was assumed to have a dry matter loss of half that found by Nieto-Ordaz et al (1984). The results of this analysis are shown in Table 8. Manipulation of these results by Holmes (1996a) shows a significantly higher loss of total stored silage for the sod covered silage vs. a plastic cover.

TABLE 8. Estimated Dry Matter Loss in 8.5-foot Deep Bunker Silo Derived by B.J. Holmes (1996a) from Work of Nieto-Ordaz et al. (1984)

Time Post Filling (days)	**Plastic Cover**	**Wheat Sod Cover**
	- - - - - Total Dry Matter Loss (%) **- - - - -**	
20	8.0	9.5
60	8.5	13.8
100	9.0	18.0
140	9.6	22.3
180	10.0	27.0

Minson and Lancaster (1965) studied the effects of different methods of covering silage in 3.5-foot deep bunker silos filled with direct cut (80% moisture) grass forage. The following cover system were applied.

- None — Exposed to the atmosphere.
- Roof — No cover touching the silage. Structural roof shed rain from bunker.
- Sawdust — 5-inch layer of sawdust on top of silage.
- Soil — 3-inch layer of soil on top of silage.
- Limestone — 3-inch layer of ground limestone of top of silage.
- Plastic — Plastic on top of silage weighed with 5 inches of soils.

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 9.

TABLE 9. Effects of Cover Type on Dry Matter Losses 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 provided the preservation characteristics of plastic covered with soil. Deducting the 2.5-3.0% effluent loss that occurred due to juicing (plastic, roof) yields an effluent loss of 2.5-5.0% caused by rainfall percolating through the more porous covers.

The large visible waste loss (4 inches and 10% DM) in the roofed structure was probably facilitated by the diffusion of oxygen deeper into the silage as the top surface dried out. The other cover system had similar visible waste losses except for the plastic which had very little.

The gaseous loss for the plastic covered bunkers was lowest of all systems. Movement of oxygen through the remaining surface covers by diffusion and/or percolation has contributed to significant losses caused by aerobic microbial activity. The sum of all losses results in a 2-2.9 times increase in loss compared to that of the plastic cover which did a good job of excluding oxygen and precipitation.

STORAGE

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 9 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 9. 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.

Shape the top of the silage in a bunker to shed water from the silage after forage settling has occurred. Exclude runoff from flowing between the silage and bunker walls. This can be done by forming flow channels several feet from the walls and sloping toward the back of the bunker. Water flows over the plastic and exits the bunker onto the ground.

Bolsen (1993) studied the effect of cover type and time of application on a 3.5-foot deep bunker silo. This study also considered the effect of exposure time in storage. Table 10 shows that covering immediately with a plastic cover results in dry matter recovery exceeding 85% (15%) DM loss) at all depths for storage periods up to 180 days. The top 13 inches experienced the largest dry matter loss. Depths greater than 13 inches had losses in the range of 5-8%. The average dry matter loss of 9% compares very closely with the 9.4% (corrected for seepage) found by Minson and Lancaster (1965) in their plastic covered bunkers.

When no cover was used, significant dry matter loss occurred to the 26-inch depth. Loss values of 62% in the top 13 inches and 34% in the next 13 inches were experienced after a 180-day storage period. This 34% average loss compares closely to the 32% (corrected for seepage) found by Minson and Lancaster (1965) in their uncovered bunker silos.

By delaying covering for a period of 7 days, Bolsen et al. (1993) was able to demonstrate significant dry matter losses in the top 13 inches during the delay period. After the cover was added, further dry matter loss was similar to that of the immediately covered bunker. Thus covering is effective on a "better late than never" basis but is most effective when applied immediately. This data and analysis strongly support the recommendation of covering the bunker silo/pile immediately with a material which excludes oxygen and rain water.

What does this mean to the producer in the upper Midwest who wilts hay silage valued at \$100/TDM before placing it in a 8.5-foot deep bunker silo? Using the loss values in the top 3.5 ft of Table 9, let's assume adequate wilting and the 2.5% effluent loss does not occur due to juice seepage. Assume the choice is to cover with plastic and tires or not to cover at all. Assume the bottom 5 feet of silage experiences a gaseous loss of 8.6% in both cases. Assume the silage is packed to a density of 40 lbs/ft^3 (14 lbs/DM/ft^3) in a bunker silo 25 feet wide by 100 feet long. The silage placed in the bunker is 148.8 TDM valued at \$14,880. The average loss in the plastic covered silo is

$$\{[(0.8\% + 8.6\%) \times 3.5\ ft] + (8.6\% \times 5\ ft)\} / 8.5\ ft = 8.93\%$$

The average loss in the uncovered bunker is

$$\{[(5.6\% + 5\% + 21.1\%) \times 3.5\ ft] + (8.6\% \times 5\ ft)\} / 8.5\ ft = 18.1\%$$

The dry matter loss in the plastic covered bunker is 13.3 TDM valued at \$1330, while the loss in the uncovered bunker is 26.9 TDM valued at \$2690. The \$1360 difference in lost value can defray the cost of the plastic. If the plastic costs \$100 and the labor to cover and uncover is 20 man hours, the

TABLE 10. Effects of Covering and Time on Dry Matter Recovery from a 3.5-foot Deep Bunker Silo (Bolsen et al., 1993)

Silage Depth (inches)	**Time Post Filling** (days)	**Dry Matter Recovery**		
		Cover Immediately	**No Cover**	**Cover after 7 Days**
0-13	7	91.4	85.9	85.9
	21	91.7	69.4	80.9
	90	87.5	46.9	80.5
	180	86.5	37.7	78.1
13-26	7	95.6	92.6	92.6
	21	96.6	90.8	90.7
	90	93.6	67.9	89.3
	180	92.1	65.8	91.9
26-39	7	96.2	93.1	93.1
	21	96.9	93.2	92.8
	90	95.5	88.3	92.7
	180	94.6	92.6	95.6

payment for investing this labor is

($1360 - $100) / 20 hr = $63/hr,

which is not a bad wage for a good manager!

Falling from the wall of a bunker silo can cause serious injury and/or death. Take precautions when working near the wall. Face the wall while working on the silage or plastic cover. Use a tractor with front end loader to carry tires/weighting materials up the silage filling face to the area where workers are covering the plastic. Keep the plastic mostly weighted to avoid plastic billowing in the wind. If possible, delay covering until the wind is at a minimal level. Recruit enough workers to handle the plastic and weighting material so they can be handled safely. Select a plastic cover that is greater than 6 mil. It will reduce silage spoilage better than thinner plastics and some workers find it easier to handle. Thicker plastic is also less prone to punctures.

Feed Out

Silage feeding from storage should not occur until the fermentation process is complete. Opening the silage mass prior to the stable phase of fermentation results in dairy cow digestive upsets and lowered milk production. Once feedout occurs, the silage is exposed to oxygen, allowing yeast and molds to convert nutrients into carbon dioxide, water and heat. Fully fermented forages resist these losses of dry matter through the production of acid that lowers the pH to 4.0 or less. At that time, fermentation sugars are depleted and bacteria die off leaving a stable storage environment. The full fermentation phase takes between two and three weeks to stabilize the silage.

Feedout losses can represent up to 30% of the total dry matter loss in the ensiling process (Roth and Undersander, 1995). Losses occur from the exposed face and top as well as from loose silage lying on the floor between feedings. Therefore, only the amount of silage that will be fed in a short period should be uncovered at one time. Plastic can be pulled back from the silage top or cut off each day. At no time should more than three days worth of silage be exposed.

Spoilage happens. Particularly top spoilage even when covered. Spoilage also occurs from the spillage of loose material during feedout and from exposed areas as a result of damage to the cover. A comparison of silage harvest and storage losses may be referenced in "Preventing Silage Storage Losses" by Holmes and Muck, 2000.

A common attitude is that "if the cows eat it, it will be fed". Bolsen and workers at Kansas State University tested the effect of feeding four different levels of spoilage to steers (Bolsen et.al., 2000). Inclusion rates included 0%, 5.4%, 10.7% or 16% of ration DM. Dry matter intake, and the digestion of dry matter, organic matter and starch were evaluated. All measured parameters declined with increasing level of spoilage in the ration, including dramatic declines in fiber digestibilities. Even at the lowest level of inclusion, spoilage totally destroyed the rumen forage mat. This study, along with others including work by Holmes (1996a) "You Can't Judge a Bunker Silo by It's Cover", and Muck and Holmes (2000) "Preventing Silage Storage Losses", on the economics of covering horizontal storage structures, underscores the necessity of minimizing spoilage and of excluding any spoilage that does occur from the ration.

The rate and method of silage removal from the face critically affects feedout loss and animal performance. Removal rates should never be lower than 4 inches per day in the summer and 3 inches in the winter. Minimal removal rates are most critical with hay crop silages, high moisture corn and drier silages (Bodman and Holmes, 1997). One method of determining if enough silage is removed at each feeding is to take a sample 12-inch boring into the removal face at the beginning of a feeding and check for heating. If adequate silage is being removed and the appropriate removal management is employed so a tightly packed, smooth face results, the sample should be cool. If any part of the sample is warm, adjustments are in order.

The following discussion derives from Holmes and Muck, 2000. Pitt and Muck (1993) determined the dry matter loss during feed out of bunker silos as a function of silage removal rate. They determined the dry matter loss was 3% at the recommended removal rate of 6 inches per day for 35% dry matter silage with a density of 14 lbs DM/ft^3. They also concluded dry matter loss was reduced as silage density increased. Muck and Pitt (1994) state that dry matter loss is proportional to silage porosity. Porosity is inversely related to dry matter density and dry matter content. Based on this information, Figures 1-3 were developed to establish the dry matter loss as a function of dry matter density, silage removal rate, and dry matter content. In Figure 1 (9 inches per day removal rate), the dry matter loss during removal is less than 3% when the dry matter density is greater than 14 lbs DM/ft^3 and forage is ensiled at less than 40% dry matter. For the forage ensiled at 50% dry matter, the dry matter density must be greater than 17 lbs DM/ft^3 before the removal dry matter loss is 3% or less. Note that porosity must be less than 55% for the removal dry matter loss to be less than 3% when the removal rate is 9 inches per day.

In the situation where the silage face removal rate is 6 inches per day (Figure 2), the porosity must be 43% or less for the removal dry matter loss to be 3% or less. As the forage dry matter content increases, higher and higher dry matter densities are needed to keep the removal dry matter loss under 3%. If the dry matter density is less than 13 lbs DM/ft^3, it will be difficult to keep dry matter loss under 3% for any dry matter content graphed with a 6-inch silage face removal rate.

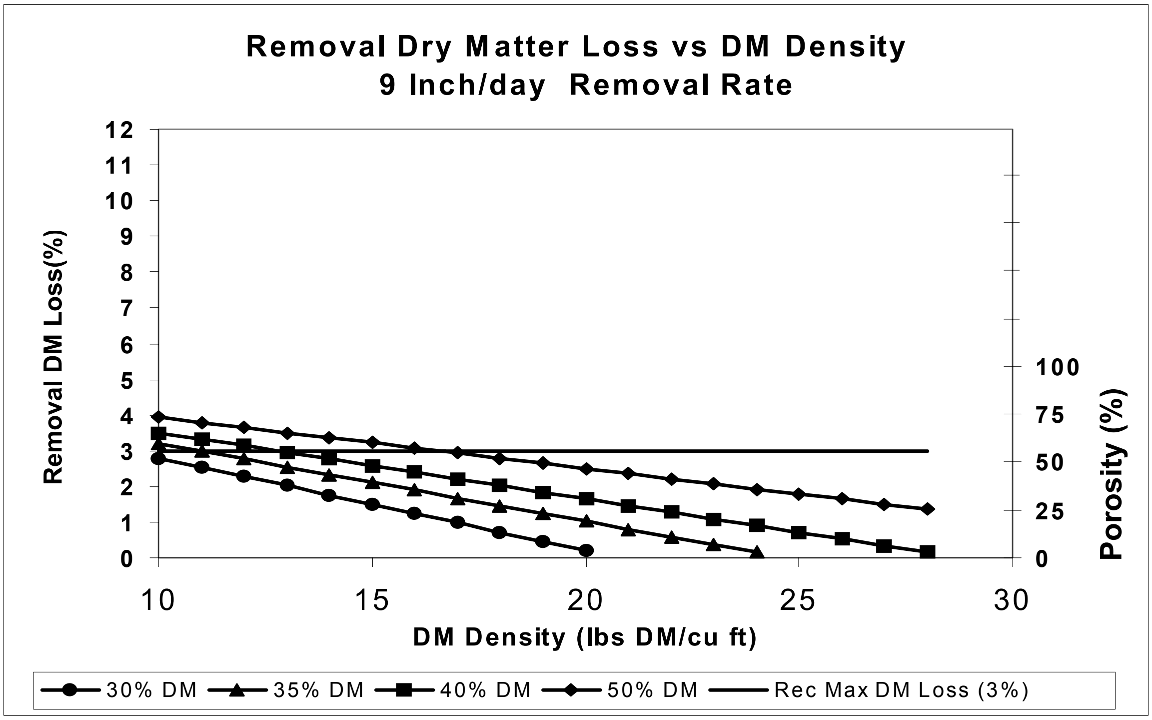

Figure 1. Dry Matter Loss vs Silage Density During Silage Removal From a Bunker Silo Face at the Rate of 9 Inches/Day.

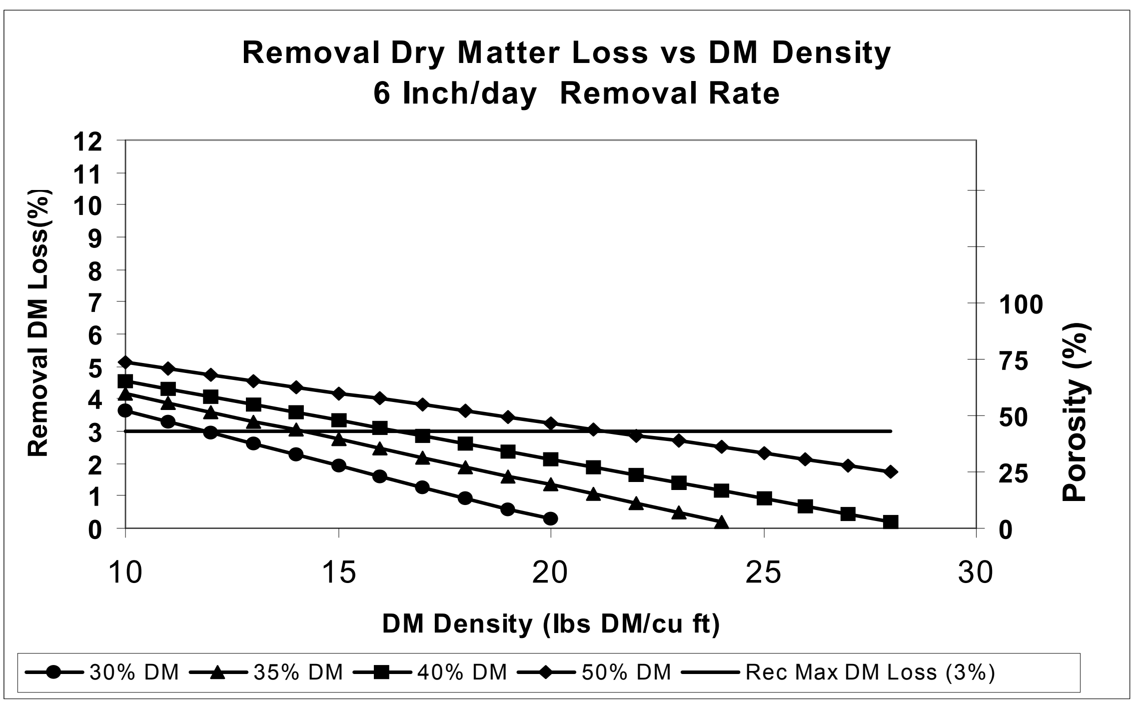

Figure 2. Dry Matter Loss vs Silage Density During Silage Removal From a Bunker Silo Face at the Rate of 6 Inches/Day.

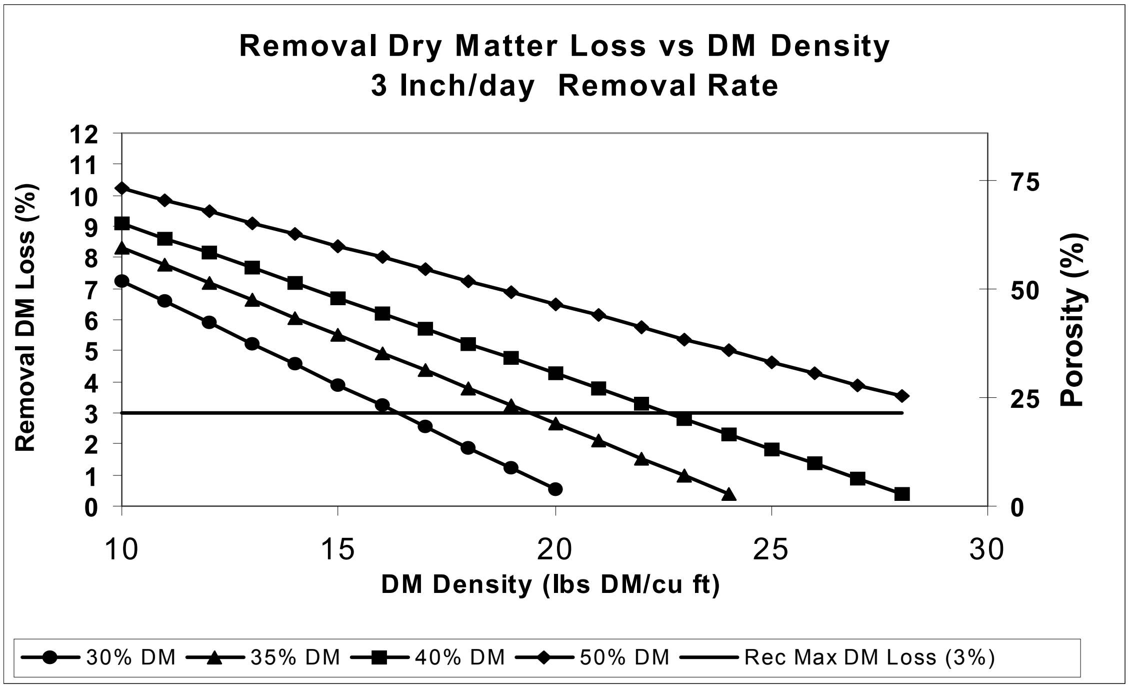

Figure 3. Dry Matter Loss vs Silage Density During Silage Removal From a Bunker Silo Face at the Rate of 3 Inches/Day.

Figure 3 presents the removal dry matter loss as a function of dry matter density when a 3-inch silage face removal rate is used. Under these conditions, the porosity must be less than 23% to keep the removal dry matter loss under 3%. The dry matter density must be greater than 16 lbs DM/ft^3 for this to occur. Face removal losses will be higher than 4.5% when the dry matter density is less than 14 lbs DM/ft^3. In fact, dry matter loss can be as high as 10% when forage is 50% dry matter and density is 10 lbs DM/ft^3.

As the silage face removal rate decreases from 9 inches per day to 3 inches per day, forage must have a lower dry matter content (more moist) and/or a higher dry matter density to assure dry matter loss is kept under 3%.

Many methods of silage removal are used on farms. Perhaps the most common method is the bucket loader. The preferred method of silage removal is to slice the silage from the top, and allow it to fall to the floor. Another method is to undercut the silage several inches up from the floor and then slice the balance of the face into the crevice. Any method that results in dislodging the face silage, creating gouges, cracks and potholes allows air to penetrate deep into the stack leading to increased deterioration. In a silo with very tall walls, the loader may not be able to reach the top of the stack to slice down the entire face. In this instance, operators should still use the down slice method attempting to minimize the disruption caused by lifting the upper portion to dislodge silage and the extent of the overhang which represents a safety hazard for workers.

It is easy, even under conditions of excellent face management, to become over zealous in the amount of silage dislodged from the face. Experienced feeders are able to accurately gauge the amount of silage to dislodge and assure that all loose feed is cleaned up from the floor by the end of each feeding. This approach minimizes silage deterioration and the inclusion of spoiled silage in the ration.

The determination of silage density is important for three reasons. To determine if adequate packing has occurred, to determine the face removal rate and to manage feed inventories. Two methods of density determination are available. Some consultants are using a silage probe similar to that used in the Wisconsin Bunker Density study that provides a known volume and weight from which density is calculated (Holmes and Muck, 1999b). A very practical approach that can be used on farms involves marking on the silo walls where silage removal starts and ends, weigh out the silage in the feeder wagon and determine density. Silage volume is calculated by; Silage Volume in cubic feet = (Average Silo Width in feet) x (Distance Between Marks in feet) x (Average Silage Height in feet) where Average Silage Height in feet = ((Height of Silage at the Wall in feet) + (Maximum Silage Height in feet))/2. An example where 72,000 lbs. AF silage is removed from a silo 40 feet wide, with an average height of 11 feet and a 4-foot slice of silage removed follows:

Silage Density = 72,000 lb. AF/ ((40 feet) (4feet) (11feet)) = 40.91 lb. AF/ft^3.

To determine the density on a dry matter basis, multiply the As Fed density by the percent dry matter:

DM Density = 40.91 lb. AF/ft^3 x 0.35 = 14.32 lb. DM/ft^3.

Safety is an issue in all phases of horizontal silage storage management. During feedout, loader operation must be such that neither the surface stability nor the structural stability of the equipment is compromised. Silage overhangs that occur as a result of equipment that is undersized for the structure and from crust formation as a result of spoilage are a danger. A person walking out on top of an overhang can be seriously injured if the overhang collapses. Similarly, serious injury can occur if the silage collapses on someone working underneath it.

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