Managing Factors That Affect The Production and Utilization of Quality Forages

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Maximizing dry matter intake is a major concern in today's high producing dairy herd. It is essential to get fresh cows smoothly onto feed in early lactation to make sure they reach their genetic potential for milk production and at the same time maintain health and reproductive capability. To optimize production, energy density must be high, protein quality must by good and rumen bacteria must be presented with the appropriate nutrients on a timely basis. Accomplishing these goals requires the offering to the animal of only high quality and highly palatable nutrient sources.

Forage is an essential part of the ration offered to the high producing cow. The forage offered in the ration must be of extremely high quality to maintain optimum intake in the fresh cow. Production of high quality forage requires careful attention to many factors before, during and after the crop is harvested.

When discussing improvements in an existing forage program the question is often asked, "what opportunities exist to improve forage quality?" Basically, there are three opportunities to improve the quality and they include management, plant genetics and forage additives.

Plant genetics is not within the scope of this presentation and will be mentioned only briefly. Plant breeders determine the needs of the producer and continually test new hybrids and varieties that meet these needs. Some attributes that are being tested include winter hardiness, resistance to various diseases, improved dry matter yields and improved nutrient digestibility to name only a few.

Forage additives are an important part of a quality forage program. Additives are available that effectively control the fermentation in ensiled crops. These additives dominate the fermentation and by doing so limit the loss of dry matter by improving the efficiency of the fermentation. Other benefits offered by a few quality bacterial additives include better protein quality, improved fiber digestibility and improved aerobic stability during feedout.

Although developing new plant characteristics through genetics and the use of forage additives are important, monitoring and improving management techniques is by far the biggest opportunity for the producer to improve forage quality in his operation.

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Optimum management of forage quality involves careful planning before harvest, during harvest and ensiling and post ensiling during feedout.

Pre-Harvest Management: Selecting a Crop For Quality Forage

Pre-harvest management involves choosing the correct hybrid or variety that will best fit the needs of the producer. Other pre-harvest management considerations include soil preparation, fertilization and irrigation. A qualified agronomist should be consulted to aid in making these pre-harvest decisions.

Choosing between hay or silage is an important consideration for many producers. The advantages of harvesting as silage as compared to hay include: 1) more nutrients preserved per acre due to lower field losses; 2) less chance of weather damage by reducing time from cutting to harvest; 3) silage is a better ingredient in total mixed rations; and 4) more mechanization of harvesting and feeding is available. Conversely, the disadvantages of silage compared to hay include: 1) storage losses can be extremely high with poor management; 2) high spoilage losses can occur if feedout is slow; 3) high initial investment in storage facilities and harvest equipment and 4) marketing silage is limited by high transportation costs and susceptibility to spoilage.

Choosing the type of crop to harvest as forage is another important consideration for producers.

Tall summer annuals include corn, forage sorghum, grain sorghum, sudangrass, sorghum-sudangrass and sunflowers. Tall summer annuals are sensitive to soils with poor drainage. Prolonged periods of cloudy weather will decrease growth rates and slow maturity. Soils and fertility are very important for normal crop development. Lack of available nutrients will reduce height, slow growth rate and maturity.

Corn silage is a high energy crop with high grain yields and good whole plant digestibility. Corn silage for storage in bunker silos should be harvested at 30-35% dry matter. This occurs when the milk line is about halfway down the kernel. Black layer stage of development is still recommended in some areas but harvest at this stage does not improve quality and makes management of storage difficult. Black layer corn silage will be drier and will be difficult to chop and pack in many structures.

In many areas of the country percentage of corn grain yield is still the primary factor in determining which hybrid should be utilized for corn silage. Recent research has shown that other factors should be considered when choosing a hybrid for harvest as corn silage. Of primary importance is quality of the stover, especially the stalk. Many researchers are now rating corn silage hybrid quality based on whole plant digestibility as well as grain yield potential.

Planting density influences corn silage yield and quality. As density increases yield normally increases but grain yields decrease. Under adverse weather conditions, plant maturity can be delayed and plant lodging can increase with higher plant densities. As a rule of thumb, plant densities can be increased from 10 to 25% over those normally used for corn grain.

Both grain and forage sorghums are used as silage in warmer climates of the United States. Research has shown that grain sorghum silages are nutritionally superior to forage sorghum silages. They are higher in protein and are usually more digestible than forage sorghum silages.

Sudangrass and sorghum-sudangrass hybrids are shorter and finer stemmed than forage sorghums and usually yield from 2-5 cuttings per year depending upon location. These warm season grasses produce excellent quality silage if harvested in the late boot stage of plant development. Higher yields are realized at later maturities but digestibility is greatly reduced. These crops can have high levels of nitrate and/or prussic acid if stressed during their growth. They should be tested if adverse conditions occur during growth or harvest.

The annual small grains such as wheat, oats, rye, triticale and barley can make excellent silage. If harvested in the boot stage they can provide high yields from a single harvest and have excellent digestibility. These crops are often grown in rotation with tall summer annuals to provide soil protection during the winter and to provide early spring silage. These cereals have hollow stems and packing in a bunker structure can be difficult if harvested too dry. The crop should be wilted to 30-35% dry matter and chopped fine, about 3/16 to 1/4 inch theoretical length of cut.

Winter rye is the earliest small grain to mature but will lose quality rapidly after boot stage. Oat forage is one of the more productive of the winter annual crops and is one of the most palatable of the small grain forages. Oats are known accumualtors of nitrates and should be checked for nitrate nitrogen even if a problem is not suspected. Hard and soft red winter wheats are more productive than other small grains harvested at the boot stage.

Quality of small grain silage is directly related to maturity and dry matter yield. Dry matter yield increases rapidly as the crop matures from boot to dough stages but quality declines. Due to rapid yield increases, quality yield per acre also increases, even though the quality percentage decreases. A decision must be made on quality percentage or quality yield when producing small grain silage. The small grains remain in the boot stage only about 3-7 days making the decision on harvest time critical.

Small grains are often used as a companion or nurse crop when establishing perennial grasses or legumes. These crops compete with weeds and help protect the soil as the slow growing perennial becomes established. In this situation the small grain should always be harvested at the boot stage because allowing further maturity may have adverse effects on the developing perennial.

Perennial grasses and legumes are used extensively for forage and include alfalfa, orchardgrass, ryegrass, timothy, bermudagrass, bromegrass and various others. In many areas the first cutting of these grasses are harvested for silage with later cuttings dried and baled.

Perennial forages are managed three ways for silage: 1) direct cut; 2) field wilted to 30-35% dry matter; or 3) allowed to wilt to 50% dry matter. Perennials have variable water soluble carbohydrate concentrations and this may vary within a growing season and by fertilizer management. With low water soluble carbohydrate levels under very wet conditions fermentation may be extended and resulting forage quality will be poor. As perennials reach later maturity water soluble carbohydrates may reach low levels which will decrease the activity of the lactic acid bacteria in the silo. Fertilization with nitrogen also can markedly lower the water soluble carbohydrate levels in perennials.

As perennial crops mature, dry matter yields increase and the quality decreases. After the boot stage and into seed development, digestibility of all grasses declines at about the same rate. Stage of maturity at harvest is the single most important variable in the production of high quality perennial grass and legume silage.

Tropical grasses, such as bermudagrass, can be utilized as silage. High levels of nitrogen fertilization on this crop should be avoided since it will lower the water soluble carbohydrate levels and may interfere with fermentation.

Pre-Harvest Management: Selecting Storage Structure Type and Size

The decision on the type of storage system for ensiled forage should be based on the following factors: 1) type of silage; 2) herd size; 3) available labor; 4) capital investment; 5) access to equipment and equipment service and 6) feeding management.

Bunker silos are most commonly used when large capacities are needed, however, long narrow bunkers can work well in smaller operations. Bunkers can be filled and emptied with conventional farm equipment and require less energy to move the forage. Tower silos allow greater mechanization during filling and feedout, require less area for construction and have less surface area of exposed silage. Open stacks are a very low cost way to ensile surplus forage but have to be managed very carefully. Loss of dry matter in open stacks can easily approach 30-35% of the total forage harvested. These losses are associated with the large amount of exposed surface area and the difficulty with proper packing.

The losses associated with the various silage storage systems are shown in Table 1. The greatest variation among systems is associated with the losses during storage. One of the key factors to minimize loss is to harvest at the right moisture and limit exposure to oxygen. Figure 1 shows the relationship between silo type, capacity and storage losses which can be expected. Bunker silos tend to have the greatest amount of loss while oxygen-limiting towers, concrete towers and bags have the least.

The costs associated with the common silage storage systems are shown in Table 2. These data are from Florida. The trend in all economic analysis of silo costs is for the concrete bunker and bagger to provide the least expensive storage system.

Choosing the right size storage structure for a given size of operation can greatly reduce the management required to minimize losses associated with feedout. Data shown in Tables 3 through 5 can be used to estimate the storage capacities of silos of different dimensions. The storage capacity of the bag system is estimated at one ton of wet forage per linear foot (9 foot diameter bag) and .8 ton per linear foot (8 foot diameter bag) when forage is ensiled at 40% dry matter. The amount of silage which can be stored varies with forage type and dry matter content. It is important not to construct a storage structure larger than is needed for a given number of animals being fed. The general thumb rule is to try and feed at least six inches per day off the face or surface of the silage. Figure 2 shows equations that can be used to determine proper height and depth required for bunker structures.

Management decisions made at harvest and during ensiling are usually the most critical of all. Proper management at this time is required to insure proper ensiling, preservation and stabilization of the forage crop. Factors to be considered at this stage of forage management include crop maturity (to aid in determining cutting schedules), wilting times (to aid in reaching optimum moisture levels for ensiling), chop length, distribution in the silo, compaction, type of cover to be used on the structure and what type of additive to use on the silage.

Post ensiling management considerations include those factors which affect feedout of the ensiled forage. Factors to be considered include face management, amount of forage to be removed from structure, feedout methods and feed bunk management. Most management steps during this time are aimed at minimizing the losses that occur do to yeast, mold and aerobic organism growth that occur after the silo has been opened. It should be remembered that nearly 50% of the dry matter losses that occur in ensiled feeds occur on the surface, on the face and in the bunk during the feedout stages of silage management.

Management Practices To Optimize Fermentation

At harvest time nearly all management practices are directed at optimizing the speed and efficiency of the fermentation process by eliminating oxygen, minimizing plant respiration, reducing breakdown of protein and setting up favorable growth conditions for lactic acid bacteria which drive the fermentation process toward a favorable conclusion.

Six phases of silage fermentation are generally recognized by silage researchers. These and the management factors that work best with each phase will be discussed in the following paragraphs.

During phase I the cut plants and the aerobic bacteria present on the plant at harvest continue to use oxygen trapped in the silo and oxygen still left in the plant material itself. Phase I provides little benefit to the total ensiling process other that to utilize residual trapped oxygen and to allow the still growing aerobes to produce some anti-mycotic compounds that may extend stability of the silage during feedout.

The disadvantages of the respiratory phase are several. Excessive loss of dry matter, primarily energy rich plant sugars, can occur if respiration is extended. This may have additional negative effects on the fermentation. Lowered available sugars may inhibit the growth of lactic acid bacteria later in the fermentation process. Lowered sugar levels also contribute to total dry matter lossers and may affect animal performance and economics during feedout.

Prolonged respiration can also lead to excessive heat production in the ensiled mass. Ideally the fermentation process should not result in temperatures higher than 10-15 degrees Fahrenheit above ambient temperature during ensiling. If the temperature in the silage mass exceeds 130 Fahrenheit the Maillard reaction can occur resulting in excessive amounts of bound protein unavailable to the animal upon feedout.

Plant enzymes also remain active during the respiratory phase and can have considerable effect on the final product. Hydrolysis of starch and hemicellulose to monosaccharides continues until enzymes are inactivated. This hydrolysis can increase sugars available for lactic acid bacteria use later in the fermentation. Hydrolysis of hemicellulose does lower the NDF of the ensiled forage but undigestible fiber usually remains unchanged.

Proteolytic enzymes are also active during the respiratory phase of fermentation. Enzymes convert protein nitrogen to soluble non-protein nitrogen forms such as peptides and free amino acids. Further degradation of these compounds to ammonia and amines is caused by microbial activity in the silage mass. Up to 50% of plant protein may be broken down during the respiratory phase. Total protein degradation is dependent on rate of ph drop. Below pH 5.0-5.5 acidification denatures the proteases and reduces their subsequent activity.

Most managment practices just prior to harvest, during harvest and during silo filling are directed at minimizing the negative effects of phase I. Oxygen is the number one factor affecting the fermentation process in a negative way. Rapid elimination of oxygen is essential in obtaining a high quality final product.

Maturity and moisture at ensiling are two important factors in optimizing the fermentation process. Proper maturity assures adequate fermentable sugars for the lactic acid bacteria. Maturity also has a major impact on moisture levels in unwilted crops such as corn silage and direct cut grasses. Proper moisture during silo filling is critical to insure a good pack of the silage mass and reduce oxygen penetration. Optimum moisture levels vary between crops and silo structure type. (Table 6). Moisture levels above 70% may lead to an undesirable clostridial fermentation described later in this paper.

Length of cut is important in preventing oxygen penetration into the silage mass. 1/4 to 1/2 inch is the optimum lenth of cut and varies within these ranges depending on the crop to be ensiled. Cutting shorter than these recommendations may lead to digestive upset in ruminants on high forage diets. Cutting longer than these recommendations will make packing difficult and allow oxygen to penetrate the silage mass.

Filling rapidly, packing adequately and sealing the structure are all important management steps. Delayed filling results in prolonged respiration and increased air penetration of the silage surface. Packing should begin immediatlely in bunker structures and should continue for at least 24 hours after it has been determined the silage mass has been adequately packed.

Bunker silos should be covered as soon as possible after packing is completed. The entire surface should be covered with 4-6 mil plastic. The edges should be sealed and tires should be placed edge to edge to hold the plastic down. Research at Kansas State University has shown a minimum of a 4:1 return on investment by sealing pit silos with plastic and tires. The value associated with covering silos is shown in Table 7.

Phase II of fermentation begins after oxygen levels in the silage mass have been reduced. This phase consists of the growth of heterofermentative bacteria, primarily Enterobacteria species and some lactic acid producing species. These bacteria are usually heat and acetate tolerant and produce various levels of acetic acid, ethanol, lactic acid and carbon dioxide. (Table 8)

This phase of fermentation is not extremely efficient but does set up the silage mass with conditions necessary for phases III and IV. When pH levels drop below five these bacteria decrease in numbers and activity. This phase of fermentation generally ends in 24-72 hours. The use of a good bacterial silage additive containing only strains of homofermentative lactic acid producing bacteria can reduce the dry matter losses associated with phase II. This can only occur if those strains used have the ability to dominate the fermentation in a short period of time.

Phase III is often considered a transition phase. As pH continues to decline, there is a rapid increase in the numbers of homofermentative lactic acid bacteria which leads to a more rapid and efficient reduction in silage pH.

Phase IV is characerized by rapid production of lactic acid by homofermentative lactic acid bacteria. During this phase temperatures in the silage mass begin to stabilize and lactic acid accumulates. This is the longest phase of fermentation and ends when pH is low enough to inhibit growth of all organisms in the silage. Under typical conditions, in untreated silage, this phase will last from 10 days to 3 weeks. This time factor is greatly affected by the management factors previously described under phase I. This time can also be greatly reduced by the use a good homofermentative bacterial silage inoculant, often resulting in a considerable improvement in dry matter retention.

When moisture levels in the silage are greater than 70% during ensiling lactic acid producing bacteria may not dominate the fermentation. At high moisture levels, large populations of clostridial organisms can proliferate in the silage. These anerobic organism can rapidly degrade lactate and amino acids. In addition they can produce large amounts of butyric rather than acetic acid. This results in silage with a pH greater than 5.0 and leads to very unpalatable silage. On the other hand, clostridial fermentation leads to a high degree of aerobic stability but because of the detrimental effects on protein quality and palatability this is an extremely undesirable fermentation pathway. The pH at which clostridial activity ceases is dependent upon water activity which is related to the dry matter content of the silage. Unwilted silage may require a pH in the low 4 range to effectively inhibit clostridial growth.

Phase V is a so-called "terminal" phase of the ensiling process. Silage in this phase should remain stable and in a "preserved" state for an extended period of time providing oxygen is prevented from entering the silage. Stability of the mass in this phase can also be threatened if certain spoilage organisms such as anerobic yeasts elevate the pH by metabolizing fermentation acids.

Legumes with initial low water soluble carbohydrate levels and high buffering capacity will stabilize at pH of around 4.5. Corn silage will stabilize at pH of 4.0 or slightly below. Wetter silages such as grasses ferment longer and require high water soluble carbohydrate levels and lower pH levels for stability. Ph measurement alone is not an accurate measure of the rate or quality of the fermentation.

Phase VI is the stage of fermentation referring to the silage as it is being fed out of the storage structure. This is an extremely important phase because research has shown that nearly 50% of all the losses that occur in silage dry matter are due to the growth of aerobic spoilage organisms on the surface, on the face of the silo and in the feedbunk. Conditions which predispose silage to poor aerobic stability include high background populations of yeasts, molds or aerobic bacteria. These high background counts are often the result of damage done to the crop while still in the field i.e. drought stress or hail damage. Other factors include high levels of unfermented water soluble carbohydrates, high manure applications which may lead to an overgrowth by Bacillus organisms and crop contamination by high levels of soil-borne organisms.

Unloading practices and face management are just as important as management practices followed when filling the silo. Silage can be stored for long periods of time if the structure is well sealed but the general recommendation is to feed within one year if possible. When the silo is opened and feeding begins careful removal of material from the face will greatly reduce losses due to growth of aerobic spoilage organisms. Avoid knocking down any more material than will be used for one feeding. Loose material on the ground will have high oxygen exposure and will begin to heat and spoil within a few hours, especially in warm weather. Try and keep the face of the exposed material straight and uniform.

Management of the feedbunk is also important to reduce losses of valuable nutrients. Feed only what will be consumed by the number of animals in a group. Avoid dumping fresh feed on top of that material left from a previous feeding. Bunks may need to be scooped if large amounts of feed are left over and have begun to heat. Consider at least two and possibly more feedings per day in warm weather. Remember that it only takes a few hours of oxygen exposure before spoilage organisms begin to grow and deplete the forage of valuable nutrients.

Post-Ensiling Management: Sampling of Forages

Routine sampling is a good part of silage management and should be done for normal as well as problem silages. Sampling the forage as it is being put into the structure is recommended. This gives a good reference point for future analysis and it allows the nutritionist to balance the ration properly when the silo is opened and incorporated into the ration.

To sample fresh forage try to obtain 3-5 handfuls from each load coming to the silo. Try to get a composite sample from each field and from each cutting. Marking the area in the silo when fields and cuttings change is a helpful reminder of when to look at re-balancing the ration to compensate for nutrient differences.

Forages should be sampled for nutrient content several times during the year. Remember that nutritional values will vary from field to field and between cuttings. Samples of moisture should be made on a weekly basis if possible. This allows the nutritionist to adjust for nutrient density as the feed changes.

Proper sampling technique is necessary for accurate results. In a bunker the best method is to dig 1-2 feet into the mass in at least six locations high, medium and low on the face of the silo. Mix these samples together and send a 1/2 pound composite to the lab for analysis. Before shipment to the lab, freeze the sample in an airtight plastic container for 24 hours. Pack the sample in an insulated cooler with ice packs for shipment.

To interpret the results requires some standard guidelines to follow. Fermentative, microbiological and nutritional silage goals are shown in Table 9. Many of the values given here are not routinely checked in normal silage. In problem silages, consultation with a forage specialist to determine what analyses may be required to diagnose the problem is advised.

Conclusion

Management of a quality forage program is essential. It is important to monitor and control all aspects of the program from "plow to cow". The two primary nutrients in a cow's diet, protein and energy, are high cost items when they have to be purchased. Providing the animal with high quality, highly palatable and highly digestible forage can improve the efficiency and reduce the cost of production in all phases animal production.

TABLE 1

ESTIMATED LOSSES FROM VARIOUS STORAGE SYSTEMS UNDER GOOD MANAGEMENT

	Storage system and crop DM content at harvest					
Source of dry matter loss[1]	Horizontal trench or stack 35%	Horizontal bunker 35%	Concrete tower 35%	Oxygen-Limiting tower 55%	Bag 35%	Round Bale 35%
	---% of the standing crop DM in the field---					
Respiration and weathering	4	4	4	6	4	4
Harvesting	2	2	2	3	2	4
Storage	15	12(10-15)	9(8-9)	5	7(5-9)	18(10-25)
Feedout	4	4	2	2	4	4
Total	25%	22%	17%	16%	17%	30%

[1] Losses are highly variable and can be much higher depending on management and climatic conditions. Oxygen-limiting steel towers and concrete towers are the least affected. Polyethylene deteriorates with time, so systems most dependent on it for excluding oxygen having greater losses with long-term storage.

Source: Alberta Agriculture (1988).

TABLE 2

ANNUAL OWNERSHIP COSTS AND OWNERSHIP COST PER TON OF SILAGE DRY MATTER FOR COMMON STORAGE SYSTEMS[1]

Silo type and dimensions, ft.	Capacity[2]	Investment cost	Annual ownership cost[3]	Ownership cost/ton of DM stored
	(ton)	($)	($)	($/ton)
Concrete stave				
20 x 70	171	30,950	6,796	39.75
30 x 80	444	53,250	10,375	23.37
Poured concrete				
20 x 70	171	38,950	8,276	48.40
30 x 80	444	74,250	14,871	33.49
Metal oxygen-limiting				
20 x 80	197	82,300	17,144	87.03
25 x 80	346	121,300	24,519	70.87
31 x 90	532	200,500	41,267	77.57
Concrete oxygen-limiting				
20 x 72	176	69,850	13,417	76.23
30 x 80	444	118,250	22,371	50.39
30 x 100	560	128,750	24,313	43.42
Concrete bunker				
10 x 30 x 96	150	21,000	4,405	29.37
12 x 40 x 112	300	25,500	5,147	17.16
14 x 50 x 112	450	28,500	5,642	12.54
Bagger				
5 bags	248	34,625	10,010	40.44
15 bags	743	37,875	13,260	17.86
25 bags	1,238	41,125	16,510	13.34
Round bale[4,5]				
500 bales	150	20,750	6,705	44.70
1000 bales	300	22,500	8,455	28.18
500 bales	450	24,250	10,205	22.67

[1] Storage investment cost includes the capital outlay for the silo, unloaded and blower, tractor, front-end loader, and bags. The ownership costs per ton of silage DM provides a measurement for unit-cost comparison.

[2] The DM capacity, measured in DM units, was estimated for 60 to 65% moisture silage. When storing lower moisture material, such as haylage, a different DM capacity might be appropriate.

[3] The annual ownership cost is the sum of the depreciation, interest, repairs, taxes, and insurance for the various capital items.

[4] Source: Kunkle et al. (1988).

[5] Investment cost includes wrapper, plastic, tractor, and loader.

Source: Cromwell et al. (1989).

TABLE 3

APPROXIMATE BUNKER AND TRENCH SILO CAPACITIES

Dimensions: width x height x length, ft.	Total volume	Fillable volume[1]	Capacity[2] Alfalfa silage	Capacity[2] Corn silage
20 x 8 x 40	6,400	5,760	34	40
20 x 8 x 80	12,800	12,160	72	85
20 x 12 x 40	9,600	8,160	48	57
20 x 12 x 80	19,200	17,760	105	124
40 x 12 x 80	38,400	35,520	210	249
40 x 12 x 120	57,600	54,720	324	384
40 x 12 x 160	76,800	73,920	438	518
40 x 16 x 80	51,200	46,080	273	323
40 x 16 x 120	76,800	71,680	424	502
40 x 16 x 160	102,400	97,200	576	682
40 x 20 x 80	64,000	56,000	332	393
40 x 20 x 120	96,000	88,000	521	617
40 x 20 x 160	128,000	120,000	710	841
60 x 16 x 120	115,200	107,250	637	754
60 x 16 x 160	153,600	145,920	864	1,023
60 x 16 x 200	192,000	184,320	1,091	1,292
60 x 20 x 120	144,000	132,000	781	925
60 x 20 x 160	192,000	180,000	1,066	1,262
60 x 20 x 200	240,000	228,000	1,350	1,598

[1] The entire volume cannot be filled with silage; the front surface is assumed to be a 45 degree slope.

[2] Based on DM densities of 11.8 and 14.0 lb/ft3 for alfalfa and corn silages, respectively, which are representative of good silage management (i.e., adequate packing).

Source: Isher et al. (In Press).

TABLE 4

ESTIMATED WET FORAGE CAPACITIES OF BUNKER AND TRENCH SILOS CONTAINING 35 TO 40% DRY MATTER SILAGE[1]

Silage depth, ft. and average silage density, lbs/ft.^{3}	Silo width, ft.	Silage/ 4 inches of removal, tons	Silo capacity, tons[2] Per linear foot	Silo length, ft. 60	80	100
8 32 lbs/ft.^{3} (density ranges from 30 to 36 lbs/ft.^{3})	20	.85	2.56	125	173	221
	24	1.02	3.07	150	207	265
	30	1.28	3.84	187	259	331
12 36 lbs/ft.^{3} (density ranges from 34 to 38 lbs/ft^3)	24	1.73	5.18	249	353	456
	36	2.59	7.78	373	529	684
	48	3.46	10.37	498	705	912
	60	4.32	12.96	622	881	1,140
16 40 lbs/ft.^{3} (density ranges 37 to 42 lbs/ft.^{3})	36	3.84	11.52	507	737	968
	48	5.12	15.36	676	983	1,290
	60	6.40	19.20	845	1,229	1,163

[1] Capacities are dependent on average densities of silage. Silage density increases with increasing moisture content, shorter cut length, packed silage depth, and degree of packing.

[2] Capacity is calculated on the assumption that the far end at the silo is vertical and the front has a 2 to 1 slope, i.e., twice as long as the height of silage in the silo.

Source: Alberta Agriculture (1988).

TABLE 5

BUNKER AND TRENCH SILO CAPACITIES: TONS OF WET FORAGE PER FOOT OF LENGTH[1]

Depth, ft.	Bottom width, ft[2]						
	20	30	40	50	60	70	80
8	3.4	5.0	6.5	8.1	10.0	11.3	13.0
10	4.3	6.2	8.4	10.2	12.2	14.2	16.2
12	5.2	7.5	10.0	12.3	14.6	17.0	20.0
14	6.0	8.7	11.5	14.3	17.0	20.0	22.7
16	7.0	10.0	13.1	16.3	20.0	22.7	26.0

[1] Capacities are based on 70% moisture silage weighing 40 lbs/ft 3.
[2] Sidewalls slope out 1 ft. in 8 ft. of height.

Source: Cromwell et al. (1989).

TABLE 6

Harvest Maturity and Moisture Recommendations				
		Silo Type		
Crop	Maturity	Bunker	Stave	Oxygen-Limiting
Corn silage	1/2 to 2/3 milk line	67-72%	63-68%	50-60%
Corn, ground ear	Full dent to black layer	34-40%	32-38%	30-36%
Corn, cracked shelled	Full dent to black layer	26-32%	26-32%	22-26%
Sorghum grain, whole	Medium to hard dough	------	------	22-26%
ground or rolled	Medium to hard dough	26-32%	26-32%	22-26%
Alfalfa	Mid-bud to 1/10 bloom	65-70%	60-65%	50-60%
Cereal silage	Milk to soft dough	67-72%	63-68%	50-60%
Grasses	When first stems head out	67-72%	63-68%	50-60%
Clover	1/4 to 1/2 bloom	67-72%	63-68%	50-60%
Forage sorghum	Varies by hybrid	70-75%	65-75%	50-60%
Sorghum-sudangrass	24-30" or boot stage	67-72%	63-68%	50-60%
Baled alfalfa hay	Late bud to early bloom	Baled at 15-25%		

TABLE 7

DRY MATTER LOSS, TEMPERATURE, AND CHEMICAL COMPOSITION AT TWO DEPTHS IN COVERED VERSUS UNCOVERED ALFALFA SILAGE ENSILED AT 44% DRY MATTER

	Temperature at 49 days, F°	DM loss, % of the DM ensiled	pH	Lactic acid, % of the silage DM
Covered				
top of silage		4		3.0
bottom of silage		3		3.3
overall average	98	4	4.9	3.2
Uncovered				
top of silage		51		.6
bottom of silage		13		2.8
overall average	129	32	6.8	1.7

Source: Oelberg et al. (1983).

TABLE 8

SIMPLIFIED SILAGE FERMENTATION PATHWAYS

HOMOFERMENTATIVE:

1 Glucose → 2 Lactic acid

Sum:	1 Glucose	2 Lactic acid	Recovery (%)
Dry matter (g)	1000	1000	100
Energy (kcal/mole)	673	652	97

HETEROFERMENTATIVE:

1 Glucose → 1 Lactic acid + 1 Ethanol + 1 CO_2

Sum:	1 Glucose	1 Lactic acid	1 Ethanol	Recovery (%)
Dry matter (g)	1000	500	256	76
Energy (kcal/mole)	673	326	327	97

3 Frutose → 1 Lactic acid + 2 Mannitol + 1 Acetic acid + CO_2

Sum:	3 Frutose	1 Lactic acid	2 Mannitol	1 Acetic acid	Recovery (%)
Dry matter (g)	3000	500	2022	333	95
Energy (kcal/mole)	2025	326	1456	209	98

CLOSTRIDIAL FERMENTATIVE:

2 Lactic acid → 1 Butyric acid + 1 CO_2 + 2 H_2

Sum:	2 Lactic acid	1 Butyric acid	Recovery (%)
Dry matter (g)	2000	978	49
Energy (kcal/mole)	652	524	81

3 Alanine → 2 Propionic acid + 1 acetic acid + 3 NH_3 1 + CO_2

Sum:	3 Alanine	2 Propionic acid	1 acetic acid	Recovery (%)
Dry matter (g)	3000	1662	674	78
Energy (kcal/mole)	1166	734	209	98

1 Leucine → 1 Isobutyric acid + 1 NH_3 1 + 1 CO_2

Sum:	1 Leucine	1 Isobutyric acid	Recovery (%)
Dry matter (g)	1000	671	67
Energy (kcal/mole)	855	517	60

YEAST FERMENTATIVE:

1 Glucose → 2 Ethanol + 2 CO_2

Sum:	1 Glucose	2 Ethanol	Recovery (%)
Dry matter (g)	1000	511	51
Energy (kcal/mole)	673	654	97

Source: McCullough, M. 1984. Feeding Quality Silage. Animal Nutrition and Health Magazine. Sept./Oct 1984. p. 34.

TABLE 9

SILAGE GOALS

(1) pH 3.8 - 4.5

- upper range for legume silages
- lower range grass, corn and cereal silages
- higher range for wilted vs. direct-cut silages

(2) FERMENTATION ACIDS (% dry matter (DM) basis)

a) Lactic Acid	6-8% - wet silages [>65% moisture] 3-4% - wilted silages [>55% moisture] 1-3% - high moisture grains
b) Acetic Acid	<2% - forage silages <.1% - high moisture grains
c) Butyric Acid	<.1%
d) Propionic Acid	0-1%

(3) WATER SOLUBLE CARBOHYDRATES (6-carbon reducing sugars, DM basis)

1-4% - high moisture grains, upper level if cob included
4-6% - legumes and grasses
6-8% - corn silage

(4) PROTEIN PARAMETERS

a) Ammonia Nitrogen (NH_3-N, % of Total Nitrogen)

<5% Corn & Cereals
<10-15% Grass/Legumes

b) Heat damage (bound or unavailable protein)

1. If the ratio of bound protein (BP)/crude protein (CP) is <12%), fermentation proceeded normally. Use CP values to balance rations.
2. If the ratio of BP/CP is >15%, considerable heat damage has occurred. Use Available CP (ACP) values to balance rations.

(5) SILAGE TEMPERATURE

- No greater than 15-20^{o}F above ambient temperature at ensiling

TABLE 9 (cont.)

(6) MICROBIAL ANALYSIS (Colony Forming Units/gram of silage DM)

a) Total Aerobes: <100,000 (10^5) cfu/gram of silage
Example: Bacillus species

b) Molds: <100,000 (10^5) cfu/gram of silage
Example: Species of Fusarium, Gibberella, Aspergillus and Penicillium

c) Yeast: <100,000 (10^5) cfu/gram of silage
Example: Acid-metabolizing species Candida and Hansenula are more concern than fermentative species such as Saccharomyces and Torulopsis

FIGURE 1

EFFECTS OF SILO TYPE AND CAPACITY ON PREDICTED STORAGE DRY MATTER LOSSES

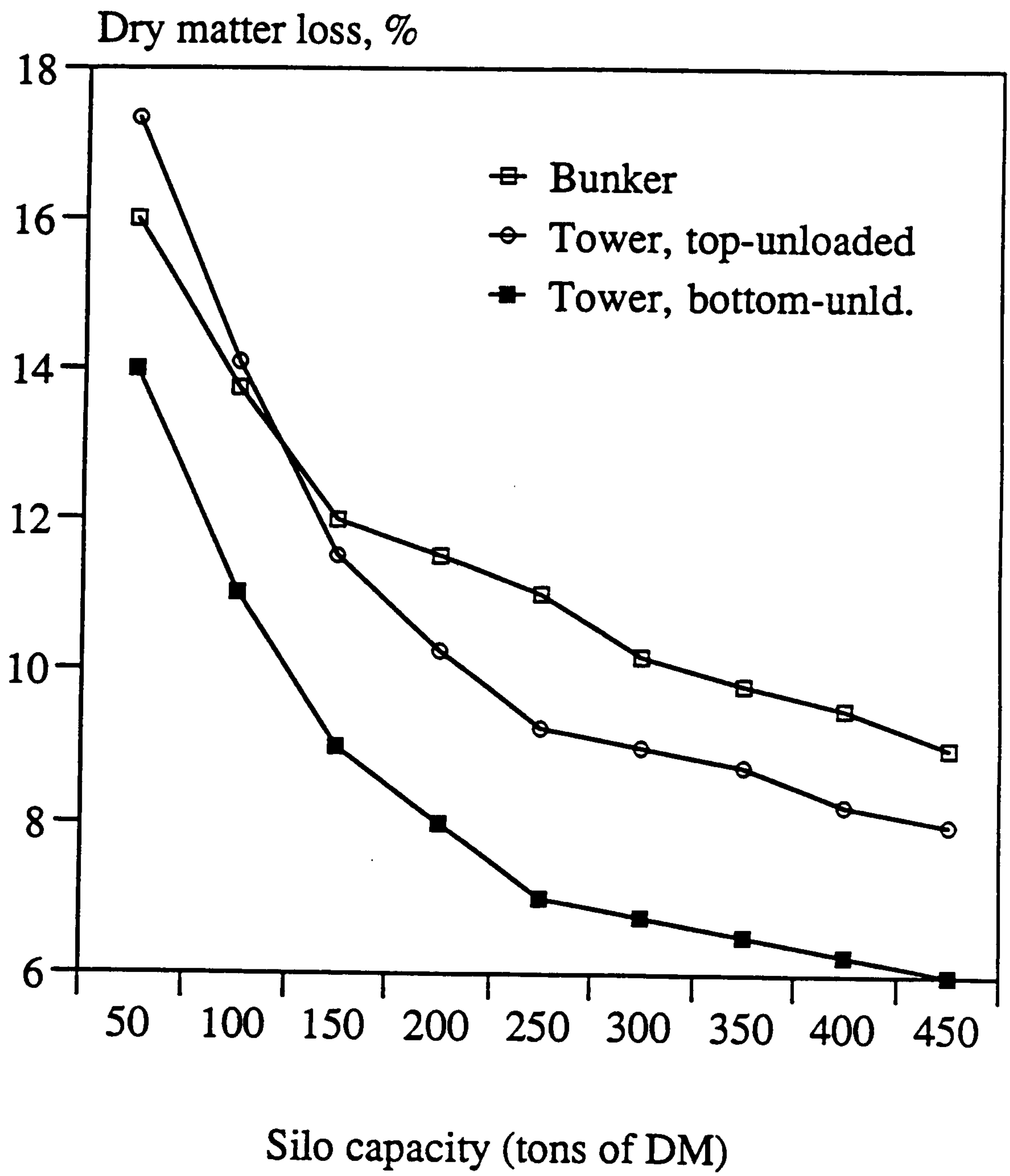

FIGURE 2

DETERMINING THE NUMBER OF COWS TO FEED OR DRY MATTER TO OFFER: BUNKER SILOS

1. Grass or legume silage (density of 11.8 lbs of DM/ft3).

   A. Forage DM intake /cow, lbs/day

   $$= \frac{\text{Silo width,ft)} \times \text{(Silo vertical depth, ft.)} \times \text{(6 inches/day)}}{\text{(Number of cows)}}$$

   B. Number of cows

   $$= \frac{\text{(Silo width, ft)} \times \text{(Silo vertical depth, ft)} \times \text{(6 inches/day)}}{\text{(Silage DM intake/cow, lbs/day)}}$$

2. Corn silage (DM density of 17.7 lbs of DM/ft3)

   A. Silage DM intake

   $$= \frac{\text{(Silo width, ft)} \times \text{(Silo vertical depth,ft)} \times \text{(6 inches/day)} \times \text{(1.475)}}{\text{(Number of cows)}}$$

   B. Number of cows

   $$= \frac{\text{(Silo width, ft)} \times \text{(Silo vertical depth,ft)} \times \text{(6 inches/day)} \times \text{(1.475)}}{\text{(Silage DM intake/cow, lbs/day)}}$$

Example: You decide to feed 15 lbs of grass silage DM per day from a 20 ft wide, 10 ft deep bunker silo. How many cows do you need to feed?

Number of cows:

$$= \frac{\text{(20 ft)} \times \text{(10 ft)} \times \text{(6 inches)}}{\text{(15 lbs/cow/day)}} = 80 \text{ cows}$$

APPENDIX

DIAGNOSIS OF COMMON SILAGE PROBLEMS

SPECIFIC SYMPTOMS	POSSIBLE CAUSE(S)
Hot silage >120°F	Heat is generated by oxidative reactions occurring with extended respiration or the growth of yeast/mold/bacterial populations. Caused by slow filling, structure air leaks, slow feedout, low moisture, overly mature crop, long chop length, poor distribution or compaction.
Caramelized, dark brown kernels in corn silage. Dark colored haylage with cooked or tobacco smell.	Signs of excessive heat damage. Caused by entrapment of excess oxygen in silage mass. Also by low moisture content, long chop and poor compaction.
Moldy silage	Molds grow in the presence of oxygen and adequate substrate. Caused by ensiling "stressed" crops with high yeast/mold loads, slow filling, slow feedout, long chop, low moisture and poor compaction.
Rancid milk odor	Generally caused by clostridial fermentation with the production of butyric acid. Caused by high moisture content, low plant sugar and inadequate lactic acid bacteria (LAB) for proper fermentation.
Vinegar odor	Fermentation dominated by bacteria which ferment sugars to acetic acid (vinegar). Promoted by wet silage, inadequate LAB , low crop sugars.
Alcohol odor	Fermentation dominated by yeast which ferment sugars to alcohol. Yeasts can also metabolize lactic acid, thus raising silage pH and allowing conditions more suitable for other spoilage organisms to grow. Problematic in dry, poorly compacted silages that are slowly fed out.
Frozen silage	Caused by high moisture content, extended respiration, or bruised crop cells. More problematic in upright silos.
Poor aerobic stability (bunklife)	Caused by slow feedout, high yeast or mold populations, especially on "stressed" crops, low moisture, poor compaction, low sugars in crops ensiled at advanced maturities.
Seepage/run-off	Caused by too high crop moisture, dull chopper knives causing torn cells and overpacking causing bruised cells.
Poor intake	Caused by many factors: clostridial fermentation, high ammonia-N content, overly wet or dry silage, high fiber (mature crop), contamination with molds, toxic weeds or nitrates.

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