



Harvesting and Utilizing Silage



PENNSTATE



College of Agricultural Sciences
Cooperative Extension

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INTRODUCTION

Feeding adequate quantities of high-quality forages is the basis of profitable milk and livestock production. Forage production, harvest, storage, and feed practices have changed greatly over the past 50 years in Pennsylvania. Silage has grown in popularity because it increases the potential yield of nutrients from available land, decreases feed costs, lowers harvest losses, and often increases forage quality. Silage also offers the possibility of greater mechanization of harvesting and feeding with reduced labor requirements. However, high-level management and sizeable financial outlays are necessary to efficiently produce, harvest, store, and feed silage.

A trend toward greater silage use is likely to continue as more dairy and livestock producers go to year-round feeding of stored forages and as livestock enterprises increase in size. Many considerations regarding crop selection, harvest and feed equipment, and storage facilities are important in developing efficient and economical forage systems. The following information should enable more effective decisions in the planning, managing, and feeding of silage.

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MANAGEMENT CONSIDERATIONS

Advantages of silage

Relative nutrient yield. Of the feed crops adapted to Pennsylvania, corn harvested as silage yields greater quantities of energy per acre, and alfalfa produces greater quantities of protein per acre. Alfalfa and grass usually provide more energy and protein when harvested as silages than as hay.

Few field losses. Both hay and corn crops harvested as silage avoid many of the losses due to weather. Hay-crop silages that are either direct-cut or wilted have lower field losses when compared to hays, no matter what the weather conditions. Direct-cutting of hay-crop silages avoids extended exposure to weather damage and leaf shattering, even wilting hay-crop silages may result in reduced losses when compared to hay. Losses from ear dropping, which occur during corn silage harvest, and grain shattering are lower than those occurring during grain harvest.

Flexible harvest dates. Since row crops and broadcast crops can be ensiled, they offer flexibility in providing adequate livestock forage if supplies of hay-crop forages fall below normal. Producers can also decide late in the growing season how much corn to harvest as silage and as grain to fit their particular feeding programs. Similarly, small grains and other annuals such as sorghum-sudan hybrids may be harvested as silage.

Efficient use of labor. Timing of harvest and scheduling of labor can be extended by planting corn varieties of differing maturities. Corn silage harvest also occurs when less management and labor are demanded for other cropping enterprises. The many possibilities for mechanization of silage harvesting and feeding permit increased labor productivity.

Disadvantages of silage

High storage losses. Silage storage losses can be high if crops are not harvested at the proper moisture content, if facilities are inadequate, or if the crop is not chopped fine enough (or too fine), not packed well, and not sealed properly.

Potential spoilage. Silage must be fed soon after removal from storage to avoid spoilage. Storage facilities with an exposed silage surface must be matched to the feeding rate to prevent spoilage; also, when silage feeding is discontinued for a long period of time, resealing is required to avoid greater storage losses and spoilage problems.

High handling and storage costs. Silage is bulky to store and handle; therefore, storage costs can be high relative to its feed value. Storage facilities are specialized and have limited alternative uses. Silage is costly to transport relative to its bulk and low density of energy and protein. Therefore, it is usually more economical to store and feed silage relatively near the fields where the crop is produced.

High investment costs. The machinery and equipment investment per ton of silage harvested, stored, and fed can be high unless a large quantity is handled annually. Custom harvesting can reduce or eliminate this disadvantage.

High initial capital outlays. The total cost of machinery, equipment, storage, and feeding facilities is considerable. Where large amounts of money are needed to finance the investment, inadequate cash flow during the financing period may cause difficulties in carrying out what appears to be a profitable investment.

Few market outlets. There are few ready off-farm markets for silage, except for close neighbors in most areas. It is difficult to establish a selling price that is fair to both buyer and seller. Moving silage from one silo to another is risky, especially for haylage. Therefore, when a crop is harvested as silage, the farmer is usually committed to feeding it to livestock.

MANAGEMENT DECISIONS TO PLAN THE FORAGE SYSTEM

Decisions for producing, harvesting, storing, handling, and feeding of crops are neither simple nor short-run processes. Frequently, farmers look only at one segment of the system in deciding to change production practices, equipment, or facilities. This approach often has adverse operational and economical effects on other parts of the system. Also, a change may require additional system redesigning for increased volume of business at considerably more expense than would have been necessary had better planning considered future expansion.

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Planning considerations

Most farmers strive to maximize long-run returns. Therefore, they must consider management decisions for the entire forage system. Planning consideration must be given to the following aspects.

A crop rotation matched to land resources, livestock, and feeding requirements of the livestock. Soils, topography, and climatic conditions place general restrictions on the kinds of crops that can be grown profitably. For most Pennsylvania farmers, a combination of crop and livestock enterprises maximizes net returns to their land, labor, and investment. The most profitable cropping program generally is one adapted to the feeding requirements of the livestock and the potential of the cropland to produce the required feed. This requires determination of what crops will be grown and the acreage of each. Table 1 contains typical silage yields for various crops.

Table 1. Yields of crops grown for silage.

Forage crop	Tons/A as-fed basis ^a
Alfalfa	4.0–6.0
Birdsfoot trefoil or red clover	2.5–4.0
Tall grasses—orchard, brome, reed canary, and timothy	4.0
Corn silage or sorghum-sudan silage	15.0–30.0
Oatlage	7.0–9.0

^a Expected ranges based on varying soil types and weather conditions.

This information can be used to plan the cropping strategy that best matches animal needs. A large deviation from these values could indicate problems in soil fertility and/or planting, weed control, and/or harvest practices (assuming normal weather conditions).

Two basic feed nutrients for animals are energy and protein. These are needed in varying amounts by different classes of livestock for the production of milk and meat. For example, a cow producing 18,000 pounds of milk in one year would need approximately 9,800 pounds of total digestible nutrients (TDN) and 2,300 pounds of total protein (TP). To raise a beef steer from a calf to 1,100 pounds would require 7,300 pounds TDN and 750 pounds TP. To put 700 pounds of gain on a 400 pound steer would take 3,900 pounds TDN and 540 pounds TP. While the cost per pound of TP may be four to five times that of TDN, the amount of TDN required makes the

total cost of energy about 55 to 65 percent of the total feed cost. In planning a feeding program, the unit cost of the feed nutrient should not overshadow the total cost of supplying the nutrients. A major emphasis in the cropping program must be placed on economically supplying the total energy and protein needs.

Feed crops adapted to Pennsylvania, such as corn silage and corn grain, have the potential for producing the greatest amounts of energy per acre. Alfalfa and soybeans produce greater quantities of protein per acre. But which crops produce the highest feed value per acre over the costs to produce them? The "profit margin" formula ("profit margin" = unit feed value x yield - cost to produce) will indicate which crops produce the highest net over costs. This will also indicate the priority for land use among the various feed crops. However, the amount of land for each crop on a specific farm will need to be modified by the land capability restrictions and the amount of forage required by the number and kind of livestock kept. For livestock farmers who produce most of their feed, forages are generally the lowest cost source of feed, with corn silage the cheapest energy source and alfalfa-grass forages the cheapest protein source. Under the usual price relationships between the costs of energy and protein feeds, lower feed costs generally result from feeding both corn silage and hay-crop forages. Furthermore, restricting the forage feeding program to principally hay-crop forages where a high percentage of corn could be grown in the rotation, may result in higher-cost feeding programs.

Before a decision is made on the types of crops to be grown, it is necessary to look at the proportions of energy, protein, and fiber that occur among crops (table 2). Composition of hays and silages should be similar if harvested properly. Yields and losses in harvesting, handling, and storage can affect the quality of hays and silages. Losses are affected by weather and management techniques, along with harvesting equipment, storage facilities, and feeding practices.

Table 2. Composition of forages typically fed in the Northeast.

Forage type ^a	CP ^c	Protein solubility	Components (% dry matter basis) ^a				Energy content (Mcal/lb) ^a		
			ADF	NDF	NSC ^d	TDN	NEL	NEM	NEG
Legume hay	18.2 (15.1-21.3)	28.8 (23.6-33.9)	34.4 (29.0-39.8)	46.5 (39.7-53.4)	21.7 (13.9-29.5)	62.3 (58.8-65.8)	.62 (.56-.69)	.58 (.52-.64)	.33 (.26-.40)
Legume haylage	19.3 (16.2-22.3)	52.6 (43.8-61.4)	39.4 (34.3-44.5)	50.0 (43.4-56.5)	13.6 (7.2-20.0)	59.0 (55.7-62.4)	.56 (.50-.62)	.52 (.46-.58)	.27 (.20-.33)
MMLegume hay	15.5 (12.4-18.7)	26.8 (21.3-31.3)	36.9 (32.9-41.0)	52.8 (46.5-59.0)	20.0 (14.5-25.5)	61.7 (58.9-64.5)	.56 (.51-.61)	.55 (.50-.60)	.30 (.25-.35)
MMLegume haylage	17.3 (13.9-20.7)	50.3 (41.7-58.9)	40.8 (36.1-45.5)	53.8 (46.8-60.7)	13.9 (8.0-19.7)	59.0 (55.7-62.3)	.51 (.45-.57)	.50 (.45-.56)	.25 (.19-.31)
Grass hay	10.3 (7.2-13.4)	22.1 (16.5-27.7)	39.4 (35.1-43.6)	62.4 (56.7-68.0)	16.8 (11.6-21.9)	60.7 (57.3-64.1)	.49 (.43-.56)	.52 (.47-.57)	.27 (.21-.32)
Grass haylage	12.6 (9.2-16.0)	44.5 (33.9-55.2)	42.7 (38.2-47.3)	62.9 (56.1-69.7)	11.2 (6.0-16.3)	58.0 (54.4-61.7)	.44 (.38-.51)	.48 (.43-.53)	.22 (.17-.28)
MMGrass hay	11.6 (8.3-14.8)	23.0 (17.8-28.2)	39.0 (35.1-42.9)	60.1 (54.3-65.8)	17.0 (12.4-21.6)	60.3 (57.6-63.0)	.53 (.48-.58)	.52 (.47-.57)	.27 (.22-.32)
MMGrass haylage	13.7 (10.3-17.0)	45.5 (36.0-55.1)	42.7 (38.5-47.0)	60.6 (54.2-67.0)	11.0 (6.1-15.9)	57.7 (54.6-60.7)	.48 (.43-.54)	.48 (.43-.53)	.22 (.17-.28)
Corn silage	8.6 (7.2-10.0)	42.4 (31.9-52.8)	28.4 (23.6-33.2)	47.7 (41.3-54.1)	33.4 (23.1-43.7)	68.8 (66.8-70.9)	.71 (.67-.75)	.65 (.59-.71)	.41 (.35-.48)

^a CP = crude protein, ADF = acid detergent fiber, NDF = neutral detergent fiber, NSC = nonstructural carbohydrates, TDN = total digestible nutrients, NEL = estimated net energy of lactation, NEM = estimated net energy of maintenance, NEG = estimated net energy of gain.

^b Ranges for each component are listed below the average value.

^c Crude protein for the fermented silages does not take into account heat damage.

^d The NSC number is generated by the following equation: NSC% = 100% - (CP% + NDF% + Fat% + Ash%). Typical values for fat and ash are used in routine calculations, therefore NSC is just an estimate.

Source: Northeast Dairy Herd Improvement Association, May 1, 1989 to April 30, 1990.

The operational feasibility of harvesting, storing, and handling the crops under prevailing weather conditions and available labor. This phase of putting the system together considers the operational feasibility of handling the kinds and quantities of feed needed by the livestock and produced by the cropping rotation. No one method of harvesting, storing, and handling is best for all farms. For example, a small dairy farm of 30 cows with limited hay acreage will have a different operational problem than the large dairy farm with 100 or more acres of hay-crop forage. The small dairy operator may readily handle the hay crop as field cured hay, while the dairy farmer with a large herd will probably need to ensile a considerable portion of the hay-crop forage to ensure timely harvest under prevailing weather conditions.

Another consideration will be competition for the use of labor, not only among crops, but between crops and livestock. The daily amount of labor required by livestock chores usually competes with getting crop work done as timely as would be desirable—especially the planting and harvesting operations.

The physical equipment and facilities to harvest, store, and feed the crop. This phase of planning the system ties in closely with the aforementioned. There are many combinations of systems and different kinds of equipment and facilities. The selection of individual pieces of equipment and facilities must be a balancing of advantages and limitations in their effect on the overall efficiency and eventual cost to the operation. The high productivity of the modern commercial farm results from the effective use of well-selected equipment and well-arranged facilities.

The costs and net returns of alternative systems. Which forage system with its harvesting equipment, storage facilities, and labor requirements will contribute to the lowest costs and ultimately to the highest net farm returns? Budgeting is a management tool which can bring this phase into focus. This phase of planning must consider the initial investment cost, the annual operating and overhead costs, and losses in harvesting, storing, and handling before the net costs and maximum returns are determined. The annual cost for storage facilities will total 10 to 15 percent of the initial investment, for silage-making equipment it will be 15 to 20 percent.

Financing of equipment and facilities, and cash flow management during the financing period. Any time money must be borrowed to finance new investments, consideration must be given to cash flow during the repayment period. The annual cash flow necessary to carry interest payments and repay principal will vary with the interest rate and the number of years for repayment. Inadequate cash flow during the debt repayment period may cause difficulty in carrying out what appears to be a profitable adjustment. Frequently, the repayment period is somewhat shorter than the useful life of the asset and the cost-recovery period for depreciation. Investment credit allowances on equipment and storage facilities reduce costs as well as help the initial cash flow requirements. Leasing or renting equipment, and custom planting and harvesting may be used to spread capital expenditures over a longer time span.

Adequate forages for the dairy herd

Profitable milk production depends on feeding sufficient quantities of high quality forages. Adequate and reasonable amounts of forage dry matter intakes should be attained for the quality

of forages used and the relationships of milk price, forage cost, and grain cost. This usually is close to 1.8 to 2.0 pounds of forage dry matter per 100 pounds of body weight when grain is cheap and milk price is not depressed. Intake may rise to 2.25 to 2.40 when forage quality is good and concentrate is high priced in respect to forage and milk prices.

If higher forage feeding rates are to be attained, adequate amounts of high-quality forages need to be available. In Pennsylvania, this usually means producing forages on the farm where they are fed. While adverse weather conditions may reduce the quantity anticipated, inadequate supplies, in many cases, are the result of insufficient production planning.

In planning the production of forages, consideration should be given to the quantity needed for the herd (table 3), land capabilities or limitations, profitability of different crops, available and additional storage facilities required, and feasible operational practices. Consider the following example. A dairy producer wants to calculate the feed inventory for a 70 cow herd plus 60 replacement heifers (figure 1). In this example, it is assumed that the cows' average body weights are 1,300 pounds and that the herd is experiencing a feeding loss of about 10 percent. The dairy farmer would also like to feed 26.8 pounds of forage dry matter per cow equivalent per day (table 4).

Table 3. Silage needed per cow on an as-fed basis.

Silage fed /cow/day	Days			
	180	240	300	365
(lb)	(tons)			
20	1.8	2.4	3.0	3.6
40	3.6	4.8	6.0	7.2
60	5.4	7.2	9.0	10.8

Table 4. Pounds of stored forage dry matter needed per cow per day.

Cow's body weight	Forage dry matter intake ^a	Feeding losses ^b			
		5	10	15	20
(lb)	(lb/cow/day)	(%)	(%)	(%)	(%)
1,100	20.4	21.5	22.7	24.0	25.5
1,200	22.2	23.4	24.7	26.1	27.8
1,300	24.1	25.4	26.8	28.4	30.1
1,400	25.9	27.3	28.8	30.5	32.4
1,500	27.8	29.3	31.9	32.7	34.8

^a If planning forage to harvest and store, include allowance for harvest and storage losses.

^b Forage dry matter in storage (FDMIS) = forage dry matter intake ÷ [(100 - % feed loss) ÷ 100]
Example: FDMIS = 20.4 ÷ [(100 - 5) ÷ 100] = 21.5

Figure 1. Managing your feed inventory, worksheet.

I. FARM INFORMATION

Name _____ Address _____ City _____ Inventory date _____

70 + (0.5 X 60) = 100
Number of milking and dry cows Number of heifers Number of cow equivalents

II. FARM INVENTORY OF ENSILED FORAGE DRY MATTER

	Forage type	Silo diameter and height	Dry matter when full	Depth removed	Dry matter removed	Dry matter remaining
SILO #1	Haylage	20 X 60 feet	159 tons	22 feet	77 tons	82 tons
Bottom unloading						
SILO #2	Corn silage	20 X 70 feet	198 tons	10 feet	14 tons	184 tons
Top unloading						

FORAGE ANALYSES (% DM BASIS)

Forage type	Dry matter	Crude protein	Available protein	ADF	NDF	TDN	NEL (Mcal/lb)
Haylage	45	17.4	16.7	43	56	54	.55
Corn silage	34	8.8	—	29	50	68	.69

The example farm has one bottom-unloading and one top-unloading silo (figure 2). The bottom-unloading silo is 20' x 60' with 38 feet of haylage remaining. From table 5, the 20' x 60' silo capacity is 159 tons dry matter and has 82 tons of dry matter remaining (20' x 38' = 82 tons dry matter remaining, table 5). Since 22 feet of silage was removed, 77 tons of haylage has been fed (159 tons - 82 tons = 77 tons).

The top-unloading silo is 20' x 70' with 60 feet of corn silage remaining. Table 5 indicates a capacity of 198 tons of dry matter. Fourteen tons dry matter has been fed and 184 tons dry matter remain (20' x 10' = 14 tons dry matter then 198 - 14 = 184 tons dry matter). These values should be entered on the worksheet shown in figure 1. When using table 5, calculate how much has been removed from a top-unloading silo, and how much remains in a bottom-unloading silo.

An inventory of dry forages requires an accurate count or estimate of the number of bales or stacks, as well as a good estimate of their weight. If possible, several bales or stacks should be weighed to get a reliable average weight (figure 3).

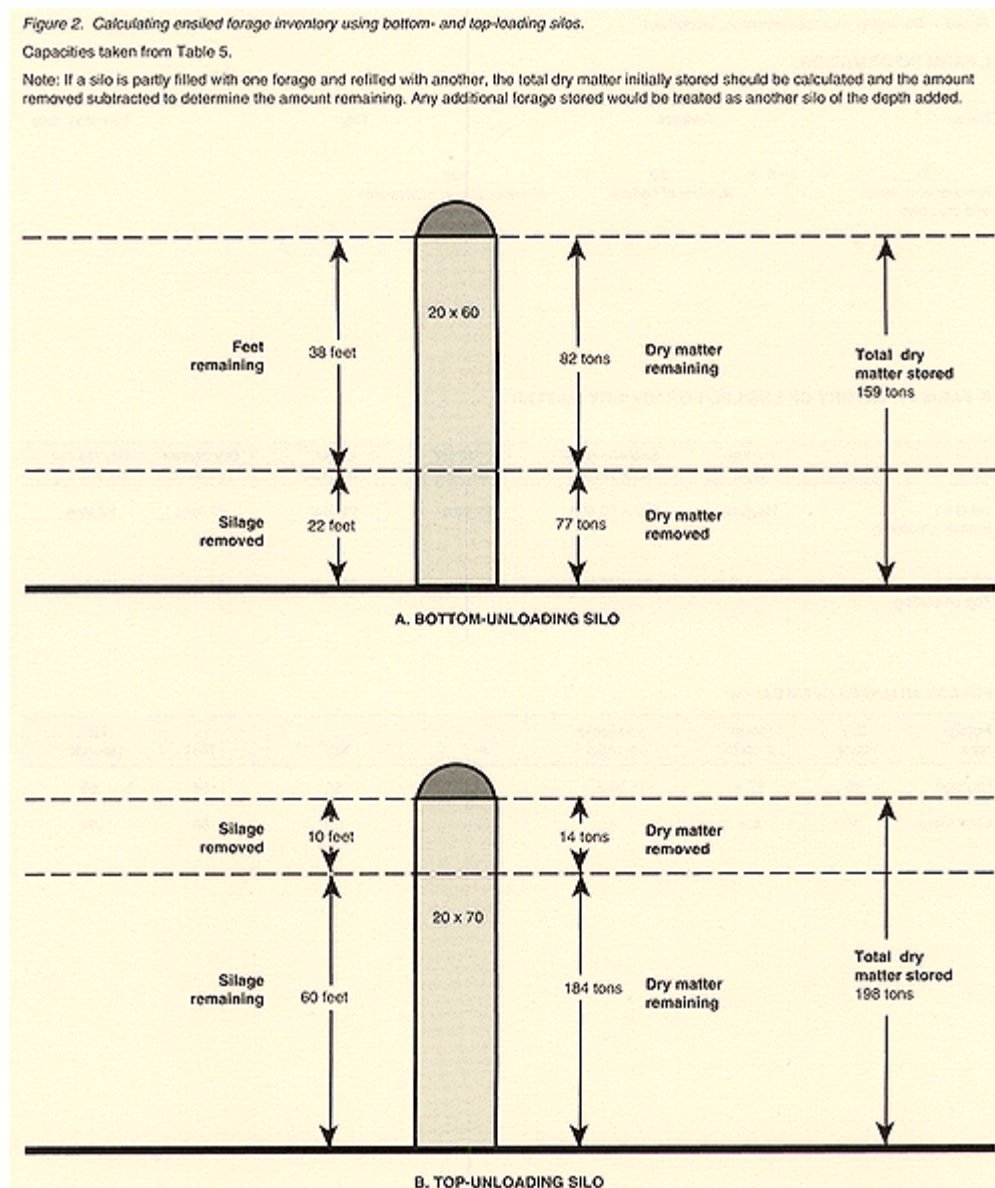


Table 5. Approximate dry matter capacity of upright silos.

Depth of settled silage (ft)	Inside diameter of silo (ft)										
	10	12	14	16	18	20	22	24	26	28	30
	tons										
2	0	1	1	1	2	2	2	2	3	3	4
4	1	2	2	3	4	5	5	6	8	9	10
6	2	2	3	4	5	7	8	10	11	13	15
8	3	4	5	7	9	11	13	16	18	21	24
10	4	5	7	9	11	14	17	20	24	28	32
12	5	7	9	11	14	18	22	26	30	35	40
14	5	8	11	14	17	22	26	31	36	42	48
16	6	9	12	17	21	26	32	37	44	51	58
18	7	11	14	19	24	29	35	42	49	57	65
20	8	12	16	21	27	33	40	47	56	65	74
22	9	14	19	24	30	38	46	54	64	74	85
24	11	15	21	27	34	43	52	61	72	83	96
26	12	17	23	30	38	48	58	68	81	94	107
28	13	19	26	35	44	53	64	76	90	104	119
30	15	21	29	38	47	59	71	84	99	115	132
32	16	23	32	41	52	65	78	93	109	127	145
34	18	25	34	45	57	70	85	101	119	137	158
36	19	28	37	48	62	76	92	109	129	150	172
38	21	30	41	53	67	82	100	118	139	161	185
40	22	32	44	57	72	89	107	127	150	173	199
42	24	34	47	61	77	95	115	137	161	186	214
44	26	37	50	65	82	102	123	146	172	200	229
46	27	39	53	69	88	108	131	155	183	212	244
48	29	42	56	74	93	115	140	166	195	226	260
50	31	44	60	78	99	122	148	175	206	239	274
52	32	47	64	83	105	129	157	186	219	254	291
54	34	49	67	88	111	137	165	197	231	267	306
56	36	51	71	93	117	144	174	207	243	282	324
58	38	54	74	98	123	151	183	218	261	297	339
60	40	56	78	102	129	159	192	228	273	309	357
62	To find the tons remaining in a silo after part of the silage is removed: (1) find the tons of silage when the silo was filled, (2) find the tons in a silo filled to the height equal to the depth of silage removed, (3) subtract the number of tons in Step 2 from the number of tons in Step 1.				135	167	201	239	287	324	374
64					142	174	210	250	301	339	391
66					149	182	219	260	314	354	407
68					155	190	228	271	328	369	424
70					162	198	237	282	342	384	441
72								293	356	400	458
74								305	371	415	476
76	Example: A 20-foot silo is filled to a settled depth of 60 feet and 22 feet were removed (1) 20 x 60 equals 159 tons (2) 20 x 22 equals 38 tons							316	385	431	493
78								328	400	446	511
80	(3) 159 minus 38 equals 121 tons remaining.							339	462	462	528

Source: Adapted from Silo Dry Matter Capacity Tables by the National Silo Association.

Figure 3. Managing your feed inventory, worksheet (continued).

III. FARM INVENTORY OF DRY FORAGE

	Forage type	No. bales or stacks	Wt/bale or stack	Total as-fed basis	Total as fed	Dry matter	Total dry matter
HAY STORAGE AREA #1	2nd-cut alfalfa-grass hay	3,000 X	40 lb =	120,000 lb + 2,000 =	60 tons X	.89 =	53.4 tons
HAY STORAGE AREA #2	1st-cut grass hay	2,000 X	35 lb =	70,000 lb + 2,000 =	35 tons X	.89 =	31.2 tons
Total forage dry matter 82 + 184 + 53.4 + 31.2 = 351 tons dry matter							
FORAGE ANALYSIS (% DM BASIS)							
Forage type	Dry matter	Crude protein	ADF	NDF	TDN	NEL (Mcal/lb)	
2nd-cut alfalfa-grass hay	89	17	39	56	57	.58	
1st-cut grass hay	89	10	43	70	55	.56	

Figure 4. Managing your feed inventory, worksheet (continued).

IV. FORAGE INVENTORY SUMMARY

	Total tons dry matter	No. cow equivs.	Tons dry matter per cow equiv.	DM available per cow equiv.	Feeding period	DM per cow equiv. per day
A. Haylage	82.0	÷ 100	= 0.82 tons	X 2,000 = 1,640 lb	÷ 225 days	= 7.3 lb
B. Corn silage	184.0	÷ 100	= 1.84 tons	X 2,000 = 3,680 lb	÷ 340 days	= 10.8 lb
C. 2nd-cut MML hay	53.4	÷ 100	= 0.534 tons	X 2,000 = 1,068 lb	÷ 225 days	= 4.75 lb
D. 1st-cut grass hay	31.2	÷ 100	= 0.312 tons	X 2,000 = 624 lb	÷ 225 days	= 2.8 lb
Total forage DM/cow equiv. (A + B + C + D) =						25.7 lb/day
Forage DM needed in storage/cow (from Table 4) =						26.8 lb/day
Subtract needed forage from DM available to get surplus or deficit =						-1.1 lb/day

Figure 5. Managing your feed inventory, worksheet (continued).

V. CALCULATING SURPLUS OR DEFICIT FORAGE SUPPLY FOR FEEDING PERIOD

A. To determine tons of hay surplus or deficit

- 1.1 lb deficit DM/cow/day x 100 no. cow equiv. = 110 lb deficit/herd/day x 225 days in feeding period = 24,750 lb total DM ÷ 2,000 = 12.4 tons DM deficit ÷ 0.9 = 13.75 tons deficit as hay equiv.

B. To determine cow number reduction to match available forage

110 lb deficit for herd/day ÷ 26.8 lb DM needed/cow/day = 4.1 reduction of cow equivs. to match available forage inventory.

The tons of forage dry matter, number of cow equivalents to receive each forage, and the length of the feeding period for each forage are entered in figure 4. The pounds dry matter available per cow-equivalent for each forage source and the total amounts of forage available per cow has been calculated. The total forage available is 25.7 pounds of dry matter per cow per day. As stated earlier, the dairy producer would like to feed 26.8 pounds of forage dry matter per cow equivalent per day. This leaves a deficit of 1.1 pounds dry matter per cow per day or 12.4 tons for 225 days. The additional forage needed until next harvest should be calculated (figure 5). In this farm example, it is assumed that 225 days remain until the next hay crop harvest and 340 days until the next corn harvest. Reducing the feeding losses by half would give the farmer a surplus of 3.4 tons of forage dry matter (from the 10 percent loss the herd is experiencing to 5 percent loss).

The dairy farmer must consider some options:

1. Reduce the herd size to match the forage supply; in this case, reduce the number of cow equivalents by 4.1.
2. Feed less forage and more grain.
3. Reduce feeding losses.
4. Purchase additional forage.

Storage costs

The overall silage storage costs depend on the type of silo selected: the conventional tower, the oxygen-limiting tower, and the horizontal bunker. There is no one best type for all farm situations. They differ in costs, convenience, and storage losses. With proper management, there

is little difference in silage quality from the various types. However, in practice, silage quality can vary greatly because of moisture level and stage of maturity at which a crop is stored.

Before a realistic economic decision can be made on what type of silo to use, and eventually which specific make, consideration should be given to the following factors on a specific farm.

1. What forages will be stored? (corn, hay-crop, or both)
2. What will be the moisture level when stored? (low, medium, or high)
3. How much of each crop will be stored?
4. How much will be used daily?
5. How will the ensiled crops be moved from storage to the feed bunk?

Corn can be stored satisfactorily in a variety of facilities with few critical management or operational problems. However, ensiled hay-crops, especially low-moisture ones, require silos in good condition and more precise attention to harvesting and storage. The following factors are important economic considerations in the selection of a silo.

1. **Capital investment.** Table 6 shows the approximate initial investment for various sizes of the conventional, oxygen-limiting, and horizontal silos in Pennsylvania in 1991. Silo prices vary among dealers and the total price depends on accessories and installation costs. Generally, the quoted price of a dealer includes the cost of erection after a suitable base has been provided for construction. The size of the investment will have a bearing on the ability to repay a silo loan. Careful consideration must be given to cash flow during repayment. Tax accounting depreciation represents the cost recovery of an investment over its useful life, which may be somewhat longer than the repayment period. In many cases, the repayment period will be approximately one-half the depreciable life. Silos qualify for investment credit, which helps reduce the initial investment as well as the cash flow during the financing period. Farmers contemplating an investment in a

Table 6. Typical cost of various silage structures, 1991.

Silo type, size	Capacity (dry matter, tons)	Useful life ^a (years)	Initial cost ^b (\$)	Cost per year average ^c (\$)	Cost per ton dry matter going in ^d (\$)	Cost per ton dry matter coming out ^e (\$)
Metal, oxygen-limiting (used)						
20 x 50	100	30+	23,000	3,565	36/18	39/20
20 x 77	190	30+	34,500	5,348	28/14	30/15
25 x 88	385	30+	47,000	7,285	19/9	21/10
Concrete stave, oxygen-limiting						
16 x 60	95	20	36,000	5,580	59/29	64/32
20 x 70	180	20	53,000	8,215	46/23	50/25
30 x 80	480	15	134,000	20,770	43/22	47/24
Poured concrete, oxygen-limiting						
16 x 60	100	30+	59,000	9,145	91/46	99/50
20 x 72	200	30+	72,000	11,160	56/28	61/30
30 x 76	515	30+	110,000	17,050	33/17	36/19
Concrete stave						
16 x 60	95	20	25,500	3,953	42/21	47/23
20 x 70	180	20	36,000	5,580	31/16	34/18
30 x 80	480	15	77,000	11,935	25/12	28/13
Poured concrete						
16 x 60	100	30+	25,000	3,875	39/19	43/21
20 x 72	200	30+	32,000	4,960	25/12	28/13
30 x 76	515	30+	55,000	8,525	17/8	19/9
Concrete bunker						
20 x 80 x 10	85	20	20,400	2,754	32/16	37/19
20 x 105 x 12	200	20	32,900	4,442	22/11	26/13
50 x 150 x 12	490	20	53,250	7,189	15/7	17/8
Bagger^f						
1 bag (8 x 150)	45	20	14,600	2,331	52	58
2 bags (8 x 150)	90	20	15,000	2,745	30	33
4 bags (8 x 150)	180	20	15,800	3,573	20	22

^a Typical life depends on condition of use as well as structure type, and any life beyond 20 years requires excellent management and care of the structure.

^b Includes cost of unloader in all cases, except bunker and bagger which require a loader tractor for unloading.

^c Average annual use cost is based on zero salvage value after a useful life of 20 years; a 10 percent interest rate on 50 percent of the initial cost; typical costs for taxes (1.5 percent), insurance (2 percent for tower silos), and repairs (2 percent) expressed as a percentage of the initial cost.

^d Assuming one filling per year, second value is for two fillings per year.

^e Assumes an average storage loss: 8 percent storage loss for oxygen-limiting silos, 10 percent storage loss for conventional upright silos, 14 percent storage loss for bunker silos, and 10 percent storage loss for bag silos.

^f Bags cost \$400 each, bagger costs \$14,200.

silo structure will want to calculate the economic variables. Although the useful silo life may be longer than that given in table 6, using a longer life is not recommended because of possible obsolescence. A shorter useful life may be more reasonable in some cases.

2. Interest on the investment. This may be a direct out-of-pocket expense as interest payments on a loan. If the silo investment is made from funds already accumulated, the cost is represented by returns foregone by not investing in some alternative project or interest-bearing investment (opportunity cost).

3. Annual operating costs. Outlays for repairs, plastic covers, energy, and insurance must be considered not only in respect to their amount among various silos, but also as limiting the money available for other enterprises. In Pennsylvania, silos are excluded as a basis for real estate taxes; this is not so in all states.

4. Multiple use of storage and unloaders. Refilling the silo during the year will not vary the total cost much, but it will reduce the cost per ton of feed stored. The multiple use of an unloader and/or its use in more than one silo will affect the unloader costs. Under the usual forage production and feeding practices, it is difficult to utilize the total storage space more than 1.33 to 1.5 times; this would require a fairly even distribution of the total forage fed among hay crop, corn, and/or annual crop silages. In addition, such a system would reduce the amount of total time during which both hay-crop and corn silages would be available simultaneously for feeding. There would be digestive transition periods from one type of forage to another and the need to adjust protein supplement, which may not be conducive to the most economical feeding strategy. Where both a hay and corn silage forage program is used, the overall operational and economical consequences of using two or more silos should be analyzed, even if one large silo would result in a lower total investment.

5. Harvest and storage losses. Losses will vary from farm to farm and year to year, and will depend upon such factors as weather conditions, crops stored, moisture content of crops stored, fineness of chop, kind of silo used, and the level of management in handling the crops and facilities. Losses in forage-making can be classified in two broad categories: harvest and storage. Harvesting losses include plant respiration, leaching, and leaf shattering due to rain and machine-induced losses. Plant respiration refers to utilization of nutrients by the plant before it completely dies or is placed in storage. Storage losses include those from spoilage, seepage, and fermentation or respiration. Forages exposed to the elements during storage also are subject to weathering losses. Losses from fermentation and respiration are invisible.

A major factor influencing harvest and storage losses is the moisture content of the crop as it is removed from the field. Losses expected with various methods of forage making are shown in figure 6. Note that field or harvest losses are highest for hays and lowest for high moisture or direct-cut hay-crop silage. However, storage losses are lowest for hays and greatest for high-moisture silages.

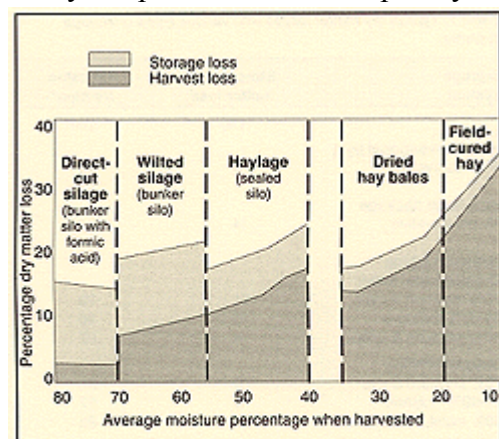


Figure 6. Typical dry matter losses in legume-grass forages harvested at various moisture levels. Source: Rotz, C.A., L.R. Borton, and J.R. Black. 1991. Harvest and Storage Losses with Alternative Forage Harvesting Methods. Proc. American Forage and Grassland Conference.

Whole-plant corn silage has relatively low total losses of dry matter due primarily to low storage losses. It is a natural silage crop due to its high content of soluble carbohydrates and low protein content. The moisture level in corn silage, however, may influence losses of dry matter during storage.

The storage dry matter losses indicated in table 7 represent those expected when crops are ensiled in conventional, oxygen-limiting, and horizontal silos, and are compared to conventional hay bales. Storage of large hay packages under cover may decrease losses by 5 to 10 percent. Losses for annual silages other than corn are similar to those given for hay-crop silages.

Moisture content of the crop at ensiling also influences the amount of dry-matter loss which occurs in various types of silo structures. Oxygen-limiting silos have their greatest advantage in dry matter loss with low-moisture silages. Storage losses for high-moisture silages tend to be less in horizontal bunker or trench silos. This results from lower seepage losses. Storage losses in horizontal silos, however, are heavier with wilted and low-moisture forage. Inadequate packing is responsible for losses at lower moisture level in horizontal silos. Thus, it is difficult to justify wilting below 55 to 65 percent moisture when forages are to be ensiled in horizontal structures.

Protein and energy losses when harvesting forage generally run somewhat higher than dry matter losses, when expressed on a percentage basis. This stems from preferential leaf loss and removal of the more soluble constituents through weathering. Heat damage can be a problem in all types of silo structures when susceptible crops are ensiled.

Forage utilization losses go beyond those encountered in harvesting and storage; feeding losses also occur. These vary according to feeding practices, types of material, and handling systems. They include losses from handling as well as wastage and refusal by the animals. At least one forage should be fed to the point of some refusal, once an economic grain feeding level is established. Forages left in mangers or bunks by milking cows may be fed to heifers or dry cows.

Table 7. Typical dry matter losses with various types of storage systems.

Storage system	Storage dry matter loss (%)	Feedable fraction ^a (%)
Hay, conventional bale		
No preservative	4	96
Hay, large package		
No preservative	14	86
Hay-crop silage		
Conventional tower		
70% moisture & over	21	79
61-69% moisture	10	90
60% moisture & under	8	92
Oxygen-limiting		
70% moisture & over	19	81
61-69% moisture	8	92
60% moisture & under	5	95
Horizontal		
70% moisture & over	13	87
61-69% moisture	14	86
60% moisture & under	16	84
Corn silage, whole plant		
70% moisture & over	13	87
61-69% moisture	6	94
60% moisture & under	6	94

^a Example: One ton corn silage with 65 percent moisture at ensiling could provide $2,000 \times .94 = 1,880$ pounds of feedable silage (120 pound loss). Dry matter loss = $.35 \times 2000 \times .06 = 42$ pounds. Source: Waters, W. 1987. Dairy Farm Analysis Workbook: Feed Crop Selection and Planning. Penn State University, page 142.

Table 8. Typical feeding losses with various types of storage systems.

Storage system	Feeding loss dry matter (%)	Consumable fraction ^a (%)
Hay, conventional bale		
No preservative	5	95
Hay, large package		
No preservative	15	85
Hay-crop silage		
Conventional tower		
70% moisture & over	11	89
61-69% moisture	11	89
60% moisture & under	11	89
Oxygen-limiting		
70% moisture & over	11	89
61-69% moisture	11	89
60% moisture & under	11	89
Horizontal		
70% moisture & over	11	89
61-69% moisture	11	89
60% moisture & under	11	89
Corn silage, whole plant		
70% moisture & over	4	96
61-69% moisture	4	96
60% moisture & under	4	96

^a Example: One ton corn silage with 65 percent moisture removed from silo. Consumable silage is $1,890^b \times .96 = 1,805$ pounds of silage available for feeding (75 pounds loss), that would compute to 26 pounds dry matter loss ($1,880 \times .35 \times .04$).

^b Value from Table 7.

Source: Waters, W. 1987. Dairy Farm Analysis Workbook: Feed Crop Selection and Planning. Penn State University, page 142.

Expected losses obtained when feeding to the point of slight refusal are presented in table 8. These may be adjusted to individual farm experience. Greater feeding losses may be encountered with hay-crop silage than with comparable quality hay. This may stem in part from quality or chemical differences that occur during the ensiling period detailed later, as well as a tendency for more waste of material at the beginning and ending of silage feeding periods.

SILAGE STORAGE SYSTEMS

Selecting silage storage facilities involves the system concept because the silo itself must be a planned component within the feeding system. Crop types, harvesting machinery, silo unloading, kind of livestock, type of housing, and feeding equipment must all be considered. When determining how to feed your livestock, many options exist, and selections become difficult. Perhaps the most useful planning method is to visit other farms to see the many ideas and options available. As a facility is being planned, answer the following questions.

1. What are your likes and dislikes?
2. Does it fit in with your present facilities?
3. Can you get service on the equipment?
4. Will the new system allow for future expansion? Is there room for another silo in the same system?
5. Will the investment save labor or make your production more efficient?
6. Can you meet future regulations as to zoning, manure management, and milk sanitation requirements?



Figure 7. Upright silos.

Upright silos

Tower silos have been a symbol of dairy and livestock farming for many years, as these enterprises have grown in size. The two types of upright silos are the oxygen-limiting silo and the conventional tower silo (figure 7).

Sealed or oxygen-limiting silos, may be an excellent choice where low-moisture forage is used and where the cropping system requires refilling throughout the season. Oxygen-limiting silos use bottom unloaders, which allow filling at the top while removing silage from the bottom. Oxygen-limiting silos work best when hay-crops are ensiled at 40 to 55 percent moisture and corn silage at 55 to 60 percent moisture. Moisture levels below 40 percent can result in severe heat damage of the forage.

When corn is the main silage crop, the conventional tower silo is an excellent choice because corn crops mature over a short period of time and the silo can be filled quickly, with less need of

refilling. For upright conventional silos, the ideal moisture level for ensiling hay-crops is at 55 to 65 percent. If the silage is chopped too dry (less than 50 percent moisture), a good pack can not be obtained. Corn silage should average about 63 to 68 percent moisture when plants are harvested at the full dent to one-half milk line (50 to 55 days after silking).

Length of chop for silage affects compaction in the silo for proper fermentation and affects roughage value for proper rumen function. The recommended length of chop for corn silage is 3/8- to 3/4-inch with 15 percent of the particles 1.0 to 1.5 inches long. Chopping too long makes compaction difficult, entrapping air in the silage and resulting in heating and spoiling. The theoretical cut for haylage is 3/8-inch and 15 to 20 percent of the particles greater than 1.0 to 1.5 inches long. Chopping haylage finer than 3/8-inch theoretical length of cut reduces particle length greatly and reduces roughage value of the forage. Haylage chopped at 3/8-inch should enhance both the compaction in the silo and the fermentation of the silage.

Prospective buyers should budget out the long-term costs and benefits of both types before making a decision. Tables 9 and 10 list the average capacities for upright silos.

Silo location. The site chosen for the silo should be convenient to the area where the silage will be fed and easy to fill. Silo placement should also allow for easy access from the crop-producing fields and enable wagons to be driven past the blower without the need for backing or steering into tight corners. If several silos are used, they should be close together and in a line, if possible, to make filling and unloading more efficient. However, do not place silos where they limit expansion of the barn area.

For dairy operations consisting of stanchion barns, the silos should be surrounded by a feed room. This allows for housing of the silage cart, the inclusion of a grain bin, and mixing equipment for total mixed rations. This keeps most of the feeding equipment together and reduces labor requirements. The silage feed room should be ventilated separately from the dairy barn since silo gases are sometimes formed and are dangerous to animals confined in the barn and to people.

When silage is fed in long bunks with an automated feeding system (e.g., in free stall barns or beef feedlots), the silos should be placed strategically to minimize the complexity of the feed conveying system. A feed room and a feed mixer are beneficial for bunk feeding of total mixed rations. Silos should be located near the bunks when feed carts will be used to transport the feed from the silo to the feed bunk, yet there should be ample space for maneuvering the tractor and feed cart.

Silo size. Year-round feeding of silage is possible when the silo size has been properly planned for a particular farming operation. This can allow for more uniform forage quality and for better control of amounts and kinds of ration ingredients.

The type of silo structure influences spoilage during warm weather. At least three inches of silage should be removed from conventional tower silos and it may be necessary to remove up to six inches. Feeding rate is not as critical with oxygen-limiting silos as with conventional upright silos. Feeding can be stopped for a time with less concern about spoilage. The silo diameter

should be selected to match the rate of removal and the amount of silage needed. Tables 9, 10, and 11. can be used to size the silo for the required daily volume of silage and for the amount needed to be fed to avoid spoilage problems.

Table 9. Approximate dry matter capacity for top-unloading concrete silos.

Diameter x height	Haylage	Corn silage
	tons	
18' x 40'	87	61
18' x 50'	113	83
18' x 60'	138	105
18' x 70'	168	129
20' x 40'	108	77
20' x 50'	111	106
20' x 60'	157	134
20' x 70'	202	165
22' x 40'	131	95
22' x 50'	169	130
22' x 60'	207	167
22' x 70'	245	205
24' x 50'	202	158
24' x 60'	247	203
24' x 70'	292	248
24' x 80'	337	293
26' x 50'	238	188
26' x 60'	290	241
26' x 70'	343	294
26' x 80'	398	347
28' x 60'	337	282
28' x 70'	398	344
28' x 80'	460	405
30' x 50'	317	256
30' x 60'	388	327
30' x 70'	458	397
30' x 80'	528	467

Source: Farm Structures and Unloaders, A.O. Smith, Harvestore Products, Inc. 1975.

Table 10. Approximate dry matter capacity for oxygen-limiting silos.

Diameter x height*	Haylage	Corn silage
	tons	
20' x 32'	56	58
20' x 36'	69	69
20' x 41'	83	81
20' x 50'	111	106
20' x 58'	124	118
20' x 63'	140	132
20' x 68'	157	145
20' x 73'	173	159
20' x 78'	185	173
20' x 82'	200	179
21' x 65'	177	162
21' x 70'	196	177
21' x 74'	216	194
24' x 64'	210	194
24' x 69'	235	203
24' x 74'	261	237
24' x 79'	287	258
24' x 84'	313	279
24' x 96'	393	344
24' x 104'	437	379
25' x 33'	96	97
25' x 37'	118	116
25' x 42'	141	137
25' x 44'	153	147
25' x 48'	173	167
25' x 52'	193	187
25' x 56'	213	207
25' x 60'	233	227
25' x 64'	253	247
25' x 68'	273	267
25' x 72'	293	287
25' x 76'	313	307
25' x 80'	333	327
25' x 84'	353	347
25' x 88'	373	367
25' x 92'	393	387
25' x 96'	413	407
25' x 100'	433	427
25' x 104'	453	447
25' x 108'	473	467
25' x 112'	493	487
25' x 116'	513	507
25' x 120'	533	527
25' x 124'	553	547
25' x 128'	573	567
25' x 132'	593	587
25' x 136'	613	607
25' x 140'	633	627
25' x 144'	653	647
25' x 148'	673	667
25' x 152'	693	687
25' x 156'	713	707
25' x 160'	733	727
25' x 164'	753	747
25' x 168'	773	767
25' x 172'	793	787
25' x 176'	813	807
25' x 180'	833	827
25' x 184'	853	847
25' x 188'	873	867
25' x 192'	893	887
25' x 196'	913	907
25' x 200'	933	927
25' x 204'	953	947
25' x 208'	973	967
25' x 212'	993	987
25' x 216'	1013	1007
25' x 220'	1033	1027
25' x 224'	1053	1047
25' x 228'	1073	1067
25' x 232'	1093	1087
25' x 236'	1113	1107
25' x 240'	1133	1127
25' x 244'	1153	1147
25' x 248'	1173	1167
25' x 252'	1193	1187
25' x 256'	1213	1207
25' x 260'	1233	1227
25' x 264'	1253	1247
25' x 268'	1273	1267
25' x 272'	1293	1287
25' x 276'	1313	1307
25' x 280'	1333	1327
25' x 284'	1353	1347
25' x 288'	1373	1367
25' x 292'	1393	1387
25' x 296'	1413	1407
25' x 300'	1433	1427
25' x 304'	1453	1447
25' x 308'	1473	1467
25' x 312'	1493	1487
25' x 316'	1513	1507
25' x 320'	1533	1527
25' x 324'	1553	1547
25' x 328'	1573	1567
25' x 332'	1593	1587
25' x 336'	1613	1607
25' x 340'	1633	1627
25' x 344'	1653	1647
25' x 348'	1673	1667
25' x 352'	1693	1687
25' x 356'	1713	1707
25' x 360'	1733	1727
25' x 364'	1753	1747
25' x 368'	1773	1767
25' x 372'	1793	1787
25' x 376'	1813	1807
25' x 380'	1833	1827
25' x 384'	1853	1847
25' x 388'	1873	1867
25' x 392'	1893	1887
25' x 396'	1913	1907
25' x 400'	1933	1927
25' x 404'	1953	1947
25' x 408'	1973	1967
25' x 412'	1993	1987
25' x 416'	2013	2007
25' x 420'	2033	2027
25' x 424'	2053	2047
25' x 428'	2073	2067
25' x 432'	2093	2087
25' x 436'	2113	2107
25' x 440'	2133	2127
25' x 444'	2153	2147
25' x 448'	2173	2167
25' x 452'	2193	2187
25' x 456'	2213	2207
25' x 460'	2233	2227
25' x 464'	2253	2247
25' x 468'	2273	2267
25' x 472'	2293	2287
25' x 476'	2313	2307
25' x 480'	2333	2327
25' x 484'	2353	2347
25' x 488'	2373	2367
25' x 492'	2393	2387
25' x 496'	2413	2407
25' x 500'	2433	2427
25' x 504'	2453	2447
25' x 508'	2473	2467
25' x 512'	2493	2487
25' x 516'	2513	2507
25' x 520'	2533	2527
25' x 524'	2553	2547
25' x 528'	2573	2567
25' x 532'	2593	2587
25' x 536'	2613	2607
25' x 540'	2633	2627
25' x 544'	2653	2647
25' x 548'	2673	2667
25' x 552'	2693	2687
25' x 556'	2713	2707
25' x 560'	2733	2727
25' x 564'	2753	2747
25' x 568'	2773	2767
25' x 572'	2793	2787
25' x 576'	2813	2807
25' x 580'	2833	2827
25' x 584'	2853	2847
25' x 588'	2873	2867
25' x 592'	2893	2887
25' x 596'	2913	2907
25' x 600'	2933	2927
25' x 604'	2953	2947
25' x 608'	2973	2967
25' x 612'	2993	2987
25' x 616'	3013	3007
25' x 620'	3033	3027
25' x 624'	3053	3047
25' x 628'	3073	3067
25' x 632'	3093	3087
25' x 636'	3113	3107
25' x 640'	3133	3127
25' x 644'	3153	3147
25' x 648'	3173	3167
25' x 652'	3193	3187
25' x 656'	3213	3207
25' x 660'	3233	3227
25' x 664'	3253	3247
25' x 668'	3273	3267
25' x 672'	3293	3287
25' x 676'	3313	3307
25' x 680'	3333	3327
25' x 684'	3353	3347
25' x 688'	3373	3367
25' x 692'	3393	3387
25' x 696'	3413	3407
25' x 700'	3433	3427
25' x 704'	3453	3447
25' x 708'	3473	3467
25' x 712'	3493	3487
25' x 716'	3513	3507
25' x 720'	3533	3527
25' x 724'	3553	3547
25' x 728'	3573	3567
25' x 732'	3593	3587
25' x 736'	3613	3607
25' x 740'	3633	3627
25' x 744'	3653	3647
25' x 748'	3673	3667
25' x 752'	3693	3687
25' x 756'	3713	3707
25' x 760'	3733	3727
25' x 764'	3753	3747
25' x 768'	3773	3767
25' x 772'	3793	3787
25' x 776'	3813	3807
25' x 780'	3833	3827
25' x 784'	3853	3847
25' x 788'	3873	3867
25' x 792'	3893	3887
25' x 796'	3913	3907
25' x 800'	3933	3927
25' x 804'	3953	3947
25' x 808'	3973	3967
25' x 812'	3993	3987
25' x 816'	4013	4007
25' x 820'	4033	4027
25' x 824'	4053	4047
25' x 828'	4073	4067
25' x 832'	4093	4087
25' x 836'	4113	4107
25' x 840'	4133	4127
25' x 844'	4153	4147
25' x 848'	4173	4167
25' x 852'	4193	4187
25' x 856'	4213	4207
25' x 860'	4233	4227
25' x 864'	4253	4247
25' x 868'	4273	4267
25' x 872'	4293	4287
25' x 876'	4313	4307
25' x 880'	4333	4327
25' x 884'	4353	4347
25' x 888'	4373	4367
25' x 892'	4393	4387
25' x 896'	4413	4407
25' x 900'	4433	4427
25' x 904'	4453	4447
25' x 908'	4473	4467
25' x 912'	4493	4487
25' x 916'	4513	4507
25' x 920'	4533	4527
25' x 924'	4553	4547
25' x 928'	4573	4567
25' x 932'	4593	4587
25' x 936'	4613	4607
25' x 940'	4633	4627
25' x 944'	4653	4647
25' x 948'	4673	4667
25' x 952'	4693	4687
25' x 956'	4713	4707
25' x 960'	4733	4727
25' x 964'	4753	4747
25' x 968'	4773	4767
25' x 972'	4793	4787
25' x 976'	4813	4807
25' x 980'	4833	4827
25' x 984'	4853	4847
25' x 988'	4873	4867
25' x 992'	4893	4887
25' x 996'	4913	4907
25' x 1000'	4933	4927

*The diameter and height of the silo include the silo unloader.
Source: Farm Structures and Unloaders, A.O. Smith, Harvestore Products, Inc. 1975.

Table 11. Approximate amount of dry matter in next three inches in top-unloading tower silos.

Depth of silage already unloaded (ft)	Silo diameter (ft)										
	10	12	14	16	18	20	22	24	26	28	30
	(lb)										
0	100	250	250	400	500	600	750	900	1000	1100	1250
4	100	250	400	500	600	750	900	1000	1250	1400	1600
8	250	250	400	500	600	900	1000	1250	1400	1600	1900
12	250	400	500	600	750	1000	1100	1400	1600	1900	2100
16	250	400	500	600	900	1100	1250	1500	1750	2000	2250
20	250	400	600	750	900	1250	1500	1750	2000	2250	2750
24	400	500	600	900	1100	1400	1600	1900	2250	2600	2900
28	400	500	600	900	1100	1400	1750	2000	2400	2750	3250
32	400	600	750	1000	1250	1500	1750	2100	2500	2900	3400
36	400	600	750	1000	1250	1500	1900	2250	2600	2900	3400
40			900	1000	1250	1600	2000	2400	2750	3400	3750
44			900	1100	1400	1600	2100	2500	2900	3400	3900
48			900	1100	1500	1600	2100	2500	3000	3400	3900
52			900	1100	1500	1750	2100	2600	3000	3400	4100
56			900	1250	1500	1900	2250	2600	3100	3500	4100
60			900		1600	1900	2250	2600	3100	3900	4250
64					1600	2000	2250	2600	3250	3750	4250
68								2600	3250	3750	4100
72								2600	3250	3400	3900
76								2600	3250	3500	3900

Silo maintenance. The inside surfaces of tower silos should be tight and smooth, and the silo doors should be air tight. Silage acids can erode concrete or unprotected metal and can cause severe silo deterioration when seepage occurs. Seepage can be reduced or eliminated by harvesting forages at the correct moisture content.

Old silos can be smoothed by trowelling a concrete plaster mix on the inside. This low-cost coating will last for several years. High priced coatings are not often recommended since no material will adhere for a long time on badly eroded walls.

Raw linseed oil can be brushed or sprayed on silo walls to form a water-repellent coating. It works best on walls in good condition, as it does not fill in rough spots. Boiled linseed oil should not be used as it may contain toxic additives.

Coatings of plastic or epoxy can be used to extend the life of concrete silos. The National Silo Association indicates that coatings are not used on most concrete stave silos, but are being used by the builders of monolithic concrete silos.

Older silos can be a hazard when they are not maintained properly. In many cases the silos look fine, but in actuality they are ready to collapse. All silos over 10 to 15 years old should be checked periodically by a professional. A quick inspection may save lives and thousands of dollars.

Automated feeding systems. Getting silage from the silo to the feeder can be accomplished by a transfer conveyor. Single and double chain or belt conveyors are most common because of their durability and low power requirements, however auger conveyors are sometimes used.

Most feeding systems need some weather protection to reduce mechanical problems of water and ice, to prevent wetting of the silage in the bunks, and to keep rain and snow off animals as they are eating. Feed conveyers that drop the silage should be sheltered against wind to prevent feed loss. This does not significantly affect the bunk cost.

Safety must be considered for people and animals. All exposed chains, belts, and especially augers should be covered by sturdy guards and all electrically driven equipment should be properly grounded. Guards can reduce the number and severity of accidents to both humans and animals.

All mechanical feeding systems require routine maintenance and occasional emergency repairs. The person operating the system should know how it works and should be able to stop trouble before it happens. "Machinery sense" is important. Troubles are often spotted when the machinery does not "sound right." Spare parts should be on hand for quick repairs to the silo unloader, transfer conveyor, and the bunk feeder. Spare chain links, shear pins, and V-belts should be on hand. Also, buy the brand of equipment that will have good service on parts and repairs in your locality. When shopping for feeding equipment and an associated dealer, realize the consequences of downtime. Feeding time is important and downtime must be of short duration when it occurs. In general, keep the system as simple as possible. In large operations,

mechanical feeders may become too long for practical use. Descriptions of the most common bunk feeders are listed below.

Shuttle/traveling feeder. The most common versions of this feeder type use chains or a dumping trough to empty the feeder. Feed is loaded in the center of the feeder, and the feeder travels back and forth from one end of the bunk to the other. These feeders are simple, need only be one-half the length of the bunk, and can place feed uniformly over the length of the bunk. Two different pens and different rations can be easily fed with a two-sided bunk.

Dumping belt or auger feeders. Feed is placed into these simple feeders at one end and is dumped uniformly into the bunk (some belt feeders have moving scrapers rather than a dump mechanism). Two different pens can easily be fed different rations with a two-sided bunk. Some belt feeders offer options which allow for more than two pens.

Open auger feeders. These inexpensive feeders fill the bunk unevenly as the dropped silage becomes the bottom of the feeder. The bunk fills from one end toward the other. Multiple pens cannot be easily fed varying rations.

Wagon feeding. In contrast to mechanical bunk feeding, or continuous flow handling systems, wagon feeding can be classified as a large-batch handling system. Batch handling is not well suited to small operations because it requires labor to load and distribute the feed to the cattle. For large operations it can be excellent because large amounts can be fed to many animals in a short time. A wagon can put feed into a bunk 300 feet long in three to four minutes. The side-unloading wagon plus a tractor scoop-loader is an efficient system for feeding silage from a horizontal silo and where silage is used at more than one location. A side-unloading box mounted on a truck can reduce travel time for widely separated feeding locations. Wagon feeding offers high flexibility as to kinds of material fed to animals; and if the feed wagon breaks down, a pick-up truck or forage wagon could be used.

Horizontal silos

Trench silos or above-ground bunker silos can reduce the investment in storage facilities that are needed with large animal enterprises (figure 8). These silos are quite flexible; extra capacity can usually be created by piling the silage higher or by adding length to an existing silo. Very large quantities can be stored at minimum cost.

Horizontal silos work best for large herds where 400 tons or more will be stored. Where silage is to be handled in large quantities and fed from a truck or wagon, the silage can be loaded with a tractor scoop loader or a special horizontal-silo unloader. The trench or bunker is best suited to corn silage or any crop that allows rapid filling.

The horizontal silo does have some limitations. It is less desirable for small herds, stanchion barns, and where push button feeding is desired. Spoilage will be higher compared to tower silos, especially when filling with small amounts of forage over long periods of time. This will leave



Figure 8. Horizontal silo.

much of the surface exposed and will result in spoilage. In addition, bad weather can make silage removal unpleasant, and there must be an all-weather road from the silo to the point where silage will be fed. The labor requirement to remove silage from a trench or bunker silo can be high if high-capacity loading is not available, and it can be difficult to remove only a thin layer from the silo without a good unloader.

Removal rate. Horizontal silos should be constructed with a cross-sectional area that will provide for the removal of at least three inches of silage daily to reduce spoilage in cool weather. More than three inches probably should be removed when a tractor-mounted bucket loader is used, because it tends to leave the silage face rather ragged. Thus, the silo should be long rather than too wide. Also, plan to feed at least four inches of corn silage and six inches of haylage a day in warm weather to reduce spoilage. When temperatures fall below freezing, feeding smaller amounts from the exposed face daily will keep the silage fresh. Select the proper length for horizontal silos to match the rate of removal to the amount of silage needed. It is recommended to keep silo depth greater than 6 feet to minimize spoilage. See table 12 for capacities and examples of determining removal rate.

Packing. Thorough mechanical packing is required to store silage in horizontal silos. Earth-walled horizontal silos should be reshaped before each filling. Each load of silage should be leveled as it comes into the silo. The packing tractor should be operating continually during filling. An efficient team to fill a horizontal silo usually includes an extra person to operate a tractor with a blade for distribution and compaction. A wheel-type tractor packs silage better than crawler tractors because the wheels concentrate the tractor's weight over a smaller area; this applies more pressure to the silage. It is best to continue packing about one-half hour after the last load for the day has been put in the silo and to start packing again the next filling day about one-half hour before the first load is added. To complete the silo filling, crown the last one or two feet of silage in the center and put somewhat higher moisture silage on the top layer; this helps give a tighter pack.

To pack silage safely, a respectable distance should be kept from unsupported edges. A tractor should be backed onto the pile and driven forward off the pile. A tractor should never be backed off the pile because it could roll over. Safety factors limit the height of silo walls to less than 20 feet. Generally a minimum width of 16 feet is needed for maneuvering equipment.

Properly packing silage to limit excess air infiltration in horizontal silos helps ensure a high quality forage. The sidewalls of wooden bunker silos should be lined with plastic to minimize air leakage. Trench or bunker silo walls should slope outward about 1.5 inches for each foot of

Table 12. Approximate bunker silo capacity.

Size ^{a,b} W x H x L	Total volume	Fillable ^c volume	Capacity ^d	
			Alfalfa silage	Corn silage
(ft)	(cu ft)	(cu ft)	(tons DM)	(tons DM)
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	107,520	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

- ^a Example removal rate for haylage: 100 cows are each eating 10 pounds of haylage dry matter per day and are being fed from a bunker silo which is 20-foot wide and 8 feet deep.
Removal rate = (Haylage dry matter/cow, lb/day) x (No. of cows)
(Silo width, ft) x (Silage vertical depth, ft)
Removal rate = 10 lb/day x 100 cows ÷ 20 ft x 8 ft
Removal rate = 6.3 inches/day
- ^b Example removal rate for corn silage: 100 cows are each eating 10 pounds of corn silage dry matter per day and are being fed from a bunker silo which is 20 feet wide and 8 feet deep.
Removal rate = (Corn silage dry matter/cow, lb/day) x (No. of cows)
(Silo width, ft) x (Silage vertical depth, ft) x 1.2
Removal rate = 10 lb/day x 100 cows ÷ 20 ft x 8 ft x 1.2
Removal rate = 5.2 inches/day
- ^c The entire volume cannot be filled with silage; the front surface is assumed to have a 45-degree slope.
- ^d Based on dry matter densities of 12.0 and 14.0 lb/cu ft for alfalfa and corn silage, respectively, which are representative of good bunker silo management (i.e., adequate packing).

depth so the silage will stay tight against the walls as it settles. Generally, finer, wetter materials pack tighter than coarser, drier particles. Corn silage stored in trench or bunker silos should be chopped about a week earlier than corn stored in upright silos.

Density. Greater silage density limits excess air penetration, but nutrients will be squeezed out if density is too high. Silage density is the weight of a specific volume and depends on several factors which include plant species, crop maturity, moisture content, length of cut, silo filling method, distribution, and compaction. In vertical silos bulk density runs close to 20 pounds per cubic foot (pcf) at the top surface and 60 per cubic foot (pcf) near the base. In horizontal silos the average bulk density can range from 53 pcf for finely chopped high moisture crops packed with heavy tractors in deeper silos, to 35 pcf for drier and longer-chopped hay crops in more shallow silos with moderate packing.

Table 13. Typical range and relationships of density and dry matter for several crops ensiled in horizontal silos.

Crop	Bulk density (pcf) ^a	Dry matter percentage (%)	Dry matter density (pcf) ^a
Corn silage	40	25	10.0
Corn silage	50	35	17.5
Haylage	35	30	10.5
Haylage	35	50	17.5
Haylage	40	35	14.0
Haylage	40	45	18.0

^apounds per cubic foot

Note: Silage crop bulk density x dry matter percentage = dry matter density.

Source: Selecting and Sizing Horizontal Silos, Extension Bulletin 460, Cornell University, 1989.

Bulk density and the dry matter density of silages are linked to the percentage of forage dry matter. The relationships shown in table 13 indicate the expected range in density and dry matter from grass-legume haylage and corn silage. Seepage from silos will occur if dry matter is less than 25 to 30 percent, and heat damage is probable with 50-percent dry matter forage. Seepage occurs as bulk density approaches that of water (62.4 pcf). Oxidation, molds, and spoilage tend to increase as the density approaches 10 pounds of dry matter per cubic foot.

Coverings. When silo filling is complete, cover the surface immediately to minimize undesirable fermentation and spoilage due to excess water or air at the surface (table 14). Black plastic (polyethylene or polyvinyl) is a practical cover which should be secured along all edges and the entire surface weighed down. An unweighted plastic cover will flap in the wind, and can pump air from small leaks or punctures over the entire silage surface and cause spoilage. Plastic covers should be protected from punctures by rodents, livestock, dogs, cats, and small wild animals. Mowing around the silo tends to discourage rodents.

Table 14. Temperature, dry matter losses, and chemical composition at two depths in covered versus uncovered horizontal silos filled with alfalfa haylage which has 44 percent dry matter.

	Temp. at 49 days (°F)	Dry matter losses (%)	pH	Lactic acid (%DM)	Crude protein (%DM)	ADF (%DM)
Covered						
top of silage		4		3.0		
bottom of silage		3		3.3		
overall average	98	4	4.9	3.2	21	39
Uncovered						
top of silage		51		0.6		
bottom of silage		13		2.8		
overall average	129	32	6.8	1.7	22	47

Source: J. Dairy Science 66:1057-1068, 1983.

Stack silos

Stack silos are another alternative for silage storage and are useful for emergency storage. Stacks have been used fairly successfully when filled with corn silage in late fall and fed out before warm weather in spring, however, they have not been very successfully adapted for permanent use.

The stack should be considered only as a short-term storage system. This may be convenient if an upright silo is full and the remaining silage needs stored. Silage from a stack is sometimes moved to an upright silo so it can be fed with the silo unloader and mechanical feeder system. Such work should be done only in cold weather.

When a silage stack is needed, choose a site with good drainage. Spread the silage from the middle toward both ends to produce a stack that is best suited for driving over while packing. The stack usually is wide and low because it is dangerous to run a tractor close to a steep edge.

Silage can be piled without packing, but losses will be very high. To eliminate further losses, the stack should be covered immediately with black plastic, the edges weighed down, and the plastic covered with heavy objects.

Bag silos

Plastic bags can be used as temporary storage for silage (figure 9). The storage site should have a firm base for ease in filling and unloading. Costs of filling the bag include purchase of the bag plus custom machine filling.

The most practical use of this type of storage system is that a fairly valuable crop can be stored for five months or less during cold weather; or it can be used for temporary storage of excess forage for eventual refilling in a conventional storage unit with the use of mechanical feeders.



Figure 9. Bag silo.

In any storage unit, silage quality is related to the airtightness of the unit. Dry matter losses in bags can run close to 12 to 13 percent, but mechanical and rodent damage can cause heavy losses because oxygen enters the bag. A few small leaks are not serious during cold weather, but heavy losses will result if storage goes into the spring and summer with air leaks present.

Silage removal may be difficult if the right equipment is not available. However, this type of temporary storage system may fit in well if forage is added to a mixing unit for a total mixed ration. The decision to invest in this type of system depends on the crop value and the losses in an alternative storage system.

Balage

Balage is an alternative to a facility for storing silage. It consists of taking grass or legume forage wilted to 40 to 60 percent moisture, baling it in a round baler, and either wrapping it with a plastic cover or placing it into a bag (figure 10). Forage containing less than 40 percent moisture should not be handled by this method. Round



Figure 10. Balage.

bale silage allows the producer to make silage when weather conditions do not permit the making of field-cured hay. Balage can be made with haying equipment: a round baler and transport fork or lifting probe.

Other advantages are that making round-bale silage takes about a third less fuel compared to silage chopping, and the bales often can be self-fed to eliminate the everyday feeding chore usually required with chopped silage. Another convenience is that silage can be placed in favorable locations around the farm to provide small feeding units. A good alternative to bagging is wrapping. This method of sealing and storage requires a special machine, but generally results in better feed with less labor input.

Management. Bales should be made when moisture levels are 40 to 60 percent. Higher moisture bagging may result in seepage and lower-moisture bagging may allow improper fermentation. Bags should fit bales snugly, but should be big enough to slip over the bales without difficulty. Also, at 60 percent moisture the bales can not be the six-foot size because they would weigh 3,500 pounds. Bales four to five feet in diameter and containing 50 percent dry matter should weigh close to 2,000 pounds. Size and weight of bales depend upon moisture content, type of baler, and type of forage.

Bagged bales should be stored in a well-drained site that is free of vegetation and trash. A clean site reduces the potential for rodent damage to the bags. When the bags are tied off and well sealed, the bag will swell with gases for a few days during the ensiling process. This is the sign of a good seal and means the bags have no leaks. All bagged bales should be inspected for holes in the plastic and patched immediately regardless of size.

Round bale silage should not spoil as long as the plastic remains intact. However, the quality of round bale silage is best if fed within a few months. The risk of damaging the plastic is proportional to the length of time round bale silage is stored. Bag quality also affects the storage life. High quality bags are designed to prevent oxygen infiltration for long periods of time, whereas low quality bags allow more oxygen to infiltrate.

Bags come in a variety of sizes and thicknesses. Black bags tend to weather better than white bags, but silage may become hot in high temperatures. White bags have been improved with ultra-violet inhibitors which stop light from breaking down the plastic. Reusing bags is not normally recommended. The cost of bags can range from \$5 to \$10 each (1991 price).

Disadvantages. All silage production systems have their weaknesses, including balage. Since the bales are going to be heavier, machinery that can handle the extra weight will be needed. Plastic bags or sheet plastic will need to be purchased. Additional problems include wind whipping the plastic and breaking the seal, cattle having difficulty pulling forage out of the bag, rodents causing damage to the bags, and the chance of damaging the seal if silage bags need to be moved. Another disadvantage is that storage costs more per ton of forage dry matter compared to silage stored in a concrete silo. It takes at least one extra person to put the bales in the bags. There is also the potential for pollution. Wrapping or bagging individual bales requires large amounts of plastic. Certain types of bags will not burn, and some communities have laws

restricting outside burning. As society becomes more concerned about environmental issues, burning and other disposal methods may have a strong impact on the large-scale use of round bale silage.

Round bale silage is not ideal for every livestock operation, but it can help manage feed rations, especially by part-time farmers and during wet times of the year. Researchers are developing and testing new plastic formulations that limit air exchange through the bag covering.

Table 15 lists a summary of practices that will minimize respiration losses in common silage storage systems.

Table 15. Practices to minimize respiration losses in silage.

Tower silo	Bunker silo	Bag silos	Baleage
Chop at 3/8-in. ^a	Chop at 3/8-in. ^a	Chop at 3/8-in. ^a	—
Fill rapidly.	Fill rapidly.	Fill rapidly.	—
Top off with one or more feet of wet forage.	Compress forage with tractor.	Use good filling machine.	Bale tightly.
Cover top with plastic.	Cover with plastic.	Seal ends carefully.	Wrap or seal carefully.
Treat concrete with sealant.	Seal cracks in wall.	Repair damaged bags.	Repair damaged bags.
Do not open for 14 days.	Do not open for 14 days.	Do not open for 14 days.	Do not open for 14 days.

^a A theoretical length of cut. Average particle size is 3/8 to 3/4 inch and 15 to 20 percent of the forage is 1.0 to 1.5 inches long.

SILAGE FERMENTATION

The ensiling process involves the fermentation of plant sugars into organic acids. The acidity produced effectively 'pickles' the crop into a stable state. Silage fermentation is controlled by four primary factors.

1. Moisture content
2. Fineness of chop
3. Exclusion of air
4. Carbohydrate (sugar) content

Fermentation phases

The ensiling process may be described as taking place in phases (figure 11). Normal silage fermentation is complete in about 21 days and occurs in four phases. A fifth phase may occur if improper silage production practices cause undesirable or abnormal silage fermentation.

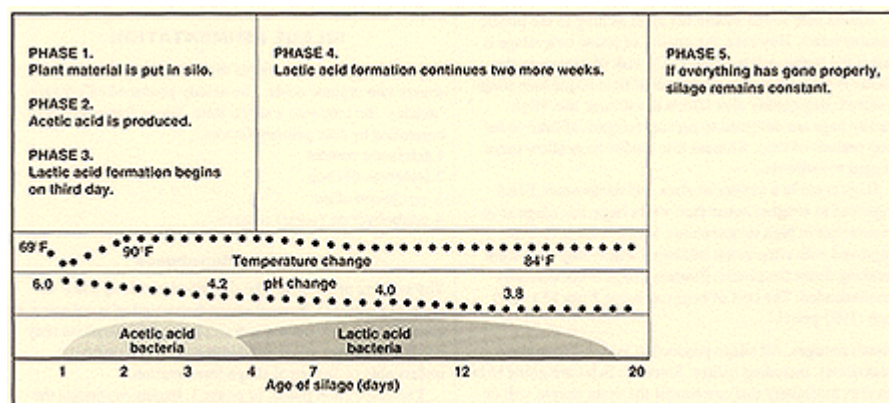


Figure 11. Diagram of silage fermentation.

The respiration phase, or phase 1, begins as soon as the chopped forage is placed in the silo. Green plants, when chopped and placed in the silo, continue to live and respire for a short period of time. The plant cells within the chopped forage mass continue to take in oxygen because many cell walls are still intact. At the same time, aerobic bacteria naturally present on the stems and leaves of plants begin to grow. These processes consume the more readily available carbohydrates and produce carbon dioxide, water, and heat.

Sugar + oxygen --> carbon dioxide + water + heat

Too much oxygen in the forage mass increases the use of carbohydrates which are essential in the production of lactic acid and cause high dry matter losses in the silo. Excessive heating of the forage also encourages the growth of undesirable fermentation organisms and lowers protein digestibility. Respiration results in a loss of available nutrients and energy and therefore the tendency for neutral detergent fiber (NDF) and acid detergent fiber (ADF) to increase, and net energy of lactation (NEL) to decrease. These changes result in lower quality forage.

Phase 1 or plant respiration causes an initial rise in temperature of the silage. An ideal environment for acid-producing bacteria is a forage mass temperature of about 80°F to 100°F. Excessive oxygen trapped in the forage mass will cause initial temperatures well above 100°F. The respiration phase will usually last from three to five hours, but this time depends on the supply of oxygen present. This phase should be kept as short as possible to avoid improper fermentation. Practices to exclude air from forages are (1) finely chop forage to about 3/8- to 3/4-inch lengths, (2) harvest at proper moisture to get greater density, and (3) distribute uniformly to improve packing.

Phase 2 or the **acetic acid** production phase, begins as the supply of oxygen is depleted in phase 1. Bacteria that grow without oxygen begin to multiply. The acetic acid bacteria begin the silage 'pickling' process. They acidify the forage mass, lowering the pH from about 6.0 in green forage to a pH of about 5.0. The lower pH causes the acetic acid bacteria to decline in numbers. This phase of the fermentation process continues for one to two days and merges into phase 3.

Phase 3 of the fermentation process begins as the acetic acid-producing bacteria begin to decline in numbers. The increased acidity of the forage mass enhances the growth and development of another group of anaerobic bacteria, the *lactic acid*-producing bacteria. Bacterial strains within this group are capable of growing with or without oxygen. The production of acid, especially lactic acid, is the most important change in the fermentation process.

Phase 4 of the fermentation process is a continuation of phase 3 when the lactic acid production reaches its peak. It is the longest phase of the fermentation process. This phase will continue for a period of about two weeks, or until the acidity of the forage mass is low enough to restrict the growth of all bacteria. The silage mass is stable within about 21 days and fermentation ceases if outside air is excluded from the silage. However, improper practices will result in an undesirable continuation of the process discussed below.

Phase 5 of the overall fermentation process involves the production of butyric acid and other undesirable products such as ammonia. This phase of silage fermentation will not occur when proper silage production practices are followed, provided the forage contains an adequate supply

of readily available carbohydrates. Butyric acid production is undesirable in silage fermentation. Its production increases dry matter losses during fermentation. *Butyric acid*-producing bacteria consume plant proteins and any remaining carbohydrates or sugars as well as acetic, lactic, and other organic acids already formed. These bacteria produce a sour-smelling silage that has a low nutritional value.

Legume crops such as alfalfa possess relatively low carbohydrate levels compared to corn silage and require field wilting. The wilted moisture level should average 65 percent or less, depending on the type of storage structure. Wilting to reduce the forage moisture content increases the concentration of carbohydrates in the forage mass. But moisture content greater than about 70 to 72 percent favor the growth and development of undesirable fermentation bacteria. These conditions, low carbohydrate levels and forages that are too wet, set the stage for phase 5 of the fermentation process which is the production of butyric acid.

Note: The various phases of the normal fermentation process tend to overlap one another due to the variety of fermentation bacteria present and their tolerance to the presence of oxygen and different forage acidity levels. Lactic acid-producing bacteria begin to grow and multiply shortly after the chopped forage is placed in the silo. They reach near peak populations during phase 3 of the fermentation process, which is complete within three to four days. Silage that has undergone proper fermentation will have a pH of 3.8 to 4.5 for corn silage and a pH of 4.0 to 5.0 for haylage. The actual range depends on moisture content.

Bacterial spoilage

Numerous species of bacteria cause undesirable fermentation in silage. Two which can cause some major problems are the different species of clostridial bacteria and listeria monocytogenes.

Clostridia are spore-forming bacteria that normally live in manure and soil and which can grow in silage when it is anaerobic. Low dry matter levels in forage promotes their action following that of lactic acid bacteria during fermentation. Different species of clostridia have varying effects on fermentation (Table 16). Some species ferment lactic acid and sugars to produce butyric acid, gaseous carbon dioxide, and hydrogen while others can ferment free amino acids to acetic acid and ammonia.

Table 16. Clostridial species often found in silage.

Species	Characteristics
<i>Clostridium tyrobutyricum</i> <i>Clostridium sphenoides</i>	Ferments sugars, lactic acid.
<i>Clostridium bifermentans</i> <i>Clostridium sporogenes</i>	Ferments amino acids.
<i>Clostridium perfringens</i>	Ferments sugars, lactic acid, and amino acids. May produce toxins causing enterotoxemia in some cases.
<i>Clostridium botulinum</i>	May produce toxins that result in deaths.

Source: Silage and Hay Preservation, NRAES-5, 1990.

Sugar --> butyric acid + carbon dioxide + hydrogen gas

Lactic acid --> butyric acid + carbon dioxide + hydrogen gas

Amino acids (alanine + glycine) + water --> acetic acid + ammonia

Clostridial characteristics include silage with a pH above 5, a high ammonia-nitrogen level, more butyric acid than lactic acid, and a strong unpleasant odor. Clostridial spoilage represents a loss of digestible dry matter and energy along with depressed dry matter intake by livestock. The best preventative action to avoid clostridial spoilage is to dry forage to at least 30 percent dry matter,

or use some type of additive if forage dry matter is below 30 percent. Some clostridia may produce toxins, including those that cause enterotoxemia.

Listeria is a species of bacteria that may proliferate in poorly fermented silage. *Listeria* requires oxygen and a pH above 5.5 to grow in silage. *Listeria* may be present where there is slow diffusion of oxygen into the silage mass, such as a poorly sealed silo, or near the closed end of a silage bag, or a puncture in the bag. *Listeria* can grow over a wide range of temperatures (40°F to 100°F) and dry matter contents (20 to 75 percent). *Listeria* causes a disease called listeriosis, which afflicts both animals and humans. In animals, it causes encephalitis or inflammation of the brain tissue. This nervous disorder is often characterized by animals going around in circles. Listeriosis can also cause abortion and death in animals and people. Some preventative measures to avoid *Listeria* in silage are maintaining an anaerobic environment by ensuring good compaction and sealing, allowing forage to ferment for two weeks, ensiling forage at the proper moisture range (50 to 70 percent), keeping a clean environment in the barn around the silo, and discarding silage that appears spoiled through contact with oxygen.

SILAGE CROPS

The predominant forage crops utilized on dairy operations are corn silage, perennial hay crops such as legumes and grasses, and small grains. Each of these crops has advantages and disadvantages, depending upon the particular farm operation, that need to be considered when planning the forage program. This includes the quality and quantity of the forage, and how well these forages meet the management practices of the operation and the nutrient requirements of the animal.

Corn

The digestible nutrient content of corn harvested as silage is generally higher than that of other silage crops. If harvested at the proper time, and otherwise properly managed, the yield of total digestible nutrients (TDN) may exceed 9,000 pounds per acre. The management involved when harvesting corn for silage is usually less critical than with other silage crops. Corn silage generally keeps well in properly made stacks and in trench or bunker silos.

Studies at Penn State and elsewhere indicate that no appreciable improvement in digestibility can be expected by extra processing of silage corn that is harvested at the recommended stage of maturity. Rolling, crushing, grinding, or recutting at ensiling time does not appreciably alter digestibility. Other research has demonstrated the importance of ensiling the entire corn plant. Ensiling only the center portions of the plant, for example, may slightly raise the energy content of the ensiled mass, but it considerably reduces TDN yield per acre.

Some farmers make silage of the stalks after the ears are picked or the grain is harvested. This material is a satisfactory feed for beef cattle when properly supplemented. Its greatest use is for wintering beef cows. To ensure satisfactory ensiling and preserving with this material, it may be necessary to add water at time of ensiling.

Maturity stage and moisture level. Harvesting corn for silage at the right stage of maturity is important for at least three reasons: (1) to get maximum yield of TDN per acre, (2) to ensure minimum field and storage losses by ensiling at the appropriate moisture content, and (3) to ensure high palatability and maximum intake by animals.

Moisture content can be estimated by the stage of kernel development. Kernel development can be characterized by the position of the kernel milk line.

The kernel milk line appears as a whitish line separating the kernel starch and milk. It appears near early dent and moves down the kernel as the grain matures. Data from Penn State indicate silage moisture contents at full dent, half milk, and black layer stages average 68, 61, and 53 percent, respectively (table 17). These are only

estimates, however, and may vary by about plus or minus four percentage points depending on the year and the hybrid. Consequently, to ensure accuracy, the moisture content should be monitored if possible.

Table 17. Kernel development related to whole-plant moisture and dry matter yield (corn silage).

Kernel stage	Moisture content (%)	Dry matter yield lb/A
Early dent	68	12,303
Half milk line	61	13,553
Black layer	53	13,210

Source: The Penn State Agronomy Guide, 1989-1990, page 55.

As a general rule, harvest should begin at the full dent to one-third milk line stage for upright silos. Harvest slightly earlier for trench silos and slightly later for sealed upright silos. This will usually maximize digestible dry matter yields and help to avoid harvesting fields that are overmature. Avoid moisture levels of less than 62 percent because they may increase the risk of abnormal fermentation, higher dry matter losses, lower energy content from hard grain, and silo fires. When corn silage provides over 65 percent of the forage dry matter in dairy and livestock rations, harvesting at the early dent stage should be considered to provide more fiber and fat soluble vitamins.

Corn allowed to stand in the field until winter can be harvested for silage if water is added and silage is stored properly. However this practice results in a reduction of both dry matter yield per acre and digestibility; several studies indicate field losses in excess of 20 percent. Penn State researchers also measured a 7 percent reduction in digestibility when feeding this mature material as compared with corn silage harvested at the dent stage. Such dry material has been the cause of numerous silo fires and explosions.

Weather related problems. Crops stressed by unfavorable weather conditions are a possibility in any farming operation and require special management considerations. Corn that has been planted for silage can be frost-damaged whether it is immature or mature. When frost occurs on immature plants, it will appear drier than unfrosted corn of the same moisture content. Even though leaves may brown off along the edges and dry rapidly after a few sunny days, the green stalk and ears do not. The crop will continue to accumulate dry matter and should be left in the field until it reaches the appropriate moisture content. Plants that are killed and still immature will likely contain too much moisture for immediate ensiling. These plants will dry slowly and dry matter losses will increase as the dead plants drop their leaves. The best option is to leave the crop in the field to dry to an acceptable level, unless dry matter losses appear too high or harvesting losses will increase dramatically.

Killing frost that occurs when the plant has reached maturity causes the whole-plant moisture content to fall rapidly. The corn should be ensiled before the moisture drops below 60 percent.

Corn that has been stressed all summer due to drought may have few if any ears, and usually will have an energy value 85 to 100 percent of normal corn silage. Droughty corn silage typically has a higher protein content than normal silage. However, most of this protein is found in the plant rather than in the grain, making it more easily degradable in the rumen. As a result, NPN or nonprotein nitrogen supplementation does not work as well as compared to normal silage. It becomes especially important to supplement drought corn with a natural protein source for heifers up to 600 to 700 pounds and high-producing dairy cows in early- to mid-lactation.

The dry matter content of droughty silage must be in the normal range to make good silage because normal silage packing and removal of oxygen must always occur. If the corn did not set ears and is green, or if the ears are all brown and the stalk is green, the moisture content will be too high; but hot, dry weather can cause rapid moisture drops. Carefully observe changes in moisture content to determine when to harvest.

Nitrate toxicity. Although nitrate levels in drought-stricken corn may be high, ensiling will reduce more than half the nitrates to ammonia, which can be utilized by the rumen bacteria. For this reason, nitrate toxicity rarely occurs when feeding ensiled drought corn. However, if the drought damage was extreme, and high levels of nitrogen were applied to the soil, a nitrate test on the silage should be conducted (table 18).

The following precautions will reduce nitrate levels in plants and reduce feeding problems in rations.

1. Do not harvest suspected crops for three to five days after an appreciable rain or long cloudy spell.
2. Harvest as close to usual maturities as possible.
3. Cut the crop somewhat higher above the ground than usual because nitrates often accumulate in stalks.
4. Utilize suspected material for silage rather than greenchop because ensiling breaks down some of the nitrates.
5. Test suspected forages for nitrate content, preferably before feeding them.
6. Feed another forage prior to feeding suspected or high nitrate forage to help limit meal size.
7. Gradually introduce suspected forage into the ration over a period of one to two weeks to allow for adaptation and to reduce risks.

Table 18. Nitrate levels in forages for dairy cattle.

Nitrate ion (NO ₃) (%)	Nitrate nitrogen (NO ₃ -N) (ppm)	Recommendations
0.0–0.44	0–1,000	Safe to feed under most conditions.
0.45–0.75*	1,000+–1,700*	Gradually introduce to ration. Feed some concentrate. Test all feeds and water. Dilute to .40% NO ₃ or 900 ppm NO ₃ -N in total ration dry matter. Restrict single meal size.
0.76–1.00+	1,700+–2,300+	Possible acute toxicity. Feed in a balanced ration with concentrate included. Dilute to .40% NO ₃ or 900 ppm NO ₃ -N in total ration dry matter. Restrict single meal size.

* If one forage contains over .44% NO₃ or 1,000 ppm NO₃-N, test all forages, water, and possibly concentrates. Include nitrate intake from water as part of dietary intake.
Source: Penn State Dairy Science Extension Mimeo 91-31, Prevention and Control of Nitrate Toxicity in Cattle.

8. Feed forages and total mixed rations more frequently to reduce meal size when suspected or high nitrate forage is used or silo gas is present.
9. Feed at least three to five pounds of concentrate per head daily to cattle to reduce possible toxic effects when suspected forages are fed.
10. Limit dry matter intake per single meal if stored forage contains 1,000 ppm $\text{NO}_3\text{-N}$ or more on a dry matter basis. Allow a delay of two to three hours after completion of a meal before feeding a high nitrate forage again.
11. Retest suspected and high nitrate forage periodically, due to large variations which often occur in forage.
12. Test all forage and water for nitrates if one stored forage contains over 1,000 ppm $\text{NO}_3\text{-N}$.
13. Consider blending high nitrate silage or haylage with those containing lower amounts before feeding to provide less than 1,000 ppm $\text{NO}_3\text{-N}$ in the blend dry matter and thus enable free-choice feeding.
14. Restrict the $\text{NO}_3\text{-N}$ content of the total ration dry matter, including contribution from water to not over 400 ppm to 900 ppm when using stored forage in addition to meeting any maximum forage dry matter intake for a single meal. Rate of nitrate intake is the most critical factor influencing possible toxicity. This is affected by rate of forage dry matter intake in a given period of time and its nitrate content. Forages containing under 1,000 ppm nitrate nitrogen ($\text{NO}_3\text{-N}$) on a dry matter basis may be fed free-choice or with no restriction on meal size, provided the total level of $\text{NO}_3\text{-N}$ in the total ration dry matter, including that from water, is kept at a safe or low-risk level. Stored forages containing higher levels generally require limiting meal size to avoid elevated methemoglobin levels in the blood and other toxic effects.

A single meal refers to the amount of stored forage dry matter consumed during one episode of eating which may range from a few minutes to two hours. This interval is dependent upon the maximum forage dry matter intake per hundred pounds of body weight as indicated for forages containing various levels of $\text{NO}_3\text{-N}$. High nitrate forage should not be fed again for two to three hours after completion of the previous feeding. Recommended maximum forage dry matter intakes per hundred pounds of body weight in a single meal for forages containing various levels of $\text{NO}_3\text{-N}$ on a dry matter basis are as follows:

- 1,100 ppm $\text{NO}_3\text{-N}$ - 1.15 lbs. / cwt of body weight
- 1,700 ppm $\text{NO}_3\text{-N}$ - 0.67 lbs. / cwt of body weight
- 2,300 ppm $\text{NO}_3\text{-N}$ - 0.41 lbs. / cwt of body weight
- 2,800 ppm $\text{NO}_3\text{-N}$ - 0.31 lbs. / cwt of body weight
- 3,400 ppm $\text{NO}_3\text{-N}$ - 0.24 lbs. / cwt of body weight

In addition, observe animals closely for symptoms of toxicity two hours following the start of a meal consisting of a suspected or high nitrate forage (over 1,000 to 1,300 ppm $\text{NO}_3\text{-N}$). The color of mucous membranes in the vagina, mouth, or eyes will turn from pink to a grayish-brown at a methemoglobin content of 20 percent or higher. This is the earliest sign of a possible toxicity occurring with slight to acute symptoms. Acute symptoms will include rapid breathing, incoordination or staggering, and signs of suffocation.

Perennial hay crops

Any perennial which can be used for hay can also be made into silage. These crops may be put in the silo when weather does not permit curing them as hay. When properly harvested and stored, ensiled hay crops make nutritious, easy-to-handle feeds.

Stage of maturity at the time of harvest is the single most important factor influencing the feeding value of hay-crop silage. This is especially true for the first cutting of both legume and grass forages. As indicated in table 19, perennial legumes cut in the early stages contain 66 percent TDN. Left until they reach full bloom, these same legumes contain only 46 percent TDN. The same general relationship is true for perennial grasses. Table 19 also shows the nutritive values that result from different stages of maturity.

Table 19. Forage composition based on stage of maturity.

Forage	Avall. CP	ADF	NDF	TDN	NEL ^a
% dry matter basis					
MMLegume haylage					
Pre-bud	23	33	45	66	.68
Bud	19	38	48	60	.61
Bloom	15	42	58	53	.54
Full bloom	11	49	66	46	.46
After math	18	38	49	55	.56
Late fall	20	35	48	59	.60
Grass haylage					
Early head	16	39	58	58	.60
Full head	12	45	67	52	.52
Mature	8.5	50	73	45	.45
After math	16	40	59	54	.54
Late fall	18	36	58	58	.58

^a Mcal/lb

Next to stage of maturity at harvest, excessive moisture is the second most serious factor affecting the quality of hay crops harvested as silage. Both research and the experience of farmers indicate it is difficult to make good quality direct-cut, hay-crop silage consistently unless: (1) a good feed additive is used at recommended levels, or (2) a recommended chemical preservative such as those containing acetic and/or propionic acid is added to minimize formation of undesirable acids such as butyric acid. The undesirable acids, or something associated with their development, apparently limit forage intake and may adversely affect thyroid function of animals that consume improperly fermented forages. Also, high butyric acid silage has been shown to make dairy cows more susceptible to ketosis or acetonemia.

High quality silage made from either alfalfa, clover, or cool-season grasses requires field wilting to the appropriate moisture content, that moisture level depends on the type of storage unit. Making a good, tight pack assures an oxygen-free environment, and the pack density depends on fineness of chop, moisture content, and rate of fill.

Most studies indicate that milk production from high-moisture silage is similar to that from wilted or low-moisture silage, assuming the silage quality is similar. This is true despite the greater intake of forage dry matter with lower-moisture silage. However, too often, direct-cut silage is inferior in quality and limits intake severely, thus animals are adversely affected.

The moisture content of perennial hay-crops at the time of ensiling also has a pronounced effect on both harvest and storage losses of dry matter. Storage losses are highest with direct-cut forage, and harvest losses normally increase with increased field wilting.

Small grains

Small grains will normally produce up to twice as much TDN per acre when harvested for silage as they will when harvested for grain. But it is more difficult to make good quality silage from small grain forage than from other commonly used silage crops. Thus, it is often best to utilize small grain forage in the form of pasture or green chop.

Oat crops are the best small grain for silage. In addition to a higher yield of TDN per acre, another advantage for harvesting oats as silage is that early removal of the crop results in more vigorous growth of any legume or grass seeded with the oats. Any oat variety proven for a certain area will make satisfactory silage yields. However, studies indicate that later-maturing, taller varieties produce more tonnage, especially when harvested later than the boot stage (table 20).

Table 20. Yield and quality of oat forage.

Maturity	Dry matter (tons/A)	Moisture (%)	Crude protein (%)
Boot	1.4 ^a	85.6	17.4
Head	1.8	84.8	14.0
Flower	2.2	78.9	11.6
Milk	2.4	70.9	11.6
Dough	3.0	57.6	9.3
Seed	2.8	46.0	8.8

^a Two cuttings of 1.1 and 0.3 tons per acre.

Source: Hoard's Dairyman Dairy Forage Guide, 1984, pg.27.

When growing oats specifically for silage, plant early and seed for a thick stand—at least three bushels per acre. If lodging is not a problem, fertilize with up to 90 pounds nitrogen per acre, and phosphorus and potassium as indicated by a recent soil test for the legume-grass seeding as well as the oats. If lodging is a problem, use no more than 30 to 40 pounds of nitrogen per acre.

Studies conducted at Penn State, reveal that oats ensiled at the head stage made the best feed. In terms of both yield and quality, oats, wheat, or barley should not be harvested before heading or later than milk stage. Rye, for reasons of palatability, should be ensiled when in the late-boot to heading-stage of growth or earlier.

For milking cows, the highest quality small grain silage comes from the boot stage. A second cutting is possible if it is harvested in the boot stage and if the soil moisture levels are favorable for good regrowth. Since small grain forage in the boot stage contains more than 85 percent moisture, it must be wilted and conditioned just like a legume or legume-grass silage. Ensiled small grains can serve as the sole forage for late lactation cows, low producing cows, and dry cows because the crops contain less calcium, energy, and protein than alfalfa. If the forage is intended for growing heifers or dry cows, small grains may be harvested just before or at the dough stage for more tonnage per acre. Early-cut small grain forage may be lower in magnesium and higher in phosphorus than other forages.

Small grains make the best silage when ensiled at 65 to 70 percent moisture. Thus, conditioning and wilting of early-cut small grain forage prior to ensiling is desirable. Additional practices to help assure good quality feed are chopping the forage at the recommended length of cut, the addition of a chemical preservative such as those containing acetic and/or propionic acid at the recommended rates, and thorough packing in the silo.

Sorghum, sudan grass, and sorghum-sudangrass hybrids are similar to corn in their adaptability for silage. They preserve well when harvested at the appropriate moisture content and make an acceptable feed. However, silages made from these annuals normally will not equal corn silage in either yield or quality (table 21).

Table 21. Quality of sorghum-sudan silage versus other small grain silages.

	Crude protein	TDN	NEL ^a	NEM ^a	NEG ^a
	% dry matter basis		Mcal/lb		
Sorghum-sudan silage	10.8	55	.56	.52	.26
Sorghum silage	7.5	60	.61	.60	.34
Corn silage, well eared	8.1	70	.73	.74	.47
Corn silage, few ears	8.4	62	.64	.63	.36
Oatlage	11.5	60	.61	.60	.34
Ryelage	12.8	53	.54	.49	.24

^aNEL = net energy of lactation, NEM = net energy of maintenance, and NEG = net energy of gain.
Source: NRC, revised edition, 1989.

Grain sorghums, the one-cut forage sorghums, and sudangrass are best suited for silage. Sudangrass and sorghum-sudangrass hybrids can be ensiled, but their yields are lower, and at least two cuttings are necessary for best production. Sudangrass and the sorghum-sudangrass hybrids are better suited for pasture or green chop than for silage. The sorghum-sudangrass hybrids usually out-yield sudangrass for silage.

Grain sorghums for silage should be selected on the basis of the time needed for maturity and their ability to produce grain. The hybrid selected should reach maturity before the first frost.

Forage sorghum hybrids should be selected for their ability to produce forage dry matter rather than grain. Grain yields are low and some hybrids produce no grain. Silage yields of forage sorghum are usually quite similar to those for corn. However, their nutritive value is lower and total feed energy produced per acre is usually less.

Grain and forage sorghums for silage should be harvested when the grain is at the medium- to hard-dough stage. Material going into the silo at this state will carry 70 to 75 percent moisture. The digestibility of sorghum silage, especially from grain sorghums, may be increased considerably by recutting at the time of ensiling.

In a one-cut system, sudangrass and the sorghum sudangrass hybrids are best harvested between the time heads emerge from the boot and early bloom. If harvested more than once, they may be cut whenever the plants reach an average height of 30 inches or more (table 22). However, when cut at this stage, it is

Table 22. Value of sorghum-sudan silage.

	Plant height		
	36 in.	54 in.	Dough
Cuts	3.0	2.0	1.0
Dry matter, (tons/A)	2.8	3.4	6.0
Crude protein, (%)	15.2	11.6	5.8

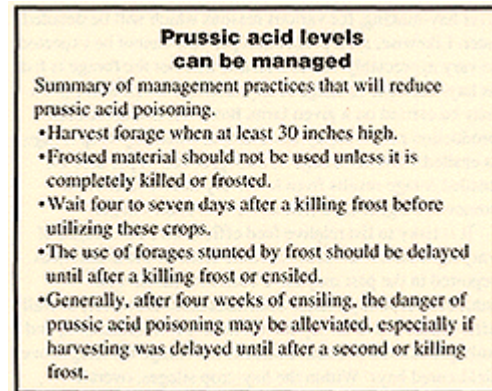
Source: Heard's Dairyman Dairy Forage Guide, 1984, pg.28

important to wilt the crop to remove excessive moisture and to use a preservative at recommended rates. Occasionally sudangrass is grown with soybeans for silage. When ensiling this mixture, harvest when the sudangrass is at early head to early bloom stages. Millets, when grown for silage in Pennsylvania, should be cut between early heading and early bloom.

Sorghum, sudangrass, and their crosses may accumulate nitrates when stressed. Risk of nitrate poisoning can be reduced with the same precautions recommended earlier for corn silage.

Another problem that is restricted to sorghum, sudangrass, and their crosses is prussic acid poisoning. It may result when these crops are used at a too immature stage or are severely stressed by weather such as drought and frost.

Risk of prussic acid poisoning may be reduced if sorghum-sudangrass is at least 30 inches high before harvesting and piper sudangrass is at least 18 inches high. Frosted material should not be used unless it is completely killed or dried and should be cut no earlier than four to seven days after a killing frost. If material is stunted by frost, delay using it until after a killing frost or ensile the material. Ensiling does not always alleviate the danger of prussic acid poisoning. It generally does, however, after about four weeks of ensiling. This is especially true if harvest is delayed until after a second or killing frost occurs. The same precautions used to reduce nitrate poisoning in corn silage can be followed for prussic acid poisoning.



COMPARATIVE FEEDING VALUE OF FORAGES

Forages vary considerably in feeding value. Their values depend upon such factors as species, maturity, harvesting methods, and weather. This is why forage testing is so important when farmers wish to do a good job of balancing rations and feeding livestock. A variety of other forages meet other needs. Some are better choices where conditions are not ideal for growing certain crops such as alfalfa. Others, like corn silage, meet different nutritional needs.

Legumes versus grasses

The crude protein content of legume and mixed legume-grass forage runs higher than that for grasses. This is also true for the energy content, although the differences are less pronounced than for protein. Grasses cut at comparable stages of maturity as legumes may contain about 5 percent less crude protein, but approximately equal amounts of TDN or energy. Levels of major minerals, particularly calcium, magnesium, and sulfur also average higher for legume or largely legume forage than for grasses or annual forages. Animal intake often favors legumes over grasses of similar quality.

Hay versus silage

Theoretically, it might be expected that hay-crop forage made as silage would contain more available protein and TDN than similar material made into hay. This is not the case. Available protein usually runs appreciably higher for hays than silages. Generally, acid detergent fiber values average higher for silages than hays. This results largely from heat damage and loss of soluble carbohydrates during ensiling. As a result, estimated TDN or energy levels can run appreciably lower for silages than hays.

Ensiling hay-crop forage may preserve more nutrients for feeding because of less dry matter loss. However, ensiling should not be expected to improve forage quality greatly over hay-making, for

various reasons which will be detailed later. Likewise, milk production per cow cannot be expected to vary appreciably on most farms, whether the forage is fed as hay, haylage, or silage at any moisture level. More cows may be carried on a given farm, however, and more milk production per acre may be obtained, when hay-crop forage is ensiled. This advantage in milk production per acre for ensiled forage results from lower dry matter losses and somewhat higher feed efficiencies for some silages.

It is risky to list relative feed efficiencies for forages of varying moisture contents because some of the differences reported in the past may have been associated with inaccuracies in dry matter determinations. However, overall efficiencies based on dry matter losses, feed utilization, and milk production indicate a distinct advantage for silages over field-cured hays. Within the hay-crop silages, overall efficiencies favor a moisture level of 60 to 69 percent. Next highest in efficiency is a level of 70 percent or higher. Silages containing 59 percent moisture or less rank lowest in overall efficiency from harvest through milk production. This results from higher harvest losses and greater dry matter intake with little or no increase in milk production. Barn-dried hay ranks similar to the low-moisture silages or haylages. Forages may have to be ensiled at less than 60 percent moisture to avoid mechanical problems in some oxygen-limiting silos.

General management considerations. Practical experience and research have indicated that cattle may be fed an all-hay, all-silage, or combination forage ration. However, the feeding of an all-silage ration increases the need for good management and ration balancing. A single forage system provides one with less of a safety factor in meeting nutritional needs. A high corn silage ration tends to lower rumen pH and may result in more digestive or metabolic upsets, especially when ensiled or acid-preserved grain is also fed. This rumen acidosis problem may be controlled by feeding buffers and making certain that cows are not overfed grain or concentrates. It is also important not to chop forages too fine for an all-silage ration. A theoretical cut of 3/8 to 3/4 inch is adequate. Forage particle-size may become too fine when recutters or screens are used on forages harvested at recommended moisture levels. Forage dry matter intake on an all-corn silage ration may not exceed 2.0 pounds per hundred pounds of body weight daily compared to 2.3 pounds or more on a combination of forages. Somewhat greater total dry matter intake has been obtained in some research when limited amounts of hay are kept in the ration.

Several factors may keep silages or haylages from equaling or exceeding hays in feeding value. Heat damage is much more prevalent in hay-crop silages than hays. This may reduce energy digestibility or TDN as well as protein digestibility. Acid detergent fiber levels frequently are increased in heat-damaged forages. It is important to obtain a test for heat damage when silages other than corn silage are submitted for analysis. The effects of heat damage may be offset by heavier feeding of supplemental protein and energy.

NPN considerations. Nonprotein nitrogen (NPN) or soluble nitrogen and degradable protein levels also are higher in ensiled forages and grains. The higher NPN contents for ensiled materials result from the breakdown of true protein to simpler forms of nitrogen. When NPN is present beyond certain levels in the total ration dry matter (forage plus grain), it is not utilized as well as true protein and may reduce performance. Problems with excessive NPN or soluble nitrogen intake or lack of rumen undegradable protein may be avoided by proper feed programming.

Grain mixtures for livestock on all-silage rations may need to contain less NPN with little or none in the form of urea. Some ingredients such as dry corn, hominy, soybean oil meal, and brewer's grains are relatively low in NPN content. Others such as ensiled grains, wheat bran, wheat midds, distiller's grains, corn gluten feed, and NPN additives contain relatively high levels of NPN or soluble nitrogen. When soluble nitrogen levels are below optimum, such as on some all-hay rations, various ingredients including urea may be used in the grain mixture.

The higher NPN or soluble nitrogen levels in silages should not keep farmers from using all-silage or high-silage rations. However, they do necessitate more careful management and attention to feed programming. The effects of greater heat damage and higher NPN or soluble nitrogen levels in silage usually result in somewhat lower protein or nitrogen utilization on all-silage rations. This may be offset by feeding grain to increase protein and energy as well as by balancing for undegradable protein.

pH levels. Silage making is a biological process involving microorganisms. During fermentation certain acids may be produced at higher than usual levels. Excessive intake of these acids may depress feed intake. Silage intake may have to be reduced in such cases. Toxic amines sometimes are present in silage at abnormally high levels. These may also result in depressed feed intake as well as digestive and metabolic upsets. When silage pH fails to fall below 5.0, there is more risk of problems with botulism, listeriosis, and mycotoxins. These conditions are quite rare, but may become more widespread in certain growing seasons and may result in heavy losses on an affected farm. Generally, well-preserved corn silage will have a pH of 3.8 to 4.5, while hay-crop and other annual silages will range from a pH of 4.0 to 5.0. Silage pH tends to remain at a somewhat higher level in oxygen-limiting silos.

Dry cows. The special forage needs of dry cows should be kept in mind when planning a forage program for a dairy farm. To keep health and reproductive problems at a minimum, corn silage should not provide over 50 percent of the forage dry matter consumed by dry cows. Likewise high-protein, high-calcium forage (legume or mixed, mainly legume) should not furnish over 25 to 40 percent of the forage dry matter for dry cows. All-hay or all-silage rations may be used for dry cows provided these guides are reasonably met and rations are properly balanced. When possible, providing all cows with some fresh forage or pasture may be beneficial in restoring body stores of fat soluble vitamins.

Producing cows. All corn-silage rations may be fed to producing cows when close attention is paid to feed programming, including neutral detergent fiber. Some level of corn silage feeding often is needed to ensure a total ration with sufficient digestibility and rate of passage in the digestive tract to maintain good levels of milk production. When other forages are of average or good quality, corn silage probably should furnish at least 25 percent of the forage dry matter. If other forages are poor or considerably below average in quality, corn silage may need to provide at least 50 percent of the forage dry matter. This assumes that sufficient acreage suitable for corn is available and that it is an economical crop, as it usually is. Hay-crop forages cut at very immature stages could substitute for these levels of corn silage.

Forage rations for herds averaging up to 50 pounds of milk per head daily should contain a minimum of 60 percent TDN on a dry matter basis whenever possible. The forage ration for

high-producing herds should contain at least 68 percent TDN. This often is attainable only with corn silage or other types of forage cut at considerably earlier maturities than generally recommended for economical yields of nutrients per acre.

The points in this section are made not to discourage all silage or high-silage rations, but to alert farmers to the somewhat greater risks and the needs for better management on such rations. A switch from hay to silage is not a cure-all for improved nutrition and performance.

SILAGE ADDITIVES

Cutting forages at the proper stage of maturity is the most important factor in producing high quality feed. Forages grown for silage should be harvested at the proper moisture level, chopped fine (3/8- to 3/4-inch theoretical cut), and placed rapidly into a well-sealed silo.

Preservatives are designed to inhibit undesirable bacterial and fungal (mold) activity, or promote the desired type of fermentation. The organic acid mixtures inhibit bacteria and mold. They work primarily as fungicides, or they make a mixture acid enough that undesirable bacteria do not grow. These preservatives work best when they come in contact with as much of the surface area of the silage as is possible.

Preservatives can be applied to forages in the field or at the silage blower. Pumps driven by a tractor battery can be used to spray preservatives directly onto the forage as it enters the silage chopper or blower. Rates of application should be monitored by use of flow meters or pressure regulators and must be put on according to the dry matter content of the silage. Alternatively, preservatives can be applied at the blower using a container with a spout and a hose.

During storage, forages undergo a heating period due to the presence of microorganisms. This heating results in a loss of energy and decreased dry matter and protein digestibilities. Preservatives designed to inhibit microbial activity lessen the effects of heat on forage quality (table 23).

Table 23. Temperatures of treated haylage during storage and feeding.

Dry matter percentage (%)	Treatment material	Average temperature (°F)	Maximum surface temperature	
			Storage ^a (°F)	Feeding ^b (°F)
53	none	109	126	113
62	.4% Prop ^c	100	127	111
69	.6% Prop	100	100	102
60	.5% AIB ^d	97	115	104
55	1.0% AIB	104	113	102

^aWeeks 3-7

^bWeeks 1-6

^cPropionic acid

^dAmmonium isobutyrate

Source: Yu and Thomas, 1975, *J. Animal Sci.* 41:1458.

Fermentation inhibitors

Several compounds work as fermentation inhibitors and most of them are not recommended. Formic acid is commonly recommended. It works best for direct-cut silages by decreasing pH, limiting fermentation, and causing direct acidification. Formic acid is applied at 0.3 percent per ton for direct-cut silage (20 percent dry matter) and it can be used at 0.6 percent per ton for wilted silage (35 percent dry matter).

Propionic acid is an aerobic inhibitor and is one of the more popular additives used. Propionic acid is most effective when added at the level of 0.8 to 2.0 percent (16 to 40 pounds per ton) of the forage. Propionic acid treatment reduces dry matter loss (table 24), prevents increases in

temperature, and reduces yeast growth. It retards aerobic fermentation of the silage during feeding. It is corrosive to equipment and people, so care should be taken. Acetic propionic acid combinations can also be used on forages.

Table 24. Sources of dry matter losses from propionic acid treated haylage.

Item	Untreated* (50)	0.8% Prop.acid* (80)
% dry matter ensiled		
Top spoilage	4.1	0
Other spoilage	2.8	2.6
Total spoilage	6.9	2.6

* Percentage dry matter of ensiled haylage.

Source: Yu and Thomas, 1975, *J. Animal Sci.* 41:1458.

Some of the **compounds that should not be used** for fermentation improvement are hydrochloric and sulfuric acid mixtures, antibiotics, and sodium chloride. Hydrochloric and sulfuric acids are corrosive and may cause problems to application handling equipment, silo walls, and people. Antibiotics are not recommended because they show inconsistent effects on silage and they have the potential for milk residue. Sodium chloride acts as a food preserver, it not inhibit growth of molds or improve forage quality.

Scientific data indicates varying degrees of successful use with preservatives. Some reports show positive effects from preservatives while others show no effect. The most important consideration is whether the improved quantity and quality of forage from the use of a preservative will offset the cost of the preservative and its application.

Stimulants

Another type of additive is stimulants. They enhance the growth of lactic acid bacteria and their production of organic acids which reduce pH. These ingredients can be used and are recommended when (1) wet forages are ensiled (corn silage with less than 30 percent dry matter and alfalfa with less than 50 percent dry matter), (2) where forages are stored in trench or bunker silos, and (3) where silage bunk life is important, for instance once-a-day feeding in hot weather.

There are two types of stimulants: inoculants and substrate suppliers. Inoculants are inactive microorganisms which become active when added to forage. The level of inoculant (mixtures of lactobacillus, streptococcus, and/or pediococcus) to be applied should be a minimum of 100,000 viable organisms per gram of fresh forage or 1 pound per ton. The cost can range from \$1.50 to \$3.00 per pound.

Substrate suppliers include enzymes and sugars. Enzyme additives break down complex carbohydrates in the forage to simple sugars for use by the lactic acid bacteria. Sugars, like molasses, sucrose, or glucose can be added directly.

Molasses (sugar-beet or sugar-cane) can be applied at ensiling time, especially to crops low in soluble sugars, such as legumes. It increases the dry matter and lactic acid concentrations while reducing the pH. To reap the maximum benefits, it is best to apply the molasses at 5 percent or 100 pounds per ton of forage. There is a small savings in nutrients and at seven to eight cents per pound it usually does not justify the cost.

Feedstuffs can also be used as fermentation stimulants. Grains, such as corn, barley, oats, and milo can add carbohydrates and enhance fermentation. They are added during ensiling at the level of 10 percent grain to alfalfa or grass silage. This is recommended for use with high moisture, high protein forage. The cost can run from four to six cents per pound.

Dried whey is the last of the major nutrient additives. It enhances the feeding value and preservation of silage. It is applied at ensiling at 1 to 2 percent. It is recommended for use on high moisture, high protein forages. It often is too high in price to warrant its use as a silage additive.

Limestone can be added at ensiling to increase the calcium content of corn silage and prolong fermentation. It is applied at 1 percent or 20 pounds per ton of forage. It is rather inexpensive at about four cents a pound, but limestone treated silage has little value for dairy cattle.

The following are suggested for additives on wilted and direct-cut silages, with the exception of whole-plant corn silage.

Additives for wilted silage

No additives are necessary when forage is wilted to recommended moisture levels. The purpose of wilting is to increase soluble carbohydrate content to a level which will enhance fermentation and preservation.

Limited studies indicate that the use of organic acids, such as propionic or acetic-propionic mixtures, may reduce silage quality problems and storage losses when they are added at the rate of 10 to 20 pounds per ton to wilted forage in the top fourth or so of a silo. This may not be necessary if forage with slightly higher moisture is used in the top portion and it is properly sealed for two to four weeks after ensiling. Addition of bacterial inoculates should be considered when ensiling silage at relatively high dry matter content, when field curing time is long, and when average curing temperature is low.

Additives for direct-cut silage

When material with over 68 percent moisture is ensiled in an upright silo, 100 to 200 pounds of a suitable feed ingredient with relatively high carbohydrate content should be added per ton of forage. Ground grains, dried beet or citrus pulps, soy hulls, hominy, and dried brewer's grains may be used for this purpose. The use of a feed ingredient at these levels will help reduce seepage as well as fermentation losses. Storage dry matter losses may be held to 13 to 18 percent with the addition of feed ingredients to direct-cut forage.

If high-moisture forage made from hay-crop or annuals other than corn is placed in a horizontal silo, recommended chemical preservatives may be considered as an alternative to the addition of a feed ingredient. Recommended chemical preservatives include sodium metabisulfite, formic acid, propionic acid, and mixtures of acetic, propionic, and other organic acids. These should be applied according to the directions of the manufacturer. It is necessary to use a weighted plastic cover to take full advantage of chemical preservatives in horizontal silos.

Additives for corn silage

No silage additives or preservatives are necessary when whole-plant corn silage is made at the recommended moisture levels. However, certain feed ingredients may be added to enhance

feeding value. These include ground limestone and various nonprotein nitrogen (NPN) additives with or without minerals.

If whole-plant corn contains less than 63 percent moisture, water should be added generously or organic acids may be used at the rate of 10 to 20 pounds per ton to aid in preservation. When corn for silage contains more than 70 percent moisture, delay harvesting until frosting, freezing, or advancing maturity lowers its moisture content. An alternative would be to add 100 to 150 pounds of a good feed ingredient per ton of forage ensiled, particularly if it is stored in an upright or tower silo.

Additives containing NPN should be used only on corn silage which contains 63 to 68 percent moisture. Less favorable results may be expected when NPN is used on forage ensiled outside of this moisture range, or on forages other than corn.

When economical, NPN additives may be used to increase the crude protein equivalent content of corn silage. It is a preferred method of providing cattle with NPN. If used, the NPN should be added at ensiling at a rate which can increase the crude protein content of the corn silage from about 8.5 to 13 percent on a dry matter basis. Using higher levels of added NPN may interfere with normal fermentation, raise pH, and adversely affect intake or performance.

NPN compounds or additives should be added at a rate to provide 0.15 pound of actual nitrogen (N) for each percentage of silage dry matter content. For example, 10 pounds of urea containing 45 percent N should be added per ton of corn silage ensiled with 30 percent dry matter or 70 percent moisture. This is computed as follows:

$$\text{lbs. N / ton} = .15 \times \% \text{ dry matter } (.15 \times 30 = 4.5)$$

$$\text{lbs. urea / ton} = \text{lbs. N / ton} + \% \text{ N as decimal } (4.5 + .45 = 10)$$

Urea and some commercial NPN-mineral additives may be used as silage additives (table 25).

When the nitrogen content of an NPN ingredient or commercial additive is not listed, it may be computed from the crude protein guarantee by dividing this value by a constant of 6.25. Thus, the nitrogen content of an additive containing 85 percent crude protein is 13.6 percent ($85 \div 6.25$) determinations, not on oven dried silage samples.

Table 25. Commonly used nonprotein nitrogen additives for corn silage.

	Nitrogen	Crude-protein equiv/NPN	Urea equivalent*
	%	%	
Urea, 42% N	42	262	1.07
Urea, 45% N	45	281	1.00
Urea, 46% N	46	288	0.98
Urea, 47% N	47	294	0.96
Aqueous ammonia	21	131	2.14
Anhydrous ammonia	82	513	0.55

* The pound of each source given will provide an amount of non-protein nitrogen (NPN) equivalent to one pound of 45 percent N urea.

Ammonia treatment of corn silage has proven to be an effective and usually an economical means of preserving corn silage while supplementing its crude protein value. Anhydrous ammonia is by far the most economical source of ammonia or nonprotein nitrogen. The addition of ammonia to corn silage has these beneficial effects:

1. Raises the crude protein level of corn silage on a dry matter basis from 8 to 9 percent up to 13 to 14 percent, depending on the rate of application.

2. Reduces silage dry matter losses from 4 to 6 percent and reduces energy losses from 6 to 10 percent when compared to untreated silage.
3. Protects the natural corn plant from degradation during the ensiling process. In untreated corn silage, roughly half of the protein in the corn plant is degraded to nonprotein nitrogen compounds during fermentation. It has been estimated that ammonia decreases this protein degradation by 20 to 40 percent.
4. Increases lactic acid content of treated silage 20 to 30 percent over untreated silage. During the ensiling process more soluble sugars in the plant are converted to lactic acid. In this case, the ammonia is acting as a buffer and is allowing more of the acids to build up in the silage.
5. Increases feed-bunk life of treated silage because the ammonia inhibits mold and yeast growth, and also inhibits heating of silage after it has been exposed to the air. Ammonia is not corrosive to most metal equipment.

Table 26 summarizes the costs and returns of treating one ton of corn silage at the normal seven-pound application rate. The protein value of ammonia is based on replacement of soybean meal in the ration. When replacing soybean meal with ammonia, the energy value of that soybean meal must also be replaced or considered an added cost; in this case the added cost is based on replacement with corn grain.

Certain guidelines must be followed when feeding ammonia-treated corn silage to dairy cows. The first is to check the moisture level on the silage. Ammonia should only be applied to corn silage in the 63 to 68 percent moisture range. The rates of application should be adjusted according to the actual dry matter percent of the silage. This should be equal to the rate of seven pounds per ton on a 35 percent dry matter basis. To assure uniform application of the ammonia, the protein level should also be checked periodically.

When changing cows over to ammonia-treated silages, gradually increase the amount fed per day over a two to three week period if possible. Avoiding abrupt changes decreases the chance of cows going off-feed. A properly balanced grain mixture for all-corn silage diets should make up no more than 40 to 50 percent of the total dry matter.

When feeding ammonia-treated silages, the grains fed should contain only natural protein sources. Dry cows and heifers (more than four months of age) can also utilize ammonia-treated corn silage. The amount fed per head per day should be limited to avoid over-conditioning.

Besides following guidelines for feeding dairy cows it also important to follow guidelines when handling anhydrous ammonia. **Handle anhydrous ammonia safely.** Goggles and rubber gloves are needed to provide eye and skin protection during the process of connecting ammonia hoses and fittings. A water supply should be readily available for immediate first aid treatment in case of ammonia burns. Noticeable ammonia odors occur with atmospheric concentration as low as five parts per million, which is well below the toxic level but often serves as a safety warning.

Table 26. Economics of treating a ton of corn silage containing 35 percent dry matter.

Costs:	
7 lb of ammonia per ton of silage @ 16 c/lb.	\$ 1.12
Application	\$ 1.00
Energy value of 82 lb soybean meal replaced by ammonia nitrogen @ 6.75 c/lb – (equal to corn)	\$ 5.54
Total costs	\$ 7.66
Returns:	
Protein - 7 lb ammonia gives 36 lb of protein—same as 82 lb of soybean meal @ 11.0 c/lb	\$ 9.02
Energy and dry matter loss - 5% of total dry matter (33% dry matter in silage) - 33 lb @ 6.75 c/lb (corn price)	\$ 2.23
Total returns	\$ 11.25
Net = \$3.59/ton (Net is returns minus costs)	

Storage of silage in zinc coated steel silos is not recommended due to the ammonia's highly corrosive action to zinc, copper, and brass. It is also important to delay entry into the silo during filling and for twenty-four hours after filling.

The addition of ground limestone to corn silage at ensiling is recommended only for use with beef cattle, while NPN additives may be used for both beef and dairy cattle. Ground limestone may be applied at a rate of 20 pounds per ton of whole corn plant material ensiled. This helps to offset the low calcium content of corn silage and increase the lactic acid level in the silage. A high lactic acid content may improve feeding value for fattening animals, but not for milking animals. A combination of 10 pounds of urea and 10 pounds of ground limestone also has given satisfactory results in some research with beef cattle.

When drought or excessive nitrogen fertilization increases the risk of the formation of dangerous silo gases, sodium metabisulfite may be added to corn silage at the rate of eight pounds per ton. This has been shown to reduce the conversion of nitrates to poisonous nitrogen oxide gases during the ensiling process, but may keep nitrate levels dissipating at usual rates.

Preservatives and additives cannot be expected to replace good forage-making practices. Heat damage in silages may be kept at a minimum by avoiding moisture contents over 70 percent and under 40 percent, and by filling silos as rapidly as possible once harvesting begins. Part of the damage found in both hays and silages actually may occur before storage.

Most farmers should avoid the use of forage additives when none is generally recommended. If conditions warrant the use of a preservative or additive, most farmers should procure one recommended by neutral parties.

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RECOMMENDED METHODS FOR MAKING SILAGE

Wilt hay-crop to moisture level suitable for particular storage structures.

- a) Conventional tower, 60 to 65 percent moisture.
- b) Oxygen-limiting, 40 to 55 percent moisture for mechanical reasons.
- c) Horizontal, 65 to 70 percent moisture to ensure adequate packing.
- d) Round bale silage, 40 to 60 percent moisture.

Direct-cut system with a recommended silage additive.

- a) Conventional tower silos: Add 100 to 200 pounds of a good feed ingredient (i.e. ground ear corn or a similar ground grain) per ton of forage to reduce seepage and fermentation losses. Cover with airtight plastic.
- b) Horizontal silos: Add a recommended chemical preservative as directed by the manufacturer or supplier to reduce fermentation losses. Cover with weighted plastic.

Ideal moisture levels for corn silage in various storage structures.

- a) Conventional tower, 63 to 68 percent moisture.
- b) Oxygen-limiting, 55 to 60 percent moisture for mechanical reasons.
- c) Horizontal, 65 to 70 percent moisture to ensure adequate packing.

The following general management practices are important in making good quality silage with any crop.

- a) Provide a tight silo. Recondition walls and doors when necessary, and plug drain holes when making haylage or low-moisture silage.
- b) Maintain proper moisture content. Start ensiling wilted or low-moisture silage when moisture levels are 15 to 20 percent higher than the desired level, to avoid over-wilting of material ensiled later. Start ensiling whole-plant corn silage at about 68 percent moisture to avoid ensiling material with less than 62 percent moisture later in the harvest.
- c) Harvest at proper stage of maturity as detailed earlier.
- d) Use the proper cut. Set shear-plate for a 3/8- to 3/4-inch theoretical cut. Keep knives well sharpened. Keep 15 to 20 percent of the forage particles at 1.0 to 1.5 inches. Avoid particles that are too fine for optimum utilization. Do not use recutters or screens unless moisture levels are below those recommended.
- e) Use covered wagons for wilted material.
- f) Distribute silage evenly in the silo.
- g) Fill the silo as rapidly as possible. Preferably, harvest continuously until silo is filled. This may be especially important in preventing heat damage.
- h) Seal the top of the silo. Use material that runs 65 to 70 percent moisture in the top one-third of conventional tower silos. Level and pack it. Cover with an air tight material such as black plastic and weight it. Pack horizontal silos continuously with a tractor while filling and pack periodically for two to three days after filling. Cover with 6-mil black plastic weighted by tires or other heavy material.

Whenever possible, suitable moisture testers should be used. Moisture testing ensures greater precision in harvesting forages and grains, as well as in feeding livestock. The use of a drying-type moisture tester or microwave oven is recommended over most electronic testers because tests may be more accurate over a wide range of moisture levels. Forage testing is recommended.