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Storage Structures for Grass Silage

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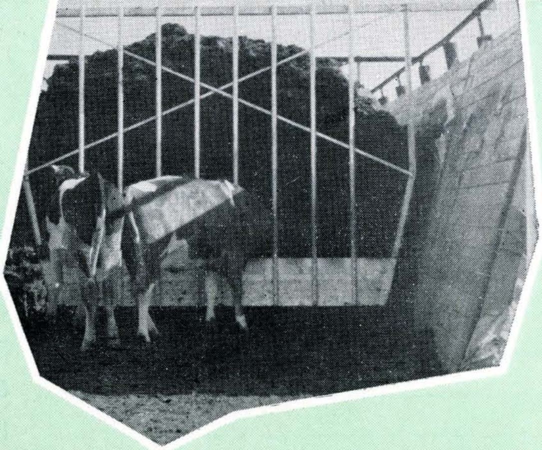

Bulletin 477 May 1959

Agricultural Engineering Department

Agricultural Experiment Station

South Dakota State College, Brookings

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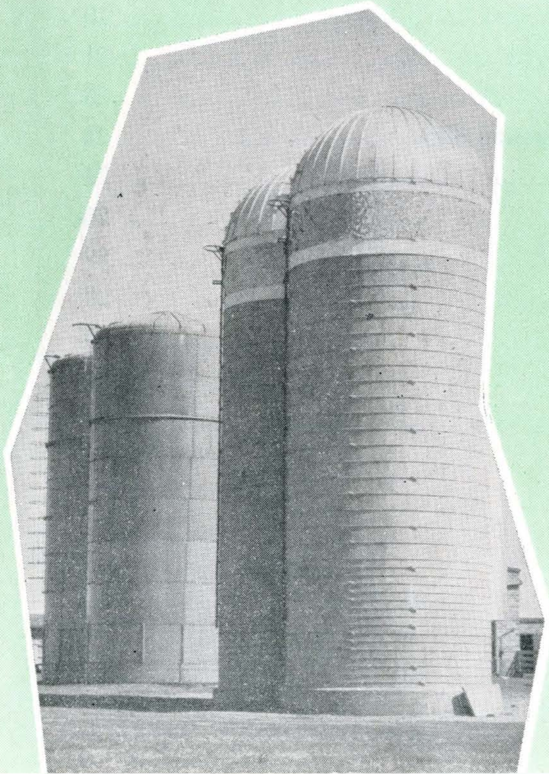
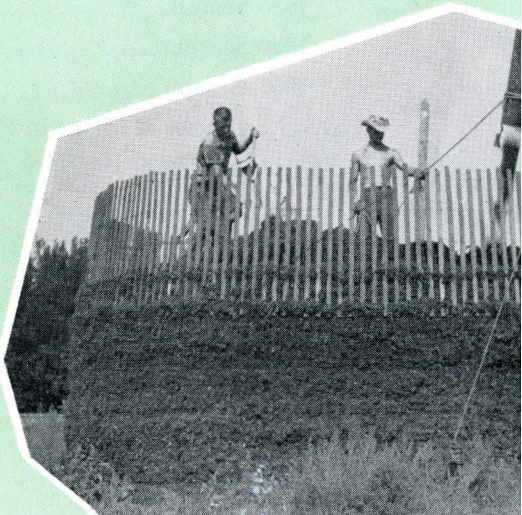
storage structures for grass silage





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Storage Structures for Grass Silage

G. C. Zoerb, H. G. Young, H. H. DeLong, and D. L. Moe[1]

INTRODUCTION

During the past decade, grassland farming has been increasing in importance in the intensified farming area of the North Central States. More and more emphasis is being placed on high quality pastures, hay, and corn and forage silage.

In particular, there has been a tremendous increase in the use of forage crops as silage. It has been estimated that the use of forage as silage has increased 80 times during the last 15 years. And it appears that silage making will continue to be one of the best ways to store legumes and grasses.

Silage is a green crop which is harvested and reduced in volume through chopping, packing, and fermentation. During fermentation, there is an increase of lactic acid and a decrease of carbohydrates. This helps preserve forage in a succulent form.

Fermentation is brought about by the action of bacteria and plant enzymes on sugars or other fermentable carbohydrates within the plant. This action produces sufficient acid to stop fermentation. However, legumes, unlike corn, are low in sugars and high in protein. High moisture of the material favors the formation of butyric acid. The butyric acid forming bacteria may produce ill-smelling, unsatisfactory grass silage. Wilting the forage crop to about 65 to 72% moisture content helps avoid this situation.

Almost any amount of moist forage will make silage if air can be kept from the material. Exclusion of as much air as possible is essential if good quality silage is to be produced.

The present interest in simplified ways to store silage (trenches, stacks, and bunkers) comes mainly from the great increase in amounts of crops to be preserved. In addition, temporary storage methods offer lower initial costs and greater flexibility in a grassland farming program.

This publication deals primarily with one phase of forage production and preservation – structures for storing grass silage. The work has been conducted in cooperation with a North Central Regional project dealing with farm structures and pertaining to handling, storing, and feeding of grass silage with comparisons of various methods of storage and losses encountered.

In addition Agronomy, Animal Husbandry, Dairy Husbandry, Eco-

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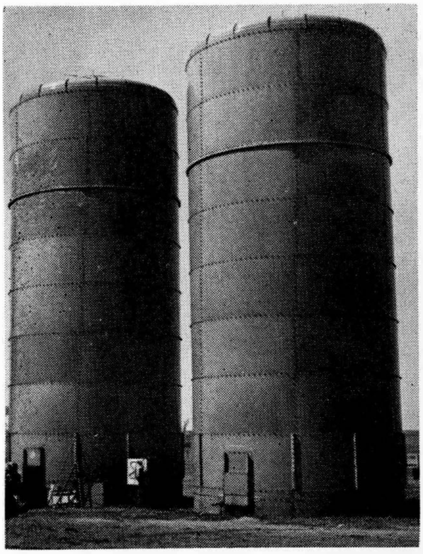


Figure 1. Glass-lined steel upright silo.

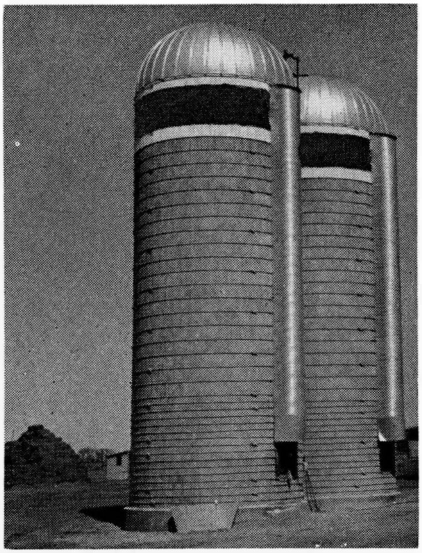


Figure 2. Concrete stave upright silo.

nomics, Plant Pathology, and Station Biochemistry departments at the South Dakota State College Agricultural Experiment Station are conducting research in other phases of silage production. Progress reports on various phases of silage research have been published by some of the departments. Future reports will be issued as additional information is secured.

STRUCTURES

Several types of storage for grass silage are being used in South Dakota. Many farmers have had upright silos for corn silage and have continued to use these for grass silage. The great increase in grass silage production in the last 10 years has, however, exceeded the capacities of available upright silos. In addition, the amount of forage utilized for grass silage varies greatly from year to year due to weather conditions. With good weather conditions the first crop may be put up entirely as hay. For these reasons farmers are using semi-permanent or temporary types of storage.

Different methods of storage for grass silage were compared and evaluated during the course of the experimental work. The types of storage were upright silos, bunker silos, trench silos, and stacks. Comparisons were made concerning, (1) cost, (2) silage quality maintained, (3) ease in handling silage both in filling and feeding, and (4) structural requirements of different types of bunker silos.

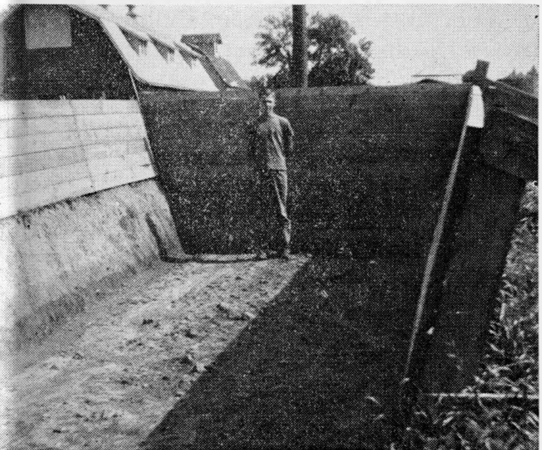
Upright Silos

Upright silos, the most permanent type, generally have lower upkeep costs than horizontal silos. There are two main kinds—(1) the glass-lined steel silo (figure 1) and (2) the concrete stave silo (figure 2).

The glass-lined silo, although high in initial cost, is a permanent air-tight structure having dry matter losses as low as 4 to 10%.[2] The complete unit includes foundation material, construction, and an unloader. Capacities vary from 190 to 400 tons, with an initial cost ranging from about $35 to $25 per ton respectively. With the unloader located at the base of the unit, this silo is well adapted to an automatic feeding system.

The concrete stave silo has been popular in South Dakota for corn silage storage. These silos are available in a variety of sizes, the most common being 16 feet in diameter and 40 feet high. This unit will hold about 198 tons of grass silage with an initial storage cost of about $10 per ton. Some type of silo unloading system should be installed to eliminate excessive labor in removing silage.

Figure 3. Trench silo built partially above ground.



Trench Silos

In areas where there is good surface drainage or where a side hill location is available, a trench silo is suitable for grass silage storage. A concrete floor is desirable if the silage is to be self fed or removed with a tractor scoop. The cost of construction per ton of storage will vary depending upon the type of floor and wall lining used (if any). Generally, the cost will range from $2 to $6 per ton.

Figure 3 shows the trench silo that was constructed in this study. Due to inadequate drainage the upper half was built above ground. Since this trench was used to store grass silage for 10 steers during a 160-day feeding trial, its size was limited to 35 tons. A materials cost in 1959 of $73 and an excavation cost of $20 resulted in a total cost of $93 (excluding labor) or $2.66 per ton of storage capacity.

Stack Silos

Grass silage is often placed in stacks. This method may be used to keep storage costs at a minimum, recognizing that increased losses due to spoilage will result. These losses must be balanced against the depreciation of an equivalent structure. This method offers flexibility. With an adverse change in weather, this type of storage provides a means of saving a forage crop intended for hay, without requiring the time and expense involved in erecting a permanent structure.

The cost of the stack storage var-

[2]The lower loss of 4% applies to forage stored at lower moisture levels than encountered in silage.

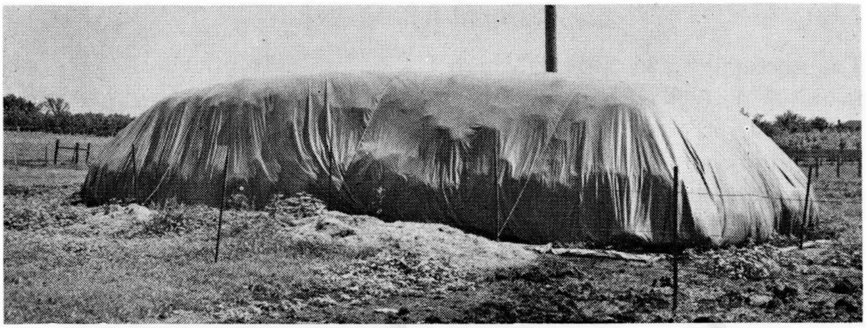
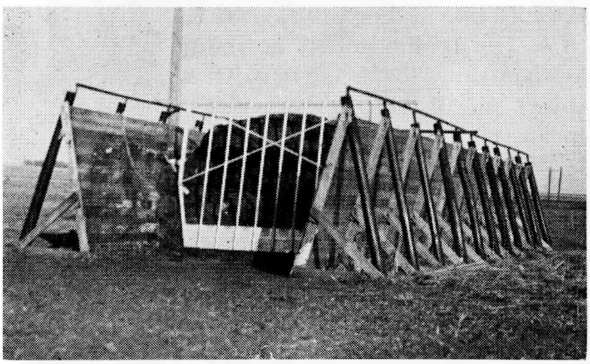


Figure 4. Stack silo with a vinyl film cover.

ies greatly, depending chiefly on the amount of fencing and poles required and the type of cover used. Generally the cost will vary from 50 cents to $1 per ton. Figure 4 shows a 102-ton stack covered with a vinyl film cover.

Different types of covers were tested. These included Sisalcraft paper surfaced on one side with a 2 mil polyethylene sheet, 4 mil polyethylene, and a vinyl plastic. Covers used under experimental conditions in this study helped reduce loss due to spoilage since they excluded air from the silage (see Pilot Silo section). The durability of the covers varied. The Sisalcraft-polyethylene covers were effective but harder to apply and not as durable as polyethylene alone. The vinyl film was satisfactory only for one season and tended to be brittle in cold weather and susceptible to wind damage. Sisalcraft paper was not durable enough to be used as a cover unless soil or additional chopped forage was placed over it to hold the cover down. In all cases it is desirable to fasten the covers securely since they are all easily damaged by wind.

Figure 5. Bunker silo with self-feeding gate.



Bunker Silos

The bunker silo is well adapted to locations where a trench silo would require special precautions for drainage. The relatively low construction cost and the adaptability to self feeding have been factors influencing the increased use of bunker silos in this area. Figure 5 shows a bunker silo built at this station in 1953, having a capacity of 120 tons of grass silage. The silo has a bottom width of 11¼ feet, a top width of 15¼ feet and a height of 8 feet. It is 60 feet long. The walls are made of 2 by 6 inch lumber supported at 6 foot intervals by an "A frame" composed of 6-inch creosoted poles and 2 by 8 inch lumber (see figure 6). Storage cost per ton

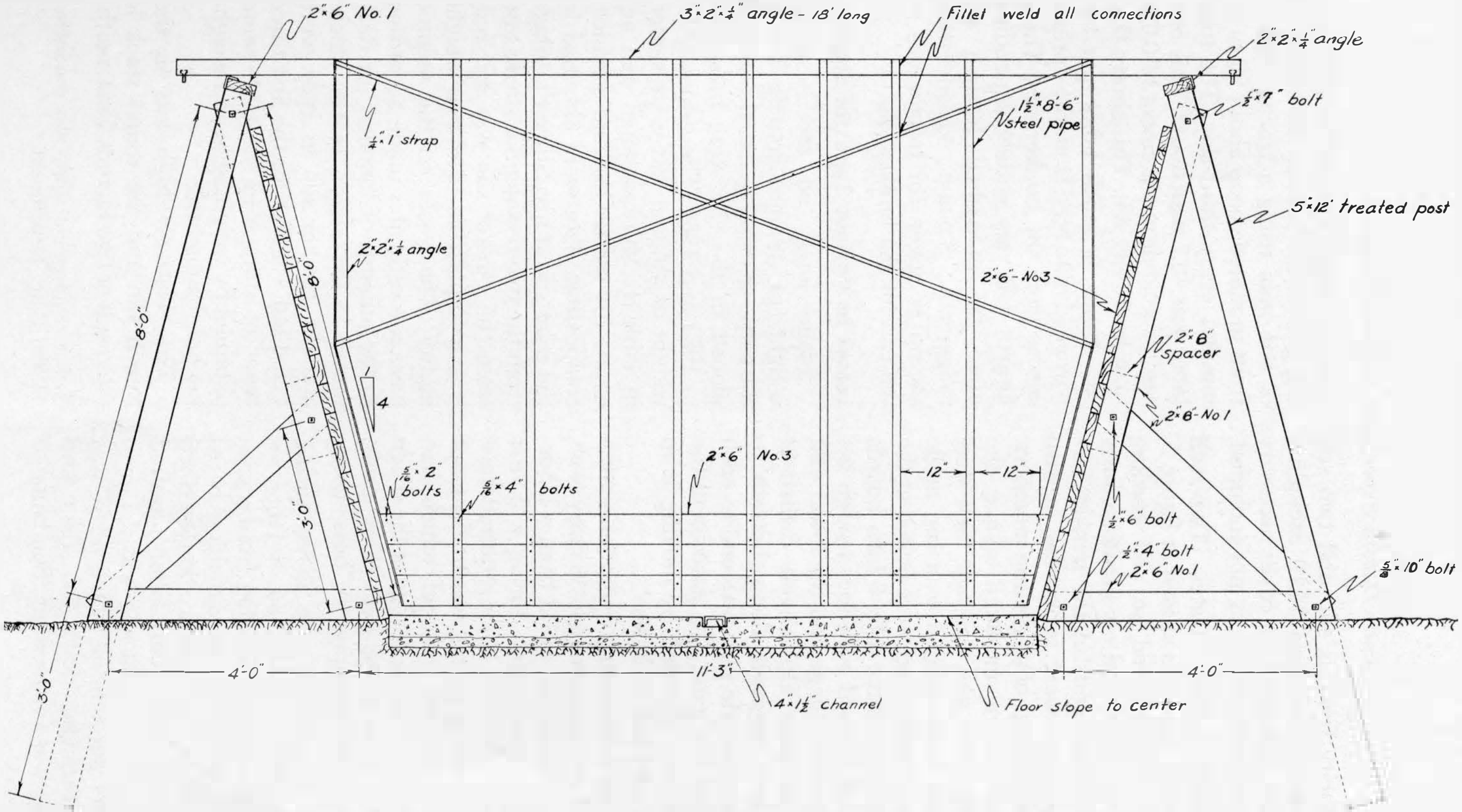


Figure 6. Self-feeding gate and cross section details of above ground trench silo.

capacity for this silo and two self feeding gates was $4.10 excluding labor. The cost of a cover necessary to reduce spoilage is not included.

Self Feeding Gates. Two self feeding gates, as shown in figure 5. were constructed so self feeding could be carried on simultaneously from both ends of the bunker silo. The gates were supported by two steel railings of angle iron members, which were mounted above the walls. One and one-half inch steel pipes were welded to a top angle iron member and were bolted at the bottom to three 2 by 6 inch boards which formed a 1½ foot trough between the silage and the lower end of the gate. Holes were drilled at 18-inch intervals along the rails to accommodate pins fastened to each end of the gate. The position of the gate was changed by moving it to the next pair of holes.

The self feeding operation with a herd of approximately 55 dairy cows has proved successful from a labor-saving standpoint during a 5-year study. The only labor required once self feeding started was to clean out some spoiled material which had fallen from the top edge of the silage to the base of the gate. Some problems may arise due to "boss" cows.

A comparison was made during the winter of 1953-54 of labor requirements for feeding from a concrete stave silo to stanchion barns and from the bunker silo described above.[3] The total labor required with the upright silo was 2.1 man hours per ton, of which 48.4% was for throwing down the silage and 51.6% was for feeding. The labor to clean up silage around the self feeding gate of the bunker silo consisted of one man using a tractor with a front mounted scoop about 20 to 30 minutes every third day. The total labor was 13.7 man hours. This represents a labor requirement of 0.064 man hours per ton. This shows that 32.7 times as much labor per ton was needed to feed from the upright silo as from the bunker silo. These figures will vary widely depending upon the individual feeding arrangement. Some consideration should be given for tractor use in the case of the bunker silo.

Losses in Various Types of Storage

Silage losses on the basis of weight (or volume) actually fed to the cattle as compared to the weight placed in the silo were measured in 1953 and 1954. The summary of weight or volume loss is presented in table 1. More detailed and accurate dry matter loss and chemical composition data were obtained in the pilot silo study. Since the silage from the two rectangular stacks and from the bunker silo was self fed, it was impossible to obtain weight figures. The losses on the volume basis are estimates made according to the amount of "spoiled" or dark brown cross section of the stacks and the bunker silo as they were being fed. Figures for the first three types of storage in the table were obtained by weighing in and weighing out the material.

The relatively high loss in the trench silo and the round stack is the result of two factors. First, neith-

[3]Labor requirement study was conducted by the Dairy Department.

er silo was covered and second, the original amount of silage was relatively small (53.8 and 63.8 tons). The uncovered surface area was large relative to the volume of silage.

DISCUSSION OF HARVESTING METHODS

Three methods of harvesting grass silage were tried here during the 1953 and 1954 seasons. The principal method used was chopped forage and this has continued through 1958. Baled silage was tested in 1953, while long grass silage was tried in 1953 and 1954.

Chopped Forage

The type of machinery required to produce chopped grass silage depends largely upon whether the material is direct cut or cut and wilted before being chopped. In the direct cut method, a power-take-off driven forage harvester with the direct-cut attachment is normally used. This method places the forage in the silo at a relatively high moisture content of 75 to 80%, and some kind of preservative is required to yield good silage. If no preservative is used with high moisture forage and with excessive packing such as occurs at lower

Table 1. Summary of Losses in Various Types of Storage, 1953 and 1954

Silo or Stack	Weight of Silage Put into Silo or Stack, lbs.	Weight or Volume of Spoiled Material: Weight or Volume	Weight or Volume of Spoiled Material: % of Original Weight or Volume	Loss Due to Crop or Leaching or Other: Weight or Volume	Loss Due to Crop or Leaching or Other: % of Original Weight or Volume	Weight or Volume as Fed to Cattle: Weight or Volume	Weight or Volume as Fed to Cattle: % of Original Weight or Volume*
Trench Silo	107,700	22,300 lb.	20.7	44,000 lb.	40.8	41,400 lb.	38.5†
Round Stack	127,700	33,200 lb.	26.0	42,200 lb.	33.0	52,300 lb.	41.0†
Upright Silo	107,190	8,790 lb.	8.2	33,500 lb.	31.2	64,900 lb.	60.6†
Bunker Silo‡	160,690 (4,140 cu. ft.)	860 cu. ft.	20.8	700 cu. ft.	16.9	2,580 cu. ft.	62.3
Uncovered Rectangular Stack‡	219,220 (6,250 cu. ft.)	1,810 cu. ft.	29.0	1,290 cu. ft.	20.6	3,150 cu. ft.	50.4
Covered Rectangular Stack‡	203,920 (5,850 cu. ft.)	1,330 cu. ft.	22.7	None	None	4,520 cu. ft.	77.3

*The loss indicated here is not dry matter loss. For dry matter losses, see table 3.

†Data supplied by Animal Husbandry Department, South Dakota Agricultural Experiment Station.

‡The figures for these silos were obtained by volume measurement. Original volume was measured after 2 weeks of storage (July 6) and the final volume was measured September 26. The difference between these two measurements is assumed to be the evaporation and leaching loss. The spoiled volume was calculated on the basis of the "spoiled" or dark brown cross section of the stacks and the bunker silo as they were being fed.

levels of upright silos, butyric (rancid smelling) silage may be formed.

The major portion of the chopped forage in this study was stored without preservatives. Some silage was made using preservatives to study the effect on temperature rise, weight loss, and feeding value (see Pilot Silos section). When no preservative was used, all chopped forage was harvested by the wilting method. The forage consisted of a mixture of alfalfa and brome grass, which was cut each year when the alfalfa was in early bloom.

Some of the methods used in making grass silage by the wilting method are:

1. Cut with a conventional mower, then rake with side delivery rake into the windrow.

2. Place in a windrow directly with a windrower.

3. Cut and windrow with a flail-type forage harvester having a down-spout or windrow attachment.

The second method has been used during this study. The windrowed material was picked up and chopped with an engine-driven forage harvester (figure 7). The average chopping rate in 1953 and 1954 was 9 tons per hour. The average moisture content of 97 samples of this wilted material as placed in the silos in 1954 was 70.4%. The silage was hauled by three dump trucks. It was placed in the stack and upright silos by means of a blower, but was dumped directly into the trench and bunker silos. A tractor and an Army surplus truck were used for leveling and packing in the trench and bunker silos.

Baled Silage

In 1953, almost one-half of the bunker silo was filled with baled grass silage. The material was baled from the same windrows as the chopped material for the other end of the silo. The green bales were placed as close together as possible, but even when an elevator was used for the upper portion of the silo, considerable time was consumed in arranging the bales. The work was very strenuous. As the average bale weight was about 150 pounds, it required two men to place them on the elevator and two men to arrange them in the silo.

Results with the green baled silage were unsuccessful, as nearly all of the 39 tons spoiled. It is believed that the chief reason for the excessive spoilage was the failure to exclude air pockets between bales and the air exposure to the surface while the silo was being filled over

Figure 7. Forage harvester which chops alfalfa-grass for silage.

a period of 1 week. Thermocouple readings in the baled silage indicated higher temperatures than in any other silo or stack containing chopped forage. Packing with a track-type tractor may have prevented some spoilage but as with most farms, none was available, and it would have been impossible to attempt packing with a wheel type tractor.

Long Grass Silage

In 1953 and 1954, a stack of loose long grass silage was made in the field. A tractor with a Farm Hand and forage fork attachment was used to buck (push or slide) the windrows the length of the field or about 240 yards. It was then lifted and dumped on the stack. An attempt was made to make the stack in the form of a ramp so that it would be packed as each fork load was hauled up. However, even with a wide front end on the tractor, it was impossible to do any degree of packing without getting stuck.

The 2-year attempt to make long grass silage in open stacks was unsuccessful from the standpoint of silage loss from spoilage. In addition, the amount of forage that could be placed in a stack in a day with one tractor and loader was small compared to the chopping method. The following precautions are considered important if long grass silage is to prove satisfactory:

1. The forage should be placed in a trench or bunker rather than in a stack. The retaining walls would help exclude air while the filling operation is taking place, and packing with a tractor would be less dangerous than in the case of a stack when the tractor must be run near the edges.

2. As large a volume to surface ratio as possible will help exclude air and increase silage packing.

3. The forage should be placed in the silo as soon after it is cut as possible to facilitate packing and air exclusion.

4. The silo top surface should be covered with an air-tight cover that is held in place.

SILAGE DENSITY

Core samples were taken from the various silos and stacks to determine density as a function of silage depth. It was desirable to ascertain the relationship between density and silage quality (or spoilage). An accurate method of securing density would also be of value in determining the weight of silage that a structure contained just before it was fed.

Figure 8 shows two augers that were used to take density samples. The small 4½-inch auger was used in 1953 studies and the 6¼-inch auger was made for use in 1954. The cutting edges were formed by brazing razor blades on the outer surface at the end of the tube after it was cut in a saw-tooth fashion with a hack saw. The larger auger proved quite satisfactory. With a larger diameter, there was a better cutting action with less tendency for the material to rotate with the auger. Each auger had a telescoping handle so that samples could be taken to a depth of 8 feet.

Figure 9 shows the large auger being used to take a core sample from the top of the bunker silo. The auger handle was marked at foot in-

tervals. The material from each foot of depth (top to bottom of silo) was weighed immediately, from which the density was calculated.

Four cores were taken from each of four silos or stacks. These four were averaged and the results plotted in figure 10. The curves show the greatest density for the bunker silo which was well packed and filled to a greater height (8 feet) than the trench silo (5 feet). The density in the rectangular stack and in the round stack, although made about 8 feet high, was less because of insufficient packing. The rectangular stack was tractor-packed to a height of 4 feet and the remainder was filled with a blower, resulting in very little packing. The higher moisture in the trench and bunker silos, as shown in figure 10, probably accounts for some of the increased density. In 1954 the bunker silo was covered with a vinyl plastic while the trench and stacks were uncovered. This fact accounts for the increased density of the first foot level (top to bottom) for the bunker silo.

The moisture of the silage as taken from the silos by the core samples is shown in the graph of figure 10. A summary of the moisture content of the forage as placed in the silo is given in table 2.

Table 2. Moisture Content of Forage as Placed in Silos

Silo	No. of Samples	Average Moisture of Samples, %
Bunker	28	71.6
Trench	5	72.1
Rectangular Stack	11	70.5
Round Stack	6	73.1

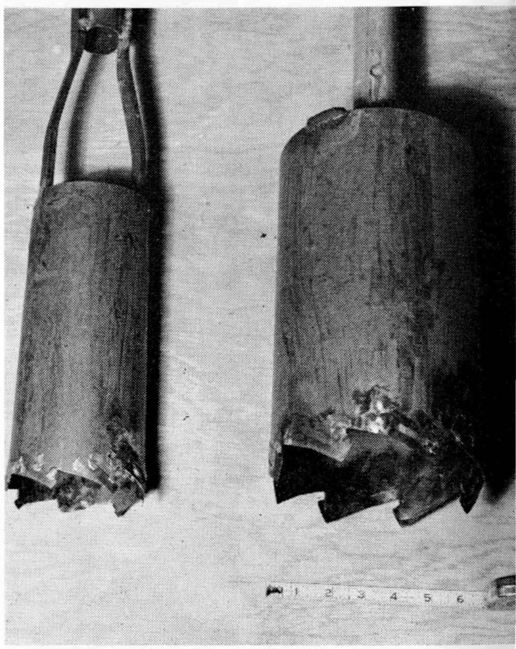
SILAGE TEMPERATURES

Another phase of this project was the extensive measurement of silage temperatures in the different types of storage. The purpose of this measurement was threefold: (1) to determine the variation in temperatures at several locations within each type of silo or stack; (2) to compare temperatures in the various silos; and (3) to correlate temperature, chemical composition, losses, and silage quality.

Measurement of Temperatures

Thermocouple junctions were placed in the silos and the stacks. In general, for the stacks and silos

Figure 8. Augers used to take density samples.

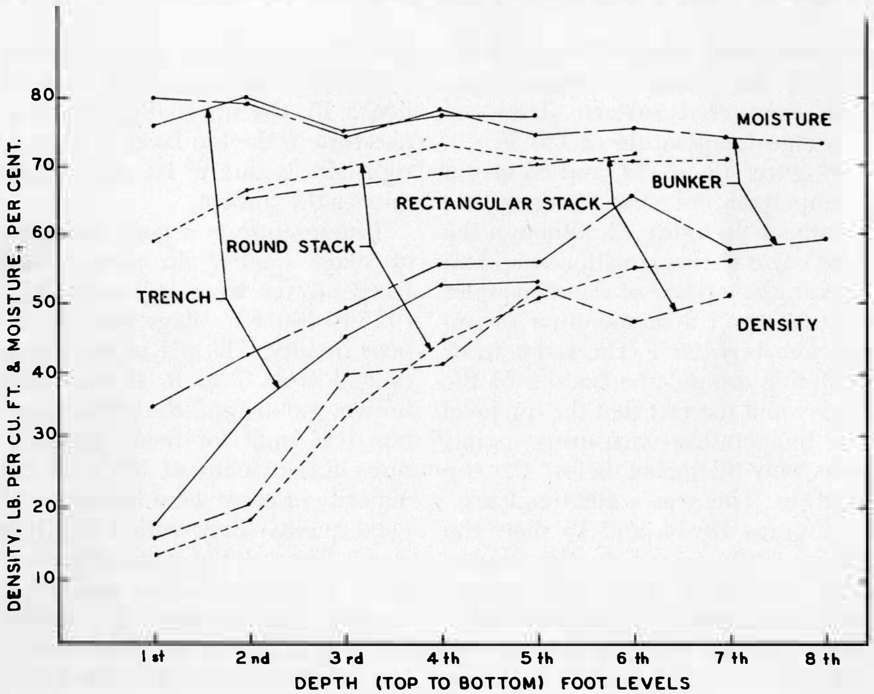


there were five measuring points at each of three levels. This was repeated at two or three sections of the silo or stack depending on its length. Three levels of five measuring points were placed in upright silos, but settling caused difficulty in obtaining readings from the middle level to the point where it became impossible to continue readings there.

Figure 11 shows the temperatures recorded for a small trench silo (35 ton capacity) only partially below ground. Since it was relatively short and shallow, only two levels (A_1 and A_2) and two sections (A and B) were measured. The average temperature at the lower level was approximately 100°F. for the 3-

Figure 9. Taking a density core sample.

Figure 10. Variation of density and moisture with silage depth by type of storage.



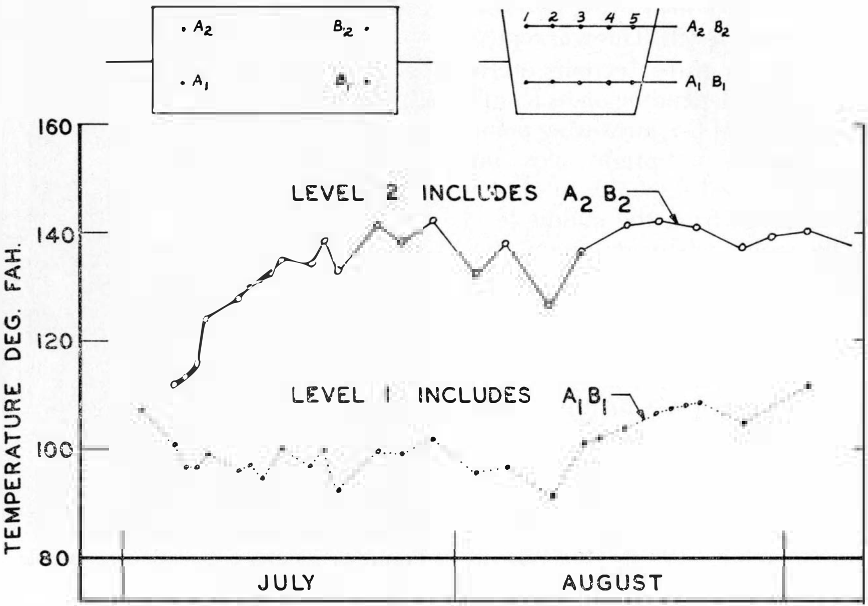


Figure 11. Silage temperatures in a small uncovered trench silo.

month period, while the upper level which was about 18 inches below the uncovered surface shows an average temperature of 135°F.

Figures 12, 13, 14, and 15 give a comparison of the temperature gradient. In figure 12, although the stack was enclosed with a vinyl film cover, the top line of thermocouples B_4 averaged a temperature of approximately 135°F. This is due to air entering around the bottom of the cover and the fact that the top level of temperature measuring points was only 12 inches below the top surface. This was a 102-ton stack.

Figures 13, 14, and 15 show the temperature record in the bunker silo, the round stack, and upright silo, respectively. Maximum temperatures in the covered bunker silo average from 10 to 20° F. lower than the maximum reached in the top level of the uncovered stack. In figure 15, the unusually high temperature in the top layer of the upright silo is due to its close proximity to the surface.

Temperature is a good indicator of silage quality. In areas where temperatures were unusually high (125 to 140°F.), silage was of very poor quality. The pH of this silage ranged from 7 to 9. It was dark brown, moldy, and the greater portion was unfit for feed. Temperatures in the vicinty of 100°F. in the majority of cases were indicative of good quality silage with a pH from 5 to 6. The color of good silage was green to greenish brown and it had a rather pungent odor. Dry matter loss and pH for three types of storage are summarized in table 3.

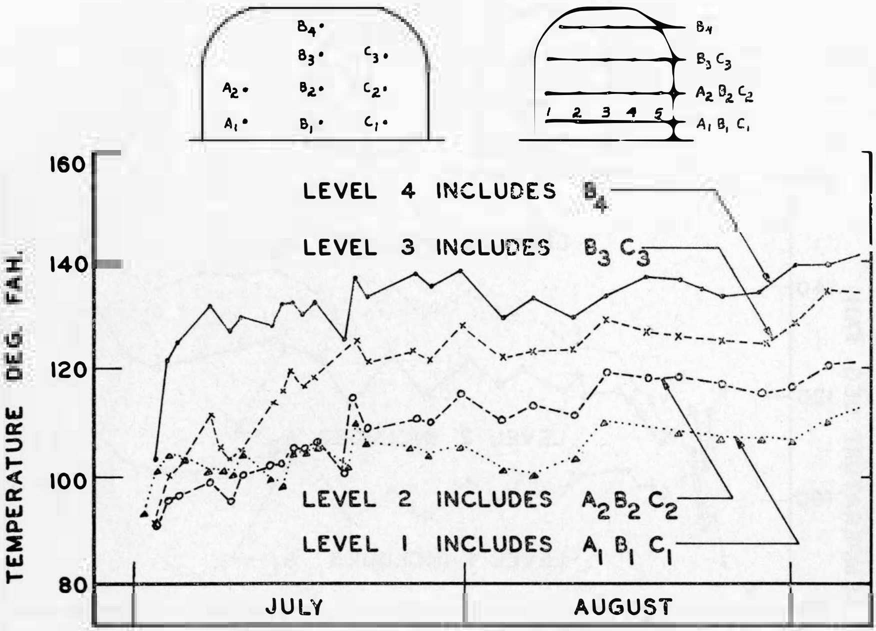


Figure 12. Silage temperatures in a covered rectangular stack.

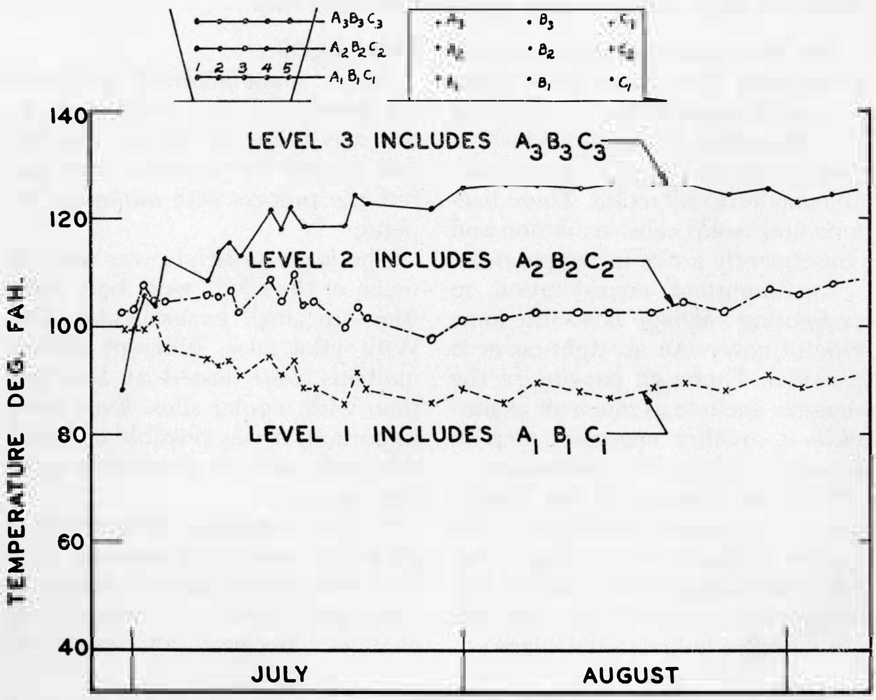


Figure 13. Silage temperatures in a covered bunker silo.

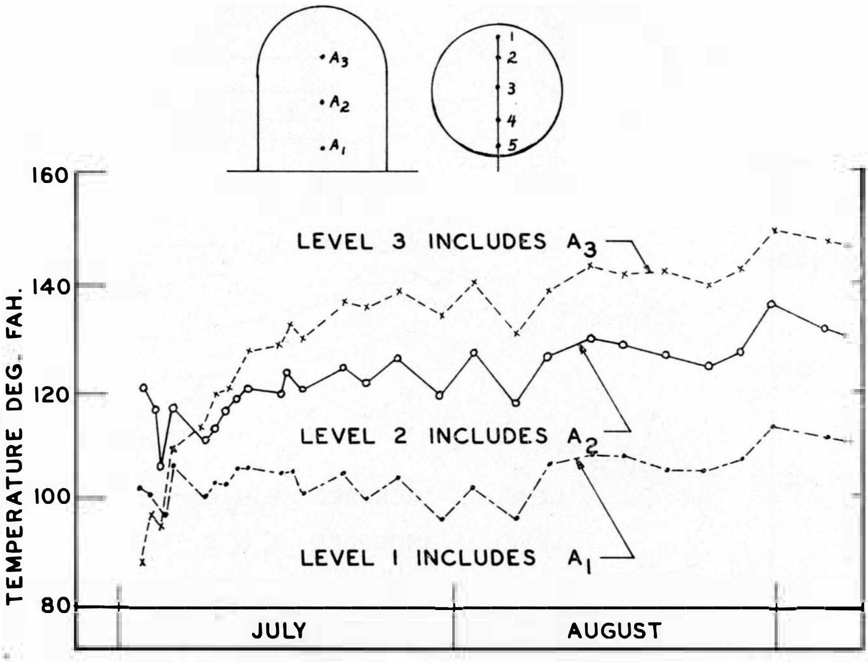


Figure 14. Silage temperatures in an uncovered round stack.

The reason for the higher temperatures near the surface or in loosely packed silage is that air, entering the silage after fermentation has begun, promotes growth of undesirable bacteria and molds. These bacteria and molds cause oxidation and consequently a rise in temperature.

An important consideration in preventing spoilage is to use some type of cover. An air tight cover is essential. Thorough packing of the silage to exclude as much air as possible is another necessary step in keeping spoilage at a minimum.

Moisture content of the forage has an important bearing on the quality of the resulting silage. Forage with a low moisture content will not pack satisfactorily and air will not be excluded from the silage.

PILOT SILOS

Many manufacturing processes are developed on a small scale. In this way the experimenter can find and correct his mistakes and perfect the process with minimum expense.

The same principle was used in much of the silage work here. Pilot silos are small experimental silos. With pilot silos, different storage methods were tested at less cost than with regular silos. Even more important, it was possible to weigh the small silos to determine spoilage losses.

To keep conditions uniform, these pilot silos were built indoors. Here they were free from the effects of wind, rain, storms, and atmospheric changes. Because all conditions

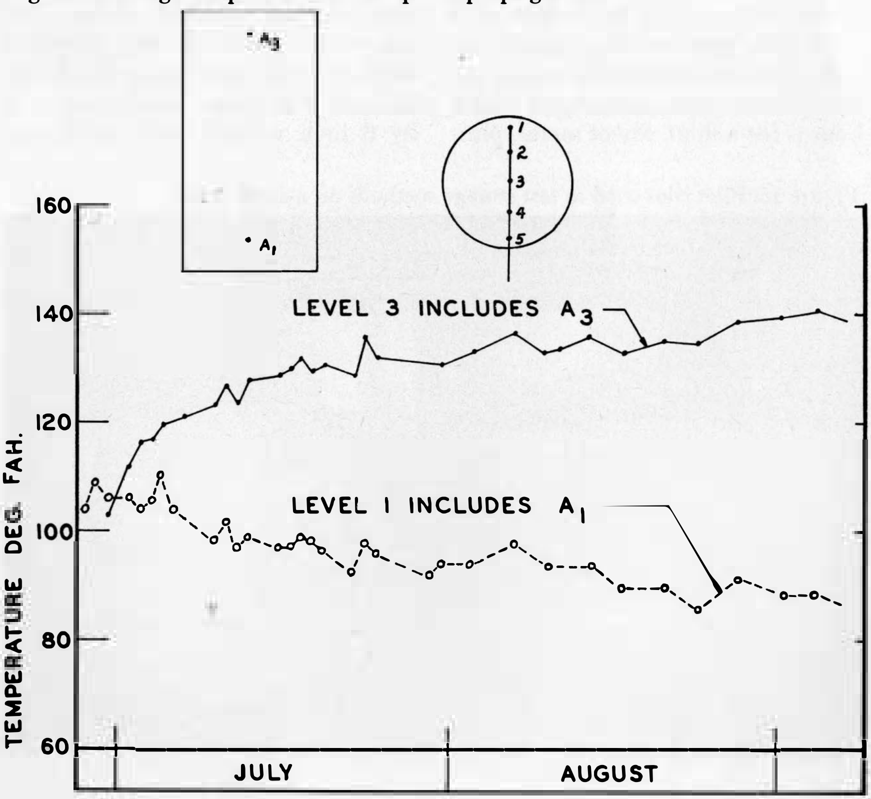
Table 3. Average Temperature, Percent Moisture, Dry Matter Loss, Carotene Content, and pH in Three Types of Storage*

Silo	Level	Average Temperature, degrees F.	Moisture %, as Analyzed	Dry Matter Loss, %†	Carotene Content, p.p.m.	pH
Bunker	3	122	73	19	1	7.65
Silo,	2	104	77	15	58	5.70
covered	1	92	80	24	232	5.66
Round	3	138	35	31	0.1	7.49
Stack,	2	128	67	7	5	4.50
uncovered	1	106	70	6	19	5.02
Upright	3	132	42	35	—	8.40
Silo,	2	—	71	13	—	5.35
open top	1	96	73	19	—	5.61

*Data supplied by Station Biochemistry Department, South Dakota Agricultural Experiment Station.

†Burlap bag technique was used to determine sample losses. These losses are from specific points within the silage and therefore do not include the higher surface spoilage losses.

Figure 15. Silage temperatures in an open-top upright silo.



were the same, differences in results were due largely to the variables used.

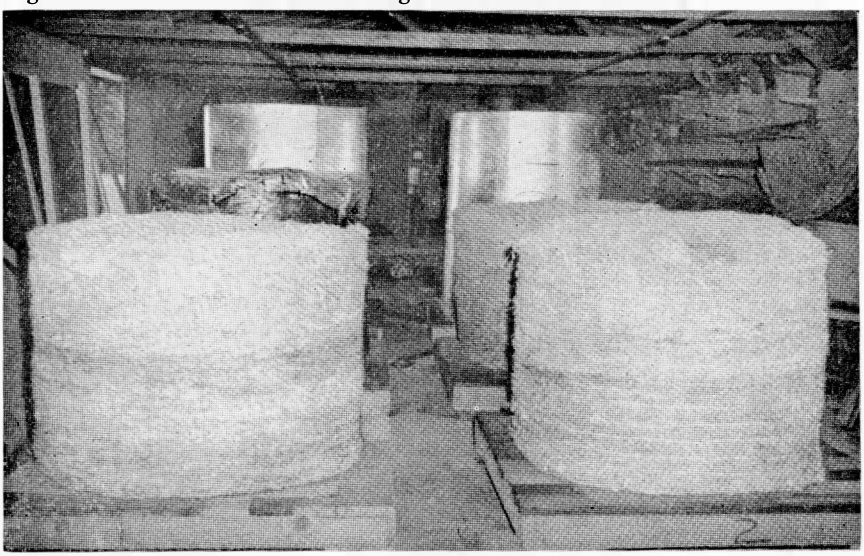
With the small pilot silos, there was a better opportunity to start all those of a series with a uniform product; although during the tests it was found that a few hours might alter the quality and condition of the chopped hay coming in from the field. At the end of each season's trial, the small silos were opened, inspected, samples taken, and measurements made all within the span of a few hours.

Procedures of Construction and Filling

The pilot silos each required a platform and these were made approximately 5 feet by 5 feet of 2 by 4 inch joist on edge, boxed in, with plywood reinforcing gussets on the corners, and a covering of 1-inch boards for a floor. Sheet metal, plastic, or some type of airtight building paper was placed over this floor before the silos were filled. These platforms were substantial enough to give stability to the silo form while filling and could be set on blocks and raised slightly for the inserting of scales for periodical weighing. The weight of such platforms was from 130 pounds to 160 pounds (see figure 16).

The form or mold for the pilot silos was made of galvanized sheet steel formed into a cylinder, and a row of bolts through a flange arranged for a side opening to remove the mold after the small silo was built. This mold, when set on a platform, formed an excellent guide; left well shaped, smooth sides; and stayed in place on the platform while the silo was being filled and packed. For extra reinforcing a 6 by 6 inch welded wire mesh was

Figure 16. Pilot silos used to test storage methods on a small scale.



placed around the sheet-metal cylinder and clamped by bolts. The metal cylinder when in place was 3.9 feet in diameter and 4.92 feet high.

In 1954, from 1,600 to 1,800 pounds of silage were compacted in each one. In later years, the silos were built higher and held 3,100 to 3,500 pounds of silage. For those silos which were removed from the metal enclosures, the outer surface shape was retained by wrapping twine string around and around at about 2-inch intervals. All silos were kept near their original diameter, and yet were allowed to settle.

Coverings used were of two kinds—metal and polyethylene sheets. One or two silos each year were left with the metal cover on. The top was then covered with paper or polyethylene, the latter being more of a vapor-tight cover. Polyethylene sheets were used to cover top, bottom, and sides of those called "covered silos." These sheets were held together and made air- and vapor-tight by the use of black plastic electrician's tape. Since the pilot silos were stored inside a building the first three seasons, no trouble from wind or sun damage occurred.

A thermo-couple wire was embedded in the center of the silo at filling time. This extended upward and the second junction came near the top of the silo. "Middle center" and "top center" temperatures were read at inspection time.

The small silos were filled by hand tools after a load was brought to the storage building. This hand work method was used to assure proper mixing and quantity control of amounts of preservatives added.

Packing was done by one or two men working in the silo, who tramped, leveled, and did additional compacting with heavy earth tampers. During one season light tamping was compared with hard tamping. The final settling showed no permanent difference. Such a procedure was limiting the weight of the silos to near 1,500 pounds, so the following seasons the silage was filled to the top, giving a final weight of 3,100 to 3,500 pounds.

Test Results

1954 Season. In 1954, nine pilot silos were built and observed. Much was learned about the techniques of filling, compacting, weighing apparatus, and covering. While the first year's work was not the most accurate, the definite trends began to show. Table 4 gives the results of the first year's trials. The weighing was done by derrick, with the scales above the platforms. This proved cumbersome and time consuming. In following years, a scale and multiplier (10 to 1) lever arm were inserted under each of the four corners of the platform, then the blocks were removed. This proved much more accurate and less time consuming.

1955 Season. Several changes were made in the methods of handling the pilot silos in the 1955 season. All silos were packed as densly as possible by tramping and additional tamping. The form ring was filled to the top. This enabled the freshly filled silos to have from 3,325 to 3,720 pounds of fresh material at

the beginning of the test. Second cutting alfalfa was used and filling dates were July 13 to 16. The comparisons were cover materials or no cover and chemical additives or no additives in both covered and uncovered silos. The final weights were taken after 30 days. Table 5 gives the net weights of the silos during the period. The great differences in weight loss shown in table 5 depended on whether or not the silage was covered. Preservatives had no noticeable effect on the weight loss. Some discrepancies appear on these weight figures, in that one may find an increase in a given silo in a week's time. When the data are placed on a graph of weight according to time and smooth curves drawn, the story of weight losses becomes meaningful and comparisons can be made. Such graphs are shown in figure 17.

The curves indicate that the covered silos lost 10% or less in 30 days, while the uncovered ones lost nearly 50% of their weight. The chemical additives used did little, if anything, to prevent weight losses of the uncovered test silos. There was little, if any, advantage of additives in a well covered and sealed silo. Some of the silos had the metal side walls left on, and another was wrapped with polyethylene cover with all joints sealed with tape. Plastic was also used to cover the top of the metal enclosed silos. There was no significant difference between the two treatments by chemical additives—sodium meta bisulphite and sorbic acid. Sodium bisulphate was added at the supplier's recommended rate of 10 pounds per ton of green material.

Temperature graphs which were constructed for the pilot silos tell part of the story of weight loss, and oxidation of silage due to exposure to air. Figure 18 shows the mid-point temperature readings on through the storage season for four silos. In one which was untreated and uncovered, temperatures soon reached 110°F. and remained there during all of the period. All of the covered silos, whether chemically

Table 4. Pilot Silo Weights, 1954

Silo	Treatment	Net Weight				
		July 20	Aug. 9	Aug. 23	Sept. 30	% Loss
#1	Plain, tamped	1,940	1,197	1,057	737	62
#2	Plain, untamped	1,650	1,066	866	666	60
#3	Packed, sodium bisulphide	1,925	1,322	1,122	822	57
#4	Packed, phosphoric acid	1,800	1,289	1,089	814	55
#5	Plain, unpacked	1,600	1,053	868	653	59
#6	Plain, packed	1,975	1,333	1,133	808	59
#7	Packed, phosphoric acid	1,700	1,253	1,053	738	57
#8	Packed, plain, enclosed in metal container	1,800	1,749	1,724	1,624	10
#9	Packed, phosphoric acid, enclosed in metal container	1,800	1,683	1,708	1,633	10

treated or not, held steady at the 80°F. temperature mark.

In figure 19, comparisons of four more silos are found. One was chemically treated and covered, and had temperatures near 80°F. for the storage period. The three uncovered silos had higher temperatures, with the untreated one being near 115°F. Chemically treated ones both had temperatures higher than 120°F.

1956 Season. The pilot silo tests were repeated again in 1956. The same equipment as in the 1955 season was used, since it worked satisfactorily. Silos were filled with 3,300 to 3,500 pounds of silage at the start—second cutting alfalfa was used. Silos were designated A through J. Table 6 gives their treatment and weight losses. Each treatment was replicated, except I and J.

The only variables studied in 1956 were covers compared with no covers and use of preservatives compared with no treatment. Four pairs of silos were used—Silos A and D, covered and untreated; Silos E and H, uncovered and untreated; Silos B and C, covered and treated with 165 pounds Carmolas[4]; Silos F and G, uncovered and treated with 165 pounds Carmolas. Silos I and J were treated with sulfuric acid—one covered, one uncovered.

Silos D and H were filled on the morning after the first six were filled. The same cutting of alfalfa was used, but it was chopped just following a night rain and the windrows were very wet. These two

[4]Carmolas—Granular Molasses product, approximately 65% molasses.

Table 5. Pilot Silo Weights (Net)

No.	Treatment	July 13	July 14	July 15	July 16	July 20	July 27	Aug. 3*	Aug. 10	Aug. 17	Aug. 24	Aug. 31	Sept. 7	Sept. 13	% Weight Loss
1	Uncovered, untreated	3,690	3,488			3,198	2,978	2,794	2,588	2,278	2,213	2,163	2,078	1,928	48
2	Plastic cover, untreated	3,440	3,278			3,433	3,483	3,388	3,418	3,458	3,383	3,453	3,433	3,283	5
3	Sorbic acid, uncovered	3,720		3,678		3,508	2,938	2,843	2,303	2,158	2,178	1,978	1,933	1,723	54
4	Sodium bisulfite, uncovered	3,510		3,390		3,160	2,740	2,705	2,415	2,390	2,060	1,935	1,940	1,695	52
5	Covered (Metal forms) untreated	3,690			3,718	3,578	3,698	3,733	3,743	3,578	3,458	3,598	3,358	3,498	5
6	Covered (Metal forms) sodium bisulfite	3,510			3,325	3,415	3,645	3,405	3,495	3,575	3,255	3,330	3,075	3,395	3

*Reset ratio of lever arms on scale August 3, 1955

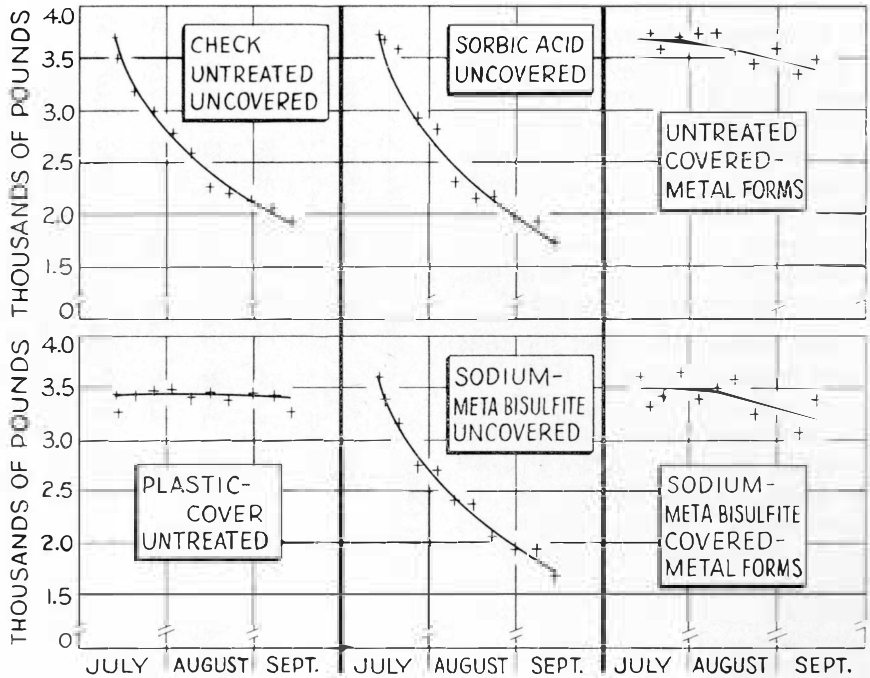


Figure 17. Weight losses of pilot silos, 1955.

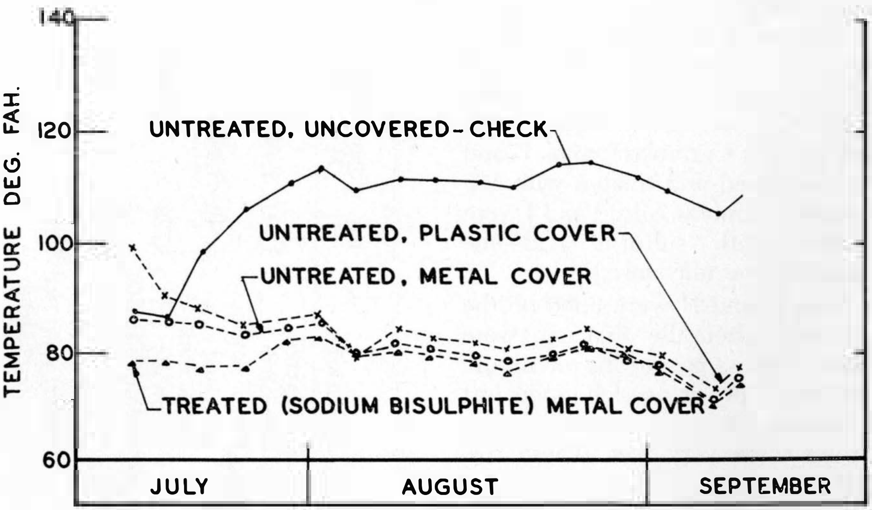


Figure 18. Silage temperature in pilot silos, 1955.

silos lost part of their weight by seepage, which was noticeable even before covering. It continued for several days. The records of D and H are omitted from table 6, although they follow the same general trend in weight loss and temperatures as their mates.

1957 Season. The pilot silo studies during the 1957 season differed in that the tests were made outdoors. The reasons for this change were to determine if there were any variations from previous studies conducted indoors and to examine the durability of plastic covers more closely.

The variables compared this year were covers and no covers, high moisture silage and low moisture silage, and the effect of covering the silos immediately and covering after 2 weeks. Four silos were used. Silo 1 was high moisture silage covered on filling; Silo 2 was high moisture silage covered after 2 weeks; Silo 3 was a high moisture uncovered silo; and Silo 4 was low moisture content silage covered on filling. The average moisture content of Silos 1, 2, and 3 was 76% and the moisture content of Silo 4 was 35%.

Third cutting alfalfa was used and all silos were filled in 1 day. Table 7 shows the results of these tests. The silo weights were taken at approximately 2-week intervals.

Silo 4 showed only 9.8% weight loss; however, inspection of this silo at the end of the studies showed that all of the silage was extremely moldy. The silo that was covered after 2 weeks exhibited the same weight loss characteristics as the uncovered silo except that the total

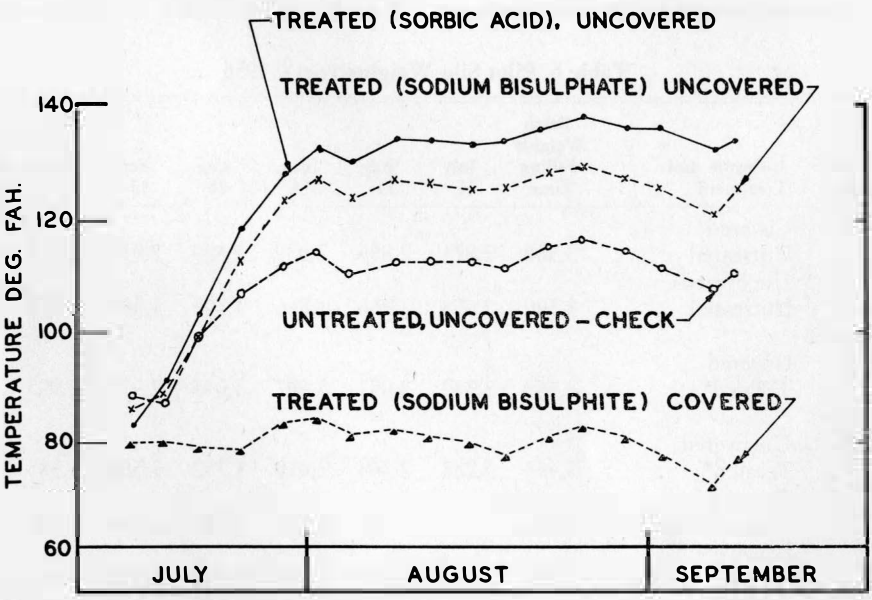


Figure 19. Silage temperature in pilot silos, 1955.

weight loss was 21.5% less. The quality of silage was similar to that of the uncovered silo and the greater portion of it was spoiled.

LATERAL PRESSURES OF SILAGE IN HORIZONTAL SILOS

A specially constructed bunker silo was built during the summer of 1955. This silo was filled with chopped alfalfa-brome silage and was used in the measurement of lateral pressure exerted by the silage on the silo walls. Information on wall pressures and overturning moments is necessary to facilitate proper design of such units.

A general view of the silo before being filled is shown in figure 20. One wall was made vertical and the other with an outward slope of 1 foot per 4 feet of height. It was thus intended to make a comparison of lateral pressure on the two walls as well as to measure the absolute pressure and observe the side wall spoilage on each. The silo was filled with 125.95 tons of silage, with an average moisture content of 70.7%.

Figures 21 and 22 show three-quarter views of the vertical and sloped walls respectively.

Silo Construction

The bunker silo was 35 feet long, and the walls were 8 feet high. With the one sloped wall, the top was 16 feet and the bottom width was 14 feet. The wall panels were made of creosoted tongue and grooved 2 by 6 inch lumber. A 5-inch concrete floor was poured for this silo. A 15-foot section in the center portion of each wall was used as the test section. On each side of the test section was a securely braced 10-foot section. The middle and end sections were separated by a space of about 1½ inches. This "crack" was covered

Table 6. Pilot Silo Weights (net), 1956

Silo Number	Inclosure and Treatment	Batch Weights Filling Time	July 17	July 31	Aug. 14	Aug. 28	Sept. 11	Sept. 25 or Sept. 27	% Weight Loss
A	Covered Untreated	3,300	2,811	2,859	2,939	2,829	2,919	2,864	13
E	Uncovered Untreated	3,300	2,658	2,066	1,816	1,706	1,581	1,321	60
Average B & C	Covered Treated*	3,465	3,342	3,052	2,987	3,045	2,937	2,995	14
Average F & G	Uncovered Treated*	3,465	3,232	2,368	2,010	1,752	1,565	1,385	60
I	Covered Treated H_2SO_4	3,300	—	3,150	2,905	2,800	2,860	2,805	15
J	Uncovered Treated H_2SO_4	3,300	—	2,449	2,159	1,754	1,599	1,354	59

*165 lbs. of Carmolas

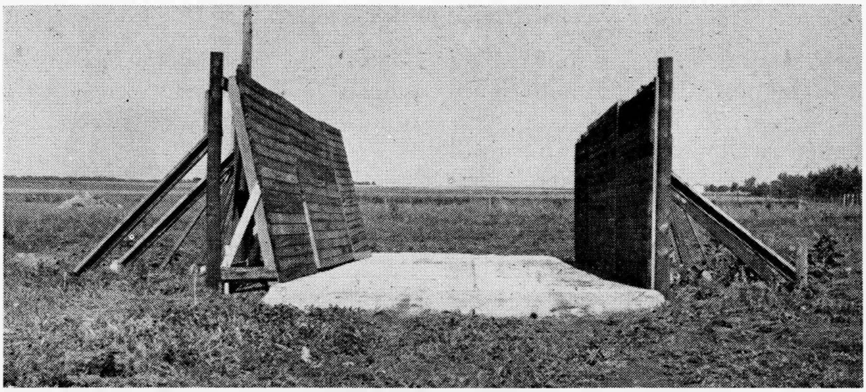


Figure 20. General view of experimental bunker silo.

with canvas, allowing the center test section to be free for slight movement. Hence the silage could be kept level in the center or test section, while it would begin sloping in the 10-foot sections toward the ends to form a ramp.

The test panels were constructed so that the force on the wall could be measured both at the top and at the bottom. A system of levers was the principle used in the measuring device. Figure 23 is a diagram of the linkage, the wall panel cross sections, and the supporting posts. Four supports were used for each 15-foot test panel, giving a 5-foot spacing between supports. To make the supports rigid for the test panel, two 5-inch by 12-foot creosoted posts were used at each 5-foot support. The posts were placed to a depth of 3½ feet, including the top depth of 8 inches in concrete. In addition, these posts were braced by means of an angle iron anchored in concrete and attached to the posts with lag screws.

As indicated in figure 23, the test wall was supported by four steel wheels, one at each lateral support. Each wheel rested on a flat steel plate which was embedded in the concrete. The mountings of the top horizontal link and the vertical lever arm used to measure the force at the top of the wall are shown in figures 24 and 25. The pivot point was a 1-inch shaft. This shaft was fastened to the posts by welding a

Table 7. Pilot Silo Weights (net) 1957

Silo No.	Inclosure and Treatment	Filling Weight	Sept. 7	Sept. 18	Oct. 2	Oct. 14	Oct. 28	Nov. 4	% Weight Loss
1	Covered	3,410	3,355	3,310	3,330	3,355	2,485	3,230	5.3
2	Covered after 2 weeks	3,530	3,215	3,110	2,900	2,215	2,027	2,240	36.6
3	Uncovered	3,080	2,670	2,670	2,450	2,050	1,475	1,290	58.1
4	Low Moisture Covered	1,940	1,870	1,810	1,800	1,715	1,710	1,750	9.3

steel strap at each end and nailing it to the posts. In addition to figure 23, figure 26 is a close-up (for sloped wall) showing the wall mounting on wheels at each lateral support. The mounting for the sloped and vertical walls was essentially the same, except that for the sloped wall, the lower horizontal link extending from the wheels to the outer vertical lever arm had to be longer (figure 23).

Test Procedure

As illustrated in figure 27, to take a reading at each lateral support of the force at the top of the wall, it was merely necessary to connect a

Figure 21. Vertical wall side of experimental bunker silo.

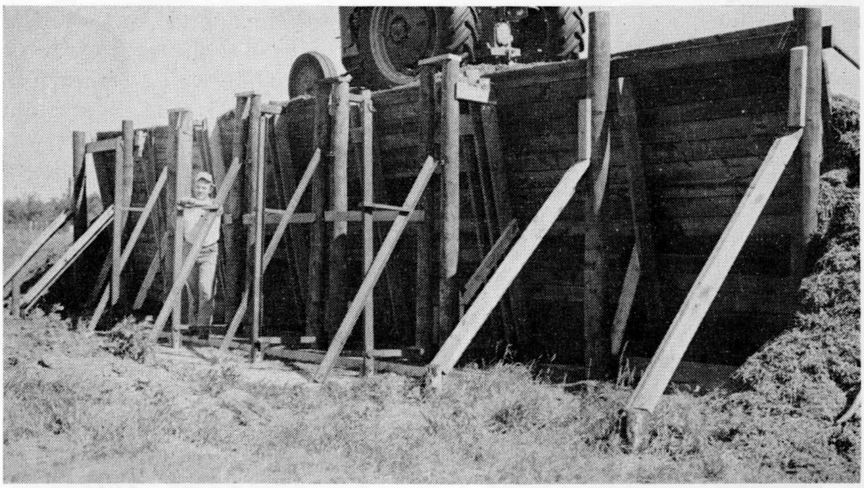


Figure 22. Sloped wall side of experimental bunker silo.

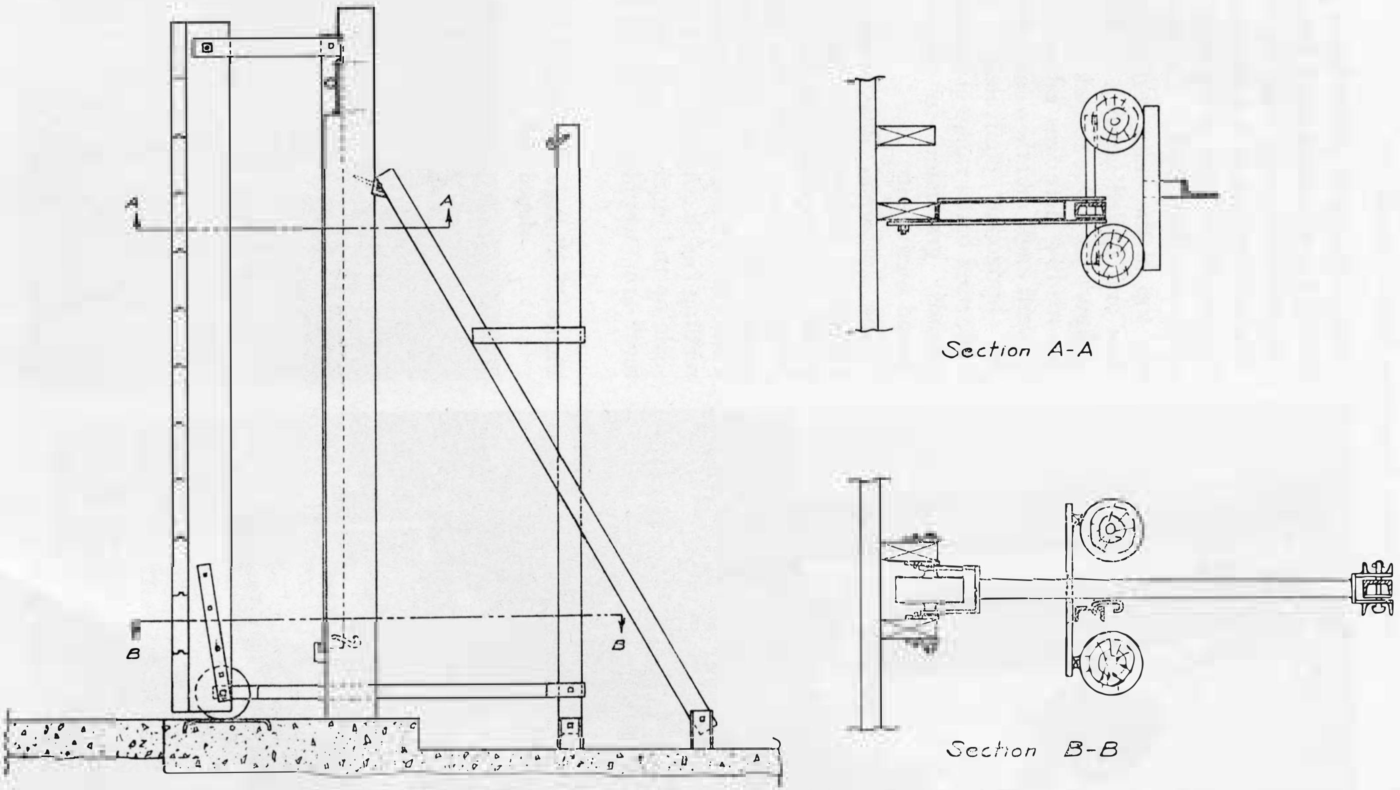


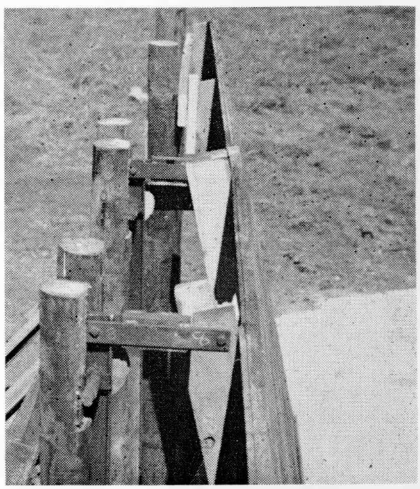
Figure 23. Vertical wall, supporting posts, and linkage used for measuring pressure on wall.

Figure 24. Top link and vertical lever used to measure force at top of sloped and vertical walls in experimental bunker silo.

scale to the hook at the lower end of the inner vertical lever arm and pull outward (away from the silo). Similarly to obtain the force readings for the bottom of the wall, the scale was connected to the hook at the top of the outer vertical lever arm and pulled inward, as shown in figure 28. (Due to lack of space, the reading here was taken on an upward angle and then corrected to the horizontal equivalent.) The scale used had a range of up to 200 pounds, graduated in one-half pound increments.

The horizontal links were attached 5 inches from the pivot points and the hooks at the ends were 77 inches from the pivot points. This gave a 15.4:1 ratio. Thus, for example, a 100 pound reading (neglecting friction) on the scale on the inner or outer vertical lever arm, would indicate a 1,540

Figure 25. Linkage connected to top of sloped wall.



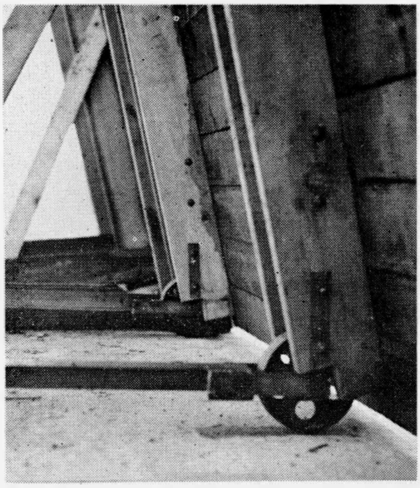


Figure 26. Wheel mounting of sloped wall

pound force on the top or bottom of the wall respectively.

Initial readings were taken before any silage was placed in the silo to determine the effect of the wall weight. With the sloping wall, for instance, the initial bottom reading was found to be negative in value. After each load was dumped in the silo or as near as possible at each foot of height of packed silage, readings were taken at the eight points for each wall. In each case readings were taken with a 4,900 pound wheel-type tractor on the silage and as close as possible to the test wall being checked. The readings were taken with the tractor stationary, so undoubtedly are smaller than for the case of dynamic loading.

It should be noted that all readings taken have yielded a force or pressure somewhat lower than the actual value. This is due to friction at each pin connection in the measuring apparatus and to rolling resistance of the wheels on the steel plates supporting the walls. Since the silage was ready to be cut as soon as the structure was built, it was not possible to calibrate the apparatus in the test setup. It is believed that the error due to friction was less than 5%. It is also obvious that too great a movement of the vertical lever arms from their stop position would produce a reading too large because of the tendency to actually compress the silage. Hence readings were taken when the lever arms were just off their stops. (A 1-inch movement at the "hook" end of the lever would only compress the wall at the horizontal link about one-sixteenth of an inch.)

Results

Total Wall Pressure. The sum of the four top and four bottom readings on each test wall section yielded the total force on the wall. In figure 29, the total force is plotted against silage depth for each wall. As would be expected, the lines diverge as the silage depth increases due to the increasing effect of the extra wedge of silage present for the sloped wall. The points plotted are with the 4,900 pound tractor on the silage and close to the wall section.

From a design standpoint the most significant points on the figure are for the maximum readings. This, of course, occurred at an 8½ foot depth or in other words when the silage was packed to an average height of 6 inches above the top of

the 8-foot walls. Table 8 shows the total and average unit pressure for each wall. As shown, considerable relaxation of pressure takes place after a period of 2 weeks. The maximum stresses occur just when the silo is filled and with a tractor on the silage.

Lateral Unit Pressure. Unit pressure data are valuable for the design of the wall section which extends between the pilasters or other upright supports. The approximate unit pressure on each wall at various depths of silage is given in figure 30. Below the top 2 feet, the unit pressures were about 60 and 73 pounds per square foot respectively for the vertical and sloped walls. Other investigators have reported different unit pressures. Esmay[5] obtained a unit pressure of approximately 100 pounds per square foot for walls with a 4:1

[5]"Lateral Stresses of Silage as Packed in Horizontal Silos," Merle Esmay and Donald Brooker. Presented at the meeting of the American Society of Agricultural Engineers, Chicago, December 8, 1954.

Figure 27. Measurement of force at top of wall.

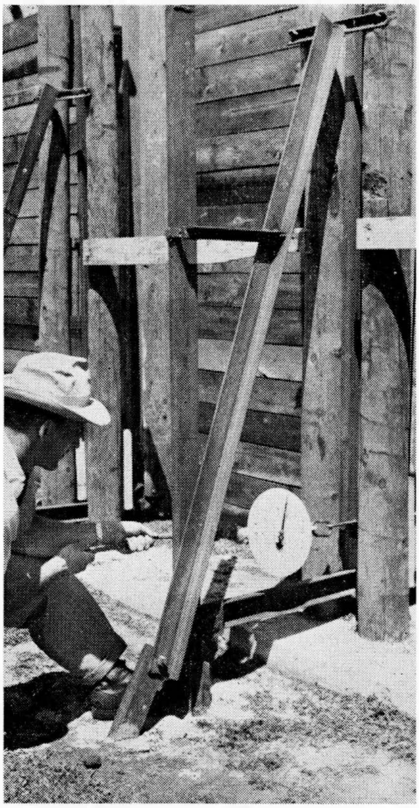
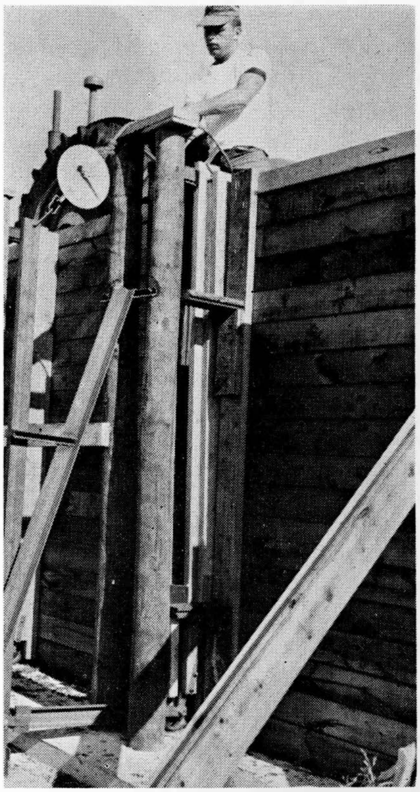


Figure 28. Measurement of force at bottom of wall.



slope and up to a depth of 6 feet. McCalmont[6] obtained unit pressures of around 180 pounds per square foot for 6-foot walls with a 8:1 slope. This variation shows the need for further testing and standarization of the test method.

Overturning Moment. From the measurement of the forces at the top and bottom of the walls, the overturning moment was calculated. (The 7-inch wheel at the lower support resulted in the force on the lower horizontal link to act at 3½ inches above the floor level.) Curves for overturning moment, per foot of wall length at various silage depths, are shown in figure

[6]"Horizontal Silo Coverings, Losses and Pressures," J. R. McCalmont. Paper presented at the winter meeting of the American Society of Agricultural Engineers, Chicago, December 8, 1954.

Figure 29. Total lateral force in 15 linear feet of side wall at various depths of packed silage.

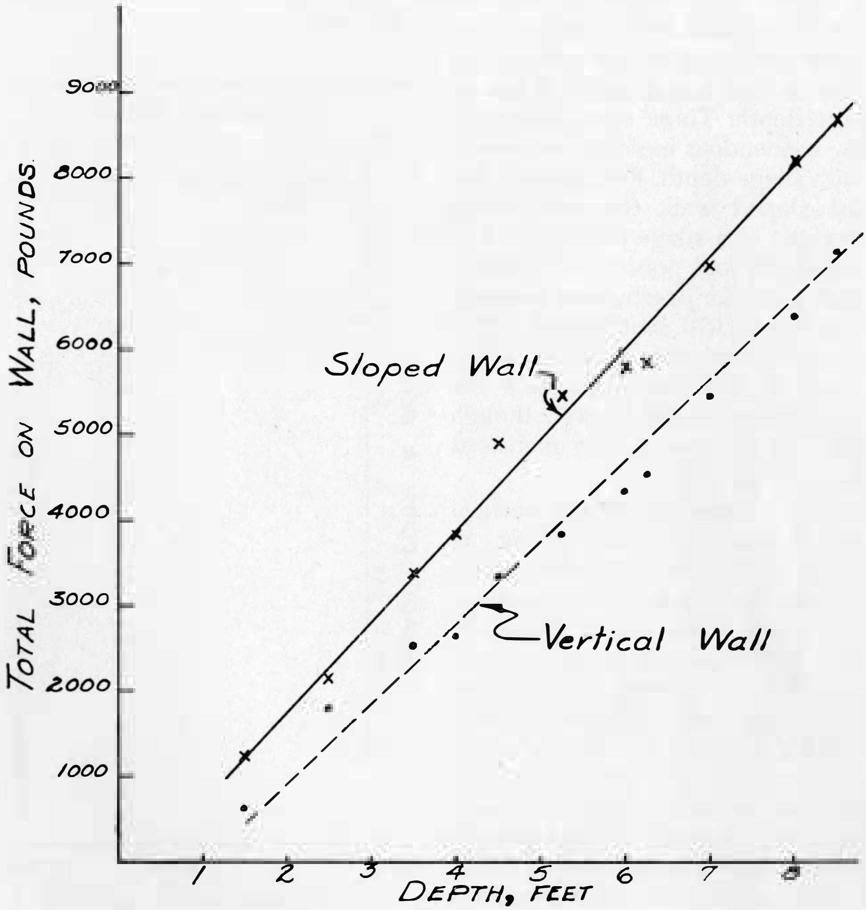


Table 8. Maximum Silage Pressure (at 8.5 feet depth) on 120 Square Feet of Vertical and Sloping Walls

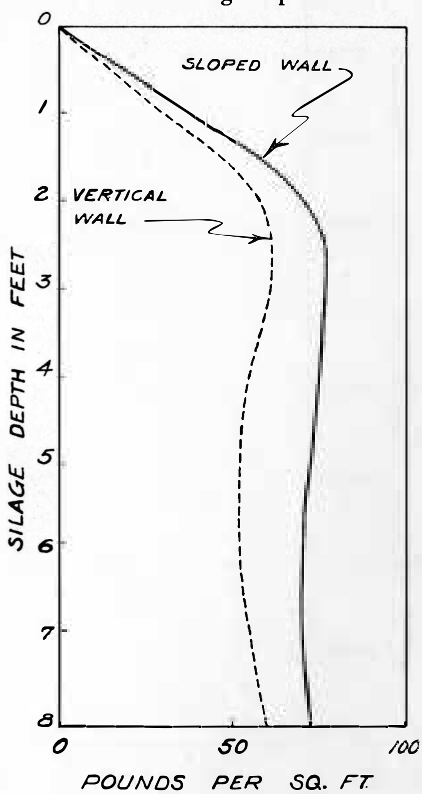
	Sloped Wall		Vertical Wall	
	Total Force, lbs.	Ave. Press., lbs. per sq. ft.	Total Force, lbs.	Ave. Press., lbs. per sq. ft.
When filled, with tractor	8760	73.1	7150	59.5
After 7 days, without tractor	8070	67.3	5840	48.6
After 18 days, without tractor	6170	51.4	5190	43.3

31. The equation $y=12.0x^{2.48}$ fits the curve reasonably close for the sloped wall, while the equation $y=7.22x^{2.53}$ represents the moment for the vertical wall. Y is the overturning moment in foot pounds per foot of wall length and x is the silage depth. These equations show the tremendous increase in moment with silage depth. For example, for the sloped wall, the overturning moment at a silage depth of 8 feet was 2,000 foot pounds. At a depth of 6 feet, the overturning moment was only 1,070 foot pounds. This shows that an extra 2 feet of height above 6 feet almost doubled the overturning moment, even though the moment arm is only increased by 2 feet or 33%.

The comparison of the vertical and sloped walls is interesting. As would be expected, the overturning moment was more nearly equal for each wall at the lower depths of silage. At depths of greater than 4 feet, the overturning moment for the sloped wall increased more rapidly than for the vertical wall. For a depth of 8 feet (a typical bunker silo wall height), the moment was about 2,000 foot-pounds for the sloped wall and only 1,400 foot-pounds for the vertical wall.

Measurement of side wall pressures was repeated in 1956 for chopped alfalfa-brome silage. The results checked to within 5% of the 1955 work.

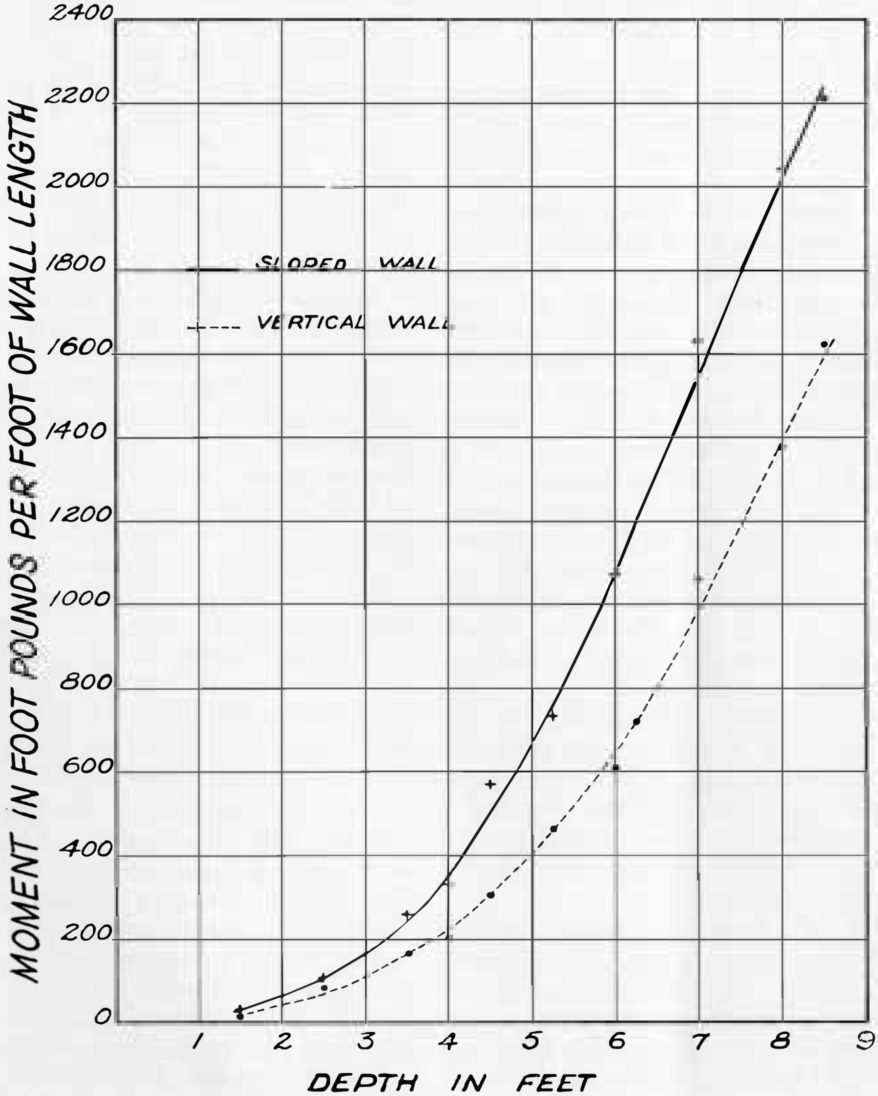
Figure 30. Unit side wall pressures at various silage depths.



SUMMARY

Four types of storage—upright silos, bunker silos, trench silos, and stacks—were used for storge of alfalfa-brome silage at the South Dakota Agricultural Experiment Station from 1953 to 1958. Comparisons were made regarding cost per ton of storage capacity, labor requirements in silo filling and feed-

Figure 31. Side wall overturning moment for sloped and vertical wall at various depths of packed silage.



ing, and silage quality maintained. Evaluation of the factors affecting silage quality was made by means of pilot silos and by the measurement of silage temperature and density at various locations in a silo. Structural requirements of different types of bunker silos were determined by measurement of lateral pressures.

The initial cost per ton of storage depends greatly upon the type and size of the structure. The permanent type silos have a higher initial cost but lower upkeep and less spoilage loss than the semi-permanent bunker silos or the temporary stacks. Generally, the glass lined steel silo costs from $25 to $35 per ton of capacity for sizes from 190 to 400 tons. The upright silo costs about $10 per ton for a 200-ton unit. A 120-ton bunker silo used in this study had an initial cost of $4.10 per ton of capacity. Trench silo costs vary considerably depending on the location, floor, and side wall used but will range from $2 to $6 per ton. The 35-ton trench silo constructed in this project cost $2.66 per ton. Stack silo costs also vary greatly, depending on the amount of fencing and poles required and the type of cover used. Several types of covers were tested on the stack silos. Generally, stack silo storage costs vary from 50 cents to $1 per ton.

In addition to chopped alfalfa-brome silage which was used each year to fill all silos, baled silage and long grass silage were tried one and two seasons, respectively. From the standpoint of labor requirements and amount of spoilage, these attempts were unsuccessful.

With a special auger, core samples were taken from the various silos and stacks to determine density as a function of silage depth. Density varied with depth, degree of packing, and silage moisture. Density ranged from an average of 20 pounds per cubic foot at the first foot level to around 55 pounds per cubic foot at a depth of 7 feet. No relationship between density and quality was found except that in the top layers, spoiled material had a density of less than 20 pounds per cubic foot.

Extensive measurement of silage temperature by thermocouples was undertaken to compare temperatures between silos and within silos and to note the relation between temperature and silage quality. Temperatures varied from a high of 140°F. near uncovered silage surfaces to 90°F. at lower levels. In areas where temperatures were high (125°F. to 140°F.), silage was of very poor quality with a pH from 7 to 9. Temperatures in the vicinity of 100°F. were indicative of good silage with a pH of from 5 to 6. Dry matter loss was excessive where temperatures were above 110°F.

Pilot silos were studied for four seasons. The following variables were studied: covers verses no covers, packing versus no packing, chemical treatment (preservative) versus untreated silage. Weight loss was recorded at weekly intervals, and temperatures were measured by means of a thermocouple in the center of the pilot silo. Where the

silo was uncovered, losses in weight up to 60% resulted whether the silage was treated or not. Losses in covered pilot silos (treated or untreated) ranged from 10 to 15%. Chemical treatment showed no benefit from the standpoint of weight loss if the silo was uncovered. Fourth year results showed the importance of covering the silage immediately after being placed in storage, although some saving in loss was achieved even if covered after 2 weeks.

Comparisons of pressures and overturning moment were made on an 8-foot vertical wall and a wall with an outward slope of 1 foot per 4 feet of height. Lateral pressures of 60 and 73 pounds per square foot, respectively, were found for the vertical and the sloped walls.