INVESTIGATIONS OF VERTICAL HAY SELF-FEEDERS FOR CATTLE AND SHEEP

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

Max Covell Christensen

1952

This is to certify that the

thesis entitled

"Investigations of Vertical Self-Feeders
for Cattle and Sheep"

presented by

Max C. Christensen

has been accepted towards fulfillment
of the requirements for

M. S. degree in Agricultural
Engineering

Walter M Carleton
Major professor

Date December 20, 1951

O-169

INVESTIGATIONS OF VERTICAL HAY SELF-FEEDERS

FOR

CATTLE AND SHEEP

By

Max Covell Christensen

Abstract of Thesis

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
In partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE

Department of Agricultural Engineering

1952

THESIS

INVESTIGATIONS OF VERTICAL HAY SELF-FEEDERS
FOR
CATTLE AND SHEEP

Michigan farmers harvest more hay than any other crop. Over three million tons are harvested annually. Hay is an important part of the diet for about two million head of cattle and calves, and four hundred and twenty five thousand sheep and lambs in the state. In view of these facts, the storage and feeding problems of this crop are important.

The labor requirements for harvesting hay have been eased considerably by the field forage harvester. However, the method of feeding chopped hay usually requires a second handling, and in many cases a third handling, of the entire crop.

The research in this thesis is concerned with the complete elimination of handling the chopped hay after it has been placed in the storage. Ideally, we would have the livestock remove all the hay from the storage without help from the operator.

Preliminary investigations indicated that the vertical type of self-feeder had the best prospects for being completely automatic. For this reason, the research was directed along those lines. The procedures of the study involved the construction of two vertical hay self-feeders, a series of lateral pressure tests, and a series of coefficient of friction tests.

A self-feeder for cattle was built within a conventional two-story barn by low cost remodeling. The barn framework was used as the main framing for the feeder. Both rigid and hinged feeder bars were installed. A central dividing wall was incorporated to divide the hay at the peak of an "A" frame at the base of the feeder.

A self-feeder for sheep was built as a separate structure using low cost building materials. Four different feeding sections were installed. The sheep feeder had an "A" frame at the base but had no central dividing wall.

Investigations of hay self-feeders in operation indicated that the frictional force within the feeder was of major importance. For this reason, a series of lateral pressure tests were made and coefficients of friction of chopped hay on five common building materials were found.

The results of the cattle feeder indicated it was desirable to have a central dividing wall, and that hinged feeder bars had the best feeding characteristics. Results from the sheep feeder were not conclusive. No roof was provided for the feeder and much of the hay molded.

The study of frictional forces indicated that they are an important reason for the non-flow of hay in hay self-feeders, especially the frictional forces along the "A" frame.

Walter M. Carleton

Approved Major Professor.

INVESTIGATIONS OF VERTICAL HAY SELF-FEEDERS
FOR
CATTLE AND SHEEP

By

Max Covell Christensen

A Thesis

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
In partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Agricultural Engineering

1952

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to the following:

Professor Arthur W. Farrall, head of the Agricultural Engineering Department and Professor Ronald H. Nelson, head of the Animal Husbandry Department. Through their cooperative efforts this study was made possible.

Professors James S. Boyd and Walter M. Carleton of the Agricultural Engineering Department for the guidance and assistance given during the course of the study.

Professor Walter H. Sheldon and Burton F. Cargill of the Agricultural Engineering Department for the helpful suggestions given.

Professor George A. Branaman of the Animal Husbandry Department for his interest and cooperation.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

INVESTIGATIONS OF VERTICAL HAY SELF-FEEDERS FOR CATTLE AND SHEEP

INTRODUCTION

Basically, hay is fed by horizontal movement from the storage, by vertical movement from the storage, or more often, by a combination of horizontal and vertical movements.

The installation in which horizontal movement dominates usually involves storing the hay on the same level as the livestock are housed, commonly referred to as ground storage. Using ground storage, feeding is usually accomplished in one of three ways:

1. The cattle eat from stationary mangers or bunks. The hay is moved by fork, basket or cart to the manger.
2. The cattle eat from movable mangers or bunks. The mangers are moved back as the hay is fed. The hay is still moved manually from storage to manger, however, the distance of horizontal movement remains relatively small.
3. The cattle eat through movable gates taking the hay directly from the storage. As the hay in front is eaten, the gates are moved toward the remaining hay. Methods (2) and

(3) both have the advantage of adding floor area as feeding progresses. At present, horizontal feeding seems to offer little opportunity for becoming completely automatic.

The installation in which vertical movement dominates, involves storing the hay at a level above the floor where the livestock are kept. This is common in the conventional two-story barn. It seems that the methods of feeding hay, where vertical movement dominates, have progressed through five basic steps:

1. The barn having a drive floor in which the hay was first thrown down to the drive floor, then through a door to the feed alley below, and from there moved horizontally into the manger.
2. The second step involved a chute leading from the feed alley up through the hay mow. With this arrangement the hay could be taken at any height in the mow and thrown directly to the feed alley below. The hay was still moved horizontally to the manger.
3. The next step progressed to having the chute or a number of chutes lead directly to the manger.
4. The chutes were enlarged and the manger redesigned so that the chutes actually became small storages. They were filled one, two, or three times a week.

5. The attempt now is to enlarge the chute to make it the seasonal storage, and to have the cattle eat from it with no help from the operator.

In the vertical type self-feeder, the hay moves downward by gravity until it is exposed to the livestock at the feeding section. Then as the hay is taken out at the bottom by the livestock, the remaining hay moves downward.

At least two attempts at vertical self-feeding of hay have been made in Michigan. One of these feeders, shown in Figure 1, was built in Huron county. The side walls were sloped to a central manger at the bottom. The attempt being to funnel the hay as it moved down. The feeder is shown at the mow floor level in Figure 2. Field cured chopped hay was placed in the feeder. The results were unsatisfactory; the hay bridged over the narrow opening at the bottom.

Another vertical type self-feeder was built in Tuscola county, Figure 3. The feeder was 17' by 19' in size and extended to the barn roof. A 4' by 4' drying duct extended up through the center of the feeder. One of the feeding sections is shown in Figure 4. Three inside walls of the feeder were sheathed vertically with lumber. The other wall used the outer siding of the barn as the feeder wall. This meant that the hay had to slide over the barn framing when moving down this wall. No attempt was made

Figure 1. Manger Section of Hay Self-feeder in Huron County, Michigan.

Figure 2. Mow Floor Level of Hay Self-feeder in Huron County, Michigan.

Figure 3. Hay Self-feeder in Tuscola County, Michigan.

Figure 4. Feeding Section of Hay Self-feeder in Tuscola County, Michigan.

to keep the walls absolutely vertical or to give them a taper outward at the bottom.

This feeder had pyramid of wood construction with approximately 45° slope at the bottom to move the hay outward. The feeding characteristics of this structure were not completely satisfactory. Hay tended to bridge over at the bottom at a point above the pyramid. This indicated that the total weight of the hay was supported by wall friction or by obstructions within the feeder.

JUSTIFICATION

Michigan harvests more acres of hay than any other crop.[12] Over three million tons are harvested annually, and some 90%[13] of this hay is fed on the same farms on which it is grown. Hay is an important part of the diet for about two million head of cattle and calves, and four hundred and twenty five thousand sheep and lambs in the state. This livestock program represents approximately 40% of the Michigan farm income.[8]

A survey conducted in 1948 reveals that 5% of the hay in Michigan is chopped.[1] The survey also indicated that the practice of chopping hay had increased five fold since 1944. It is almost certain that there has been an increase from 1948 to the present.

The important reason for the increase in the practice of chopping hay has been the field forage harvester.

From the standpoint of labor, the field forage harvester has a great deal of merit in the harvest of hay. Common practice involves chopping the hay directly from the windrow into a self-unloading wagon, hauling the hay to the storage and unloading it into a forage blower. In many cases a small amount of help by the operator is necessary to facilitate the transfer from the wagon to the blower. Simple observation reveals that the harvesting of the crop has been eased considerably by use of the field forage harvester and allied equipment.

The feeding of chopped hay is carried on in many different ways in Michigan. It is certain that much of it is stored and fed in the conventional two-story barn, still common in the state. The method of feeding will generally follow one of those discussed earlier, all of the methods will involve a second handling and in many cases a third handling, of the entire crop.

The research in this thesis is concerned with the complete elimination of handling the chopped hay after it has been placed in the storage. Ideally, we would have the livestock remove all the hay from the storage without help from the operator.

At present, the vertical type of feeder seems to offer the best prospects for complete mechanization. For this reason, the research was directed along those lines.

It is realized that the self-feeding of hay necessitates a form of loose housing. However, this is common practice with beef cattle and sheep, and loose housing for dairy herds is under continual developement.

REVIEW OF LITERATURE

Structural and Functional Requirements

Most of the published information regarding vertical self-feeding of hay was of a non-technical nature. The best references available were those published by C. H. Reed.

Reed[10] states the following functional requirements for a self-feeding structure:

1. The structure should be 100% self-feeding.
2. The structure should have sufficient capacity to store the entire forage crop.
3. Wastage should be no greater than if feeding were accomplished by conventional methods.
4. The structure should offer no hazards to livestock feeding from the structure.
5. The farmer should be able to fill the structure with machinery available.

Reed[11] also made the following recommendations regarding construction details:

1. The feeder opening at the base of the structure should vary between 5' and 7' in height, depending on the width or diameter of the structure.

2. There should be a divider at the bottom of the structure. An "A" duct in square or rectangular bins, or a cone in cylindrical bins.
3. If hinged feeder bars are used, these bars and the divider at the base of the feeder must be so designed that the livestock cannot get their heads under the swinging bars.
4. In bins more than 12' wide, the "A" frame should be as high as the feeder opening.

Feed and Space Requirements

The data taken by Carter showed that the average hay requirement for a dairy cow was 4,343 pounds annually.

A summary of cost accounting surveys made by the United States Department of Agriculture and reported by Morrison[9] gave the following hay requirements for beef cattle in the corn-belt states:

	Usual method of beef production		Baby beef Production	
	Maintaining cows per year	Wintering cows	Maintaining cows per year	Fattening calves
Hay, lbs.	1900	1218	1940	1150

Morrison also stated that it requires 400 to 600 pounds of hay to carry a breeding ewe of average size through the winter.

Wright[14] found a total average of 88 pounds of hay required to fatten a lamb in Michigan.

Brown, Cargill and Bookhout[2] gave the following space requirements for hay:

	Cubic feet per ton
Loose in shallow mows	500-600
Loose in deep mows	400-500
Field baled	200-250
Chopped long	300-400
Chopped short	200-300

Lateral Pressure and Coefficient of Friction Tests

Ketchum[6] stated that difficulty had been encountered in measuring lateral pressures in grain bins where any appreciable deflection of the measuring apparatus was required. He stated this was apparently due to the fact that the confined material did not have the elastic properties necessary to move the measuring apparatus.

Jamieson[5] used a diaphragm for measuring lateral pressure in grain bins.

Jamieson also used a tilting table for measuring the angle of repose of grains and the coefficients of friction of grains on various materials.

McCalmont and Ashby[7] used strain gages for measuring the lateral pressures in corn cribs. The strain gages were used to measure the deflection of steel bars which supported panels incorporated into the crib wall.

OBJECTIVES OF THE STUDY

The four objectives of this study were as follows:

1. Investigate the practibility of, and the facilities needed for, the feeding of chopped hay to cattle and sheep by means of a vertical type self-feeder.
   a. Determine the desirability of incorporating a central dividing wall into the feeder.
   b. Observe feeding characteristics and wastage with different types of feeder bars.
2. Demonstrate the use of the vertical type hay self-feeder, in the conventional two-story barn, by low-cost remodeling.
3. Investigate the application of low cost building materials to the construction of a vertical hay self-feeder as a separate structure.
4. Investigate the frictional forces which tend to retard the moving hay.

PROCEDURE

To fulfill the objectives set forth, the work was divided into four parts:

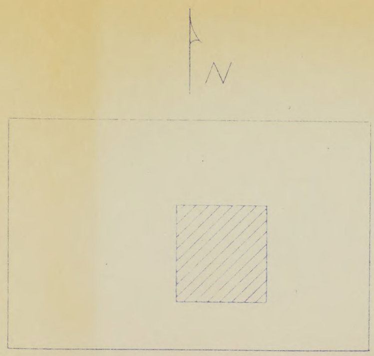
1. The construction of a vertical type hay self-feeder for cattle.
2. The construction of a vertical type hay self-feeder for sheep.
3. A series of lateral pressure tests on the cattle feeder.

4. A series of coefficient of friction tests between chopped hay and five common building materials.

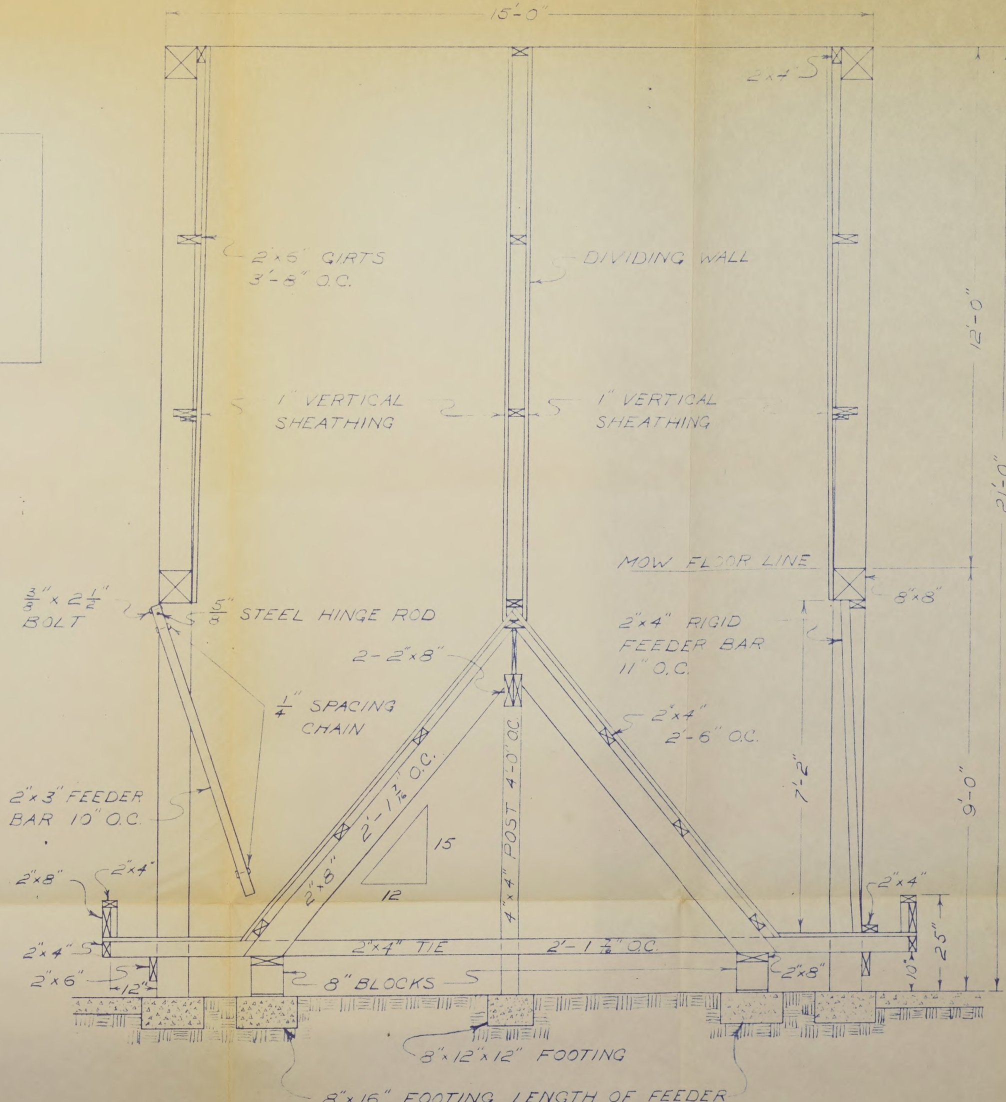
Vertical Hay Self-feeder for Cattle

A feeder for cattle was built in a 38' x 60' conventional two-story barn on Michigan State College property, four miles south of the campus. This barn is shown in Figure 5. Built to conform to the barn framework, the feeder had inside dimensions of 13'-8" x 15'-0" x 21'-0" in height, Figure 6. This gave a calculated storage capacity of approximately twelve tons, based on 300 cu. ft. per ton.

Figure 5. Two-story Barn in which Experimental Hay Self-feeder for Cattle was Built, Michigan State College.



LOCATION OF
FEEDER IN BARN



SECTION OF
HAY SELF - FEEDER
FOR CATTLE

The feeder was constructed in a way that would incorporate the barn framing as the main framing for the feeder. Approximately half of the material was salvaged from a granary that had been removed from the barn. The feeder rests on its own footing in the stable floor and extends up through the mow floor. Figures 7 and 8 show the mow floor removed.

The "A" frame at the base of the feeder was built on a concrete block foundation, Figure 9. Salvaged ash flooring was applied vertically as sheathing.

The outside framing of the feeder was constructed in a way that gave a slight taper of one inch per six feet of height, to the outside walls. The taper was such that the bottom dimensions of the feeder were larger than the top. This was done to relieve the hay as it moved downward. Wall sheathing of rough, salvaged lumber was applied vertically.

To facilitate a study of feeding and wastage characteristics, both rigid and hinged feeder bars were incorporated in the structure. The hinged feeder bars are shown in Figures 10 and 11. The bars are 2" x 3" white oak, 10" on centers. They were hinged on a 5/8" steel rod by drilling a hole near one end of the bars. A 3/8" bolt was put through the bar on each side of the rod and a ¼" chain used to space the bars at the top and bottom. Both chains were securely fastened at each end

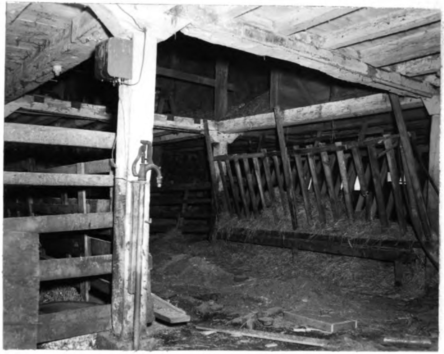


Figure 7. Mow Floor Removed for Construction of Hay Self-feeder for Cattle.

Figure 8. Footings for Hay Self-feeder for Cattle.

Figure 9. "A" Frame at the Base of Hay Self-feeder for Cattle.

Figure 10. Hinged Feeder Bars in Hay Self-feeder for Cattle.

Figure 11. Inside of Hay Self-feeder for Cattle Showing Hinged Feeder Bars.

Figure 12. Rigid Feeder Bars in Hay Self-feeder for Cattle.

and to a post in the center. The rigid feeder bars were 2" x 4"s, 11" on centers, Figure 12.

To help divide the hay at the peak of the "A" frame, a simple dividing wall, which extended the full height of the feeder, was constructed. This wall is shown in Figure 13.

When construction was complete, the feeder was filled by blower with field cured chopped hay. The hay was a legume-grass mixture chopped to an average length of 1.7 inches.

Vertical Hay Self-feeder for Sheep

A feeder for sheep was built adjacent to a two-story sheep barn on Michigan State College property, three miles south of the campus. The feeder was 8'-0" x 21'-0" x 12'-0" in height and had a calculated capacity of five tons, based on 300 cu. ft. per ton.

The sheep feeder was of pole construction with snow fence, as outside sheathing, wired to 2" x 4" girts, Figure 14. One inch sheathing was used on the "A" frame. The poles were salvaged utility poles with butts 8 to 9 inches in diameter. The total weight of the feeder and its contents was supported on the poles. The "A" frame at the bottom of the feeder was supported by girders fastened directly to the pole frame, Figure 15.

Figure 13. Central Dividing Wall in Hay Self-feeder for Cattle.

Figure 14. Hay Self-feeder for Sheep.

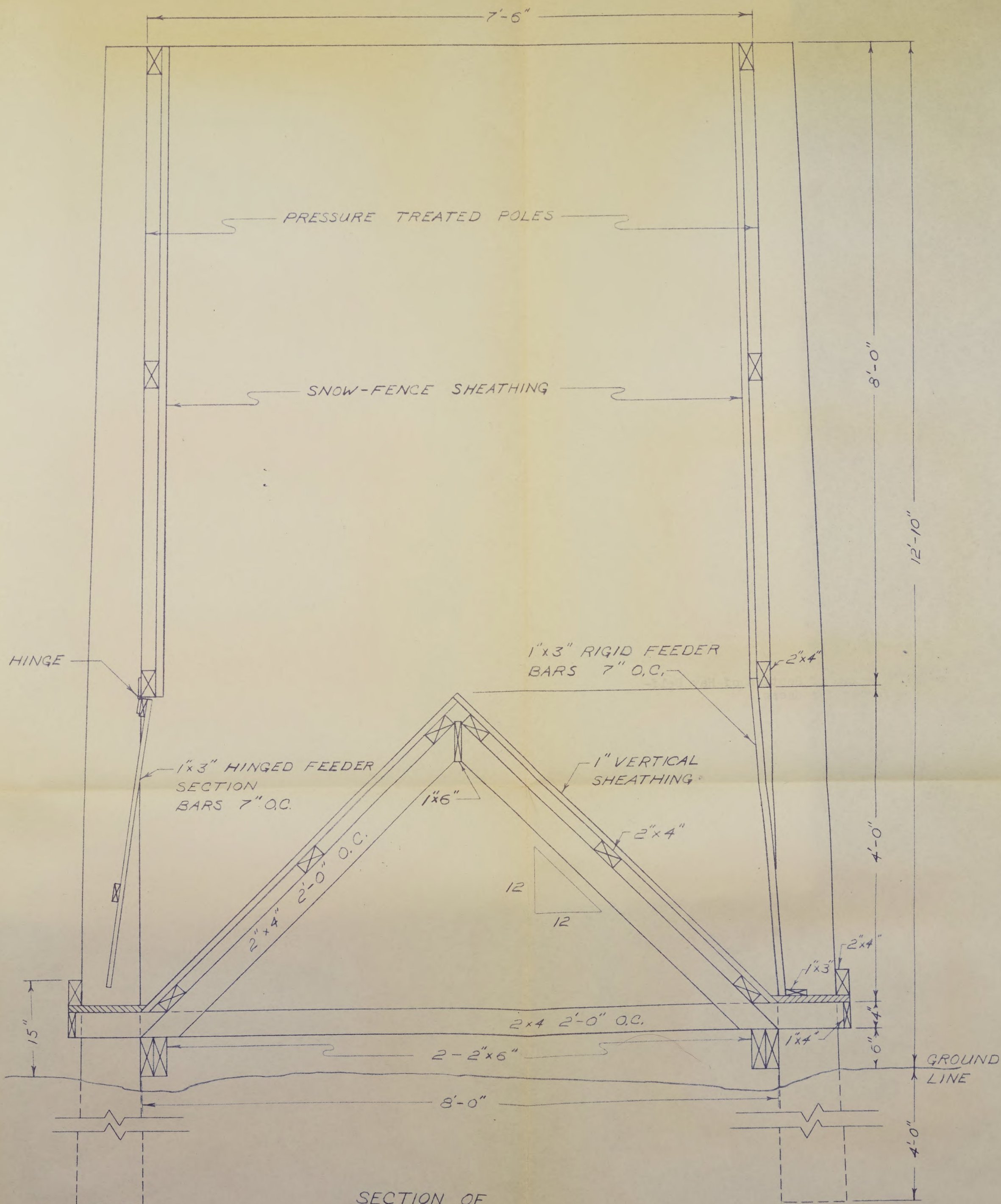
A section of the feeder is shown in Figure 16.

No central dividing wall was built into the self-feeder for sheep. This was done to compare its effect on feeding characteristics with the cattle feeder in which a dividing wall was incorporated.

Both rigid and hinged bars were used on the sheep feeder. The rigid bars are shown in Figure 17. They were 1" x 3" strips placed 7 inches on centers. The upper part of the openings between slats were filled in, as shown, to keep chaff out of the animal's wool.

The hinged feeder sections are shown in Figure 18.

Figure 15. "A" Frame of Hay Self-feeder for Sheep.



SECTION OF
HAY SELF-FEEDER
FOR SHEEP

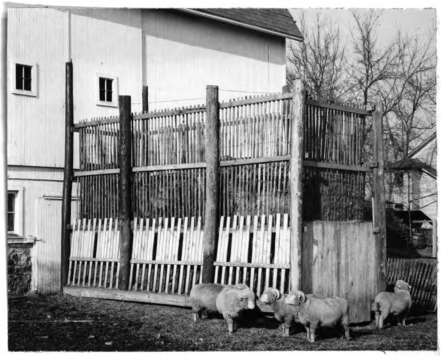


Figure 17. Hay Self-feeder for Sheep Showing Rigid Feeder Bars.

Figure 18. Hay Self-feeder for Sheep Showing Hinged Feeder Sections.

Two sections had solid doors with a 10 inch opening at the bottom. The other section had two hinged panels built with the same dimensions as the rigid bars. One panel had the upper part of the openings between slats filled in, the other did not.

When construction was finished, the feeder was filled by blower with chopped, field cured, second cutting alfalfa hay.

Lateral Pressure Tests

The investigations of hay self-feeders in operation indicated that friction on the outside walls was of great importance. An effort was therefore made to determine the magnitude of this force.

To facilitate the calculation of force between two substances, two things must be known: 1. The normal force between the two substances. 2. The coefficient of friction between the materials.

In this study the normal force between the hay and the wall sheathing was found by a series of lateral pressure tests. The coefficient of friction was found by tests described later.

The apparatus for making the lateral pressure tests is shown in Figure 19. The tests were made on the cattle feeder after it had been filled for approximately five months. To make the tests, a two foot square test panel was first marked off on the outside wall sheathing.

Then two vertical saw cuts on either side of the panel were made. Two angle iron cleats were then fastened to the top and bottom of the test panel with screws. At each end the cleats were fastened to the stationary boards with small lag screws. Between the angle iron cleats and the test panel, a one-eighth inch iron strip was placed. The strip extended only the width of the test panel. This left a one-eighth inch space between the angle iron cleat and the stationary boards at each of the four corners of the panel.

Then the top and bottom saw cuts were made. This

Figure 19. Apparatus for Making Lateral Pressure Tests.

left the panel supported by the four lag screws. Next, a number 12 wood screw was placed below each end of the top angle iron cleat. These screws later supported the total vertical load on the panel.

A lever arrangement as shown in Figure 20 was placed on each corner of the test panel. The lever converted weight in the bucket into horizontal force against the end of the angle iron cleat.

The horizontal force of the hay against the panel was found by adding sand to each bucket as the lag screw was loosened. The test progressed around the panel until all four lag screws were removed and the lateral force of the hay was just balanced by the weight of the buckets and their contents. The position of the panel was maintained by a one-eighth inch feeler gage, Figure 21. Weight was added to the bucket until the feeler gage just became snug. At that time all vertical force on the panel was carried by the screws under the top cleat. These screws and the hinges of the lever arrangement were kept well oiled during the tests.

When all four corners of the panel were in proper position, each bucket and its contents were weighed and the weights recorded with the height of the test panel above the bottom of the hay storage. The lever arms were measured and recorded for calculating the mechanical advantage. In the laboratory the weight and the centers of

Figure 20. Lever Arrangement for Lateral Pressure Tests.

Figure 21. Lateral Pressure Test Showing Feeler Gage.

gravity of the lever arms were found. The horizontal force of the hay was calculated as follows, Figure 22:

$$F_h = \frac{F_b c + Wb}{a}$$

where F_h = the force due to the hay at one corner of the test panel

F_b = the force due to the bucket and its contents

W = the weight of the lever arm

a = length of lever arm from center of hinge to F_h

b = length of lever arm from center of hinge to F_b

c = length of lever arm from center of hinge to the center of gravity of the lever arm.

Then,

$$P = \frac{\sum F_h}{A}$$

where P = pressure on one panel
A = area of panel

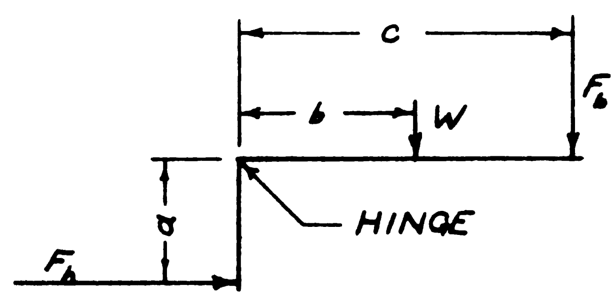


Figure 22. Schematic Diagram of Lever Arrangement for Lateral Pressure Tests.

Coefficient of Friction Tests

The coefficients of friction of chopped hay on the five building materials were obtained by use of the equipment shown in Figure 23. The equipment consisted of a tilting table arrangement. The hinge on the table had a pointer leading to a stationary quadrant which was graduated in degrees. The pointer had a vernier arrangement which made readings to one-tenth of a degree possible. The quadrant was made so that degrees of incline from the horizontal could be read directly. The tests were made on the five building materials listed below:

1. Rough lumber paralled to the grain.
2. Rough lumber perpendicular to the grain.
3. Finished lumber parallel to the grain.
4. Finished lumber perpendicular to the grain.
5. Plywood parallel to the grain.
6. Corrugated galvanized iron parallel to the corrugations.
7. Corrugated galvanized iron perpendicular to the corrugations.
8. Smooth galvanized iron.

Two different hay samples were used, both were legume-grass mixtures. Hay number one was chopped to an average length of 1.7 inches and had a moisture content of 10.1% at the time of the tests. Hay number two was chopped to an average length of 3.9 inches and had 11.2% moisture at the time of testing.

The box holding the hay had one side removed and was filled by placing this open side 2" from a smooth wall. Hay was then placed in the box through an open end. This method was used to keep the ends of the hay pointing in one direction much as they would be after settling in the storage. When the box was full, the end of the box was replaced.

No attempt was made to control the density of the hay. This seemed justifiable since the coefficient of friction is not dependent on the area involved.

The tests were made by clamping the test material on the movable incline and then placing the box on the test material as shown in Figure 24. The angle of incline was slowly increased by means of a rope and pulley until the hay just began to slide. At this point the indicator on the quadrant was clamped in place and the degrees of incline from the horizontal were read. The angle of incline from horizontal was called θ. The tangent of θ was then equal to the coefficient of friction (u') for the two materials.

RESULTS

Vertical Hay Self-feeder for Cattle

On the basis of early feeding trials, the operation of the cattle feeder was considered successful. Some difficulty was encountered in the initial starting of the hay.

Figure 23. Appartus for Measuring Coefficients of Friction.

Figure 24. Apparatus for Measuring Coefficient of Friction Showing Quadrant Lock.

When the feeding first began, the hay did not move down. After digging out the hay at the bottom, it was found that the hay had molded on the "A" frame at the base of the feeder. This had increased the coefficient of friction to to such an extent that the remaining hay would not slide down. After the moldy hay had been removed, the hay began to slide down and force itself against the feeder bars, Figure 25.

The comparison of hinged and rigid feeder bars indicated the desirability of having movable feeder bars. The rigid bars allowed such a limited reach for the cattle that, unless the hay was directly against the bars, it could not be reached by the animals. The hinged bars did agitate the hay somewhat, but what was more important, they greatly increased the reach of the animals.

The incorporation of a central dividing wall was considered highly successful. In comparison with the sheep feeder, the cattle feeder had much better feeding characteristics. In one corner of the cattle feeder, against the dividing wall, a column of hay approximately six feet square and extending half way to the top of the storage fed down early in the trails. Had it been necessary for the hay to force its way down over the peak of the "A" frame, this may not have happened.

From the standpoint of construction, the use of the vertical type hay self-feeder within the two-story barn was

Figure 25. Hay Against the Feeder Bars of the Hay Self-feeder for Cattle.

considered very successful. The timber framing of the barn can very well be incorporated as the main framing for the outside walls of the feeder. The "A" frame must be built as a separate unit and of sufficient strength to support the entire weight of hay to be stored.

The incorporation of the feeder into the barn does have a disadvantage in that it does use some of the stall space in the barn. Therefore, if stall space is an important factor, the construction of the feeder as a separate structure should be considered.

Vertical Hay Self-feeder for Sheep

In its initial trial the sheep feeder was not provided with a roof. As a result, a considerable part of the hay in the feeder molded.

However, on the basis of this initial trial the solid door feeder sections, shown in Figure 18 on page 22, were judged unsatisfactory. The reach of the animals was too limited by the small opening at the bottom. It also appeared that a dividing wall would be desirable to divide the hay at the peak of the "A" frame.

The method of construction employed was found to be simple and easy. However, this method of self-feeder construction must be proven by later feeding trials.

Lateral Pressure Tests

At the time the tests were made, only one end of the feeder was accessible. This, and the fact that the placement of test panels was limited by the feeder framework, allowed only six tests to be made. The results given are based on these six tests only. It must be emphasized, therefore, that these results can be used only as an indication of lateral wall pressures.

The results of the lateral pressure tests at the six locations are given in Table I.

Table No. I.--Lateral Wall Pressures of Chopped Hay in Experimental Hay Self-feeder for Cattle

Depth of hay (feet)	Pressure (lb./sq. ft.)
8.5	4.79
11.2	6.73
15.0	5.59
17.7	13.6
23.3	15.3
23.3	9.62

Figure 26 shows a pressure line plotted from Table I. The line is shown as a dashed line as an indication of its limited use.

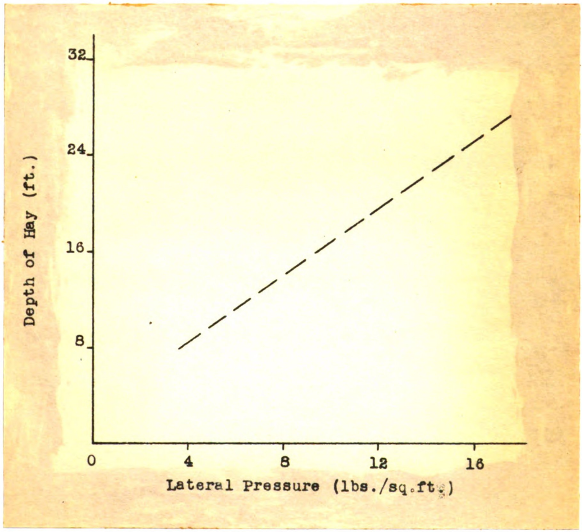


Figure 26. Curve Showing Lateral Pressures of Hay in Experimental Hay Self-feeder for Cattle

The lateral pressures did not follow a smooth curve. This could be expected since hay is not a granular material. The method of filling might affect the lateral pressure. Such things as blowing the hay into one corner or having the pile of hay tip as filling proceeds might change lateral pressures considerably.

Coefficient of Friction Tests

The results of the coefficient of friction tests are given in Table II.

Table II.—Coefficients of Friction of Chopped Hay on Five Common Building Materials.

	Hay 1	Hay 2	Average for both samples
Rough lumber parallel to the grain	.582	.568	.577
Rough lumber perpendicular to the grain	.649	.589	.630
Finished lumber parallel to the grain	.454	.380	.429
Finished lumber perpendicular to the grain	.462	.420	.447
Plywood parallel to the grain	.362	.313	.344
Corrugated galvanized iron parallel to the grain	.437	.404	.424
Corrugated galvanized iron perpendicular to the grain	.640	.622	.626
Smooth galvanized iron	.400	.396	.400

The tests indicated very little difference between the coefficient of friction parallel to the grain and that perpendicular to the grain for both rough and finished lumber. When the tests perpendicular to the grain were made, the joints of the boards were kept as smooth as possible. It was noted that when a slight irregularity existed, the coefficient of friction increased substantially. This is an important reason for vertical application of sheathing lumber in self-feeder construction.

An increase in the length of cut gave a small decrease in the coefficient of friction. This was probably due to the decrease in exposed cut stems.

As each series of tests progressed, the coefficient decreased slightly. This was probably due to the polishing effect of the sliding hay. However, a polishing effect seems of little importance in actual feeder operation. At the bottom of the feeder, for example, only the number of feet of hay equal to the depth of the hay would pass over a given point. This would occur only at every filling of the feeder.

DISCUSSION OF FRICTIONAL FORCES

To indicate the effect of friction within a vertical self-feeder, the frictional forces within a hypothetical feeder shown schematically in Figure 27 will be calculated. The calculations will be for one-half of the feeder since both sides are the same.

The lateral pressures and coefficients of friction given in the results of the study will be used in the calculations.

The coefficient of friction from Table II is .577. The average depth of hay in the feeder is 28 feet. The average lateral pressure from Figure 24 for 28 feet was the pressure for 14 feet of depth or 7.9 pounds per square foot.

The wall area in one-half the feeder will be:

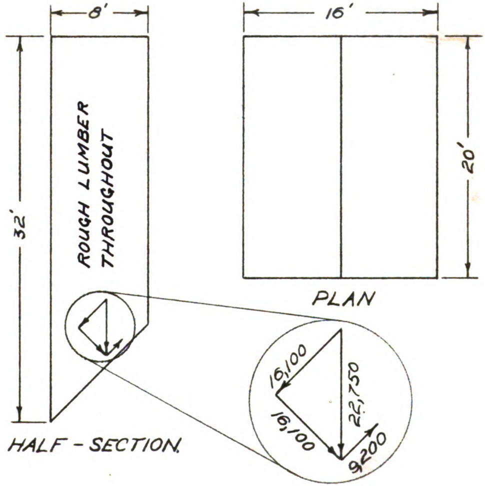


Figure 27. Schematic Diagram of Hypothetical Hay Self-feeder.

$$28\left[2(20) + 2(8)\right] = 1568 \text{ sq. ft.}$$

Then,

$$F_w = u'Pa$$

where F_w = total friction force due to the side walls in pounds.

u' = coefficient of friction

P = lateral pressure in lbs. per sq. ft.

a = wall area in sq. ft.

$$F_w = .577 \times 7.9 \times 1568 = 7150 \text{ lbs.}$$

The total weight of hay in half the feeder, based on 300 cu. ft. per ton, is equal to:

$$\frac{20 \times 8 \times 28 \times 2000}{300} = 29{,}900 \text{ lbs.}$$

The weight supported by the bottom of the feeder is then,

$$29{,}900 - 7150 = 22{,}750 \text{ lbs.}$$

This weight on the base of the feeder can be broken down into two components: one parallel to the "A" frame, the other normal to the "A" frame.

The force parallel to the "A" frame is:

$$22{,}750 \cos 45^{\circ} = 16{,}100 \text{ lbs.}$$

The force normal to the "A" frame is:

$$22{,}750 \sin 45^{\circ} = 16{,}100 \text{ lbs.}$$

The frictional force along the "A" frame which retards hay flow is:

$$F_b = u'N$$

where F_b = frictional force along "A" frame

u' = coefficient of friction

N = force normal to the "A" frame.

F_b = .577 x 16,100 = 9,290 lbs.

The force parallel to the "A" frame less the frictional force parallel to the "A" frame is the force which tended to move the hay outward against the feeding section. This will be:

16,100 - 9,290 = 6,810 lbs.

CONCLUSIONS

On the basis of the investigations made and on the initial feeding trials the following conclusions were made:

1. The feeding of chopped hay to cattle and sheep by means of a vertical type self-feeder was practical.
2. A central dividing wall, extending up from the peak of the "A" frame, proved desirable.
3. A hinged type of feeder bar proved most satisfactory.
4. It was found practical to build a vertical type hay self-feeder into the conventional two-story barn by low cost remodeling.
5. A smooth sheathing material was found to be more important on the "A" frame than on the outer walls of the feeder.
6. Results showed that hay placed directly over the "A" frame must be dry to prevent molding on the "A" frame.

PROBLEMS RECOMMENDED FOR FURTHER STUDY

1. Perform another feeding trial with the hay self-feeder for sheep after supplying a roof for the structure.
2. Perform another feeding trial with the hay self-feeder for cattle after respacing the rigid feeder bars. A spacing of 16 inches on center is recommended for trial.
3. Study thoroughly the lateral wall pressures that exist in hay storage structures. Results should be based on a large number of studies. Lateral wall pressures of self-feeders during operation should be included.

REFERENCES CITED

(1) Brodell, A. P. and Carpenter, C. G. Harvesting hay and silage. Washington, U. S. Government Printing Office. 1950.

(2) Brown, L. H. Cargill, B. F. and Bookhout, B. R., Pen-type dairy barns. Michigan Agricultural Experiment Station Special Bulletin 363. 1950.

(3) Carter, E. H. Dairy costs and returns in Detroit milk shed in 1946. Michigan Agricultural Experiment Station Quarterly Bulletin 30: 230-236. 1947.

(4) Hart, N., Vassar, Michigan. Information on the operation of a vertical hay self-feeder. Private communication. 1950.

(5) Jamieson, J. A. Grain pressures in deep bins. Engineering News 51:236-243. 1904.

(6) Ketchum, M. S. The design of walls, bins and grain elevators. 3d ed. p.324. New York, McGraw-Hill Book Company. 1919.

(7) McCalmont, J. R. and Ashbey, W. Pressures and loads of ear corn in cribs. Agricultural Engineering 15:123-125. 1934.

(8) Michigan Department of Agriculture. Michigan Agricultural Statistics 1950. May 1951.

(9) Morrison, F. B. Feeds and feeding. 21 ed. p.839. Ithaca, The Morrison Publishing Company. 1949.

(10) Reed, C. H. Farm structures designed for the self-feeding of hay and ensilage. Agricultural Engineering. 29:488-9. 1948.

(11) Reed, C. H. Progress report on the developement of structures designed for the self-feeding of hay and ensilage. Department of Agricultural Engineering. Rutgers University. 1950.

(12) U. S. Department of Agriculture. Agricultural Statistics. Washington, U. S. Government Printing Office. 1950.

(13) U. S. Department of Agriculture. Farm production, farm disposition and value of principal crops. Washington, U. S. Government Printing Office. May 1951.

(14) Wright, K. T. Economics aspects of lamb feeding in Michigan. Michigan Agricultural Experiment Station Special Bulletin 284. 1937.

BIBLIOGRAPHY

Barre, H. J. and Sammet, L. L. Farm structures. 1st ed. p.454. New York, John Wiley and Sons, Incorporated. 1950.

Besley, H. E. Self-feeders for hay and silage. Hoards Dairymen 95;259-260. April 10, 1950.

Brodell, A. P. and Carpenter, C. G. Harvesting hay and silage. Washington, U. S. Government Printing Office. 1950.

Brown, G. A. and Blakeslee, L. H. Self-feeding vs. hand-feeding fattening lambs and rations for self-feeding lambs. Michigan Agricultural Experiment Station Special Bulletin 303. 1940.

Brown, L. H., Cargill, B. F. and Bookhout, B. R. Pen-type dairy barns. Michigan Agricultural Experiment Station Special Bulletin 363. 1950.

Carter, E. H. Dairy costs and returns in Detroit milk shed in 1946. Michigan Agricultural Experiment Station Quarterly Bulletin 30:230-236. 1947.

Dial, H. M. Automatic hay feeder. Successful Farming 47:66-67. August, 1949.

Hanson, D. Ten easy ways to feed hay. Successful Farming 48:46-47. March, 1950.

Hanson, D. Work planned cattle feeding system. Successful Farming 48:48-49. October, 1950.

Hart, N., Vassar, Michigan. Information on the operation of a vertical hay self-feeder. Private communication. 1950.

Jamieson, J. A. Grain pressures in deep bins. Engineering News 51: 236-243. 1904.

Ketchum, M. S. The design of walls, bins and grain elevators. 3d ed. p.324. New York, McGraw-Hill Book Company. 1919.

Krueger, W. C. A cattle feeding barn. Southern Agriculture 76:22-23. September, 1946.

McCalmont, J. R. and Ashbey, W. Pressures and loads of ear corn in cribs. Agricultural Engineering 15:123-125. 1934.

Michigan Department of Agriculture. Michigan Agricultural Statistics 1950. May 1951.

Morrison, F. B. Feeds and feeding. 21ed. p.839. Ithaca, The Morrison Publishing Company. 1949.

O'Brien, H. R. Cattle feeders cut costs. Country Gentleman 118:28-29. April, 1948.

Reed, C. H. Farm structures designed for the self-feeding of hay and ensilage. Agricultural Engineering. 29:488-9. 1948.

Reed, C. H. Progress report on the developement of structures designed for the self-feeding of hay and ensilage. Department of Agricultural Engineering. Rutgers University. 1950.

Reed, C. H. Structures for self-feeding of hay and ensilage. Agricultural Engineering 32:375-376.

Schwanz, H. L. Roughage self-feeders cut chores. Country Gentlemen 121:22-23. June, 1951

Shier, G. R., et al. Results of a study of trends in methods of hay storage. Agricultural Engineering 23:349-51. 1942.

U. S. Deoartment of Agriculture. Agricultural Statistics. Washington, U. S. Government Printing Office. 1950.

U. S. Department of Agriculture. Farm production, farm disposition and value of principal crops. Washington, U. S. Government Printing Office. May, 1951.

Witzel, S. A. Chopped hay storage in ventilated containers. Agricultural Engineering 18:251-252. 1937.

Witzel, S. A. Trends in structures for hay and bedding storage. Agricultural Engineering 25: 375-376. 1944.

Wright, K. T. Economics aspects of lamb feeding in Michigan. Michigan Agricultural Experiment Station Special Bulletin 284. 1937.

A P P E N D I X

	Panel Number	1	2	3	4	5	6
	Panel Ht. above bottom of hay	3'-6"	3'-6"	9'-0"	11'-6"	15'-6"	18'-2"
	Size of Test Panel	2'x 2'	2'x 2'	2'x 2'	2'x 2'	2'x 2'	2'x 2'
Upper Left Corner	Short lever arm (in.)	2.25	2.19	2.19	2.12	2.19	2.12
	Long lever arm (in.)	5.0	5.0	5.0	5.0	5.0	5.0
	Mechanical Advantage	2.22	2.28	2.28	2.35	2.28	2.35
	Average weight (lbs.)	6.25	3.37	4.25	0.0	0.0	0.0
	Lever arm force(lbs.)	.80	.82	.82	.85	.82	.85
	Force (lbs.)	14.70	8.50	10.50	.85	.82	.85
Upper Right Corner	Short lever arm (in.)	2.25	2.19	2.12	2.25	2.19	2.12
	Long lever arm (in.)	5.0	5.0	5.0	5.0	5.0	5.0
	Mechanical Advantage	2.22	2.28	2.35	2.22	2.28	2.35
	Average weight (lbs.)	1.0	7.87	4.37	4.12	5.62	2.50
	Lever arm force(lbs.)	.80	.82	.85	.80	.82	.85
	Force (lbs.)	3.02	18.72	11.15	9.95	13.62	5.93
Lower Left Corner	Short lever arm (in.)	2.19	2.19	2.12	2.25	2.19	2.12
	Long lever arm (in.)	5.0	5.0	6.0	7.0	5.0	5.0
	Mechanical Advantage	2.28	2.28	2.82	3.11	2.28	2.35
	Average weight (lbs.)	2.37	6.12	8.25	3.5	3.75	2.62
	Lever arm force(lbs.)	.82	.82	.85	.80	.82	.85
	Force (lbs.)	6.22	14.72	24.05	10.75	9.37	7.00
Lower Right Corner	Short lever arm (in.)	2.19	2.19	2.12	2.25	2.19	2.19
	Long lever arm (in.)	5.0	5.0	6.0	7.0	5.0	5.0
	Mechanical Advantage	2.28	2.28	2.82	3.11	2.28	2.28
	Average weight (lbs.)	6.0	8.12	2.75	0.0	1.0	2.0
	Lever arm force(lbs.)	.82	.82	.85	.80	.82	.82
	Force (lbs.)	14.52	19.32	8.61	.80	3.10	5.38
	TOTAL FORCE (LB.)	38.46	61.26	54.31	22.35	26.91	19.16
	POUNDS PER SQ. FT.	9.62	15.32	13.58	5.59	6.73	4.79
	DEPTH OF HAY (FT.)	23.3	23.3	17.7	15.0	11.2	8.5

COEFFICIENT OF FRICTION TESTS OF CHOPPED HAY ON FIVE COMMON BUILDING MATERIALS

MATERIAL	Hay Number 1		Hay Number 2		Hay 1 and 2	
	Av. θ°	u' = tan θ	Av. θ°	u' = tan θ	Av. θ°	u' = tan θ
Rough sawn lumber parallel to grain	30.2	.582	29.6	.568	30.0	.577
Rough sawn lumber perpendicular to grain	33.0	.649	30.5	.589	32.2	.630
Finished lumber parallel to grain	24.4	.454	20.8	.380	23.2	.429
Finished lumber perpendicular to grain	24.8	.462	22.8	.420	24.1	.447
Plywood parallel to grain	19.9	.362	17.4	.313	19.0	.344
Corrugated galvanized iron parallel to corr'.	23.6	.437	22.0	.404	23.0	.424
Corrugated galvanized iron perpendicular to corr'.	32.6	.640	31.9	.622	32.4	.626
Smooth galvanized iron	21.8	.400	21.6	.396	21.8	.400