1946

Mechanical unloading of chopped forages

Walter Monroe Carleton

Iowa State College

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MECHANICAL UNLOADING OF CHOPPED FORAGES

by

Walter Monroe Carleton

A Thesis Submitted to the Graduate Faculty for the Degree of

MASTER OF SCIENCE

Major Subject Agricultural Engineering

Signatures have been redacted for privacy

Iowa State College
1946
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Table 9. Analysis of Variance. Tons per Hour

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Table 11. Summary of Data for Two Rear-Unloading Procedures

Table 12. Analysis of Variance. Minutes Unloading Time

Table 13. Analysis of Variance. Tons per Hour

Table 14. Analysis of Variance. Tons per Man Hour
INTRODUCTION

The handling of chopped forages involves a large expenditure of labor. Chopped forages include both chopped hay and silages. Woodward (8) states that some 40,000,000 acres of silage have been harvested annually in this country and that approximately 98 per cent of the silage is made from corn or sorghums. United States Department of Agriculture statistics (6) show the following:

Table 1.
Corn Silage Production in 1000 Tons

<table>
<thead>
<tr>
<th>Crop Year</th>
<th>Iowa</th>
<th>U. S. A.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1940</td>
<td>1,650</td>
<td>34,173</td>
</tr>
<tr>
<td>1941</td>
<td>1,720</td>
<td>34,119</td>
</tr>
<tr>
<td>1942</td>
<td>1,407</td>
<td>33,803</td>
</tr>
<tr>
<td>1943</td>
<td>2,117</td>
<td>35,028</td>
</tr>
</tbody>
</table>

Since the advent of the field chopper the silage harvest has been mechanized with the exception of unloading, most of which is still accomplished by the hand method. The Iowa Agricultural Experiment Station has been engaged since the summer of 1940 in research work on silage handling. One of the objects of
this research has been to test the value of existing methods of unloading and to devise new and better ones. The subject is of great interest to farmers as evidenced by the large number of letters received by the Agricultural Engineering Department requesting information. The lack of information on this subject is indicated by the small number of references located.

Most of the forage unloading equipment developed to date has been farmer devised and built. The methods that have been used may be classified according to the manner in which the material is removed from the trailer:

A. Gravity slide
   Trailer tilted to rear by hydraulic cylinders, mechanical means, or by a conventional wagon hoist

B. Power slides
   1. Movable endgates
   2. Winch-powered forks

C. Removable bottoms
   1. Woven-wire bottoms
   2. Canvas aprons

D. Movable trailer bottoms
   1. Chain drag bottom
   2. Roller-canvas bottom

E. Hand unloading with conventional silage fork
HISTORY

Feed was preserved as silage in northern Europe centuries ago (8), but not until the middle of the nineteenth century did it become well known. In the United States the construction of the first silo has been credited to F. Morris of Maryland in 1876 (8).

The common method of making silage has been to cut the feed with a corn binder and haul the bundles to the silo where they were pitched into a stationary cutter. This was exceedingly arduous work. With the introduction of the field chopper the chopped forage was hauled to the silo or barn and pitched into a stationary blower. Various methods of mechanically unloading the chopped forage have been tried by farmers as well as by a number of the agricultural engineering departments of various colleges.

In 1940 the Iowa Agricultural Experiment Station instituted project number 700, entitled, Methods and Equipment for Harvesting, Processing, and Storing Corn Silage. This project has been carried on since that time with the exception of a short period during the war. Various methods of unloading have been developed and tried and are described in later sections.
REVIEWS OF LITERATURE

A search of the literature reveals that very little has been published on either unloading methods or evaluation of methods. The references found were usually short paragraphs in popular journals with a description and picture of an unloading trailer which had been devised by an ingenious farmer.

Davidson, Shedd, and Collins (2), reporting on labor duty in the harvesting of silage, compared the corn binder and stationary cutter method with the field chopper and stationary blower method and gave data on unloading. Table 2 shows the labor required by the binder method, while Table 3 gives the labor by the field chopper method. The silage was removed at the rear of the trailers by hand forking.

Table 2.
Labor to Harvest Silage by Binder Method*

<table>
<thead>
<tr>
<th>Man Hours</th>
<th>Per Acre</th>
<th>Per Ton</th>
<th>Per Cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting</td>
<td>0.8</td>
<td>0.08</td>
<td>3.8</td>
</tr>
<tr>
<td>Loading</td>
<td>11.7</td>
<td>1.11</td>
<td>53.7</td>
</tr>
<tr>
<td>Hauling and Unloading</td>
<td>7.0</td>
<td>0.66</td>
<td>32.1</td>
</tr>
<tr>
<td>Feeding</td>
<td>2.3</td>
<td>0.22</td>
<td>10.5</td>
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<tr>
<td>Total</td>
<td>21.8</td>
<td>2.07</td>
<td>100.0</td>
</tr>
</tbody>
</table>

*Taken from Davidson, Shedd, and Collins (2, Table 1, p. 293)
Table 3.
Labor to Harvest Silage by Field Chopper Method*

<table>
<thead>
<tr>
<th>Man Hours</th>
<th>Per Acre</th>
<th>Per Tone</th>
<th>Per Cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvesting</td>
<td>1.7</td>
<td>0.13</td>
<td>11.0</td>
</tr>
<tr>
<td>Hauling</td>
<td>5.1</td>
<td>0.39</td>
<td>33.0</td>
</tr>
<tr>
<td>Unloading</td>
<td>8.5</td>
<td>0.65</td>
<td>56.0</td>
</tr>
<tr>
<td>Total</td>
<td>15.3</td>
<td>1.17</td>
<td>100.0</td>
</tr>
</tbody>
</table>

*Taken from Davidson, Shedd, and Collins (2, Table 2, p. 293)

It was observed, as shown in Table 3, that 56 per cent of the total time required was due to unloading. A technique with the field chopper method was devised, utilizing trailers with hinged sides, a conveyor the length of the trailer for side-unloading, and an automatic winch and drag fork for pulling the silage from the trailer. Table 4 gives the results of trials with the modified technique. The unloading labor was reduced from .65 to .09 man hours per ton.

Wardle (7) reported on the time required to unload silage by two methods used by the Iowa State College Farm Service during the 1945 season. Data from these tests are shown in Table 5. Three men were employed in each of the methods.

Jones and Smith (3), reporting on silage harvest by the binder and stationary chopper method, found the labor expenditure for loading, hauling, and feeding the cutter, to be 1.54 man hours per ton.
Table 4.

Labor to Harvest Silage by Field Chopper Method with Modified Technique *

<table>
<thead>
<tr>
<th>Man Hours</th>
<th>Per Acre</th>
<th>Per Ton</th>
<th>Per Cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvesting</td>
<td>0.8</td>
<td>0.09</td>
<td>20.0</td>
</tr>
<tr>
<td>Hauling</td>
<td>2.4</td>
<td>0.27</td>
<td>60.0</td>
</tr>
<tr>
<td>Unloading</td>
<td>0.8</td>
<td>0.09</td>
<td>20.0</td>
</tr>
<tr>
<td>Total</td>
<td>4.0</td>
<td>0.45</td>
<td>100.0</td>
</tr>
</tbody>
</table>

*Taken from Davidson, Shedd, and Collins (2, Table 3, p. 294)

Table 5.

Man Hours per Ton to Unload Silage

<table>
<thead>
<tr>
<th>Method</th>
<th>Man Hours per Ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side-Unloading with Power</td>
<td></td>
</tr>
<tr>
<td>Operated Canvas Aprons</td>
<td>0.192</td>
</tr>
<tr>
<td>Side-Unloading with Hand Forks</td>
<td>0.138</td>
</tr>
</tbody>
</table>

* Calculated from original data.
OPERATION OF CERTAIN TYPES
OF MECHANICAL UNLOADING UNITS
OTHER THAN THOSE USED IN THE EXPERIMENTAL WORK

There were a number of unloading methods not included in the experimental work that were being used by individual farmers. A description of several of these units follows in order that a clearer picture may be obtained of the possibilities for mechanical unloading. The variety of the units in service indicated the unsolved nature of the unloading problem and also emphasized the farmer's ingenuity in trying to eliminate arduous hand unloading.

Hydraulic Dump

A hand-operated hydraulic dump is shown in Fig. 1. In operation the bed is tilted by action of the heavy duty hydraulic jack working through linkages to multiply the movement. This type of unit usually has insufficient slope to cause either chopped hay or silage to slide to the rear. An advantage to be gained in the use of this type of equipment is that other products such as small grains may be unloaded readily without modification of the equipment and without the use of outside power units. The disadvantage of this type of
equipment as compared to a conventional wagon hoist is that one dump unit must be purchased for each trailer or wagon used.

Cable Dump Trailer

A mechanically operated tilting trailer is shown in Fig. 2. In operation the trailer is tilted to the rear by a cable which is wound around a drum connected to a hand crank. Other units similar to this have been made to be operated by the tractor power take-off.

Chain-Drag Trailer

Fig. 3 shows an unloading trailer equipped with a movable chain drag which operates in the bottom of the trailer. In operation the chain drag is driven through proper speed reducers by the tractor power take-off, causing the load to move to the rear. An interesting feature of this trailer is that in plan view the trailer bed tapers from rear to front. This was accomplished by making the sloping sides wider at the rear than at the front. This taper helps to prevent wedging of the silage as the load moves to the rear.
Modified Manure Spreader

A modified power take-off manure spreader used for unloading chopped forages is shown in Fig. 4. An endgate has been substituted for the beater which has been removed. The unit operates from the tractor power take-off.

Modified Hay Fork

Davidson, Shedd, and Collins (2) used a modified hay fork to unload silage. This fork was pulled by an automatic winch as shown in Fig. 5. The drag fork was made from one-half of a six-tined grapple hay fork. In finishing the unloading a scraper board was placed over the teeth to scrape the load clean from the trailer box. The winch was controlled by knots on the drag rope. By taking up a few feet of slack, a knot on the drag rope running through a fork actuated a clutch on the winch. Another knot threw the clutch out at the end of the desired length of travel.

The labor required for the winch and the drag fork method as compared to pitching the silage out by hand was as follows:
Fig. 1. Trailer Equipped with Hydraulic Hand-Operated Unloading Device

Fig. 2. Trailer Equipped with Hand-Operated Cable Unloading Device
Fig. 3. Rear-Unloading Trailer Equipped with Power-Operated Chain Drag

Fig. 4. Manure Spreader Modified as Rear-Unloading Trailer
# Table 6.

<table>
<thead>
<tr>
<th>Method</th>
<th>Man Hours Per Ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch Out by Hand</td>
<td>0.65</td>
</tr>
<tr>
<td>Drag Fork</td>
<td>0.09</td>
</tr>
</tbody>
</table>

A close-up view of the winch is shown in Fig. 6.
Fig. 5. Experimental Fork and Automatic Winch for Unloading Chopped Forages

Fig. 6. Experimental Automatic Winch Used for Forage Unloading
SURVEY OF FARMER-BUILT UNLOADING UNITS

As stated in the review of literature a number of farmers have constructed units for unloading chopped forages. Several farms were visited to view these units in action.

Pivoted Auger on Blower

W. D. Caldwell of Prairie City, Iowa, has devised an unloading scheme utilizing a special blower-elevator and special trailers. Fig. 7 shows the blower with the auger at a right angle to operating position. At this angle the trailers may be located for unloading with very little backing. Fig. 8 shows the trailer driven into unloading position.

The auger was pivoted on a ball and socket joint at the blower while the outer end was mounted on a small pneumatic tired wheel. The axle of the wheel was mounted on an eccentric. When the handle shown was pulled to the rear the outer end of the auger was lifted free of the ground and the auger was then easily moved into or out of operating position. The length of the auger was such that approximately seven and one-half feet extended beyond the blower housing when the auger was in operating position. This was important since it was not necessary for the driver to exercise undue care when driving in a load
Fig. 7. Forage Blower-Elevator Built by W. D. Caldwell of Prairie City, Iowa

Fig. 8. Unloading and Elevating Silage at the W. D. Caldwell Farm
of forage. An unusual feature of this homemade blower was
that it was mounted directly on the tractor and driven through
belts and chains from the tractor power take-off. It has been
used successfully for several seasons on both chopped hay and
silage.

Data were taken on several loads of silage. No scales
were available for weighing loads but, according to Caldwell,
similar loads in the past had weighed approximately two tons
each. Unloading times averaged 5.2 minutes per load. It was
noted that the trailers upon arrival from the field were
driven into place and the unloading operation started in a very
short time. The operation of placing the trailer into unloading
position has been called "stationing." Stationing times
for the Caldwell trailers averaged a little less than 1 minute
each for the loads tested.

Sliding End in Trailer

M. K. Avery of Mason City, Iowa, unloaded silage with the
unit shown in Fig. 9. This unit was about as simple and inex-
pensive as any unit that could be made. The sliding end, which
was used to pull the silage to the rear, consisted simply of one-
inch boards bolted to two pieces of wagon tire iron which were
bent at right angles. Iron braces were added to prevent
straightening of the wagon tire irons when removing the load.
The operation of the unit was as follows: the blower shown in Fig. 10 had a conveyor unit which pivoted at the blower, so that the outer end could be raised until the conveyor was in a vertical position. The trailer of silage was then pulled into place and the conveyor lowered. The tractor remained hitched to the trailer and the brakes on the tractor were set so that it would not move when the load of silage was being pulled to the rear. In the meantime a second tractor shown at the right in Fig. 10 was backed into place and the log chain attached to the tractor was hooked into a loop in the cable attached to the movable end in the wagon. The back endgate of the silage trailer was removed and the tractor operator pulled the silage to the rear at a speed suitable to the capacity of the blower. At least one man was employed at the rear end of the wagon to assure an even flow of silage into the blower, since the silage tended to fall off in large chunks.

Data on unloading were taken for several loads. The trailer boxes were of the conventional flare type capable of holding approximately one hundred bushels of grain. Unloading times average 5.4 minutes per load. No facilities were available for weighing the loads. Stationing time averaged a little less than 1 minute per load.
Fig. 9. Chopped Forage Unloading Equipment Built by Merrill Avery of Mason City, Iowa.

Fig. 10. Unloading Silage at the Merrill Avery Farm
Trailer Tilted by Converted Buck Rake

A third farmer-built unit is shown in Fig. 11. The essential feature of the unit was the farm truck which was previously converted to a power buck rake for moving hay. The carrying platform was removed when unloading silage. The load of silage was stationed in place by the tractor which brought it from the field, after which the truck was backed up to the load and a chain from each buck arm was attached to the front wheels of the trailer. The power mechanism then raised the front end of the trailer and it was backed into place at the blower. This did not elevate the front end of the trailer sufficiently to cause the silage to slide to the rear, but the operators believed it reduced the heavy labor enough to justify its use.
EXPERIMENTAL PROCEDURE

Objectives of Tests

The objectives of this investigation were:

A. The design and construction of experimental equipment required for mechanical unloading of chopped forages
   1. Roller-canvas bottom trailer for rear unloading
   2. Movable-endgate trailer for rear unloading
   3. Power unit for roller-canvas trailer
   4. Power unit for movable-endgate trailer

B. Test and evaluation of various methods for unloading chopped forages
   1. Power rear-unloading compared to power side-unloading
   2. Power side-unloading compared to side-unloading by hand

C. Evaluation of equipment used and suggestions for improvements

Selection of Test Procedures

The Iowa State College Farm Service harvests each year approximately 2,000 tons of silage. Since only a little
chopped hay is harvested annually, it was decided to compare methods of unloading corn silage. After consideration of available methods it was decided that comparative tests would be run on the following:

- **Power side-unloading.** Side-unloading by canvas aprons operated by a power winch.
- **Hand side-unloading.** Side-unloading by hand fork.
- **Rear-unloading.**
  1. With movable-endgate in trailer
  2. With a roller-canvas bottom in trailer

**Equipment**

**Unloading platform and conveyor**

The unloading platform and conveyor shown in Fig. 12 was developed by the Iowa Agricultural Experiment Station. In order that the number of trailers hauling silage could be reduced to a minimum, it was desired that the conveyor be large enough that a trailer load of silage could be dumped at one time. The trailer could then immediately return to the field after another load. Previous designs of the silage conveyor are shown in Figs. 13 and 14.

**Conveyor drive**

Fig. 15 shows the experimental drive developed for the
Fig. 11. Unloading Silage at the Victor Hueneman Farm Near Garner, Iowa. A Truck Buck Rake Was Used to Raise the Front End of the Trailer.

Fig. 12. Experimental Unloading Platform and Conveyor Used by the Iowa State College Farm Service During the 1946 Silage Harvest
Fig. 13. Experimental Unloading Platform and Conveyor Used by the Iowa State College Farm Service During the 1945 Silage Harvest

Fig. 14. Experimental Unloading Conveyor Used by the Iowa State College Farm Service During the 1941 Silage Harvest
conveyor shown in Fig. 12. The car transmission was driven from the blower shaft by a V-belt drive. The transmission operated the conveyor through a telescoping torque tube and served both as a clutch and a speed change device. The conveyor was started or stopped merely by pushing the transmission into or out of gear.

**Machines for side-unloading**

The complete system of machines for side-unloading with canvas aprons is shown in Fig. 16. This system was developed by Professor E. L. Barger of the Iowa Agricultural Experiment Station. The wire shown at (a) was used as a "load-splitter", since it was found desirable to divide the load before the canvasses were pulled sideways. Each canvas had a 3-inch loop in one end and an 8-inch loop in the other end. A 3/4-inch pipe was passed through the 3-inch loop and the pipe was attached to the top edge of the hinged side of the trailer by pipe straps. A 2-by 4-inch board was passed through the 8-inch loop and a clevis was attached to the 2-by 4-inch board.

The unit operated as follows: The trailer was pulled beside the conveyor, and the hinged side was lowered onto the conveyor. The rope from the hoist unit was used to pull the load-splitter through the load. This removed considerable silage and effectively divided the load so that the canvasses
Fig. 15. Car Transmission Mounted on Blower-Elevator. Transmission Served as Experimental Drive for Conveyor Shown in Fig. 12.

Fig. 16. Complete Experimental System of Machines for Side-Unloading Chopped Forages
could be pulled sideways one at a time to remove the remainder of the load.

**Power unit for side-unloading**

Fig. 22 shows in greater detail the power unit for unloading silage. The engine (a) was a one-cylinder, four-cycle, air-cooled engine rated at approximately 5 horsepower. No trouble was experienced with lack of power from this unit. The engine was mounted on slides and could be moved along the slides by the lever (b). Lever (b) was held in position by the sector (c). A conventional hay hoist shown at (d) was driven by means of V-belts from the engine. A car transmission is shown at (e). By means of the engine slides the belts could be changed from the hoist to the transmission pulley. The unit could then also be used to power a torque tube in much the same manner as a tractor power take-off.

**Roller-canvas bottom trailer**

The rear-unloading trailer as equipped with a roller-canvas bottom for the experimental work is shown in Figs. 17 and 18. In operation the canvas was rolled to the rear and wrapped around the large pipe to which it was attached. This pipe was turned by the power unit shown in Fig. 19. The power unit remained stationed at the unloading location and connection
Fig. 17. Experimental Roller-Canvas Bottom Trailer Used for Rear-Unloading of Chopped Forages

Fig. 18. Unloading Silage with the Roller-Canvas Bottom Trailer
was made to the trailer by a telescoping tube with universal joints.

A commercial roller-canvas bottom trailer is manufactured by the Mallory Manufacturing Company of Chapin, Iowa. The original Mallory unloading trailer was a farmer-built unit developed while the present manufacturers were engaged in the farming business. So far as could be determined the Mallory unit was the only one in commercial production.

**Power unit for roller-canvas trailer**

A speed reducer and power unit designed and developed to deliver a high torque at approximately two revolutions per minute is shown in Figs. 19 and 20. Operation of the unit was as follows:

Engine pulley (a) drove large V pulley (b). Pulley (b) was attached to a hollow shaft (c) (not visible). Chain (j) drove sprocket (h) and shaft (g). Sprocket (f) was also attached to (g) and turned sprocket (d) through chain (e). Sprocket (d) was keyed to a shaft (k) which turned inside hollow shaft (c). Crankshaft (l) was keyed to shaft (k) and operated connecting rod (m). Connecting rod (m) operated dog (n) which turned ratchet wheel (o). Telescoping torque tube (p) was keyed to shaft (q) which received power from ratchet wheel (o). Slide (r) was adjustable over the ratchet
Fig. 19. Right-hand View of Experimental Speed-Reducing Power Unit for Removing Chopped Forages from Rear-Unloading Trailers

Fig. 20. Left-hand View of Experimental Speed-Reducing Power Unit for Removing Chopped Forages from Rear-Unloading Trailers
wheel by means of a lever (s). Lever (s) could be set along sector (t) in any one of six positions so that dog (n) would cause a movement of ratchet wheel equal to the movement of either 0, 1, 2, 3, 4, or 5 teeth. Dog (u) prevented backward rotation of ratchet wheel (o).

The power unit was equipped with a two-cycle, one-cylinder Johnson Ultimotor as shown, and tests indicated the unit to be capable of exerting torque varying from approximately 1,100 inch pounds when operating five teeth to approximately 2,900 inch pounds when operating one tooth. Torque was determined by loading the reducer to stalling speeds of the engine. Fig. 21 shows the approximate variation in torque output of the reducer.

![Graph showing torque output vs. number of teeth movement per revolution.](image)

**Fig. 21.** Torque Output of Power Unit Shown in Fig. 19.
Since pulley (a) had a pitch diameter of 3.5 inches, pulley (b) a pitch diameter of 9.5 inches, sprockets (d) and (h) 35 teeth, sprockets (i) and (f) 14 teeth, and ratchet wheel (c) 75 teeth, and since the dog (n) could operate the ratchet wheel either 1, 2, 3, 4, or 5 teeth per crankshaft revolution, the following speed ratios were possible: 1275/1, 637/1, 425/1, 319/1, and 255/1.

Field tests of the reducer unit showed the Johnson Ultimate motor to have insufficient power to operate the unloading trailer shown in Fig. 17. A 1.5 horsepower Fairbanks Morse engine was installed as shown in Fig. 23 and found to provide ample power. Wheels and handles were added to simplify moving the unit when desired.

**Sliding-endgate trailer**

Fig. 25 shows the experimental trailer with the movable endgate slide as developed for the experimental work. The principle of the sliding-endgate method was described in a Purdue University Extension Service leaflet.

In operation the slide was moved to the rear as the two cables attached to it were wrapped around the 3-inch pipe across the rear of the wagon. The ratchet speed reduction device designed and developed for this trailer is shown in Fig. 25. Its operation was as follows:
Fig. 22. Experimental Power Winch Used for Side-Unloading of Chopped Forages. The Complete Side-Unloading System Is Shown in Fig. 16.

Fig. 23. Experimental Speed-Reducing Power Unit Equipped with One and One-half Horsepower Engine
Crankshaft (a) was driven by a torque tube which furnished a speed of approximately 50 revolutions per minute. Crankshaft (a) drove connecting rod (b) and ratchet arm (c). The number of teeth by which the ratchet wheel was advanced each revolution of the crankshaft depended upon the position of the mechanism (d) and this position could be varied at the sector (e). Since the number of teeth in the ratchet wheel was 77 and the number of teeth advanced per crankshaft revolution could be varied from 1 to 5, the following speed reductions were possible: 77/1, 77/2, 77/3, 77/4, and 77/5. The ratchet wheel was directly connected to a 3.5-inch outside diameter pipe to which were fastened two 5/16-inch wire cables. The other ends of the cables were fastened to the movable front end. As the ratchet wheel rotated the cables were wound around the pipe and the slide was drawn to the rear, forcing the forage out of the trailer. With a torque tube turning the crankshaft at 50 revolutions per minute, calculations show that an unloading time of approximately 3.6 minutes may be expected. If a gasoline engine were used as the source of power, the torque tube revolutions per minute and the unloading times could be varied considerably.

**Power unit for sliding-endgate trailer**

The rear-unloading mechanism shown in Fig. 25 required a torque shaft speed of approximately 50 revolutions per minute.
Fig. 24. Experimental Sliding-Endgate Trailer Used for Unloading Chopped Forages

Fig. 25. Experimental Variable-Speed-Reducing Device Used on Sliding-Endgate Trailer
Fig. 26 shows the speed reducer and power unit designed to furnish the required torque shaft speed. This unit was attached to a small Handiman tractor as shown and was equipped with a V-belt clutch so the power unit might be operated at will when the tractor engine was running. The operation of the unit was as follows:

Engine pulley (a) was directly connected to the engine crankshaft. When lever arm (b) was raised the housing pressed onto the outer race of the ball bearing (c), came into contact with the idler side of the V-belt and caused it to transmit power to the large V-pulley (d). Pulley (d) turned a worm-gear speed reducer (e) which transmitted power to the telescoping torque tube (f). Torque tube (f) then powered the unloading trailer equipped with the sliding front. Since pulley (a) had a pitch diameter of 3.5 inches, pulley (d) a pitch diameter of 14" inches, and the worm-gear speed reducer a velocity ratio of 11.5/1, the ratio of engine revolutions per minute to torque tube revolutions per minute was 46/1. An engine speed of 2,300 revolutions per minute then gave the required 50 revolutions per minute of the torque tube.

Side-unloading trailer

Fig. 27 shows the trailer designed and built by the Iowa Agricultural Experiment Station to simplify unloading. One
Fig. 26. Experimental Speed-Reducing Device Mounted on HANDIMAN Tractor. Device Served as Power Unloading Unit for Rear-Unloading Trailer Shown in Fig. 24.

Fig. 27. Experimental Silage Trailer Designed by Iowa State College Agricultural Engineering Department
side was hinged and could be let down onto a conveyor as shown. Plans for this trailer were published as Agricultural Engineering Plan Sheet No. 4.

Test Procedure

Data on the different unloading procedures were taken during the regular silage harvest. Weights were taken on the loads of silage. It was not considered feasible to run a complete time study on the silage harvesting operation. It was considered more desirable to obtain complete data on the unloading operation, including time to station the trailer and time required for unloading. All data in the first series of tests were taken when unloading into a regular John Deere No. 2 blower-elevator.

The rear-unloading equipment was tested near the end of the season with a modified John Deere No. 2 blower-elevator. The feed auger in this blower turned twice as fast as in the original and the number of fan blades was decreased from eight to four. The same items of data for rear-unloading were taken in connection with this blower as were taken with the regular blower. Tests indicated that the modified blower was capable of elevating more than twice as many tons per hour as the regular blower. This capacity provided a
means of determining if the blower capacity had any effect on unloading time.

A two-man crew was required to operate the rear unloading unit while a three-man crew was used for the hand forking and the canvas apron unloading units.
RESULTS

Classification of Data

The data were divided into three classifications: minutes unloading time, tons per hour, and tons per man hour, for each of the three procedures used with the regular blower-elevator. The data for rear-unloading into the modified blower were likewise divided into three classifications to be compared with rear-unloading into the original blower.

Summary of Data for Three Unloading Procedures with Original Blower-Elevator

Table 7.

Summary of Data for Three Unloading Procedures

Procedure 1. Three men forking silage off side of trailer, hinged side down
Procedure 2. Canvas aprons, side-unloading, three men
Procedure 3. Rear-unloading with power unit, two men

<table>
<thead>
<tr>
<th>Item</th>
<th>Procedure 1</th>
<th>Procedure 2</th>
<th>Procedure 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Loads</td>
<td>5</td>
<td>41</td>
<td>20</td>
</tr>
<tr>
<td>Average Weight of Loads</td>
<td>3.29</td>
<td>3.26</td>
<td>2.55</td>
</tr>
<tr>
<td>Average Minutes Unloading</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Tons per Hour</td>
<td>17.84</td>
<td>17.62</td>
<td>15.68</td>
</tr>
<tr>
<td>Average Tons per Man</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hour</td>
<td>5.96</td>
<td>5.88</td>
<td>7.81</td>
</tr>
</tbody>
</table>

2 men 1 man
Analysis of variance

The analysis of variance relating to each classification of data, calculated as per Snedecor (6), is shown in Tables 8, 9, and 10. A double asterisk indicates a significant value of F beyond the 1% point.

Table 8.
Analysis of Variance. Minutes Unloading Time.
Three Procedures for Unloading Silage.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Loads for Three</td>
<td>63</td>
<td>19.8</td>
</tr>
<tr>
<td>Procedure Means</td>
<td>2</td>
<td>4.92</td>
</tr>
<tr>
<td>Total</td>
<td>65</td>
<td>---</td>
</tr>
</tbody>
</table>

\[ F = \frac{4.92}{19.8} = .248 \quad F > 3.14 \]  

Table 9.
Analysis of Variance. Tons per Hour.
Three Procedures for Unloading Silage.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Loads for Three</td>
<td>63</td>
<td>23.65</td>
</tr>
<tr>
<td>Procedure Means</td>
<td>2</td>
<td>19.27</td>
</tr>
<tr>
<td>Total</td>
<td>65</td>
<td>---</td>
</tr>
</tbody>
</table>

\[ F = \frac{19.27}{23.65} = .815 \quad F > 3.14 \]
Table 10.
Analysis of Variance. Tons per Man Hour.
Three Procedures for Unloading Silage.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Loads for Three: Procedures</td>
<td>63</td>
<td>2.24</td>
</tr>
<tr>
<td>Procedure Means</td>
<td>2</td>
<td>25.90 **</td>
</tr>
<tr>
<td>Total</td>
<td>65</td>
<td>---</td>
</tr>
</tbody>
</table>

\[ F = \frac{25.90/2.25}{11.56} = 3.14 \]

Summary of Data for Two Rear-Unloading Procedures with Modified Blower-Elevator

Table 11.

Summary of Data for Two Rear-Unloading Procedures

Procedure 1. Rear-unloading into original blower, two men
Procedure 2. Rear-unloading into modified blower, two men

<table>
<thead>
<tr>
<th>Item</th>
<th>Procedure 1</th>
<th>Procedure 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Loads</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>Average Weight of Loads in Tons</td>
<td>2.55</td>
<td>2.29</td>
</tr>
<tr>
<td>Average Minutes Unloading:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time per Load</td>
<td>10.25</td>
<td>3.84</td>
</tr>
<tr>
<td>Average Tons per Hour</td>
<td>15.68</td>
<td>35.96</td>
</tr>
<tr>
<td>Average Tons per Man Hour</td>
<td>7.81</td>
<td>17.96</td>
</tr>
</tbody>
</table>
Analysis of variance

The analysis of variance relating to each classification of data is shown in Tables 12, 13, and 14.

Table 12.
Analysis of Variance. Minutes Unloading Time.
Two Procedures for Rear-Unloading.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Loads for Two</td>
<td>23</td>
<td>4.43</td>
</tr>
<tr>
<td>Procedures</td>
<td>23</td>
<td>15.78</td>
</tr>
<tr>
<td>Procedure Means</td>
<td>1</td>
<td>1645.39 **</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td>---</td>
</tr>
</tbody>
</table>

\[ F = \frac{1645.39}{15.78} = 104.27 \quad F_{0.05} = 4.28 \]

Table 13.
Analysis of Variance. Tons per Hour.
Two Procedures for Rear-Unloading.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Loads for Two</td>
<td>23</td>
<td>15.78</td>
</tr>
<tr>
<td>Procedures</td>
<td>23</td>
<td>1645.39 **</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td>---</td>
</tr>
</tbody>
</table>

\[ F = \frac{1645.39}{15.78} = 104.27 \quad F_{0.05} = 4.28 \]
Table 14.

Analysis of Variance. Tons per Man Hour.

Two Procedures for Rear-Unloading.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Loads for Two:</td>
<td>23</td>
<td>2.69</td>
</tr>
<tr>
<td>Procedures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Procedure Means</td>
<td>1</td>
<td>437.3 **</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td>---</td>
</tr>
</tbody>
</table>

\[ F = 437.3/2.69 = 151.3 \quad F_{.05} = 4.28 \]

Power Unit for Rear-Unloading

The power unit, shown in Fig. 22, used for rear-unloading was not considered entirely suitable, although the speed reduction was sufficient and the method for varying the speed of the low speed shaft was satisfactory. A study of the mechanism will show that the load applied to the ratchet wheel acted only for a short period during the connecting rod stroke. This action resulted in a mechanical advantage much less than the ratio of engine revolutions per minute to low speed shaft revolutions per minute. It was necessary to use a larger engine power unit than would have been required if the power had been applied to the low speed shaft in a steady manner. Another disadvantage of this type of reduction unit was that
the power was applied to the low speed shaft very suddenly and resulted in a high shock load. It was noted that the 2- by 9-inch oak board to which the unit was bolted tended to flex considerably each power stroke and some trepidation was experienced concerning the life of the unit parts. Some method of speed reduction was desirable that would have:

1. Permitted the power to be applied to the slow speed shaft at a steady rate
2. Permitted the speed of the slow speed shaft to be varied within a range of approximately 1 to 6 revolutions per minute independently of the engine revolutions per minute.
3. Permitted the slow speed shaft to be stopped immediately when desired without stopping the engine

**Rear-Unloading Trailer with Roller-Canvas Bottom**

The rear-unloading trailer equipped with the roller-canvas bottom as shown in Fig. 17 was satisfactory with a few minor exceptions. The canvas should be of one-piece construction, since the seams form a roll of larger diameter when wrapped around the pipe. This large roll puts all the strain along the seams and stretches the canvas more at these places. The canvas then will not lie flat when pulled back into the trailer bed.
Another disadvantage of the canvas roll is that the canvas tends to shrink both along the length and width. Although the canvas used was of the waterproof type, it decreased in width during use. This shrinkage in itself is not serious. However, it was observed that when the trailer was not cleaned thoroughly along the edges of one load, the remaining silage lying under the canvas tended to be carried backward during the next unloading operation and became wrapped in between the rolls of canvas. This resulted in damage, since the bulges created by the silage caused the canvas to rub between the roll and the rear end of the trailer.

Torque measurements were taken to determine the force required to start the full load of silage moving to the rear. It was found that approximately 100 pounds were required at the end of a 60-inch lever to start the load to moving. Since the pipe was approximately 3.5 inches outside diameter, the pull on the canvas is calculated to be about 3,500 pounds for a load of about 2.5 tons. Tests performed later after the silage had dried somewhat showed the torque required had dropped from 6,000 inch-pounds to about 2,900 inch-pounds.

Rear-Unloading Trailer with Sliding-Endgate

The rear-unloading trailer equipped with the endgate slide is shown in Fig. 24. It was found that in operation the endgate
slide tended to tip slightly to the rear. This tipping placed a great deal of weight on the back points of the end-gate slide braces and caused the boards in the bottom of the trailer to give downward. Two strips of metal 1/8-inch thick and 4 inches wide were placed along the trailer floor for support. No further difficulty was experienced due to floor failure.

Torque measurements were taken at the same time as those on the roller-canvas bottom trailer. The torque was found to be in excess of 7,500 inch-pounds which was the limit of the measuring equipment. Since the pipe around which the cable was wound was 3.5 inches outside diameter, a pull on the slide in excess of 4,300 pounds is indicated. A later test taken at the same time as the 2,900 inch-pound measurement on the roller-canvas trailer showed the torque required to be about 5,000 pounds. This indicated a pull of about 2,850 pounds required on the slide to remove the corn silage during the latter part of the season when the corn was drier.
SUGGESTED ADDITIONAL INVESTIGATIONS

Economic Study of Unloading Units

A detailed economic study of the unloading of farm products in general and chopped forages in particular could well be made. No attempt has been made to compare costs of unloading by the various procedures discussed in this work due to the fact that a great deal of the equipment was experimental and no reliable equipment costs were available. An economic study should consider such factors as:

1. Number tons yearly forage production
2. Number men available for labor during forage season
3. Equipment investment
4. Ease of operating each type equipment
5. Other uses for the mechanical unloading equipment
6. Farm crop schedule
7. Mechanical ability of farmer
8. Economic status of farmer

Study of Field Choppers

A study of field chopper performances should be made in order that the over-all performance of the forage-harvesting
equipment could be improved. In the experimental work it was frequently observed that loaded trailers congregated at the blower, leaving the field chopper idle. At other times the blower would be idle. Davidson (1) points out that the output of a machine (or combination of machines) is not necessarily proportional to its size. McKibben (4) states that as the capacity of field machines is increased, the penalty for adverse field conditions, inferior construction, and careless operation, and the reward for superior construction, and efficient operation and maintenance increases. Since the silage operation requires the use of a large number of units of machinery which are dependent on each other, the over-all performance of the combination is greatly affected by the individual performances.

Power Unit for Rear-Unloading

Additional experimental work is needed to develop a more satisfactory speed reducer to power the rear-unloading wagons. As stated in the results, the ratchet type reducer used in the experimental work was unsatisfactory. Results of the experimental work indicate that the reducer unit should be capable of supplying a variable speed of approximately 1 to 6 revolutions per minute as well as a ready means of stopping the slow speed shaft independently of the source of power. The power
should be applied to the slow speed shaft at a steady rate to prevent shock loading and to keep the power requirement as small as possible.

Forage Elevator Study

The modified blower-elevator greatly affected the performance of the unloading units. Additional work on forage elevators is needed. In addition to power and capacity requirements of elevators some thought should be given to the auger or conveyor attached to the elevator. Trial of an auger similar to that used so successfully on the Caldwell blower shown in Fig. 7 is recommended.
CONCLUSIONS

1. There was no evidence from these investigations that the unloading time or the tons per hour differed with the three unloading procedures used with the original blower.

2. There was an important difference in capacity in tons per man hour favoring rear-unloading in comparison to the two other procedures with the original blower. Since there was no important difference in minutes unloading time or in capacity in tons per hour, it was evident that the difference in tons per man hour was due to the fact that three men were used for hand forking and for the canvas-apron side-unloading units, while only two men could profitably be employed with the rear-unloading unit.

3. There was a great difference in favor of rear-unloading into the modified blower in minutes unloading time, tons per hour, and tons per man hour, when comparing rear-unloading into the original blower with rear-unloading into the modified blower. This difference in favor of unloading into the modified blower showed that blower capacity greatly affected unloading performance.

5. The ratchet-type speed-reducing power unit successfully operated the rear-unloading unit. The reducing unit
provided sufficient speed reduction and the method for varying the speed of the low speed shaft was convenient.

As the load of silage was brought to the rear it tended to fall off in large bunches. It was observed that the jarring of the load due to the intermittent ratchet motion helped to decrease the size of the bunches falling into the elevator. However, the unit was not considered entirely satisfactory, because the method of power application through the ratchet resulted in high shock loads. The ratchet method of power application also resulted in a mechanical advantage less than that represented by the ratio of engine speed to the speed of the low speed shaft. Thus it required a larger power unit than would have been necessary with a speed reducer which applied steady power to the low speed shaft.

5. The laborers preferred any of the power-unloading procedures to hand forking.

6. More research is needed on forage harvesting units in general and on unloading units in particular.
SUMMARY

The annual United States silage harvest is about forty million tons. With the exception of the unloading operation commercial machinery is available to successfully replace hand labor. The investigations consisted of a study of various unloading methods. The studies were made by field trials and analytical comparisons.

Unloading procedures may be classified as to the manner in which the material is removed from the wagon:

A. Gravity slide
B. Movable trailer bottoms
C. Removable bottoms
D. Movable slides
E. By hand

Unloading procedures compared in the studies were:

A. Three procedures for unloading into a regular commercial blower-elevator
   1. Unloading to the side by hand fork
   2. Unloading to the side with power-operated canvas aprons
   3. Unloading to the rear with power-operated units
B. Rear-unloading with two different blower-elevators

1. Unloading into a regular commercial blower
2. Unloading into a modified commercial blower

Two types of rear-unloading trailers were built for the experimental work. A speed-reducing power unit of the ratchet type was developed to supply the high torque and slow speeds necessary for these trailers.

The experimental trailers equipped with the canvas aprons for side-unloading were designed by the Agricultural Engineering Department. This type of unloading was used for the College silage harvest during the 1945 and 1946 seasons.

No important difference in minutes unloading time or tons per hour was found between side-unloading by hand, side-unloading with the canvas aprons, or rear-unloading with the power units.

There was a difference of approximately 30 per cent in tons per man hour in favor of rear-unloading when comparing it with side-unloading by hand and side-unloading with the canvas aprons. This difference was due to the fact that two men performed the rear-unloading operation while three men were occupied in the other two methods.

There was a difference of approximately 130 per cent in favor of the modified blower, in tons per hour, and tons per man hour, when comparing rear-unloading into the original blower and
rear-unloading into the modified blower. The results indicated this improvement was due to the fact that the original blower did not have the capacity to handle the forage at the rate at which it could be unloaded.

Farmers are greatly interested in the unloading problem. Several farmers have devised home unloading units which work successfully.

More research work is needed on chopped forage harvesting machinery in general and on unloading units in particular. The work should cover both equipment and economics.
LITERATURE CITED


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