

Development of corn stover harvesting and densification systems

by

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CHAPTER 1. INTRODUCTION

The traditional thinking on harvesting corn has usually focused around the collection and transportation of the grain. Over the years, the collection of other parts of the corn plant, leaves, pieces of cobs, and stalks, has been carried out on a limited basis. Currently, the highest value to the producer is in the grain, but there are new interests in the other parts of the corn plant, known as corn stover, as improved technologies develop to convert the stover to fuels and chemicals.

In order to understand why corn stover is collected from the field in the first place, one must look at what is actually in the field to be harvested. For a typical corn yield of 150 bushels of grain harvested with no grain loss, one acre of the aboveground material is made up of: **kernels**, 4.2 tons; **stalks**, 4.3 tons; **cobs**, 0.57 tons; **husks**, 0.38 tons; for a total of 9.45 tons. (Quick, 2000.) If the weight of the grain is deducted, a total amount of 5.25 tons/acre of corn stover could be harvested. At the national level, and assuming a ratio of grain to stover of 1:1, for every pound of grain harvested, there is potentially a pound of stover. The average United States corn grain production for the last four years has been 245 million tons. (DOE, 2001.) Assuming a stover moisture of 15%, a total of 208 million dry tons of stover could be harvested a year. However, this should not all be collected. Some material must be left on the field for soil erosion prevention and future crop nutrition.

Ever since the introduction of corn into the agricultural industry, there have been a number of uses for the crop residues left after the grain harvest aside from soil protection and nutrition. Baling has served for the low-end uses associated with corn stover. These include animal bedding and landscaping mulch for which fiber quality is not critical. But at the other end of the spectrum, the high end uses for stover demand a clean and uniform cut product. These high end uses include pharmaceutical and chemical carriers, particleboard stock, feedstock for renewable fuels, and especially for fiber feedstock for paper production. While new uses of stover have emerged, the current equipment used to harvest, collect, and densify stover have not kept pace.

Baling is the popular way to harvest and collect corn stover. Baling involves a two or three step operation after the combine has harvested the grain, which adds costs. Raking speeds up the time to dry the stover and to gather the material into one large windrow for easier collection. But raking also introduces dirt and rocks gathered with the stover. Stover can also be windrowed behind the combine. This is accomplished by setting the combine to deposit a tight swath. Swath width depends on the width of the harvesting head of the combine, the larger the head, the larger the windrow will be. Windrows produced by a combine take longer to dry thus delaying stover collection.

Baler pickups tend to collect dirt and rock with the stover and do not recover many of the cobs. Baling is desirable to increase density of loads, but bales need mesh net wrap or twine to hold the bale together. That introduces another problem for the end users. Plastic is unacceptable in stover for all of the high-end uses discussed previously for stover. Baling also requires a high level of competency in operation to maintain an efficient harvest of the stover. Once the stover has been baled, it must be economically transported to either the producer's storage area, or to a processing facility. The current process does not allow the producer to obtain the top dollar for their stover.

This thesis will deal with the development of new or improved systems for the collection and densification of corn stover to provide for a profitable commodity for the farmer to sell and add value to corn production. The third chapter is a literature search of stover collection methods along with other means for the densification and transportation of corn stover.

Other chapters will show the work done to produce functional full size corn stover-harvesting machines and the results of stover harvesting in the 2000 and 2001 harvest seasons. Several machines were tested. The thesis deals first with the modification of a plot harvesting combine, "Bass Combine", named after M. Duane Bass who developed the prototype at Iowa State University in 1967. The second involves the modification of a full size commercially produced combine as a one-pass harvester. Parallel tests were also conducted on other combine attachments.

Chapter 6 shows a comparison of the developed equipment and attachments. The thesis concludes with a basic economic analysis of the collection and transportation of corn stover.

CHAPTER 2. OBJECTIVES

The project was initiated by the Agricultural and Biosystems Engineering Department and funded by the Department of Energy's Office of Fuels Development under the title of "Handling and Densification for Commercial Processing of Biomass Feedstock". The overall objectives of the DOE project were to design and build new corn stover harvest and transport systems capable of the following:

- Harvest stover at any moisture level, thus eliminating the need to field dry the stover
- Simultaneously harvest the grain and stover and separate the two streams to allow for an efficient and single-pass harvest operation
- Maximize the density of the stover for economical transportation
- Assess system costs

These objectives will be pursued in the literature review and subsequent chapters detailing the development of equipment, leading to an economic analysis of the systems.

CHAPTER 3. LITERATURE REVIEW

There have been numerous attempts to harvest whole corn plant material. Primarily, corn has been harvested for silage for beef production or for the grain. To better illustrate the different machines that were made to harvest the entire corn plant, a patent search was conducted to look at the various corn stover collection methods. All bold numbers in the literature review refer to the corresponding number in the patent art. A more general literature search was then conducted looking at theses, academic papers, and other relevant sources concerning the harvesting of corn in general.

One of the earlier methods for collecting corn stover integrated collection, densification, and transportation. Gene A. Luscombe's patent of Dilliver, IA in October of 1973 was intended for the collection of hay forage crops but it could also be used in stover collection. This machine was pulled behind a tractor while straddling the windrow of the

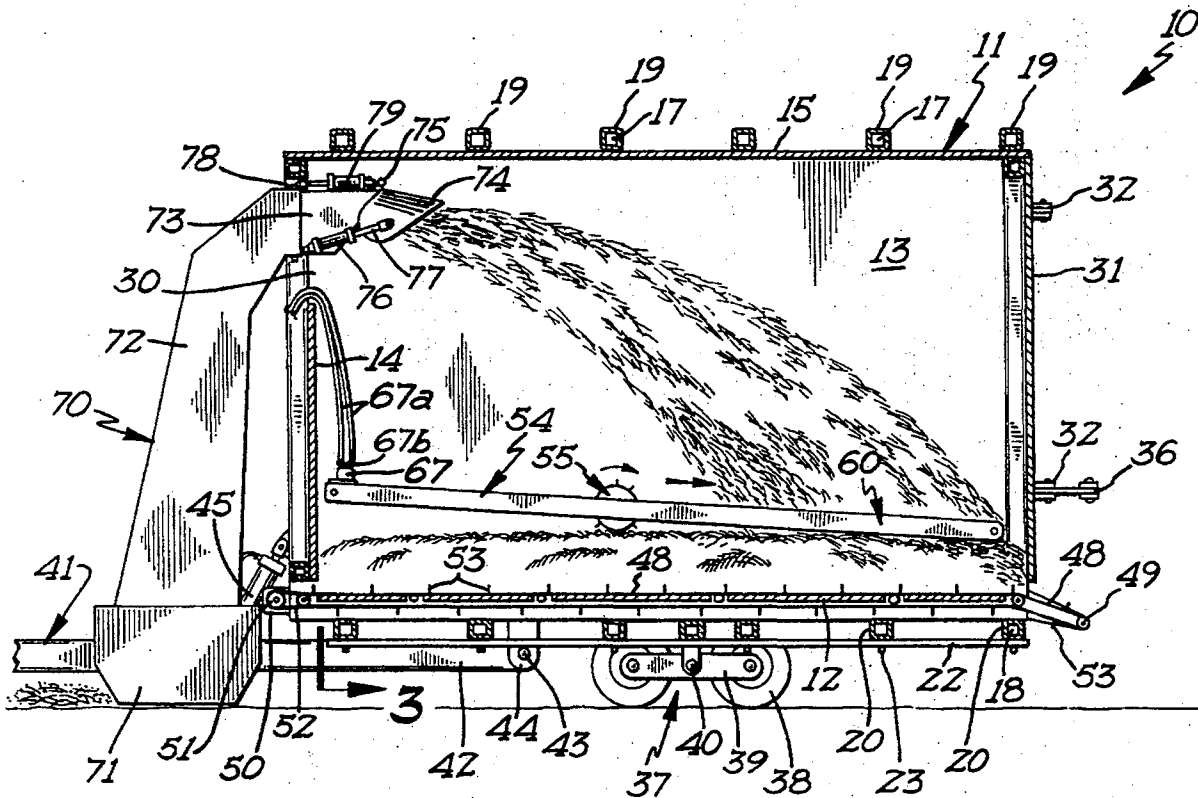


Figure 3.1 Haystack Wagon by G. A. Luscombe, 1973.

ground. The pickup **71** used a fan, which caused a pressure differential, which picked the material up off of the ground. The crop was then blown into the wagon box **11**. A compaction roller **55** attached to a moveable frame moved back and forth across the material to add density to the load. The formed stack could then be transported to a storage area or unloaded in the field. An endless belt conveyor **48** unloaded the stack. If unloaded in the field, the machine also had the ability to reverse the direction of the belt conveyor to pick the stack back up and move it elsewhere.

One major problem anticipated with this system was the pickup device that also collected dirt along with the crop. Although the machine could densify the material, the product quality would be greatly diminished by dirt collection. The maximum load of the wagon was not specified.

Another patent was issued shortly after the one for Luscombe to Charles M. Kline and assigned to the Sperry Rand Corporation of New Holland, Pennsylvania in December of 1975. This machine incorporated many of the same features as the Luscombe Haystack Wagon but also had some unique qualities. For instance, a flail type pickup **34** was used to pick the crop up off of the ground. The crop was then propelled until it contacted a deflector

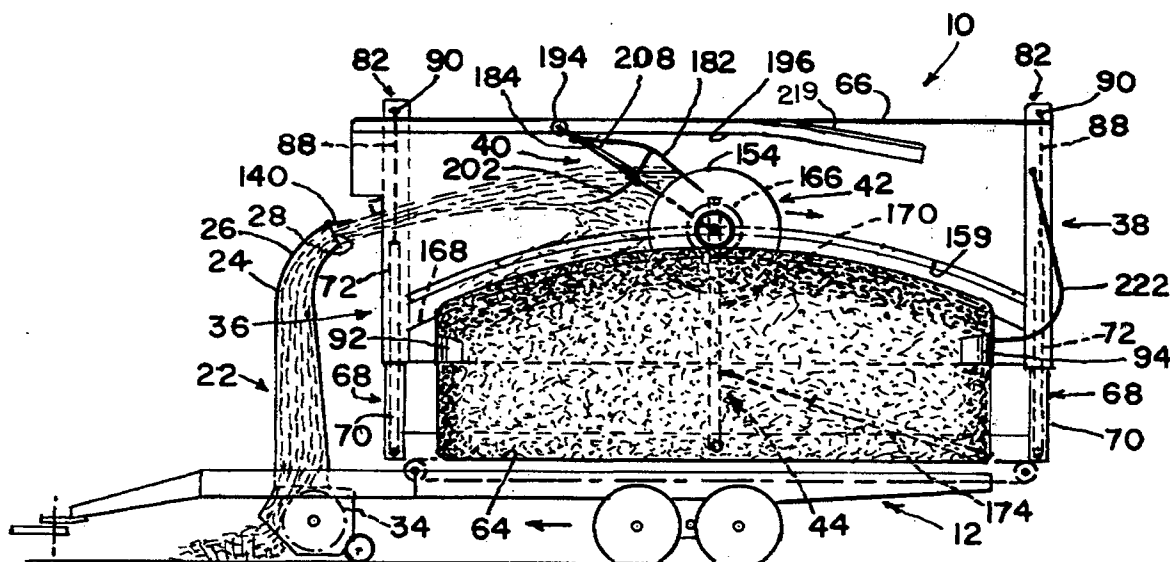


Figure 3.2 Machine for forming a compact stack of crop material by Sperry Rand Corporation, 1975.

182 that placed the crop ahead of a compacting roller **154**. The curved track that the roller was attached to was then hydraulically moved upward as the wagon became filled. The curved track **159** allowed for the crown of the stack to be curved in shape. This allowed for water to roll off the stack better than a flat crowned stack. The machine unloaded in the same way as the Luscombe design.

However, once again, dirt pickup with the crop would be a disadvantage of this design for quality stover collection. It was also a second pass operation once the grain was harvested and the crop was dry enough to collect.

A method to incorporate the stacker wagon design along with a forage harvester was the next idea patented to allow for some processing of the crop material before it was collected in the wagon. A patent was again issued to Luscombe in November of 1977 for the combination harvest system. The forage harvester **11** used a windrow pickup head to gather the crop for subsequent chopping and delivery via blower to the stack wagon. The wagon also had a few improvements from the previous design of Luscombe. It still used a compacting roller **49** to densify the crop as the wagon is loaded from the forage harvester.

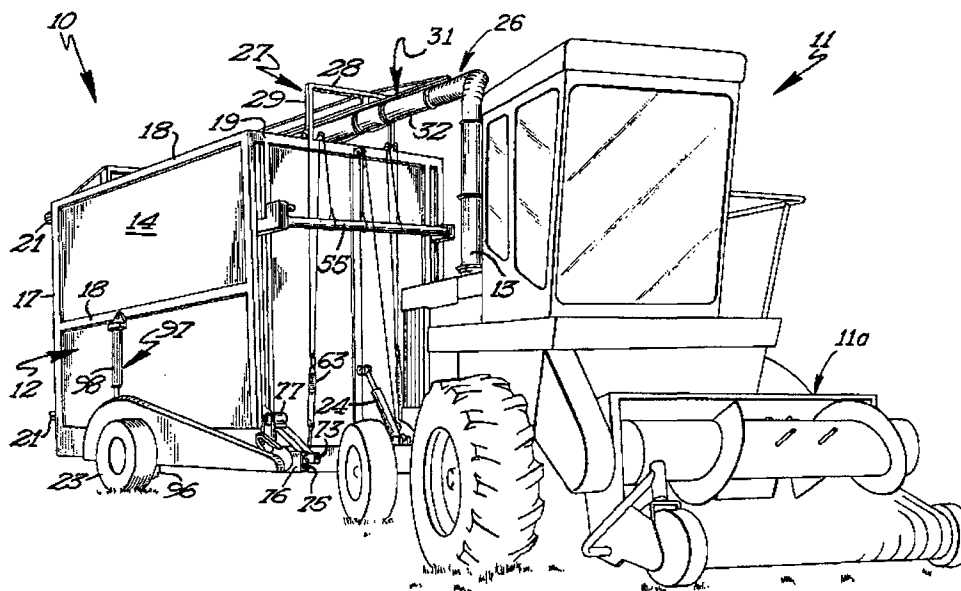


Figure 3.3 Stack forming vehicle, G. A. Luscombe, 1977.

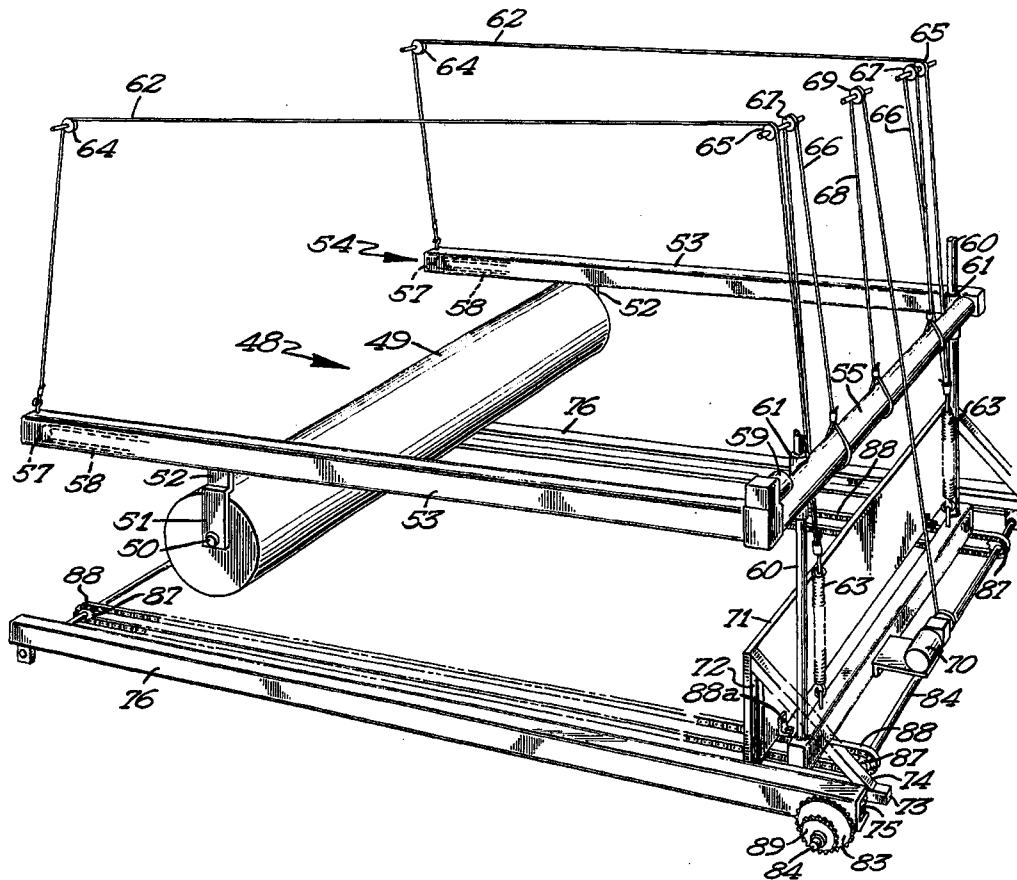


Figure 3.4 Inside of stack forming wagon, Luscombe, 1977.

The wagon also incorporated a pusher **71** to unload the formed stack in the field. This simple design allowed for the unloading of the stack only, the reloading of the stack was impossible thus requiring another means to move the stack out of the field.

The system however, would be able to lend itself for the harvesting of the whole corn plant. All that would be needed was the attachment of a row crop head to cut and gather the corn for chopping. This would allow for a dirt free collection of the stover along with the grain, but would also do major damage to the grain due to the chopping action of the cutterhead. The stover would be harvested at higher moisture giving a denser load. The major drawback was that there would be no separation of the more valuable grain from the stover.

Combine attachments

Alternative methods for the collection of stover range from attachments for combines to specialized stover harvester concepts. An early patent issued to Boris M. Fingerut of Lake Grove, Oregon in May of 1967 focused around the collection of the material other than grain, MOG, that is discharged from the rear of a combine harvester. The attachment to the rear of the combine gathered the material and used a forage blower **18** to discharge the material via direction spout **60** into a wagon **37** that was pulled behind the combine. A gas engine **M** supplied all power to the blower and trailed wagon. Once full, the wagon would rotate about an axis, with the rear of the wagon touching the ground, a rear gate would open and the collected material in the wagon would be emptied.

The overall system appeared to be able to work well for the collection of the MOG from the rear of the combine prior to unloading. The material would never touch the ground, thus allowing for dirt free collection. Overall capacity of the system and whether it would slow down the overall harvest process was not stated.

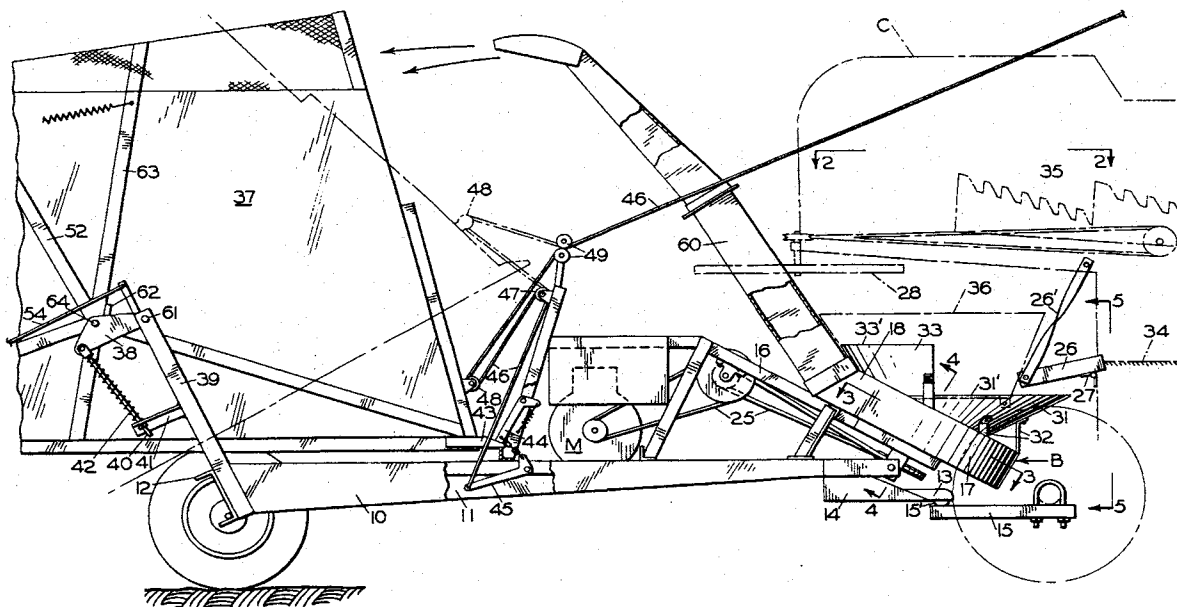


Figure 3.5 Self-contained forage wagon assembly for harvester combine by B. M. Fingerut, 1967.

Another machine was patented for the collection of the MOG from the rear of the combine. In April of 1976, a group of individuals received a patent that was assigned to Foster Manufacturing Company in Oregon. The trailing machine collected the MOG with conveyor **35** that was located under the rear of the combine. The conveyor carried the material into a forage blower **16**, which blew the MOG into a wagon **19**. When the wagon became full, a door at the rear would open, and the whole wagon would tilt to unload onto the ground. To lessen the power requirements placed on the combine by the machine, a supplemental motor **20** was used to power the conveyor and blower. The collector was made with a low profile in order to accommodate to different sizes of combines.

The design had many advantages for the collection of corn stover. The machine collected dirt free stover from the rear of the combine and would collect all of the cobs. It would apparently not slow down the overall harvesting process of the combine except for the unloading of the wagon. It was not stated whether the wagon could be unloaded while the combine was moving through the field or not. The only apparent drawback appears to be the loads on the powertrain of the combine while pulling the machine through the field.

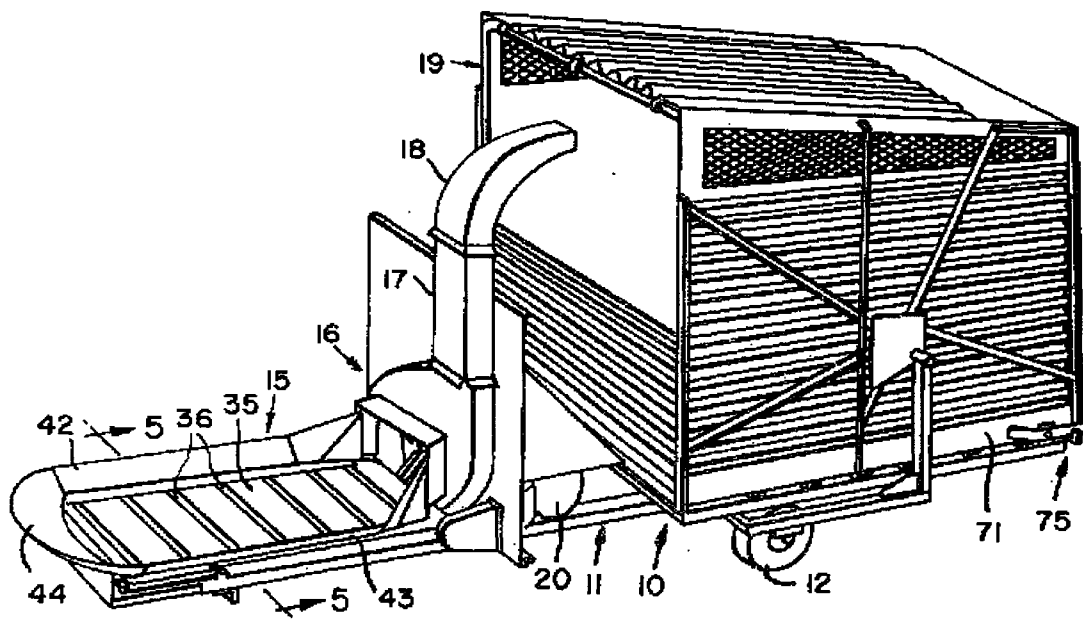


Figure 3.6 Apparatus for collection combine waste by Foster Manufacturing, 1976.

A patent issued to Wendell E. Corbett of Watertown, South Dakota in February of 1980 dealt with the collection of the MOG from the rear of a combine. This attachment was powered by a belt drive system from the harvester itself. No external power source was used. The MOG was collected in a trough **20** positioned under the rear of the shoe area of the harvester. The material was then augered **38** to the blower **29** which then was blown into a wagon or truck that was pulled beside the combine.

Even though the system looks simple and able to work effectively, there could be certain drawbacks to the attachment. Primarily, the system was using power from the combine, which would lower the overall efficiency of the combine due to a heavier load on the engine. Also, the augering of the MOG to the blower may be ineffective. Crop residue such as corn stalks may wrap around the auger causing bunching and possible failure of the attachment. The problem would also worsen as the moisture of the stover increases. The combine was also dependent on a wagon to be continuously alongside so the MOG could be blown into a wagon for transport. This required another operator and more field traffic.

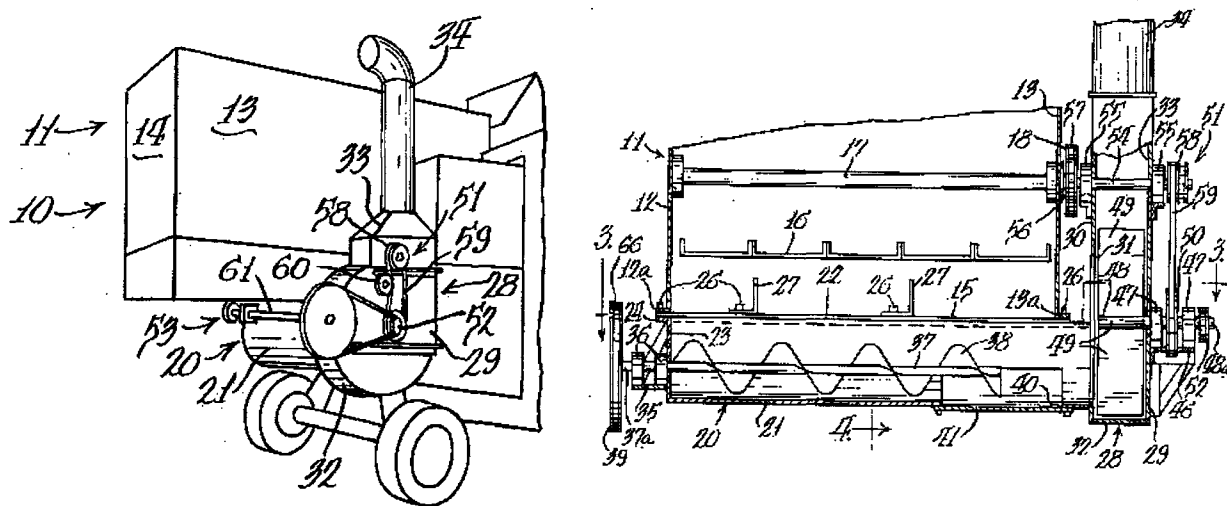


Figure 3.7 Feed residue saver for combines designed by W. E. Corbett, 1980.

In recent years, there has been an increased demand for the cost effective collection of corncobs. Seed corn companies supply some cobs, but a demand for field corncobs also exists. During August of 1999, a patent was issued to Vernon L. Flamme for a corncob collection machine, which was towed behind a combine harvester. As MOG was discharged from the rear of the combine **14**, a conveyor catches and moves the material to be cleaned. An enclosed angled conveyor **38** then lifted the MOG towards a cleaning fan **50** that passes an air stream through the residue material. The air stream separates the lighter stalks, husks, and other MOG components and discharges them onto the ground. The cobs then drop to a trough **80** to be gathered and raised by another conveyor **78** to a holding container. Upon filling the container with cobs, the combine stops allowing the floor to open hydraulically enabling the mass of cobs to fall onto the ground.

Overall, the machine worked well for the collection of cobs while the grain was harvested. The simultaneous operation collected two streams of valuable products for the

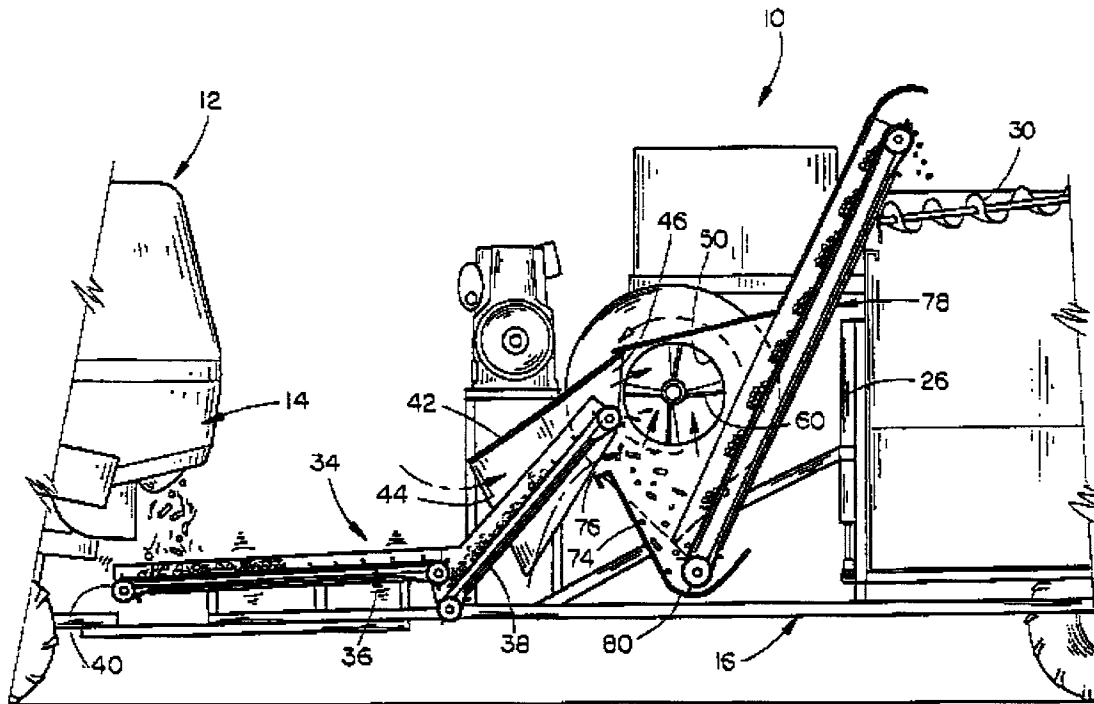


Figure 3.8 Corncob collecting apparatus developed by V. L. Flamme, 1999.

producer. However, only the cobs were collected while the other plant residues were discharged onto the ground. The machine also did not provide its' own means of propulsion thus relying on the powertrain of the combines. The combine was also required to stop each time the wagon was full of cobs in order to unload. A second operation to pick the cobs up off of the ground was also needed to transport them to a processing facility or the farm. Picking up the cobs off of the ground also may lead to dirt contamination or even collection of other foreign materials.

Collecting heads

There are other ways to modify a combine for the collection or conditioning of corn stover. In particular, modifications and attachments to the combine gathering head have been developed. One of the first patents issued was for a two tier head that gathered the entire plant for separation. The patent was issued to Shelly A. Bulin of Bettendorf, IA and assigned to J.I. Case Corporation in June 1971.

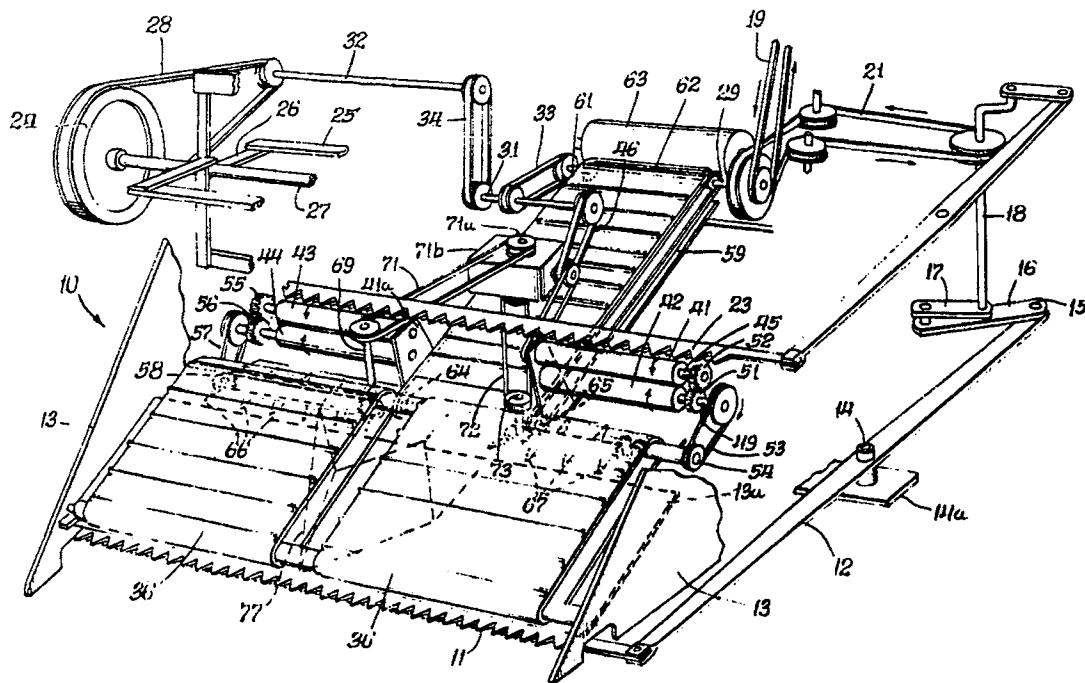


Figure 3.9 Corn header for combines by S. A. Bulin, 1971.

The header first cut the entire plant off with a reciprocating cutterbar **11** and directed the plant onto a draper roll **36**. As the plants began to lie on the draper, a reel **24** pulled the top of the plant in while a second cutterbar **23** cut the top of the plant. The lower portion of the plant was drawn through a set of snapping rolls **A1**. The ears were conveyed to the threshing cylinder **63** of the harvester. The stalks and leaves were then deposited to either end of the head via conveyor (not shown in patent art).

The unique design of the gathering head allowed for the simultaneous collection of the whole plant while snapping off the corn ears off for threshing. One possible drawback of the head may be the overall complexity of the head. An increase in maintenance and possibility of frequent breakdowns may have occurred with this head.

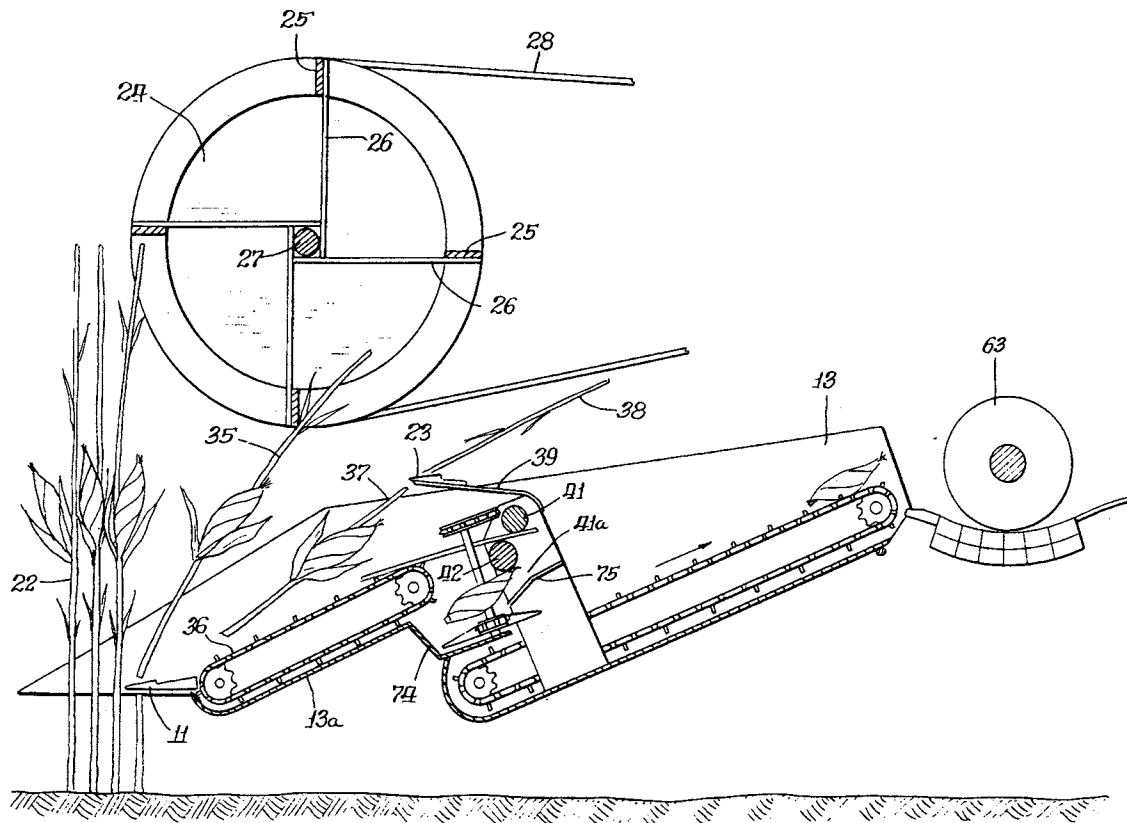


Figure 3.10 Corn header side view by S. A. Bulin, 1971.

A later attempt at a two-tier head system was in 1979 when a patent was given to Kent Miller of Brandon, IA. The design used an attachment that mounted underneath a conventional corn head. As the stalks entered the head, they were kept in line by gathering fingers. The attachment contained a paddle wheel **52** that pushed the stalks forward as they were cut by a reciprocating cutterbar **40** after the ears had been snapped off from stalks by a conventional corn head. The paddle wheel also aided in feeding the cut stalks into a horizontal cross auger **32** conveyed the stalks to the center of the head for creation of a windrow by the combine. The windrow would then be picked up by either baling or using a stacker machine to collect the stalks. The ears were collected with the conventional corn head above the attachment.

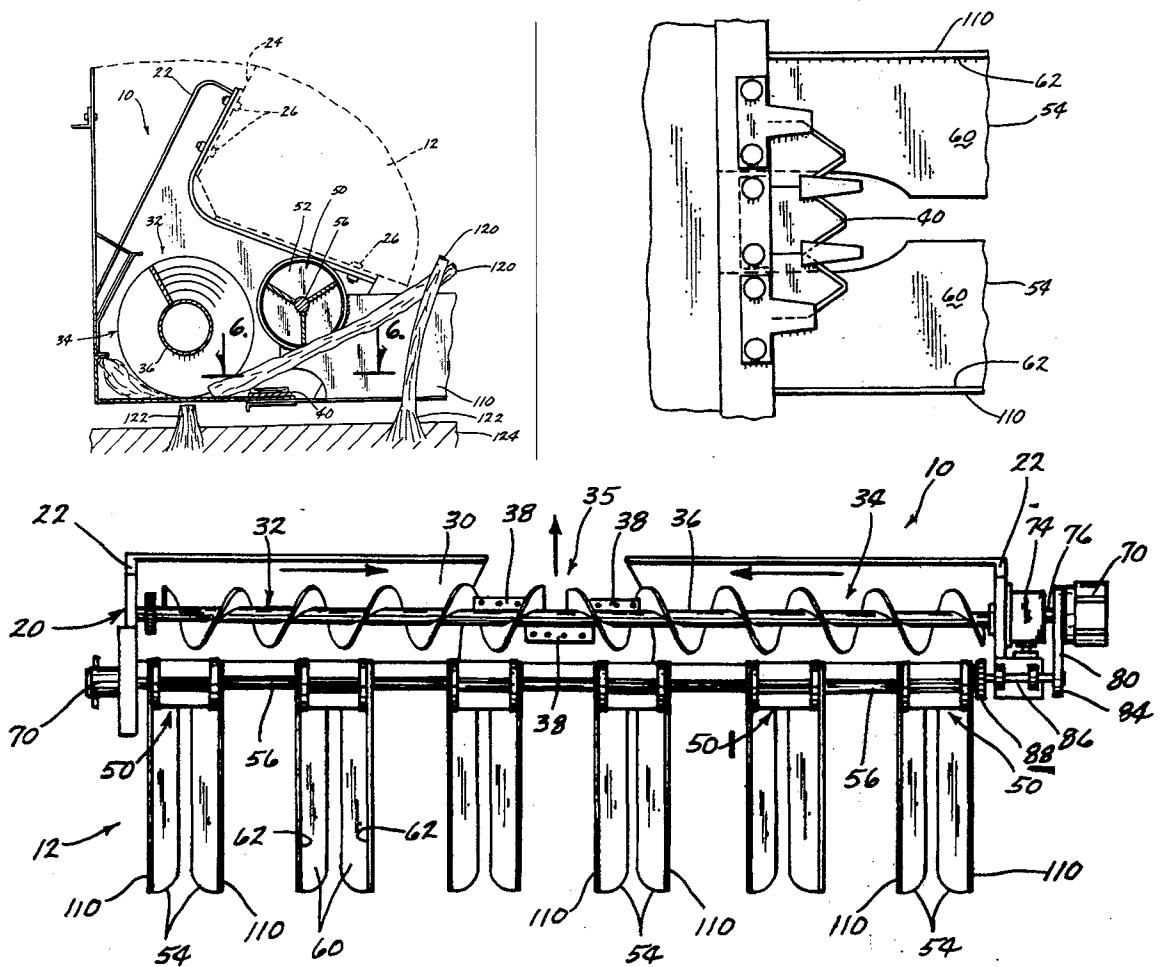


Figure 3.11 Corn stalk harvester and windrow attachment by K. A. Miller, 1979.

Another patent was issued for a gathering head that would be used for the collection of the whole plant. The patent was given to a group of individuals and assigned to Deere and Company in September 1978. The head was designed and marketed for use with a forage harvester but could have also been used on a combine harvester. As the plant entered the row unit, a reciprocating blade **49** cut the stalk while gathering belts **112** gripped the plant. The plant continued toward the cross auger **41** while a crossbar **38** pushed the stalks forward for enhanced feeding into the feeder house of the harvester. The fingers **44** of the cross auger also aid in the feeding of the crop. The row spacing was adjustable for different spaced rows.

The head could be easily adapted for use on a combine harvester. The major drawback would be the collection of the whole stalk and running it through the threshing area of the combine. This may lead to substantial power requirements and lower field efficiencies of the corn harvest. The overall harvest may be slowed due to possible slower ground speeds resulting from the whole plant going through the machine, especially with conventional cylinder and walker type combines.

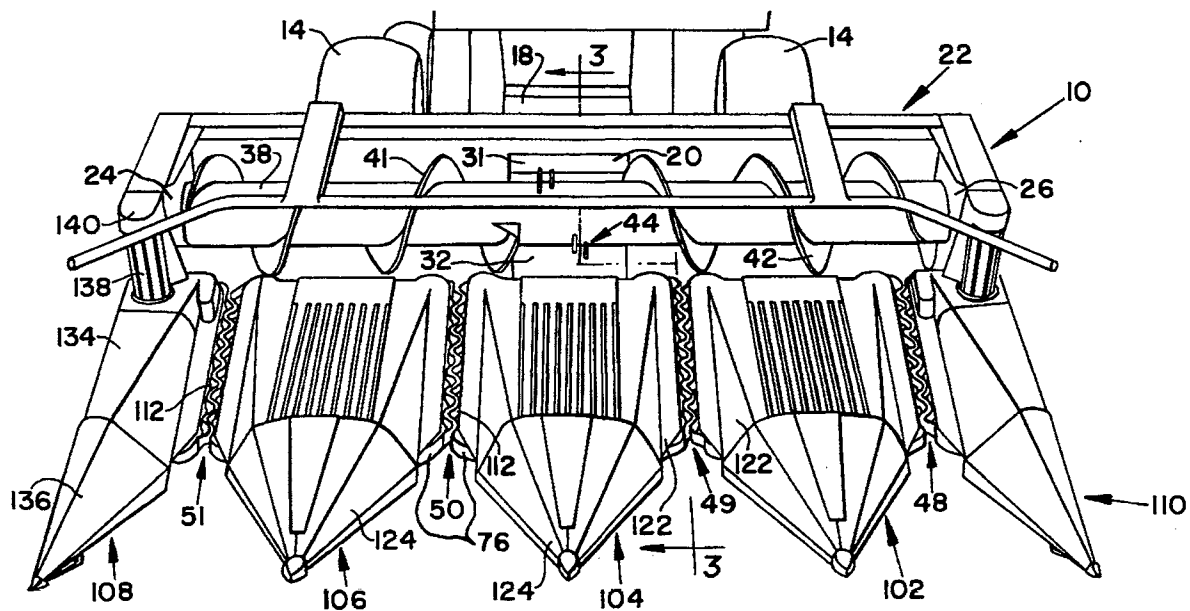


Figure 3.12 Row crop header by Deere and Company, 1978.

Kenneth J. Kass was awarded a patent for an apparatus that harvested and windrowed corn, January 1980. The attachment fit underneath the cornhead and utilized one or two conveyors. Ahead of the two conveyors **30**, a set of horizontally moving knives severed the stalks as they entered the cornhead. The knives are attached to an endless chain that moved at high speed. Two sets of counter-cutting chain mounted blades were used, moving in opposite directions to improve cutting of the stalks. As the corn plant entered the head, the ears were snapped off in the conventional fashion. The remaining standing stalk would then be cut, gathered by the conveyor and discharged either to the center of the head or to one side. The corn plant residue could then be allowed to dry in the field for later collection.

The attachment did allow for some stalk collection at the corn head. However, the material was still placed onto the ground leading to contamination with dirt and rocks. It simply provided for a means of collecting the stover into one windrow. Ground clearance may also have been a problem with this design. Downed corn would be challenging to collect without the conveyor dragging on the ground.

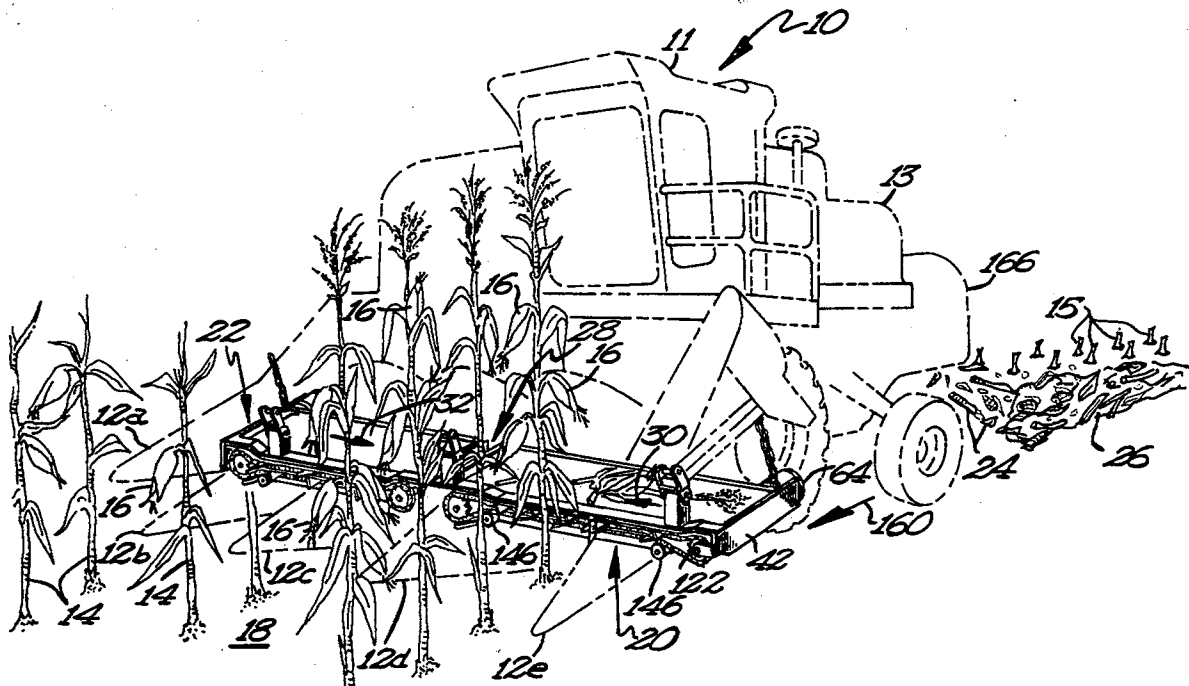


Figure 3.13 Apparatus for harvesting and windrowing corn stover designed by K. J. Kass, 1980.

An unusual design by Norman P. Kracl of O'Neil, NE, patented in April of 1986, dealt with the removal of the corn ear without processing the ears. An attachment **10** was placed between the head and the feederhouse **41** of the combine. Once the conventional head snapped off the ears, they were collected and augered to a wagon or truck that moved beside the combine. None of the ears entered the feederhouse of the combine for subsequent threshing and cleaning.

The machine had the ability to collect the ear of the corn plant easily, but did not collect any other part of the plant. The rest of the harvester was used as a means for propulsion and ear collection.

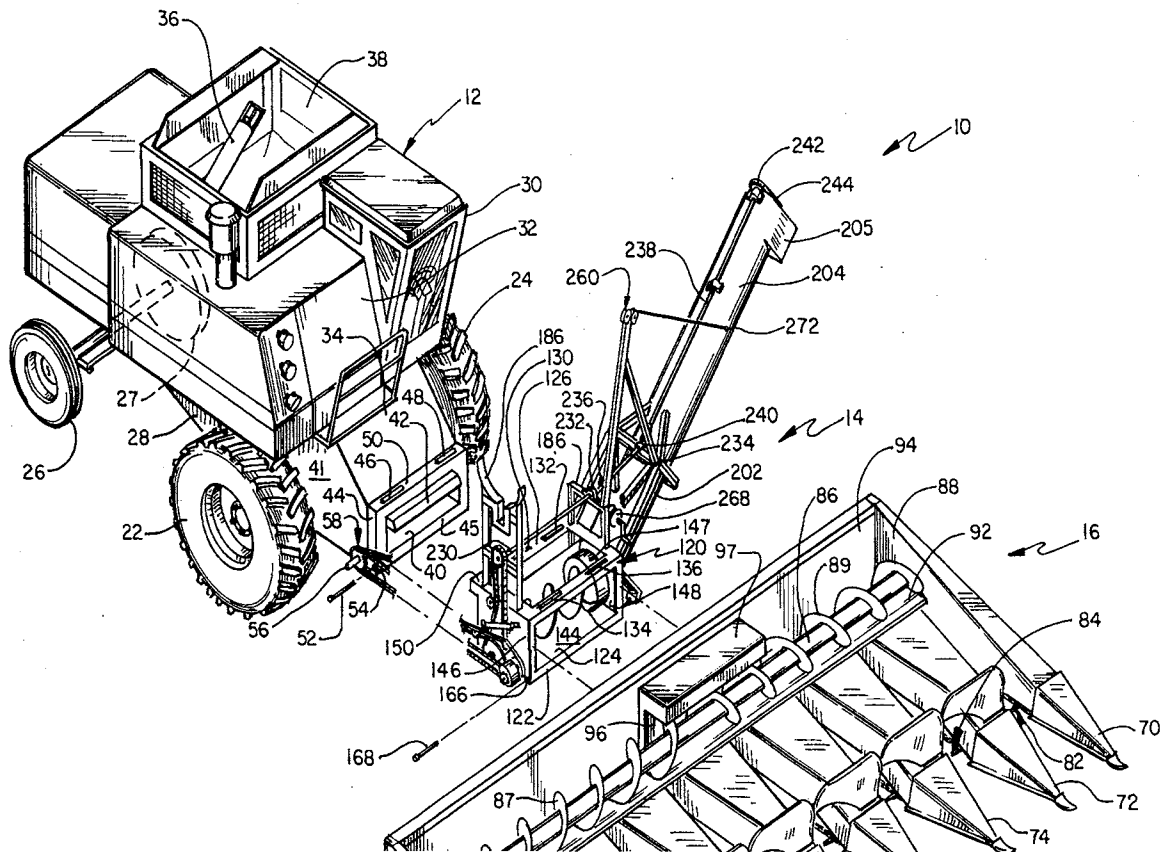


Figure 3.14 Corn removal attachment designed by N. P. Kracl, 1986.

Whole plant harvest

A complete stover harvesting system was designed and patented by Thomas E. Hitzhusen in 1971. This could harvest either the whole plant for ensilage, the corn ears separately from the chopped leaves, and stalks, or the grain itself along with the chopped leaves, cobs, husks, and stalks. The machine used a reciprocating knife **37** to cut the plant stalk while rubber belting conveyed the corn stalks butt first into the feeder rolls of the chopper. As the plants entered the chopper, the stalks first passed through a set of snapping rolls **47** to remove the ears. The ears would then be either conveyed whole **33** or sent to the shelling unit **31** via conveyer **54** for grain separation from the cobs. The grain would then be placed into a wagon **128**. The stalks and leaves would then be chopped by the cutterhead **22** and blown **27** into a towed wagon **127**. If the ears were shelled, the ears would also be chopped by the cutterhead. Hitzhusen called the prototype the “Beefmaker II” and tested it in 1971-1973.

The machine would be able to effectively separate the different streams of materials. However, it appeared to be capacity limited and had some problems with the feeding of the stalks into the unit. The machine would also compromise the threshing of the grain. There was no apparent means for the cleaning of the grain. Nevertheless, the machine would be able to chop the stover for better processing by end users of the stover.

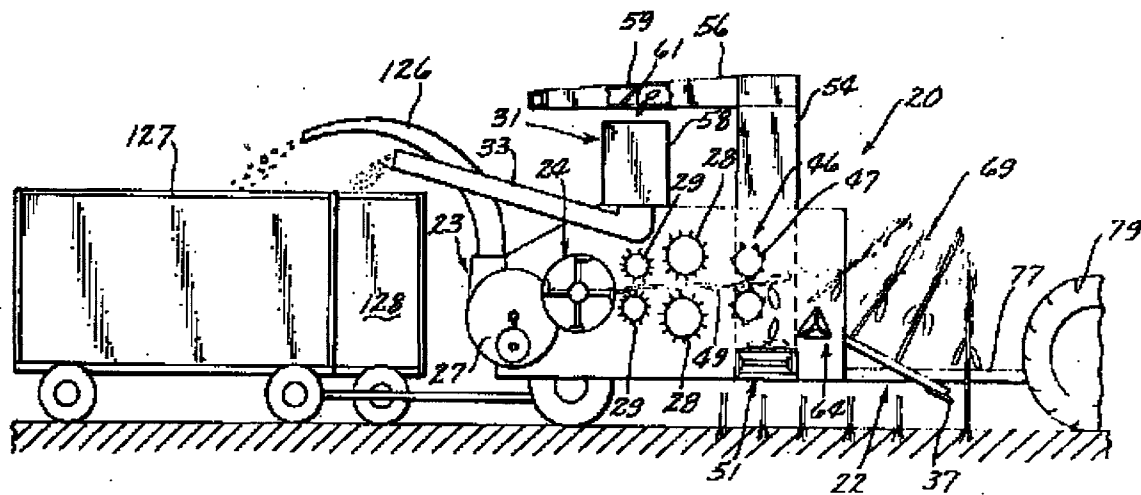


Figure 3.15 Total corn harvester machine side view by T. E. Hitzhusen, 1971.

In August of 1972, Gust Soteropulos of Ottumwa, IA was awarded a patent assigned to Deere and Company for a total corn-harvesting machine. The entire plant was gathered, processed, and separated. Ears were picked and separated from the rest of the plant and conveyed to a conventional threshing cylinder **40**. The grain then fell to a set of rollers **50** for cracking of the kernels. The processed grain was then augered to a holding bin **60** at the rear of the machine. Once the ears were collected, the stalks were cut at the bottom with a reciprocating knife **68**. The stalk was then pulled towards two sets of feed rolls **72, 74, 76, and 78** via rubber belts **70**. After the feed rolls, the stalks are chopped by the cutterhead **82** and cross conveyed to a blower by an auger. Also fed into the cutterhead were the cobs and husks from the shelling of the grain. The chopped stover was then blown into a wagon or onto the ground for later collection.

The machine achieved the functions of collecting and separating the two different streams of materials, the stover and the grain. Although fitted with a four row head, this machine may be power limited due to its small overall capacity.

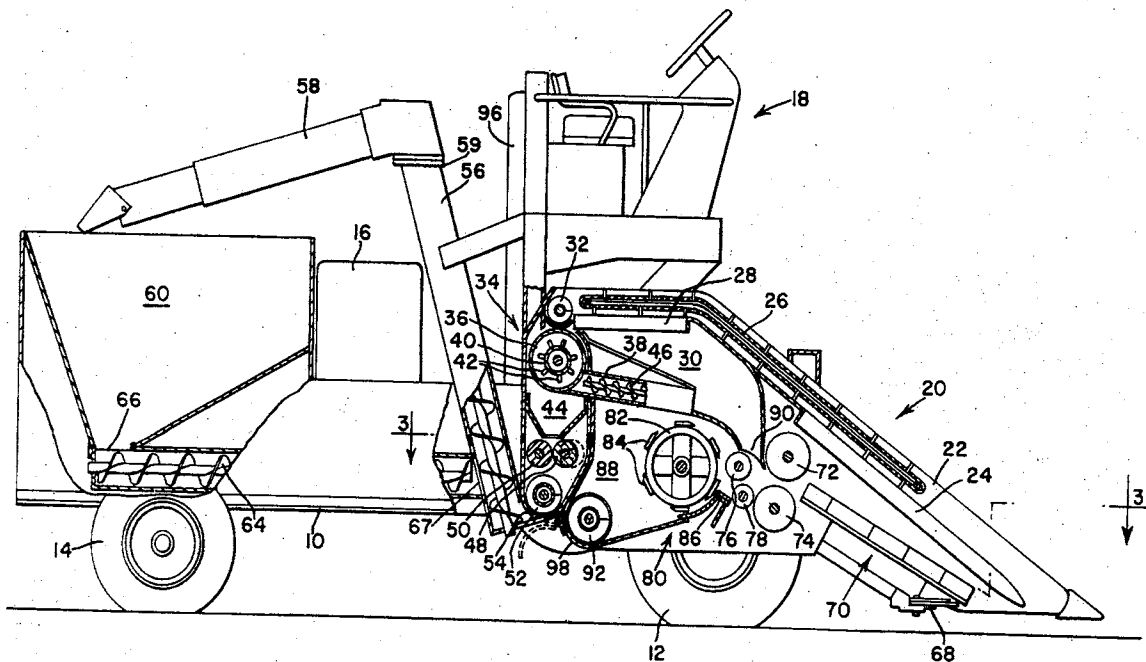


Figure 3.16 Corn harvesting machine by G. Soteropulos, 1972.

A more recent patent issued concerning corn stover harvesting was issued in March of 1999 to Eugene A. Stoll of Stanberry, MO. The system comprised a trailed harvester that cut the plant with a forage harvesting head **30**. The whole plant was chopped with a conventional forage harvester **34**. The chopped material was then conveyed to the separator unit **10**, a pull type combine that separates the grain from the chopped material. The threshed and cleaned grain was placed in a grain bin **16**. The processed MOG from the rear of the separator was blown via forage blower into a trailed wagon **86**.

The system was effectively able to collect, process, and separate the two streams, grain and stover. One drawback would be the processing of the ear along with the rest of the stalk material through the forage chopper. High grain damage would occur due to the aggressive cutterhead. Another negative would be overall machine length. Turning corners in small fields could present a challenge to the operator. A large tractor would also have to be used in order to power and pull the machine with trailed wagon through a field.

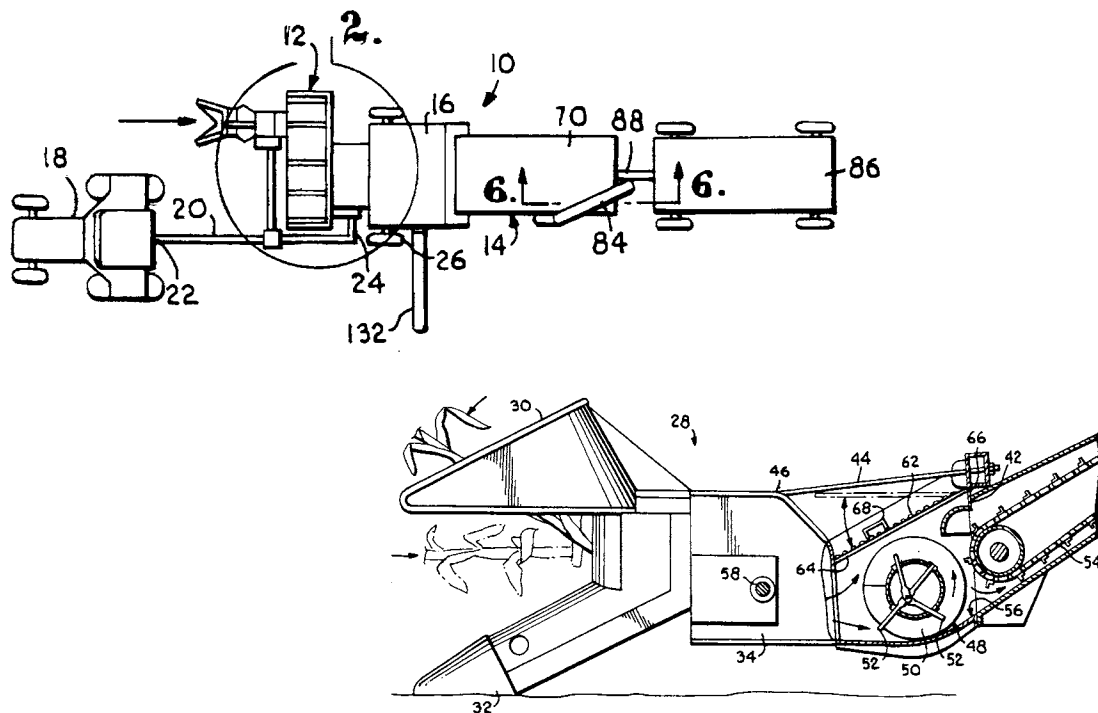


Figure 3.17 Harvesting apparatus for comminuting plant before separation designed by E. A. Stoll, 1999.

There were also some published papers concerning the topic of the whole corn harvest. The research for these papers was conducted in the late 1960's concerning the feasibility of harvesting the whole corn plant and separating the different parts in a one pass harvest operation. The motivation was to provide beef farmers the opportunity to harvest the respective parts of the corn plant for use as cattle feed at a time of high beef prices.

Ferlemann (1966) examined entire corn plant harvest for the shelled grain and silage. Ferlemann decided to use a modified John Deere model 38 forage harvester with a corn head mounted on the front of a John Deere model 55 combine harvester. The two-row forage corn head was mounted below a modified method for snapping the ears off of the corn plant. As the plants entered the two-tier head, the sickle of the forage head cut the stalk. As the stalk was pulled back towards the feed rolls of the chopper by the gathering belts, the snapping bars snapped off the ears. The ears were then conveyed by the gathering chains to the cylinder of the combine for threshing. The stalks below were chopped by the cutterhead and blown into a wagon pulled alongside the combine. The MOG from the rear of the combine was allowed to fall onto the ground as in a traditional corn harvest.

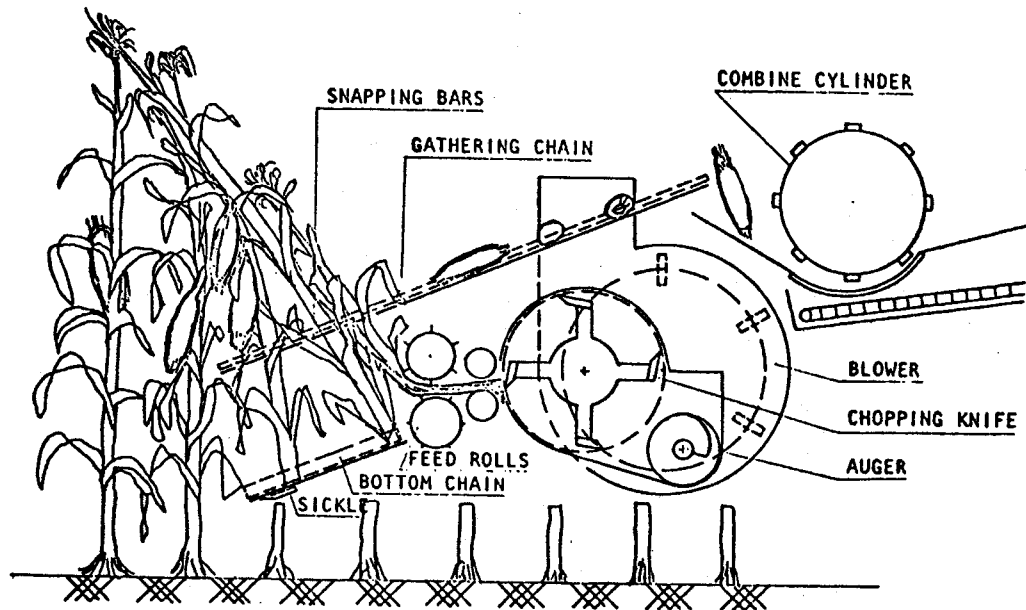


Figure 3.18 Schematic of the Ferlemann total corn harvester, 1966.

Ferlemann's prototype did not perform as expected. The arrangement of the snapping bars and the forage head did not work well together. The snapping action was not severe enough to snap the ears off of the stalk. As a result, the testing was limited while a remedy to the problem was looked into. There was also no collection of the material from the rear of the combine.

In an attempt to correct some of the problems encountered by Ferlemann, Schroeder (1968) focused on improving the overall harvesting performance of the total corn plant combine. To reduce power, the machine was reduced to a one-row machine. In order to collect the ears, a conventional corn head was mounted above the forage head. The position was further ahead of the forage head and angled more. This allowed for the aggressive snapping of the ears by the stalk rolls while the stalk was still cut and gathered by the forage head. The material from the rear of the combine was also collected and conveyed to the front of the combine to be deposited into the chopper. The machine functioned well with the modifications. The one row total corn harvester was known as the "Beefmaker I."

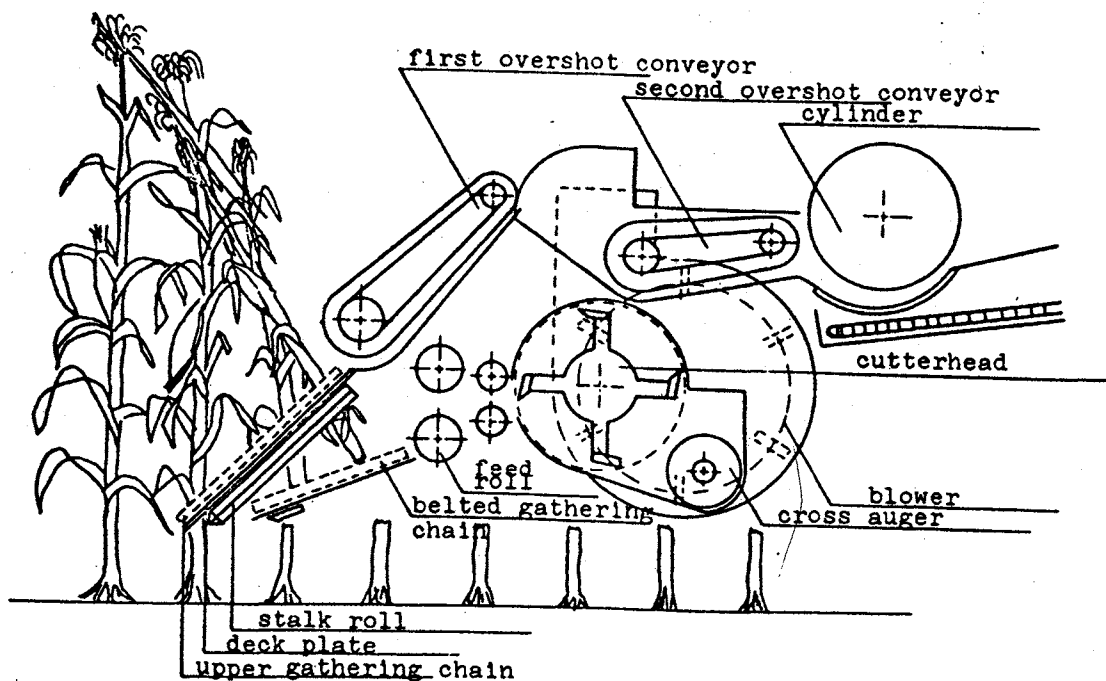


Figure 3.19 Schematic of Schroeder's Beefmaker I, 1967.

Another method for the collection of the whole corn plant was by researched by Stephens (1968). Stephens modified an Oliver 545 combine with a model 49 corn head. The four row head featured a sickle bar that cut the corn stalk off at the desired cut height. The whole corn plant was put through the conventional combine. At the rear of the combine, components an Allis-Chalmers model 50 forage harvester were mounted. All of the material from the rear of the combine was processed through the chopper that could cut to less than 1" in size. The chopper was powered by the combine and was placed under the rear hood of the combine. The chopper served to blow the chopped material into a wagon behind the combine.

Ayres (1973) evaluated several alternative-harvesting systems for the corn plant. While the Beefmaker I performed satisfactorily as an experimental machine it had low mechanical reliability, along with large amounts of grain in the harvested stover. It was suggested that the snapping unit should have been redesigned to lower the frequency of the machine plugging and to reduce the quantity of grain in the stover. Another machine tested was the Hesston Stakhand 30. An average yield of 1900 pounds of stover dry matter was harvested in the center two of six rows. The stover also contained a higher husk and cob content than stover harvested from the entire six rows. Thus shown was that the majority of husks and cobs fall directly behind the combine during harvest of the grain.

Gustafson (1969) designed and built a combine attachment for rowless agriculture that yielded some results for whole corn harvest. The header consisted of a cutterbar, draper chain, feeder roll, and two horizontal fluted snapping rolls that ran the entire width of the machine. Innovative chain-bar reels were investigated to gather the crop for cutting by the cutterbar. As the plant was cut by the cutterbar, the whole plant was conveyed via draper chain conveyor to the fluted rolls. The ears were snapped from the stalks and fell to the existing header into the combine. The stalks were then augered out the side of the head onto the ground. At the rear of the combine, an auger was placed to gather the MOG effluent and place it into a windrow along with the stalks from the header. Field studies showed that the

header could gather broadcast corn. The overall reliability of the machine was low. The drive systems needed to be improved to increase header capacity.

This literature review has highlighted designs for harvesting the different components of whole corn plants. Much of the work was motivated by a time of dramatic growth in the beef industry of the 1960's and 1970's. Some work has been conducted in recent years, but little has been done recently on whole crop harvest since beef prices have declined. With the emergence of new technologies and markets for the corn plant, there is motivation for improvements or new approaches to harvest methods.

CHAPTER 4. EQUIPMENT DEVELOPMENT AND TESTING

Plans were prepared for several streams of activity in order to assess several stover harvesting systems as a result of a Department of Energy award to Dr. G. R. Quick. First, a stover transport trailer was made for the collection and economical transportation of corn stover. Then to get a rapid start to the project, an existing plot combine was used as a test bed for whole plant corn harvest.

High capacity wagon for stover transportation

A bale trailer was acquired for modification into a stover transport wagon. The 32' "Balemaster" trailer had the bale handling equipment removed except for the hydraulic and electrical systems. Figure 4.1 shows a steel framework that was fabricated as the trailer box.

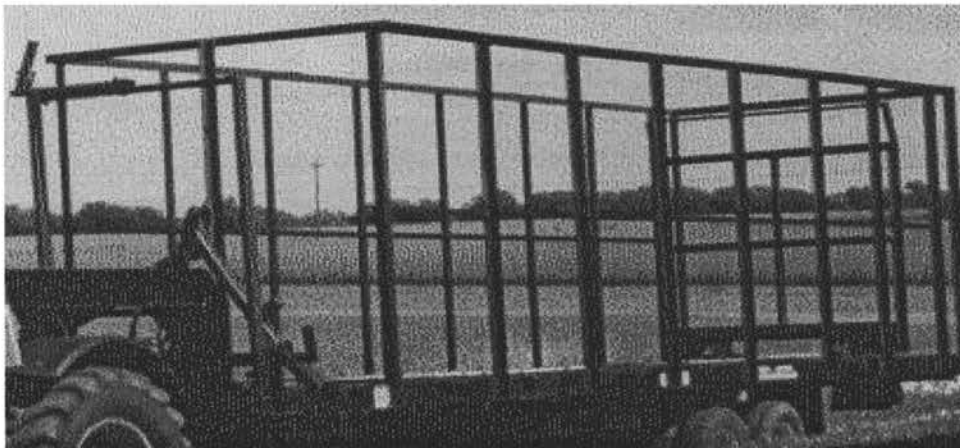


Figure 4.1 Steel framework of stover transport trailer

The walls and floor were covered with 1/4" and 3/8" plastic sheeting respectively. Plastic was used in an effort to reduce the weight of the overall design and facilitate crop sliding to unload. A set of cargo doors was developed for the rear of the trailer. These doors were vertically hinged, see Figure 4.2, so they could be opened nearly 270 degrees and fastened to the sides of the trailer for unloading. The doors were also covered in plastic

sheeting. A challenging aspect of the trailer was the floor covering to accommodate the chain-driven pusher. Along the bottom, two large rectangular steel tubes ran from the front to the rear of the trailer to make up the main frame. Short lengths of steel bridged the gap between the main frame and side rails. Also contained on top of this frame was a heavy roller chain that moved the bale pusher to unload the bales. This pusher was expanded to use it to densify the stover in the trailer. As shown in Figure 4.3, framework was added to the main pusher and covered with plastic sheeting. The pusher was controlled electro-hydraulically and automatically stopped when it reached each end of the trailer.

Once completed, the box portion of the trailer had overall dimensions of 8'3" tall, by 8' wide, by 30' long. This gave a theoretical capacity of 1,980 cubic feet. Assuming a stover density of 9 lb/ft³, a load of 17,820 pounds of stover would be possible.

The trailer was hitched to a JCB 185 FastTrac tractor, leased for the project, as shown in Figure 4.4. The JCB had a top speed of 45 mph and was equipped with air ride suspension and air over hydraulic brakes. Pulling the trailer with a high-speed tractor allowed for the rapid and cost effective transportation of the corn stover.

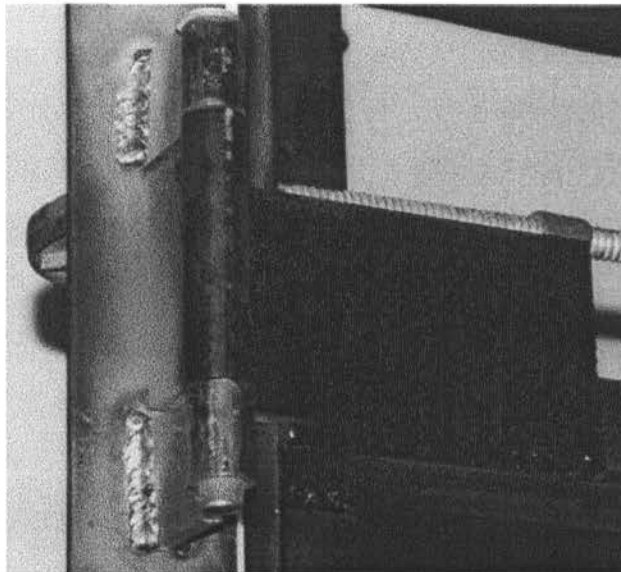


Figure 4.2 Cargo door hinge for stover transport trailer

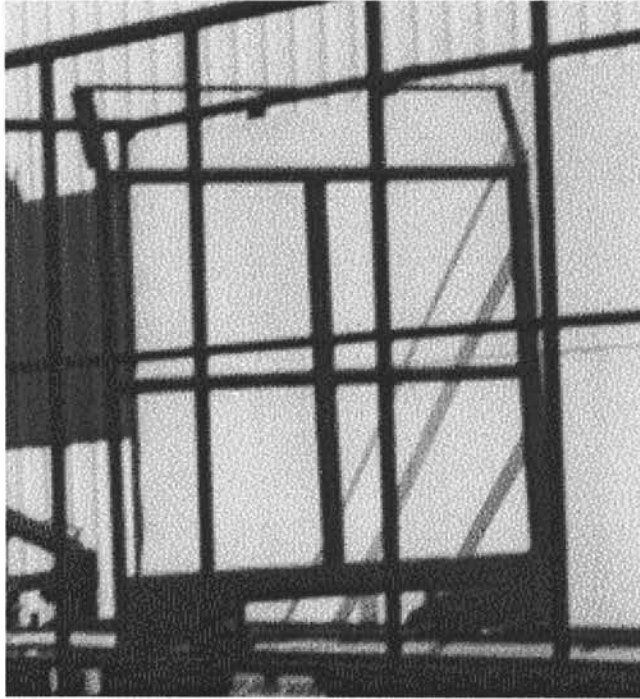


Figure 4.3 Framework of pusher for stover transport trailer



Figure 4.4 Completed stover transport system

Two-tier harvesting head

As previously stated, M. Duane Bass developed his variable row spacing corn plot combine at Iowa State University. A 64 horsepower air-cooled Wisconsin gas engine powered this plot harvester. The original machine was designed for two rows of any width and wheel spacing, hydraulically variable. Modifications were made to the combine in order to assess Geringhoff Rota Disc cornrow units imported from Germany. The row units, see Figure 4.5, snap the ears from the stalks while a set of aggressive disc blades chop the stalks into pieces three to six inches in length (Geringhoff, 2000.) The design was appealing because it met one of the objectives of uniform stalk chopping.

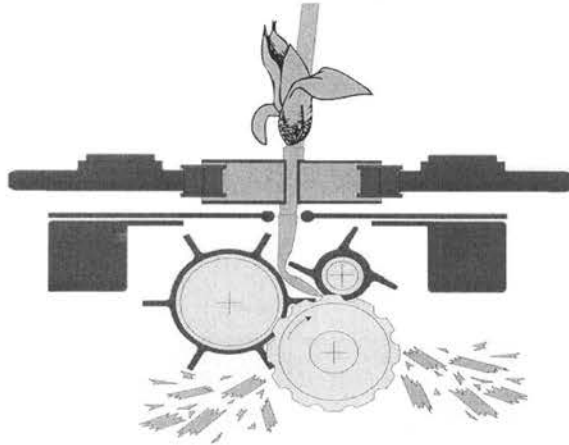


Figure 4.5 Cross-section of German Geringhoff Rota Disc row unit

Two row units were attached to the frame of a modified New Holland corn head. The units were sloped 28 degrees, as specified by the company. The previous corn head on the plot combine was removed. Extensive modifications took place for the attachment of the new corn head to the plot harvester. The connecting arms were strengthened because the Geringhoff row units were much heavier. Larger hydraulic cylinders were needed to lift the heavier head. A method to collect the chopped stalks was developed next. Under the row units, a bed of four augers was placed to collect and convey the chopped stalks to the rear of the corn head as seen in Figure 4.6. The augers were placed close to the chopping discs to

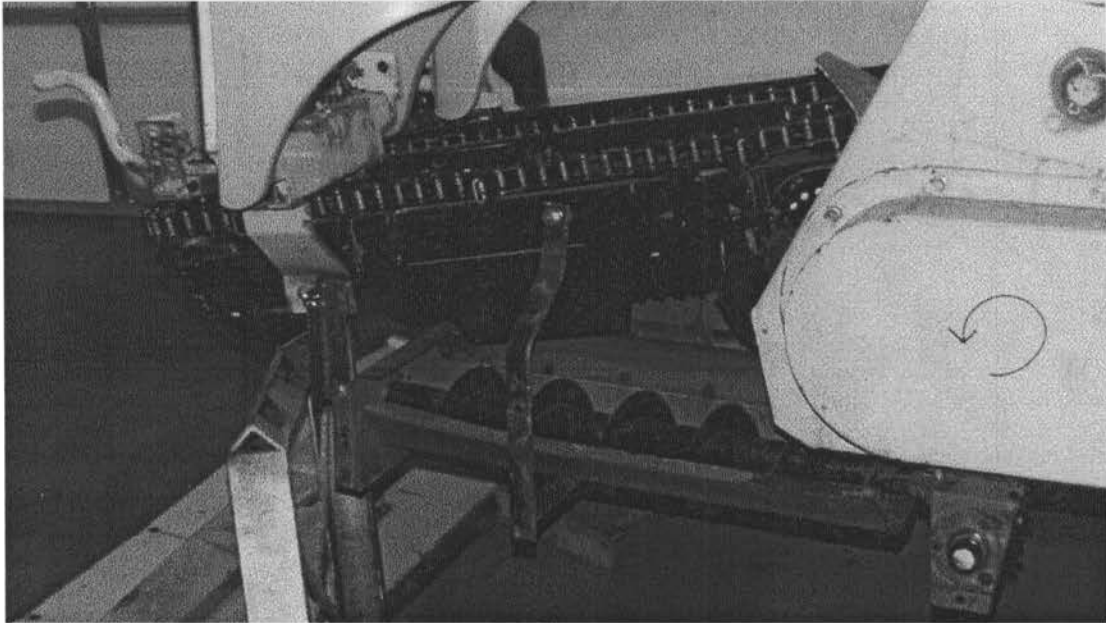


Figure 4.6 Auger bed underneath Geringhoff units

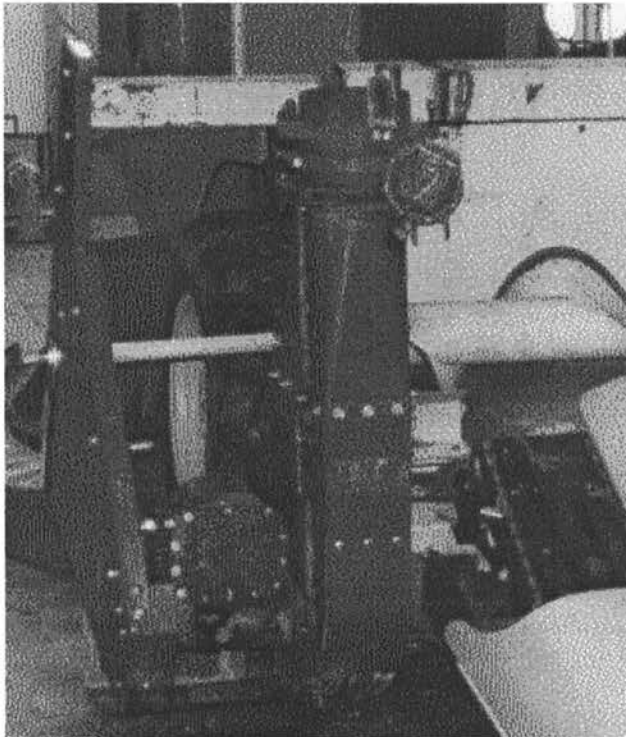


Figure 4.7 Forage blower attached to corn head

minimize ground clearance problems that may be encountered. The four augers were powered by one input shaft that was chain driven from the main input shaft of the head. A larger auger was placed at the rear of the head to cross convey the chopped material to the right side of the head.

At this point in the design and development process, in order to save time in a limited harvest time, the decision was made to not run the harvested ears through the plot harvester for shelling. They would also be cross-conveyed to one side of the head. A forage blower from a New Holland forage harvester was fitted to the side of the corn head. The blower was used to convey the chopped stover and ears of the corn plant into the stover trailer along side the plot harvester. The same input shaft powered the blower as the head. The electric controls from the forage harvester were also used on the plot combine for control of the spout and deflector.

Field testing of stover trailer and plot harvester

Initial testing of the stover harvesting system was conducted in bitterly cold conditions after the majority of the corn harvest was completed. Snow was present on the ground, but not enough to halt testing. The plot harvester was able to handle the load of powering the corn head along with the forage blower. However, there were frequent stoppages due to plugging of the head. The harvester had to travel a slow speed to accommodate the conveyance of the ears and chopped stover to the blower. The stalks appeared to be chopped well, but the uniformity of cut was poor. The stalk cut ranged from 1" to 13" in length with an average of 5.8". See Appendix 1 for the stalk data. Another problem encountered was that the ears were not feeding well into the blower. They frequently lodged at the bottom of the slide from the top auger. Making the slide larger might have alleviated this problem. The blower functioned well for blowing the chopped stalks and whole ears. As seen in Figure 4.7, the only problem was that the spout height was too short to fully reach the stover trailer. Most of the blown material was projected over the trailer with little being collected.

The preliminary test was successful in proving that it was possible to collect the stover and corn in a one-pass harvest. The stover trailer was not fully loaded due to the problems with the plot combine. After the initial test was completed, winter came in full force to central Iowa and testing was halted until spring.

Testing resumed in the spring to evaluate the changes that were made to the plot harvester. The spout of the blower was increased in length to more effectively blow the material into the stover trailer. Also improved was the transition zone between the top auger and the forage blower of the corn head. Testing was next conducted in Harlan, Iowa. Field conditions were fair but the corn was in poor condition. Due to the harsh winter, much of the corn was downed from the snow. The testing continued, although was hampered by the downed corn. More problems became apparent during testing. The chopped stalks wrapped around the augers underneath of the row units causing the head to stop functioning. The abrupt stopping of the head led to the plugging of the main cross auger and of the forage blower. After many attempts to continue the test, it was determined that the augers under the row units were not well suited for conveying chopped material to the rear of the head. The head modifications became too heavy for hydraulics to lift the head. Only with the aid of two men lifting on the front, was the head able to be raised to the proper level. This problem caused even more delays during the testing of the system. It was also concluded that in order to test the full functionality of an once-over or one-pass machine, the grain would have to be shelled and two streams of materials, the clean grain and the stover, collected. Thus, the next phase focused on the redevelopment of the plot harvester.



Figure 4.8 Field testing of stover harvest system

Full scale harvest equipment development

An International 1460 Axial Flow combine was adapted so that it could be coupled with a Hesston 10 Stakhand. The system allowed for a one-pass harvest of the grain and stover while keeping the two streams of product separate. By also combining the two processes, only one operator was required to simultaneously harvest the grain and stover.

Hesston 10 Stakhand

The Stakhand was initially developed by Hesston to collect and densify hay. The moveable roof of the machine achieved the densification of the stover. The roof was pulled down hydraulically to densify the loads when the box was full. The machine was modified in a number of ways for use with the combine. In order to lessen the loads placed on the combine, a supplemental gasoline engine was used to power the mechanical functions of the Stakhand machine and the hydraulics. Thus, the power take off assembly was removed to

save space between the combine and Stakhand. The orientation of the rotor was reversed. In normal operation, the flail pickup rotor would turn towards the front of the machine. To better accommodate the flow of stover from the combine, the lower portion of the stack was turned 180 degrees and the flail pickup driven in the other direction. The stover was then dumped into the front of the stack and impelled into the box of the Stakhand as shown in Figure 4.9. The flail pickup was belt driven directly from the gasoline engine. To engage the pickup, an idler pulley was locked into position to tighten the belts. The engine also powered hydraulics for the roof and unloading of the stack. The hydraulic components, oil reservoir, filters, and motors, were obtained from a used baler. A pump for the system was obtained from a used Gleaner combine. The hydraulics were manually controlled via valves located near the gasoline engine. Refer to Figure 4.10 for location of components.

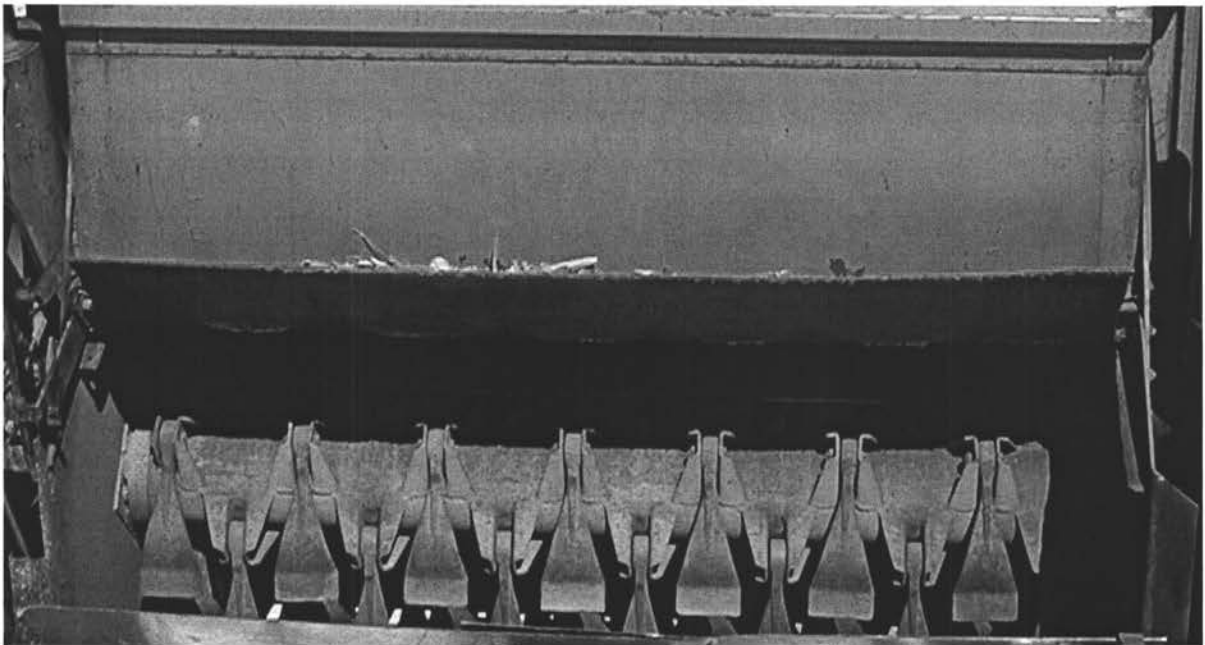


Figure 4.9 Flail pickup for elevation of stover into Stakhand

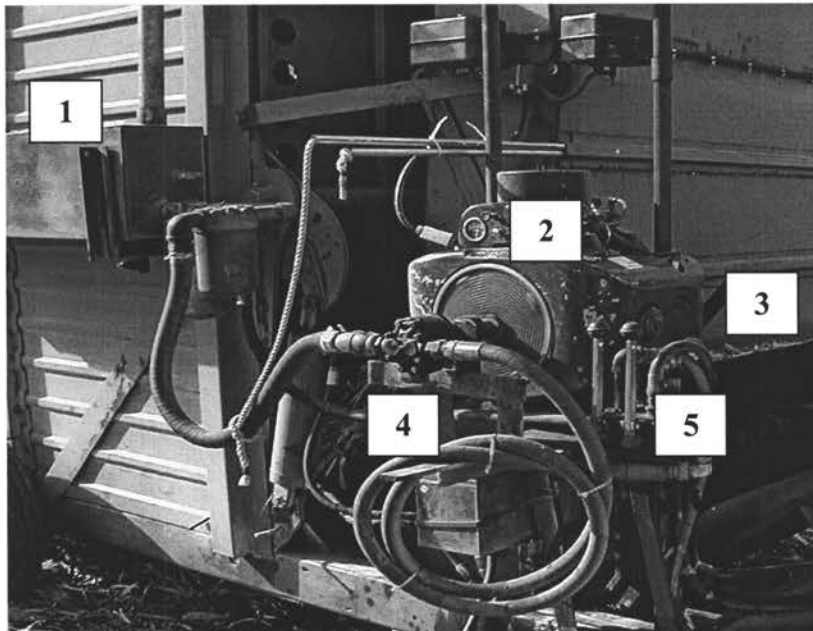


Figure 4.10 Side view of Stakhand and added components

- | | |
|-----------------------------------|-----------------------|
| 1. Oil reservoir | 4. Hydraulic pump |
| 2. Gasoline engine | 5. Hydraulic controls |
| 3. Flail engagement control lever | |

International Harvester 1460 Harvester

Three different heads were procured with this combine. Due to time constraints, it was determined that only a John Deere Model 653A soybean row head would be tested on the IH 1460. The six-row head used rotating cutters on each row unit that would sever the corn plant at pre-determined heights. The whole plant would be fed into the combine for separation of the grain. To break up and cut the stalk material coming from the rear of the rotor, two improvements were made to the combine. First, a set of “Tiger Shark” shredding teeth was installed in the rear section of the separating concave. These hardened knives were designed to cut the stalks as they were exiting the separation area of the rotor as shown in Figure 4.11. Second, the standard discharge beater of the 1460 was replaced with a

discharging chopper as seen in Figure 4.12. To collect and convey the stover from the rear of the combine, a belt conveyor was installed. The wide conveyor was partially covered to keep the stover from blowing off as a result to the air from the cleaning system of the combine. To power the conveyor, a belt and pulley system was used with hydraulic drive. The drive pulley was placed on the same shaft as used for the chaff and straw spreader of the machine as shown in Figure 4.13.



Figure 4.11 Tiger Shark teeth installed in rear separating concave

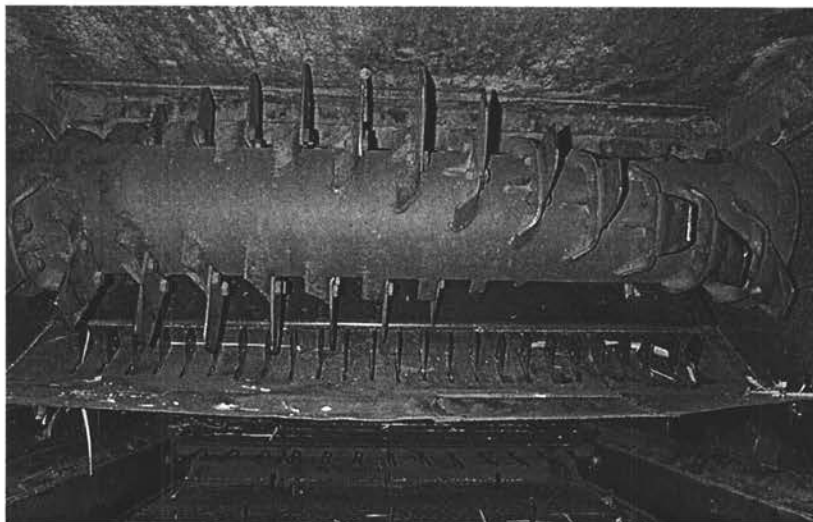


Figure 4.12 Rotor discharge chopper installed



Figure 4.13 Side view of belt conveyor and pulley system

Two-row plot harvester

In the second corn season of the two year project, the two-row plot harvester was reworked as a one-pass total corn harvester. This time, the forage blower mounted on the corn head was removed to reduce weight and relocated at the rear of the combine. Next, the bed of augers under the Geringhoff row units of the corn head were removed to make way for a single belt conveyor that collected the chopped stalks and moved them to the cross auger at the back of the head as shown in Figure 4.14. The bottom of the conveyor was covered with metal sheeting to protect the rubber conveyor from abrasion by corn stubble and the ground. The conveyor was powered by chain from the main input shaft of the head.

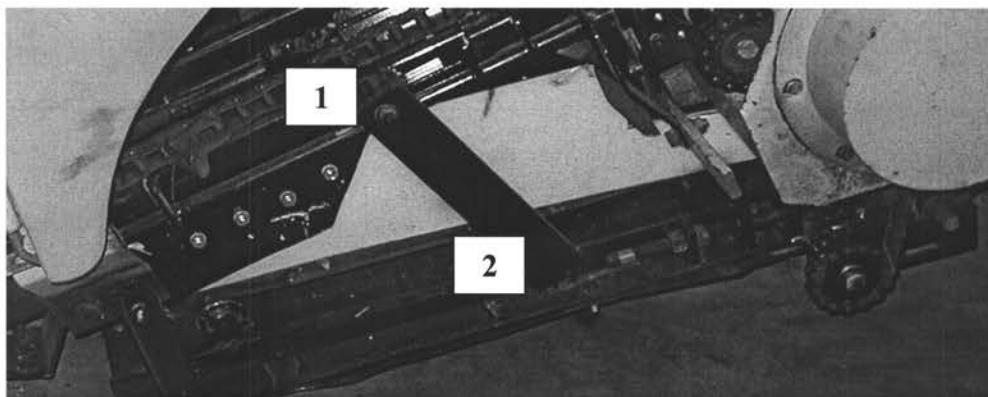


Figure 4.14 Conveyor mounted under Geringhoff row units

1. Geringhoff row unit

2. Conveyor

The weight reduction without the auger bed aided the hydraulic system and the combine was able to lift the corn head. Addition of the conveyor also increased the ground clearance of the head.

Relocation of the blower to the rear of the combine presented some new challenges. The first was the attachment of the blower to the combine. When the plot harvester was constructed, the main frame of the machine incorporated the hydraulic system reservoir. Since welding to that main frame was not possible, angle iron was bolted to the frame. The blower was welded to the angle iron along with the gasoline engine mount as shown in Figure 4.15.

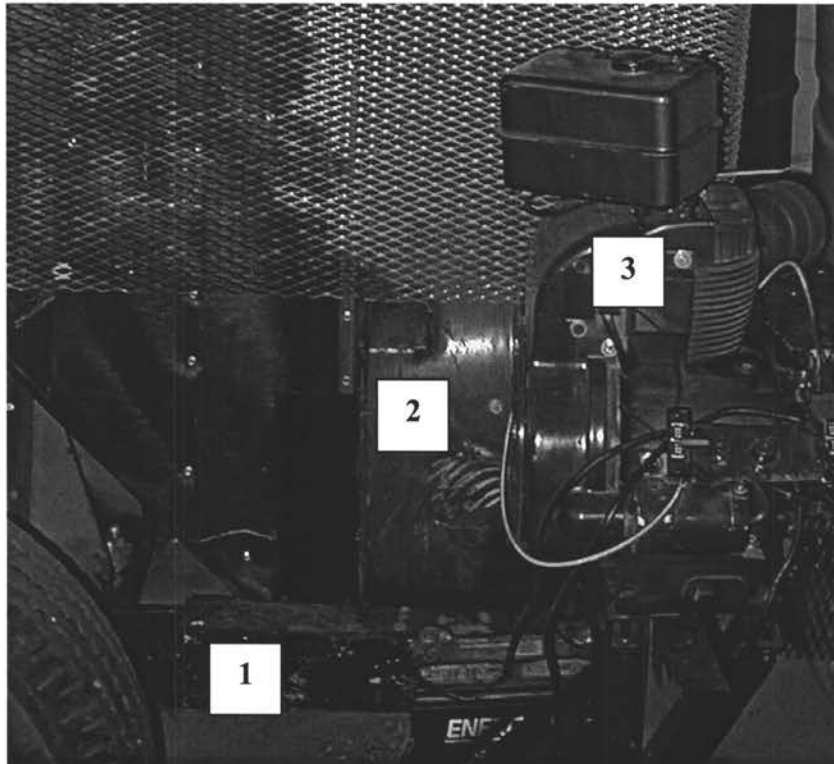


Figure 4.15 Forage blower and gasoline engine mounted on harvester

- 1. Angle iron frame
- 2. Forage blower
- 3. Gasoline engine

A long belt conveyor mounted to the right side of the combine achieved delivering the chopped stalks from the corn head to the rear of the combine for the forage blower. The conveyor collected the stalks from the cross auger under the head and conveyed them to the blower at the rear. Refer to Figure 4.16.



Figure 4.16 Conveyor for chopped stover mounted on the right side of the harvester

To power both the forage blower and the main conveyor from the head an auxiliary gasoline engine was mounted at the rear of the combine. Although the 20 HP engine was unlikely to operate the blower and conveyor at full field capacity, work continued mounting the engine to the harvester. A spring-loaded idler pulley was used as a clutch for engagement of the blower and conveyor. The blower gearbox also allowed for powering of the belt

conveyor. A simple chute was added between the top end of the conveyor to the blower for the chopped stalks to be delivered to the blower. Refer to Figure 4.17 for side view of completed harvester.



Figure 4.17 Side view of completed total corn plot harvester

With these modifications, the plot harvester became a two-row whole corn harvester. The ears could be snapped from the plant, run through the combine for threshing of the grain while the blower would collect the MOG from the rear. The head was a two-tiered design with the collection of the ears and the stalks at the same time. The stalks could also be delivered to the rear of the combine via belt conveyor for blowing into the stover transport system along side of the combine.

Stover caddy

An attachment named the “stover caddy” was designed and built for use with John Deere STS combine harvesters. The design was aimed at providing a low cost and simple approach for the collection of corn stover. The caddy consisted of a large upright silo forage blower and a 60 HP Wisconsin air-cooled gasoline engine. A frame was constructed that attached to the combine at two points on the rear axle. Two caster wheels were used on the

caddy for support of the blower and engine. These wheels allowed for the caddy to follow directly behind the combine at all times. This feature ensured that the opening of the blower and rear chopper of the harvester would be in line and overcome any problems with backing the combine with the caddy hitched on. The chopper of the combine was modified to project the chopped MOG directly into the opening of the blower on the caddy. The blown stover was then collected in a trailer that pulled alongside. The overall system, see Figure 4.17, allowed for a low cost alternative design for the simultaneous collection of the grain and stover.

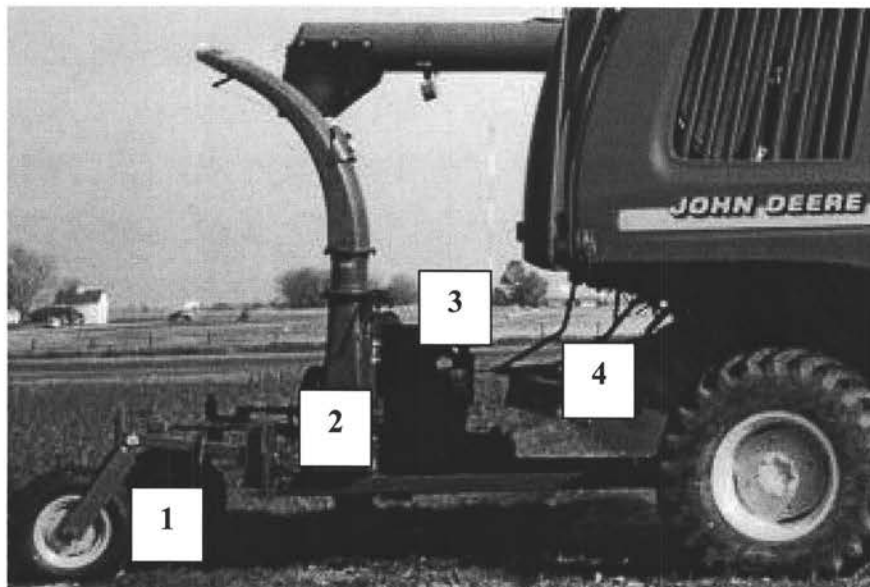


Figure 4.17 Stover caddy attached to John Deere 9750 STS combine

- | | |
|--------------------|------------------|
| 1. Caster wheels | 2. Forage blower |
| 3. Gasoline engine | 4. Straw chopper |

CHAPTER 5. FIELD TESTING OF MACHINERY

International 1460 Harvester and Hesston 10 Stakhand

The International 1460 and the Stakhand were first tested in high moisture corn, 25% MC, as seen in Figure 4.18. The machine performed well but in high moisture corn was constrained to four out of six rows of the head. Some material was lost at the top of the stack to the opening of the roof. Rubber belting was added to help correct that problem. The Stakhand engine was the capacity-limiting factor of the whole system. The quality of the grain collected in the grain tank was excellent. Little trash was present in the grain and with essentially no visible damage to the kernels. The collected stover was extremely high in moisture at 50% MC. Since the high moisture stover would not store well, the material was spread out in the field after weighing a load.

Further testing was conducted near BECON, the Biomass Energy Conversion Facility, in Nevada, Iowa using the full width of the head. Problems arose in the delivery of the cut corn plant via the gathering belts to the cross auger of the head. Plugging occurred at the furthest right row unit causing plants to become lodged under the gathering belts. After unplugging the machine and retesting, the row head continued to become lodged with stalks. It was determined that dull cutting knives of the row bean head were the cause. From the test, the Stakhand was one-half filled as shown with Dr. Graeme Quick in Figure 4.19.

Once the cutting knives were replaced alleviating the problem, testing continued at BECON to investigate the relationship between the loading rates of the Stakhand and combine grain tank. 0.397 acres of dry field corn were harvested to load the Stakhand to 3,600 pounds, for a stack density of 8.19 lb/ft³ after three roof compactions. The stover and cobs yielded at 9,057 pounds per acre of high moisture material and 186 bushels of grain per acre. The overall capacity of the grain tank was factory rated at 170 bushels. Thus, only a portion of the grain tank was filled per stack produced with this small Stakhand. The total



Figure 4.18 Initial field testing of combine-stacker harvesting system



Figure 4.19 Dr. Graeme Quick checks the density of a partially completed stack

weight of stover and grain combined was 19,473 pounds per acre that would be removed with a stubble height of 18 inches. The Stakhand engine limited the combine to a ground speed of 1.2 miles per hour in these heavy crop conditions. Any greater speed would overload and stall the engine of the stacker.

John Deere 9750 STS with stover caddy

Testing of the stover caddy was conducted with the 9750 fitted with a conventional corn head. The overall functioning of the caddy was hindered by high winds. The MOG projected from the chopper did not channel correctly into the opening of the blower. Material became plugged in the opening while also covering the air inlet for the cooling system of the engine. Due to the low weight of the MOG, the material was not blown as far as was expected.

Metal sheeting was added to the opening of the blower to aid entrance of the MOG. The guide vanes of the straw chopper were replaced to help project the material more effectively to the opening of the blower. A piece of expanded metal was also used to cover the engine for protection from MOG. A flexible boot was needed to direct the MOG stream into the blower inlet.

CHAPTER 6. COMPARISON OF MACHINERY

The full spread of test machines was transported to Harlan, Iowa for further tests and a public field demonstration. To rate the performance of the machines developed they were compared with current market machines, namely a large round baler, large rectangular baler, and stacker. These were compared to performance of the combine-stacker combination, combine-caddy and the plot harvester coupled with the stover transport system. The criteria for comparison were the ability to densify stover, machine capacity, and length of stover cut.

Stover densification was one of the objectives of the overall research project. To provide for a benchmark for comparison, laboratory experiments were conducted to determine the forces required to densify stover. A MTS testing machine with a 500-pound load cell was used for the tests. The cross sectional area of the volume used to compress the stover was 1.126 square feet. Both wet and dry stover was tested. The maximum densities achieved up to the limit of the testing, set by the test cylinder rod, were 8.32 lb/ft³ and 25.06 lb/ft³ for the dry, 15% MC, and wet, 30% MC, stover respectively. Although these tests illustrate the difference between the densities of dry and wet stover, field results could vary dramatically from the laboratory results.

Densification comparison

In order to transport maximum loads of stover and keep costs down, stover must be densified. Sokhansanj (2001) stated that the round and rectangular bale densities are 9 lb/ft³ and 14 lb/ft³ respectively for corn stover, 20% moisture. The weights of the bales were determined to be 1,700 pounds for the rectangular and 1,272 pounds for the round. For comparison to baling, tests were conducted during the fall of 2000 to investigate the capabilities of the Hesston Stakhand for stover collection. By varying the number of presses during the formation of the stack, different weights and densities were obtained. The minimum found was 570 pounds at 1.43 lb/ft³ to 1,600 pounds at 3.64 lb/ft³ of 20% MC

stover. As demonstrated with the laboratory findings, the drier the stover, the lower the density.

Using the equipment developed for the corn and stover harvest, some densities were observed as documented earlier. The maximum found using the combine stacker combination was 8.19 lb/ft³ with a stack weight of 3,400 pounds at 45% MC. Due to frequent breakdowns of the old two-row harvester, a full load of stover was not collected.

Machine capacity

Sokhansanj (2001) determined machine capacities of the rectangular and round balers. Using field efficiencies of 0.80 and 0.65 and a field speed of 5 miles per hour, capacities of 7.27 and 5.91 acres per hour were projected for the rectangular and round balers respectively. During the tests of the Stakhand, it was found that the machine had a machine capacity of 2.73 acres per hour with a pickup width of 5.0 feet and a forward ground speed of 4.5 miles per hour. The small Stakhand was capacity limited by engine power and frequent stops to compress the material in the wagon. From testing in the fall of 2001 with the combine-stacker system, the capacity of the system was limited due to the overloading of the engine on the Stakhand. With a forward ground speed of 1.2 miles per hour and a 30 inch, 6 row head, combine capacity was only 2.72 acres per hour. Testing was also conducted with the 1460 combine alone. A top ground speed of 4.5 miles per hour was reached, for a work rate capacity of 8.12 acres per hour. Thus, the Stakhand would require a much larger engine in order to match the combine capacity. Machine capacity was never a goal and thus was not measured for the plot harvester due to the small scale and the frequency of breakdowns that plagued the system.

Testing was conducted however, on the 9750 STS. Two different heads were tested on the machine, the regular 8-row cornhead and the 6-row bean head. The 6-row bean head was tested to evaluate the capacity of a large combine harvester's capability to digest the whole plants going through the machine. Two different cut heights for the corn were set for the row bean head, 7" and 15" stubble height respectively. Forward ground speeds versus

the machine harvested yield were measured. As shown in Figure 6.1, there was no significant reduction in throughput capability between the regular corn head and the 15” stubble height. There was an obvious reduction in the harvested yield by cutting lower. Also evaluated with the STS was forward speed versus grain damage. As shown in Figure 6.2, there was no significant effect on grain damage when harvesting with the bean head over the regular corn head.

Length of cut

During the public field demonstrations held in Harlan, IA on October 29, 2001, the machines were operated in the same field with a large Hesston 4760 big square baler. The process for making the large rectangular bales first included raking the stover into one windrow for better pickup by the baler. One sample from each machine was taken. The samples were then weighed to establish the sample weight and then were divided into the representative portions of the corn plant. The portions divided out from the total included fines, cobs, leaves, and short, medium, and long stalk pieces. Short pieces were deemed under three inches in length, medium were three to six inches in length, and long were six inches or greater. The portions were then weighed to find the percent of total mass of each. The results are shown in Table 6.1. All numbers represent percent of total mass. Three samples were taken from the Stakhand, front of stack, back of stack, and mixed sample to better represent the overall stack.

The data shows that each machine had unique capabilities for the collection of the different parts of the corn plant. However, due to the very limited samples that were taken, no inferences were made on the machine performance.

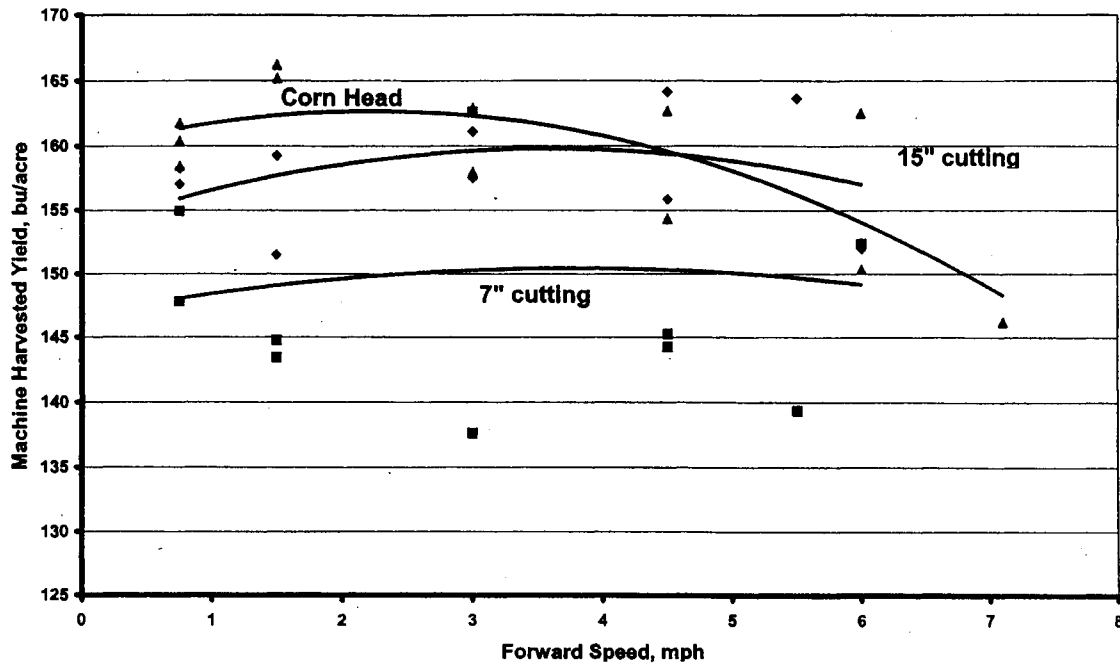


Figure 6.1 Forward speed versus machine harvested yield, John Deere 9750 STS with 6-row beanhead and 8-row regular cornhead

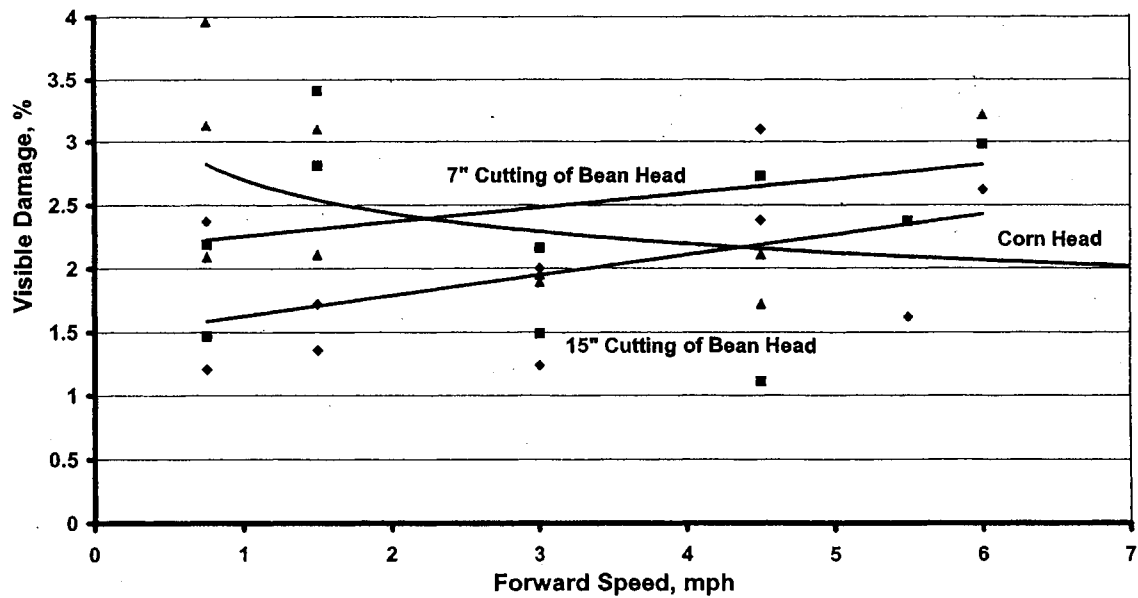


Figure 6.2 Grain damage versus forward speed, John Deere 9750 STS with 6-row beanhead and 8-row regular cornhead

Table 6.1 Breakdown of percentage of mass for each portion of stover samples from different harvest systems

Hesston Square Bale

Cob	Leaf	Short Stalks	Medium Stalks	Long Stalks	Fines	Other
10.9	30.6	5.7	10.0	41.2	0.0	1.6

Stakhand (Front of Stack)

Cob	Leaf	Short Stalks	Medium Stalks	Long Stalks	Fines	Other
19.3	27.2	3.6	7.9	40.0	0.0	2.0

Stakhand (Rear of Stack)

Cob	Leaf	Short Stalks	Medium Stalks	Long Stalks	Fines	Other
13.8	35.5	4.2	11.3	13.6	18.8	2.8

Stakhand (Mixed Sample)

Cob	Leaf	Short Stalks	Medium Stalks	Long Stalks	Fines	Other
13.8	35.5	4.2	11.3	13.6	18.8	2.8

Bass Combine

Cob	Leaf	Short Stalks	Medium Stalks	Long Stalks	Fines	Other
33.7	39.0	7.3	6.3	4.4	5.3	4.7

9750 STS with stover caddy

Cob	Leaf	Short Stalks	Medium Stalks	Long Stalks	Fines	Other
23.3	25.4	6.5	9.8	22.5	7.4	5.1

CHAPTER 7. ECONOMIC ANALYSIS OF DEVELOPED SYSTEMS

In order to understand the feasibility of harvesting the total corn plant with the systems outlined in previous chapters, an economic analysis was completed. The current method for the collection of corn stover, namely baling, was used for comparison with the developed systems. To achieve a set of data for comparison, numerous studies from varied sources were evaluated for the cost of the collection of stover after the grain harvest.

University of Nebraska-Lincoln study I

A feasibility study by Renee Sayler, et al. (1993) at the University of Nebraska-Lincoln examined the opportunities and challenges for corn residue collection. Two different methods for collection were assessed, a one-pass and a two-pass harvest. For the one-pass harvest, a pickup roll baler and pickup rectangular baler were used to collect the stover after the grain harvest was complete. The two-pass harvest involved windrowing the stover in the first pass followed by either roll or rectangular baling. Also included in the analysis was a loader tractor used for the loading of the bales onto a 44-foot trailer. The trailer had the capacity of holding 33 large rectangular bales or 26 round bales for the transportation of the bales to a processing facility.

As shown in the provided Tables 7.1 through 7.3, the cost of operating a rectangular baler was higher than that of the round baler. The lowest cost per ton delivered of stover was \$27.43 in a one-pass operation completed with the round baler harvesting 1.0 ton per acre of stover. The highest cost per delivered ton was \$33.05 with the large rectangular baler collecting 1.0 ton per acre. The higher cost with the rectangular baler was attributed to the higher machinery cost and lower collection rate of stover per acre. Also noted was that the higher tonnage of stover per acre that was harvested from the field, the lower the overall cost per delivered ton to the processing facility.

Table 7.1 One-pass system summary using pickup roll baler

	Cost per delivered ton		
	1.00	1.25	1.50
Field residue yield, tons/acre			
Field harvest, pickup roll baler	\$17.21	\$14.57	\$12.97
Field to area storage	4.12	4.12	4.12
Unload and stack	1.48	1.48	1.48
Area Storage	0.36	0.36	0.36
Load for transport	1.48	1.48	1.48
Highway Transport	7.33	7.33	7.33
Unload at plant	0.28	0.28	0.28
TOTAL	\$32.26	\$29.62	\$28.02

Table 7.2 One-pass system summary using rectangular baler

	Cost per delivered ton		
	1.00	1.25	1.50
Field residue yield, tons/acre			
Field harvest, 3' x 4' x 8' baler	\$19.06	\$16.12	\$14.3
Field to area storage	3.95	3.95	3.95
Unload and stack	1.45	1.45	1.45
Area Storage	0.21	0.21	0.21
Load for transport	1.45	1.45	1.45
Highway Transport	6.64	6.64	6.64
Unload at plant	0.29	0.29	0.29
TOTAL	\$33.05	\$30.11	\$28.29

Table 7.3 Two-pass system summary for stover collection

	Cost per delivered ton	
	Roll Bale	Rectangular Bale
Field residue yield, 1.0 ton/acre		
Field harvest, 3' x 4' x 8' baler	\$12.38	\$14.82
Field to area storage	4.12	3.95
Unload and stack	1.48	1.45
Area Storage	0.36	0.21
Load for transport	1.48	1.45
Highway Transport	7.33	6.64
Unload at plant	0.28	0.29
TOTAL	\$27.43	\$28.81

University of Nebraska-Lincoln study II

In another study completed at the University of Nebraska-Lincoln, Jose (1996) investigated the costs of harvesting corn stalks for either livestock fodder or industrial uses. The costs were calculated with the assumptions of 130-acre harvest of corn yielding 150 bushels per acre. The amount of stover harvested was assumed 4.2 tons per acre. Three different ways of harvesting the stalks decided the actual yield per acre harvested of stover. The methods included the following:

- Stalks that were shredded, raked and baled- 3.5 tons per acre
- Stalks that were raked and baled only- 2.75 tons per acre
- Stalks baled directly after combining- 2.0 tons per acre

The bales were assumed to weigh 1,100 pounds each. The labor component of the analysis was set at \$6.00 per hour while the costs for owning and operating the machinery were set as follows:

- Use of round baler- \$5.50 per ton
- Use of tractor for baling, raking, and shredding- \$23.00 per hour
- Use of rake- \$3.50 per acre
- Use of rolling shredder- \$2.00 per acre
- Moving of bales for loading- \$1.00 per bale

The baling rate was set at a conservative 6 acres per hour, the shredding rate was 6.5 acres per hour and the raking was 9 acres per hour. The estimated value of the soil nutrients removed from the field due to the stover collection was set at \$9.59 per ton of stover.

The cost to harvest the stover in the University of Nebraska-Lincoln study when the stalks were shredded, raked and baled was \$12.03 per ton or \$42.11 per acre. For baling the stalks immediately after the grain harvest, the harvest cost was \$9.85 per ton or \$19.64 per acre. Transportation costs were also included. The rate assumed was \$2.50 per loaded mile for a minimum of ten miles or \$0.152 per ton per mile. For hauling a 16.5-ton load 30 miles,

the total costs for the harvest operations rose to \$26.18 per ton for the three-step harvest and \$23.97 per ton for the direct baling after the combine.

Oak Ridge National Laboratory Study

Another study by Oak Ridge National Laboratory, Sokhansanj (2001) investigated the baseline costs for the collection of corn stover. Two different baling systems, rectangular and round were evaluated. The sequence of events for the collection of the stover included shredding-windrowing and round baling or shredding, raking and rectangular baling. Five factors were used to determine the cost for the collection of stover. The factors included:

- Stover yield of 3.6 tons per acre at 20% moisture
- The sequence and number of operations of collection
- Equipment used, service life, and capital costs
- Rates of work, collection and field efficiencies
- Interest and wage rates

The analysis also included the collection of the bales in the field and transportation to a storage site up to five miles from the field. The calculations yielded a cost of \$19.68 per dry ton or \$195.73 per hour for round baling of the stover and \$21.45 per dry ton or \$262.67 per hour for rectangular baling. The higher costs for the rectangular baling were attributed to the higher equipment cost and additional operation of raking the stover before baling.

Economic analysis of equipment developed

The economic analysis covers the costs of harvesting the corn stover with the equipment developed in previous chapters. The cost per acre does not take into account the cost of harvesting the corn with the conventional combine. It is assumed the cost for grain collection was recovered from the grain itself. The plot harvester was not considered in the analysis due to the impracticality of such a machine in a large-scale stover collection operation.

The following assumptions were made for the calculations:

- All equipment purchased new
- Interest rate of 7.5%
- Inflation rate of 1%
- Diesel fuel cost of \$1.08/gallon
- 1000 acre corn harvest
- Corn yield of 150 bushels per acre
- 10 acres/hour combine capacity
- 6 ton/stack of stover
- Labor rate for operation of loader: \$10/hour
- Stakhand capacity equal to that of the combine: 10 acres/hour
- 70% collection of all above ground stover
- Loader would be used for other purposes than just harvest: 1000 hrs/yr

Two different calculations were figured, the first considered that the harvest of the grain would not be slowed due to the addition of the Stakhand to the operation. A second analysis evaluated the system as a whole, with the grain harvest slowed due to the Stakhand.

A large capacity combine, John Deere 9750 STS, was used for the calculations. Also, a larger Stakhand, six-ton capacity, was used for the calculations in order to achieve a closer grain to stover ratio with respect to the loading of the grain tank of the combine and the Stakhand itself. With the assumption of only 70% of the above ground stover collected, for every one pound of grain harvested, only 0.7 pounds of stover was harvested. Thus, with a 56-pound per bushel test weight for the grain, the grain tank theoretically contained 306.12 bushels of grain when the Stakhand was filled with six tons of stover. Another addition to the system was a 50 horsepower diesel engine to the Stakhand for powering of the machine. The cost for the operation of the engine was also included in the analysis. The cost of gathering the stacks in the field, staging and loading them onto a semi-trailer with a telescopic loader was also included in the analysis. However, the transportation costs to the

processing facility were not included. This decision was based on the fact of discrepancies in who would be responsible for covering the costs.

Cost for on-time harvest

At a crop yield of 150 bushels per acre the combine attained a theoretical field capacity of 10 acres per hour producing 42 tons per hour at 56 pounds per bushel. With this rate, the harvest was completed at 100 hours. Using a stover to grain ratio of 0.7 to 1.0, 29.4 tons of stover was collected per hour. The loader had the field capacity of loading 40.8 tons per hour, although due to inefficiencies of the combine-stacker system, the loader was only utilized 72% of the time

While not including the lost productivity during harvest due to the Stakhand, the overall cost was calculated at \$6.32 per acre for the stacker with an additional \$3.27 per acre for the loader as shown in Table 7.4. The total cost for the stover harvest was \$9.59 per acre or \$3.26 per ton.

Cost for delayed harvest

For a fair economic representation of the combine-stacker system for stover collection, it must be realized that the addition of the Stakhand will slow down the harvest. With the same assumptions except that the combine had a field capacity of 50% of a timely harvest, the following were attained. By lowering the field capacity, the overall harvest time increased to 200 hours for the 1000 acres of corn. The combine would harvest 5 acres per hour producing 21 tons of grain per hour at 56 pounds per bushel. Using the same stover to grain ratio, 0.7 to 1.0, 14.7 tons of stover was collected per hour. The lower amount of stover harvested per hour also affected the utilization of the loader. Only 36% of the overall capacity of the machine was being used during the harvest season.

The overall cost for the addition of the stacker system to the harvest was \$6.59 per acre. The lower cost can be attributed to the fact that the Stakhand was being used for twice as many hours than in the timely harvest of the grain and stover. The cost of the loader also

increases due to the lower tonnage of material moved per hour in the slowed harvest. The loader cost \$6.92 per acre.

The total cost of the stover collection only in the slowed harvest was \$13.51 per acre or \$4.60 per ton. See Table 7.5 for data.

Table 7.4 Economic analysis for on-time corn harvest

Machine Information	Stacker Stakhand 60	Telescopic Loader
a. Current list price of a comparable replacement	\$39,000	\$94,000
b. Purchase price or current used value	35100	84600
c. Accumulated hours to date	0	0
d. Economic life, years	12	4
e. Interest rate, %	7.50	7.50
f. Inflation, %	1.00	1.00
g. Annual use, hours	100	1000
h. Engine or PTO horsepower	50	80
i. Fuel Type	Diesel	Diesel
j. Fuel price/gal	1.08	1.08
k. Labor rate, \$/hr	0	10.00
l. Capacity, acres or tons/hour	10.00	29.40
Estimating Fixed Costs		
1. Salvage Value	15210.00	46060.00
2. Depreciation	1657.50	9635.00
3. Average investment	9945.00	19270.00
4. Interest	2632.50	6345.00
5. Total fixed cost per year	4290.00	15980.00
Estimating Variable Costs		
6. Total Accumulated Hours	0.00	0.00
7. Total Accumulated Repairs	1755.00	4230.00
8. Average Repair Cost/Hour	17.55	4.23
9. Fuel Cost/Hour	2.38	3.80
10. Lubrication Cost/Hour	0.36	0.57
11. Labor Cost/Hour	0.00	10.00
12. Total Variable Cost/Hour	20.28	18.60
13. Fixed Cost/Hour	42.90	15.98
14. Total Cost/Hour	\$63.18	\$34.58
15. Total Cost/Acre	\$6.32	\$3.27
16. Total Cost/Ton	\$2.15	\$1.11

Table 7.5 Economic analysis for delayed harvest

	Stacker	Telescopic
Machine Information	Stakhand 60	Loader
a. Current list price of a comparable replacement	\$39,000	\$94,000
b. Purchase price or current used value	35100	84600
c. Accumulated hours to date	0	0
d. Economic life, years	12	4
e. Interest rate, %	7.50	7.50
f. Inflation, %	1.00	1.00
g. Annual use, hours	200	1000
h. Engine or PTO horsepower	50	80
i. Fuel Type	Diesel	Diesel
j. Fuel price/gal	1.08	1.08
k. Labor rate, \$/hr	0	10
l. Capacity, acres or tons/hour	5.00	14.70
Estimating Fixed Costs		
1. Salvage Value	15210.00	46060.00
2. Depreciation	1657.50	9635.00
3. Average investment	9945.00	19270.00
4. Interest	2632.50	6345.00
5. Total fixed cost per year	4290.00	15980.00
Estimating Variable Costs		
6. Total Accumulated Hours	0.00	0.00
7. Total Accumulated Repairs	1755.00	4230.00
8. Average Repair Cost/Hour	8.78	4.23
9. Fuel Cost/Hour	2.38	3.80
10. Lubrication Cost/Hour	0.36	0.57
11. Labor Cost/Hour	0.00	10.00
12. Total Variable Cost/Hour	11.51	18.60
13. Fixed Cost/Hour	33.05	14.05
14. Total Cost/Hour	\$32.96	\$34.58
15. Total Cost/Acre	\$6.59	\$6.92
16. Total Cost/Ton	\$2.24	\$2.35

Comparison of harvest costs

When compared to the traditional harvest costs of stover using baling, the Stakhand system cost less for both the on-time and delayed harvest. The overall cost of \$97.76 per hour for the on-time harvest was substantially lower than either conventional rectangular or

round baling, \$262.67 per hour and \$195.73 per hour respectively as found by Sokhansanj (2001). However, the comparison of the equipment by a per hour basis does not truly quantify the cost of the system. To better quantify the results, a per ton comparison should be used. The costs for the stacker-loader on time combination, \$3.26 per ton, also were lower than those found for baling, \$9.85 per ton, by Jose (1996).

Not included in the analysis was the possible loss of yield of the grain for a delayed harvest due to the addition of the stover collection equipment. The added expense for the combine due to the longer harvest was omitted. Also not included were the additional costs of repair to the combine harvester due to excessive loads placed on the powertrain by the weight of the Stakhand.

CHAPTER 8. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

The objectives set out in this thesis all centered on the development of new methods for the collection, densification, and economical transportation of corn stover. The development and testing of each different system were evaluated with the following outcomes:

1. Attaching walls, flooring, and doors to a modified round bale transport trailer provided a suitable high capacity stover trailer.
2. A two-tier head was made by the attachment of a belt conveyor underneath of a conventional corn head. Simultaneous collection and separation of the chopped stalks and whole ears were made possible.
3. With the addition of the two-tier head and means for conveyance of the chopped stalks to the rear of the combine to a forage blower resulted in a functional total corn harvester. This small harvester provided a test bed to try different means for the collection and separation of the corn plant.
4. A large combine harvester was also converted into a total corn harvester. The machine was fitted with a row bean head along with cutting mechanisms in the separation area to cut the stalks. A rear conveyor moved material into a stacker that collected the chopped stover and densified it for transportation. The whole stalk harvest and separation in a one-pass operation was successfully demonstrated with the combine-stacker combination.
5. A low-cost stover caddy attachment for combines was successfully developed and tested on two combines for the collection of stover from the rear of a combine.
6. An economic analysis showed that the collection of stover with the developed systems was considerably more cost effective than the existing methods, such as baling.

Future recommendations

The continuation of the development of corn stover collection systems plays a crucial role for furthering the progress of renewable resources. There is tremendous room for growth for future developments for corn stover. Some recommendations for future studies are as follows.

The end uses of corn stover and form of delivery must first be clearly defined in order to give a direction for an improved stover collection system. Once industry determines the quality and quantity of stover, harvesting techniques and machinery will be further defined.

In the short term, it would be valuable to develop equipment or attachments that could be utilized with current machinery on the farm. This would allow for the continued use of expensive, already owned machinery. Suggestions might include the following:

- Attachment of a high capacity square baler to the rear of the combine thus allowing for the collection and high densification of stover.
- Development of an improved means for the chopping of stover from the combine for a more uniform cut of the stover product.
- Further research and development into methods for separating the cob from the stover to further enhance the value of co-products to the grain.
- Investigation of dead space areas on current combine harvester that may prove beneficial for the addition of stover collection components.

However, a more simplistic approach could be taken for the harvest of corn stover. Equipment could be developed to allow for a one-operator, one-pass operation for the collection of the whole corn plant. The whole plant would be harvested but not separated in the field. Such a machine could entail a conventional corn forage head collecting the whole plant and conveying it into a wagon for transportation. The collected mass would then be transported to either the farm or possibly to a processing facility that would separate the grain, stalk, and cob. One obvious incentive of such a process would be the use of a simple machine for the harvest of the plant. If the ears and stover were transported together, load

density would be increased. The combine would no longer be used for the corn harvest. However, such a system would have some drawbacks. A new marketing system for the crop would have to be developed to sell the crop by the acre, ton, or other method rather than by the bushel. Another negative may include the elimination of one operation for a combine harvester, corn harvesting. This would only add to the already high cost of ownership of such a machine.

APPENDIX 1.

STALK DATA FROM GERRINGHOFF ROW UNITS

Sample Number	Stalk Length, in	Sample Number	Stalk Length, in	Sample Number	Stalk Length, in
1	4.5	40	4.4	79	6.7
2	4.3	41	6.0	80	5.4
3	10.0	42	3.5	81	2.5
4	3.5	43	4.4	82	4.0
5	2.9	44	5.6	83	3.8
6	7.5	45	8.5	84	9.0
7	4.5	46	4.1	85	3.5
8	4.0	47	5.8	86	3.7
9	4.0	48	8.4	87	5.5
10	2.9	49	6.4	88	4.0
11	7.0	50	7.2	89	3.2
12	4.0	51	2.7	90	3.7
13	10.0	52	6.7	91	3.8
14	10.0	53	4.5	92	3.8
15	2.8	54	4.6	93	8.8
16	7.9	55	12.6	94	5.0
17	6.9	56	2.8	95	7.1
18	7.9	57	3.4	96	4.0
19	6.5	58	3.4	97	5.0
20	3.3	59	7.7	98	2.9
21	5.1	60	1.5	99	3.7
22	5.0	61	3.8	100	3.7
23	2.5	62	5.9		
24	4.0	63	3.7		
25	2.3	64	3.1		
26	7.3	65	5.5		
27	8.0	66	3.5		
28	7.5	67	3.5		
29	8.0	68	2.4		
30	5.6	69	6.0		
31	7.6	70	4.6		
32	7.5	71	7.0		
33	13.0	72	6.0		
34	5.0	73	6.0		
35	4.0	74	2.3		
36	8.3	75	4.0		
37	8.0	76	6.7		
38	8.3	77	5.7		
39	7.5	78	3.5		

Minimum	1.5 in
Maximum	12.6 in
Average	5.8 in

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