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**An ASABE Meeting Presentation**

**Paper Number: 11**

## **Cornrower System of Stover Harvest**

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**Abstract.** *The Cornrower System of Stover Harvest provides a unique system that provides options for stover harvest currently unavailable. Avoiding ash (dirt) in the stover and reducing harvest costs, interference with corn harvest and moisture control are all problems with current methods. The Cornrower system addresses these problems and field tests have shown that dirt accumulation in the windrow is negligible. The windrow is left in the field at the time of corn harvest, thereby providing immediate opportunity to harvest the stover wet or leave it to dry as ambient conditions allow. Stover harvest is de-coupled from corn harvest to a great degree and labor to windrow the stover is eliminated since the Cornrower makes the windrow on the same pass as corn is harvested. Fuel use, labor costs and equipment capital requirements are all reduced compared to other systems and stover quality is enhanced.*

**Keywords.** Stover, Windrow, Density, Ash Content, Bale Weight, Cellulosic Ethanol, Cornrower, Drop in Fuel.

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## Introduction

A five-year effort to modify a chopping corn head in order to harvest corn stover in a more efficient manner than current systems was successfully completed in the Fall of 2010 with field operation of the Cornrower (Straeter 2010). This report provides insight into how the Cornrower works, what advantages it has over some other systems on the market and/or known to be under development. Data on fuel use and economic information on the operation of the Cornrower is presented. Reaction from farmers who have used the Cornrower and impact of this system on storage and transportation issues are positives. The Cornrower is an add-on attachment that fits on a New Holland 99C corn head with no modification of the header. It works by 'catching' the stover under the stalk rolls, prevents stover from contacting the soil while chopping it into smaller pieces than what is typically found in stover. Chopped stover is delivered to a raddled conveyor positioned immediately behind the corn head. The conveyor(s) then deliver the stover to a point under the feederhouse in the center of the combine. Air flow originating at the chopping point is used to help move the stover into the windrow and is used to make a loose, quick drying uniform windrow. Figure 1 illustrates that the Cornrower does not interfere with shelling and unloading operations.

## Safety Emphasis

Safety in operation of this machine has been a top priority. It is well known in the art of combines and headers that moving parts on corn head have injured too many operators. Additionally, the danger of an operator working under the header is an issue. A tool was developed that largely eliminates any need for the operator to be positioned under the head for unplugging the unit in the field. The housing design also serves as a shield that surrounds the rotating knives and makes the Cornrower safer than the chopping corn head without a Cornrower attached. Servicing of the Cornrower components doesn't increase the risk to the operator beyond that encountered when servicing standard corn header row unit components.



Figure 1 Shelling Corn, Unloading On The Go and Windrowing Stover all at the same time.

## Fuel Use With Cornrower vs Standard Corn Harvest

A major cost to collecting corn stover is direct fuel use in the process of collection, transportation and storage. The Cornrower header attachment impacts this major cost in a positive manner. Raking (usually with equipment originally intended for hay harvest) and windrowing with a stalk chopper require an extra trip across the field with a tractor. Fuel used in these operations can vary widely and no direct attempt is made in this study to compare fuel used to these systems. A quantification of fuel used to windrow the stover with the Cornrower was done in order to clearly show what the fuel use would be for windrowing with the Cornrower vs. a standard corn head. For this test, a New Holland 2010 model CR9060 combine was used. It was equipped with a 2010 New Holland 98D corn head that harvests 8 rows at 30" spacing. The Cornrower head mounted for the windrowing portion of the test was a 99C chopping corn head that also harvests 8 rows at 30" spacing. A chart showing the comparison of fuel used is provided in Figure 2.

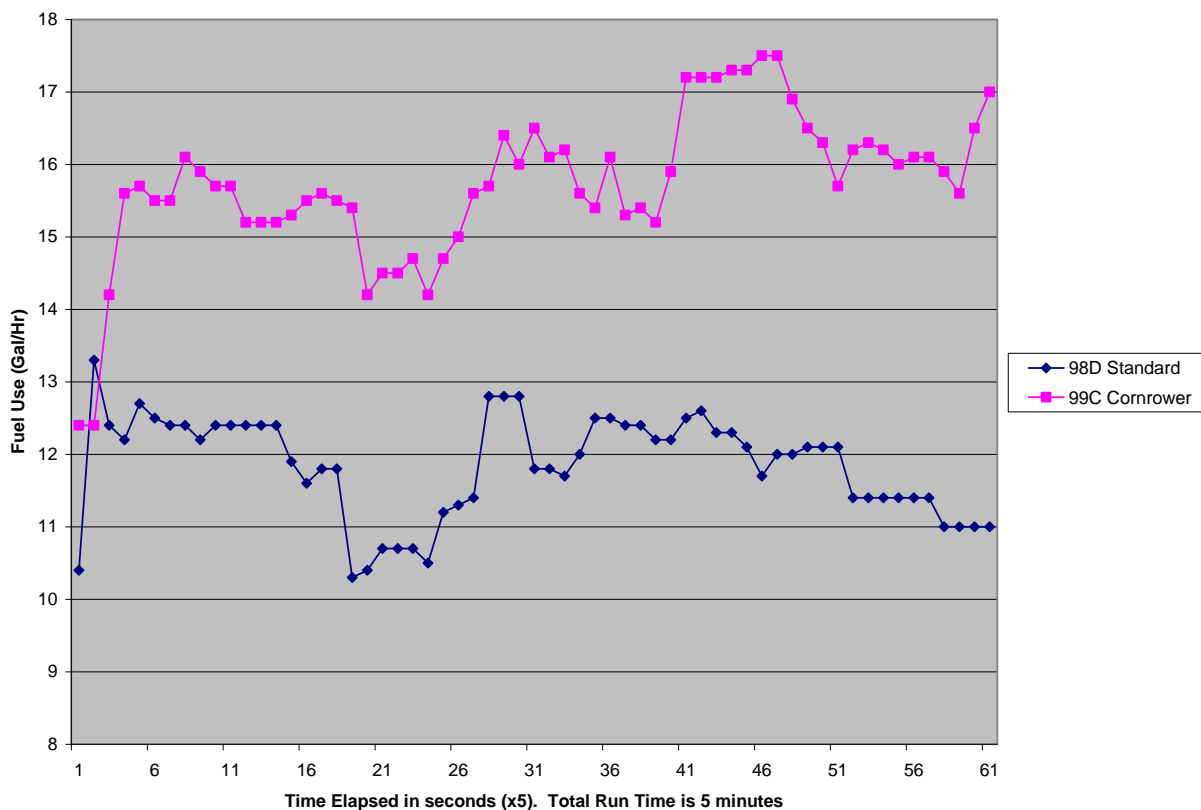


Figure 2 Fuel comparison with and without the Cornrower on a New Holland CR9060 combine.

For collection of data, a pass was made at 4 mph. with each header on adjacent sets of 8 rows in a field that was producing approximately 200 bu/acre of corn at 16% moisture. Fuel use data was collected from the combine's monitor and takes into account ground conditions, yield variations etc. as the machine traveled across the field. Since the runs were made at the same

speed with each header the only operating cost that is added for the windrowing is fuel. It is recognized that sometimes field conditions will dictate that a lower speed for the windrowing portion may be necessary and that in such case the fuel use may in fact be comparable while other costs, such as labor, will increase. No attempt at such comparisons is made at this time. Analysis of the data shows that in the first half of each test the difference in fuel used averaged 3.15 gal/hr whereas in the second half of the test fuel used averaged 4.72 gal/hr more for the Cornrower than the non-chopping, standard 98D corn head. The average difference for the entire test was an additional 3.88 gal/hr for the Cornrower. On a percentage basis, the first half of the test showed a 27.6% increase in fuel used in windrowing and the second half of the test showed an increase of 37.2% for the Cornrower. The entire test showed an increase of 32.7% for the windrowing operation vs. standard corn harvesting. The increase in net fuel used and percentage of fuel used in the second half of the test can be explained by the fact that engine load, which was also monitored, in the combine was in the range 90%+ of available horsepower for most of the second half of the test but in the 80-85% range for the first half of the test. Field conditions will dictate harvest speed in many cases for reasons unrelated to the windrowing operation. The range of cost to windrow the stover is shown by this comparison of windrow/non-windrow harvest.

With \$4.00/gal. diesel, windrowing with the Cornrower will cost from \$12.60 per hour to \$18.88 per hour. Using a 4 mph speed with an 8 row head, the combine harvests at a rate of 9.69 acres/hour. Assuming 2 tons of stover harvested per acre windrowing cost is \$0.64 to \$0.97/ton. It should be mentioned that travel to the field, unloading time, turning on the headlands etc. will reduce the acres per hour and tons harvested in an hour. Since there is no premium for such activities necessitated for the Cornrower and acknowledgement that these activities will be necessitated for normal corn harvest, the actual costs for windrowing are only incurred when harvesting grain. Therefore, the calculations of the real cost to windrow the stover with the Cornrower are correctly shown.

## Ash Content

A major concern with stover harvest is dirt contamination of the stover. Rocks are a major cost factor in those areas with rocks and it is pointed out that in windrowing stover with the Cornrower, rocks are not accumulated within the windrow. Pickup of the windrow carries a rock-ingestion risk but that risk less than picking up a windrow formed with a rake or stalk chopper since no rocks from a windrow formed by the Cornrower will exist inside the windrow. Rakes and stalk choppers can incorporate rocks in the windrow and these can be ingested fairly easily by a baler or forage harvester. No value of any kind is attempted for the difference in rock risk with the Cornrower and such valuation is left to the reader. Dirt contamination within the windrow is quantified but not valued.

Dirt is measured as “ash” in the stover. Such measurement is usually done by thermal means. After applying heat in an oxygen-limited environment the remaining material will be minerals that are naturally existing in the plant material such as phosphate and potash. Soil that is accumulated will also remain as ash. The impact this soil has varies greatly depending on what the stover will eventually be used for. Soil contamination is always viewed as a negative reality of stover harvest.

Analysis of stover from a windrow was visibly compared to stover in the bale and no difference was seen. The operation of the Cornrower generates no visible dust. This result was expected as there is no soil contact by the stover or any operating component of the Cornrower during the

harvest process. Baler pickup, however, can carry some risk of soil contamination and the skill of the baler operator in setting the baler for stover harvest is important. The baler operation did show visibly that soil contamination can occur at this point of the stover harvest.

Nonetheless, third-party analysis of baled stover from windrows formed by the Cornrower show ash content that approaches the ash content found in standing corn plants. No test of stover from the Cornrower has had ash content in the average or above average range, indicating that the Cornrower process prevents relatively large amounts of ash from dirt to enter the harvest stream even in difficult field conditions or from unskilled operators. While this observation has occurred over hundreds of acres of stover harvest, further objective analysis is warranted. Removing the impact of inexperienced operators, tough field conditions etc. on ash content is a significant advantage that can encourage adoption by more farmers.

An example of a test of small square bales is provided in figure 3 and figure 4. Testing and report of results are courtesy of Monsanto Corp. and comparison samples are from all collected stover samples analyzed during the 2009 harvest season.

Small Bale vs 540 Bale samples from 2009 bales

Ash = 5.0 %

This "small bale" sample falls in the 2.5-10% quantile (meaning that is within the lowest ash content samples)

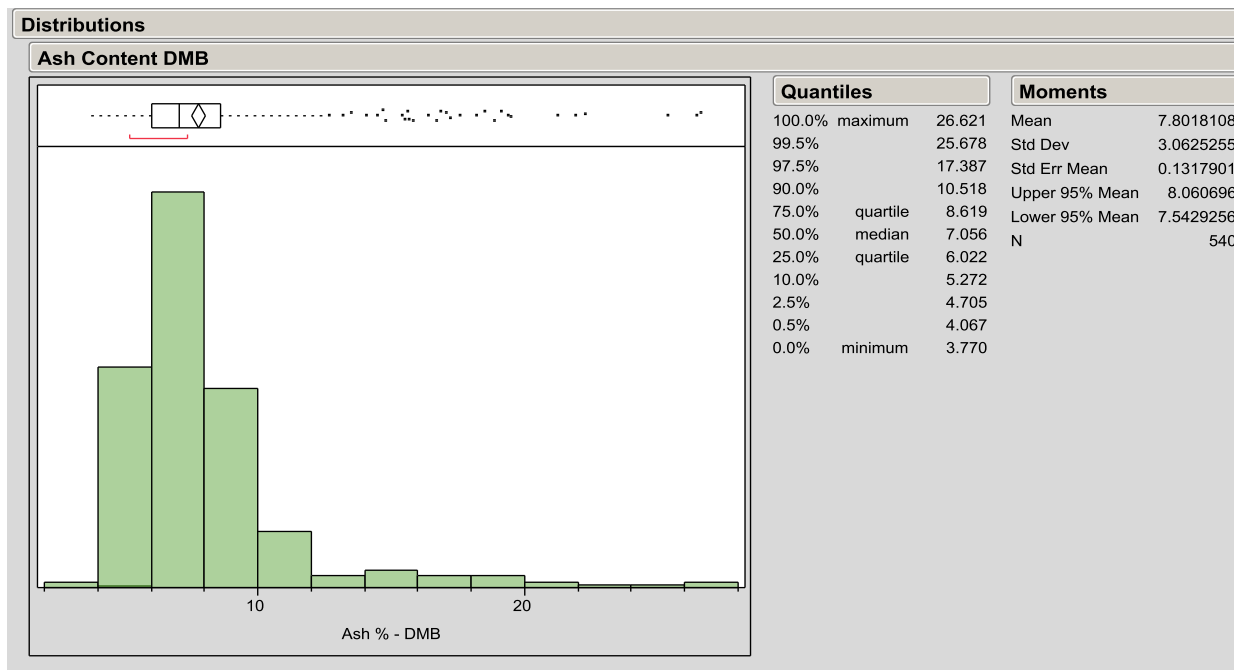


Figure 3 - Comparison of stover from Cornrower windrows to 540 baled stover samples collected from a range of harvest systems.

Figure 4 shows the same sample compared to other 2009 harvest samples but this comparison removes any data from samples showing ash content above 15%. Even with the 'abnormally high' samples removed, the Cornrower stover is still within the lowest ash content samples.

Small Bale vs 517 Bale samples from 2009 bales (only 15% Ash or lower)

Ash = 5.0 %

This "small bale" sample falls in the same 2.5-10% quantile (meaning that is within the lowest ash content samples)

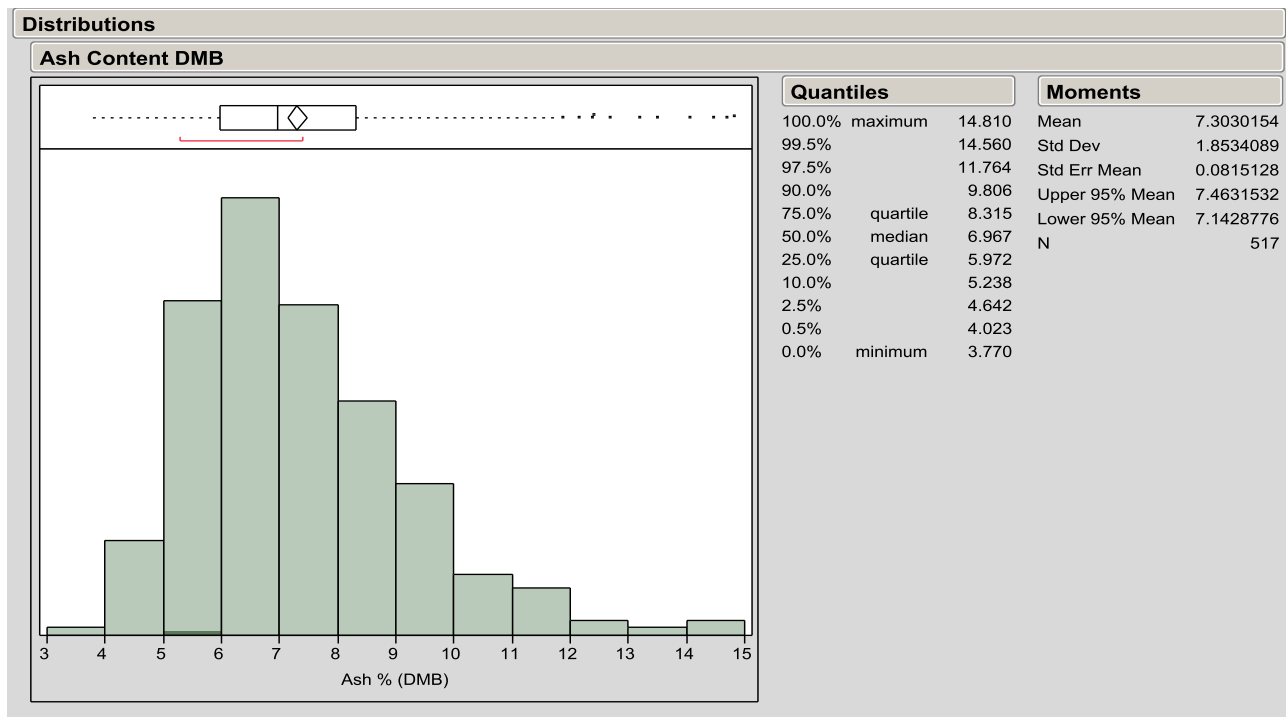


Figure 4 – Comparison of Cornrower stover to other stover samples harvested with multiple machine types in 2009 but with the highest ash content sample data removed.

The “Small Bale” was a randomly selected 14 X 18 square bale made from a windrow formed by the Cornrower in Nov. 2009. No special adjustments on the baler pickup of the New Holland 575 baler were made. A photo of the baler making the sampled bales in operation is provided in figure 5.

A separate analysis of side by side comparison of raked stover and stover windrowed with the Cornrower was done. Details of the comparison are in the section of this paper entitled “Densification of stover from the Cornrower”.

Samples from the bales in figures 6 and 7 were provided to Monsanto Corporation for comparative data in same-field harvest by regular farm labor. The results provided from the tests are shown in table 1.

Table 1. Comparison of nutrients and ash in stover from bales using two different windrowing methods. (All data shown is on dry matter basis).

ITEM	CORNROWER	RAKED ALTERNATIVE
Moisture	11.90%	10.30%
Nitrogen	1.20%	1.10%
Ash	7.00%	11.20%
Gross Energy	426 cal/gr	414 cal/gr
Phosphorous	998 ppm	772 ppm
Potassium	11500 ppm	11400 ppm





Figure 5 New Holland 575 baler baling stover windrow prepared by the Cornrower at 3.5 mph. Stover moisture is 35% and baling operation followed shelling operation by approximately one hour on a cloudy November day.

The pickup of this baler is adjusted as it would be if the baler were operating in hay. Note the stubble directly behind the baler and the clean sweep of the windrow by the baler.

## Densification of stover from the Cornrower

A major cost in the harvest of corn stover is transportation of bales from the field and storage of those bales at a collection site. While there are numerous systems and machines that contribute to this effort and costs vary significantly for a large variety of reasons, one common denominator that impacts costs in all systems is the density of the stover material. Many excellent studies, such as Biomass Densification – Cubing Operations and Costs for Corn Stover (Sokhansanj and A. F. Turhollow , 2004) have been done to quantify and analyze density of stover at harvest. While higher density is desirable in almost every case, the cost to achieve higher density can significantly impact costs of stover harvest negatively.



The Cornrower shreds stover into shorter and more thread-like particles than a rake or a stalk-chopping windrower. This shredding action exposes the center of the stalk while retaining enough length to facilitate baling. The benefits of shredding and exposing the stover material has been studied (Buckmaster, 2008; Zhang et al., 2003) and some of those same benefits for density improvement are evident in stover from the Cornrower. The smaller particles enable the balers (round baler, small square baler, and large square baler) to make a higher density bale. Data was collected in the Fall of 2010 harvest in order to determine density of bales made with stover from the Cornrower. Figure 6 shows a round bale made from stover raked into a windrow. Figure 7 shows stover from the same field made from stover windrowed with the Cornrower. The difference in particle size is readily visible.



Figure 6 Stover baled from windrow made with rake.





Figure 7 Stover baled from windrow made with the Cornrower

The raking, windrowing and baling of the bales in figures 6 and 7 were all done by personnel of Kromland Farms of Rochester, IN. No assistance by technicians was provided and no adjustment of the baler or baling speed in making the bales was made in order to make sure that density and other characteristics of the bales could be solely attributed to the difference in how the windrows were made. Bale density was 15% higher on the Cornrower bales based on weights of the bales at the time of sale. Since bale density at 15% moisture doesn't overload a standard semi loaded with 36 bales (3' x 4' x 8'), the 15% improvement in density provided by the Cornrower will result in a 15% savings of time, fuel and storage space in the process of hauling and storing of stover.

Table 2 shows a monetary comparison of Cornrower bale density at 15% above raked stover. The numbers assume a 10.3 lbs/cu.ft. density for the Cornrower bales and 85% less for raked stover bales. In a harvest of 105 acres of stover in Oct. 2010 by Showley Farms of Rochester, IN, bales sold at 15% moisture out of the field averaged 990# per bale. The bales were made with a New Holland BB9080 standard baler making 3'X4'X8' bales. The bales were weighed over a commercial scale for sale to a local farmer and average moisture content was 16%. The 10.3 lbs/cu.ft. number used for this comparison is the actual density achieved by the BB9080 baler using 430 lb. knot strength twine that is commonly used in this baler at a density setting on the baler plunger of 85% of the baler's maximum capability. It should be mentioned that the net load of 36 bales in this instance weighed 35,640 lbs. The capacity of many trucks would be

5000 lbs. more than this and therefore the opportunity is there to further improve efficiency by increasing bale density even more. Higher moisture content, which is very likely going to happen in real-world stover harvest, and capacity currently in the BB9080 baler to raise density could take up much of this load capacity that is available.

Table 2 Comparison of cost/ton for transportation 80 miles round trip at varying freight rates using stover bales made from Cornrower windrows vs. raked windrows.

<b>FREIGHT RATE (Dollar/Mile)</b>	<b>CORNROWER (Dollar)</b>	<b>RAKED ALTERNATIVE (Dollar)</b>	<b>DIFFERENCE/TON (Dollar/Ton)</b>	<b>DIFFERENCE/LOAD (Dollar)</b>
\$2.00	10.60	9.14	1.45	25.87
\$2.25	11.92	10.29	1.63	29.10
\$2.50	13.25	11.43	1.82	32.33
\$2.75	14.57	12.57	2.00	35.57
\$3.00	15.89	13.71	2.18	38.80

Note: The advantage of higher density on transportation alone more than makes up the fuel costs of windrowing with the Cornrower shown above in this report. Additional benefits of higher density in storage costs have not been analyzed at this time.

More study and evaluation of the Cornrower density issue will need to happen to determine if the Cornrower can provide for bale densities using standard baling equipment that cause transport of stover to be weight-limited instead of volume-limited.

## Harvest Moisture

Stover moisture at harvest is a huge concern. Considerable information on previous studies (Shinners et al., 2007 Birrell et al., 2010) dealing with the myriad of moisture issues highlight the unique factors of corn stover moisture and the impact it has on harvest and storage of this biomass. Differences in the harvest season from year to year are huge. Drying weather in season 2010 provided unusually good drying conditions whereas season 2009 provided equally unusually poor drying conditions. Much more experience in this area is needed but general observations about the drying time characteristics of windrows made with the Cornrower are provided.

1. Chopped and shredded stover from the Cornrower releases moisture more quickly than non-chopped stover due to more exposure of plant material, especially interior stalk material.
2. In season 2009, windrows that were left through the Winter were successfully baled in April 2010 as the stover in the windrow didn't decompose.
3. As the Fall season progresses, stalk moisture is lowered while ambient temperatures get cooler. This combination of events greatly increases the chance to bale immediately behind the combine. Successfully stored stover was baled one hour after the Cornrower formed the windrow in November of 2009.

4. Windrow depth greatly impacts drying time and roughly six inches of depth is the maximum allowed for drying to occur throughout the windrow evenly.

## Conclusion

The Cornrower machine is a unique approach to stover harvest that provides different characteristics in the stover, reduces trips across the field and reduces costs in a number of ways. The chopping and collecting system on the Cornrower can be modified to produce stover that is more finely chopped and shredded or more coarsely chopped and shredded as the operator may desire. Much more experience will be needed to find the optimal particle size as relates to energy consumed by the Cornrower and the value of the end product.

Farmer adoption of stover harvesting has been very slow for a number of reasons. Labor supply during the grain harvest season is already stretched and adding stover collection to the required tasks only exacerbates this problem. Machinery has a toll taken by the dirt and rocks that contaminates the stover in many of the stover harvest systems. The Cornrower addresses many of these problems and in season 2010 farmers in the Rochester, IN area that used the Cornrower were successful with it and found the system to be much more attractive than rakes and windrowers that they currently used. Studies to evaluate this new approach will be needed to further quantify the Cornrower's impact on cost, stover value and harvest pressure and whether there is enough advantage to the Cornrower system to finally provide wide adoption by farmers.

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