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Michigan Corn Stover Project: Cattle, Storage and Bioenergy

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Introduction

Corn stover is the non-grain aboveground portion of the corn plant, including the husk, cob, stalk, tassel, silk and leaves. After corn grain harvest, stover is the remainder of the crop often referred to as "residue." This stover has value, whether it is returned to the soil to build organic matter and supply nutrients for the next crop or harvested for other uses. Corn stover can be viewed as potential revenue for producers, who have several marketing options for it.

Residue management options include tilling, harvesting and leaving the residue on top of the soil. Over the past 30 years, average corn yield in Michigan has gone up 60 percent – from 97 bushels per acre in 1987 to 157 bushels per acre in 2016[11]. As a general rule, the amount of stover produced by weight is about the same as the amount of grain produced[10], so corn residue has also increased significantly in the past 30 years.

Increased residue production may cause management issues, especially for no-till farmers. Corn stover can interfere with planting and at times reduce seed-soil contact[6]. Corn stover slows soil warming in the spring, delaying planting[6]. Corn stover serves as a host for some pathogens that cause diseases in corn and other crops[6]. Removing corn stover from a field may help with these issues. Removing only some stover leaves the rest to add carbon to the soils and build soil organic matter. Harvesting 1 ton per acre would have minimal effect on grain yield, stover composition and soil quality factors[1]. However, one research group in Ohio found a reduction in corn grain yield when stover from previous corn crops was removed at a rate greater than 25 percent[2]. Other studies suggest that 30 percent to 50 percent of corn stover can be removed without causing a negative impact on soil quality[4,5,8].

Abbreviations: Dry matter (DM), dry matter intake (DMI), high moisture (HM), Landscape Environmental Assessment Framework (LEAF), low moisture (LM), Natural Resources Conservation Service (NRCS), nitrogen (N), phosphorus (P), potassium (K), Revised Universal Soil Loss Equation, Version 2 (RUSLE2), soil conditioning index (SCI), United States Department of Agriculture (USDA).

Uses

Corn stover has a long history of use as bedding and feed for cattle production and will continue to be used for these purposes. When used for bedding, stover eventually ends up back on the field, applied with the manure. Cattle producers may feed corn stover as part of the ration. This has become a more common practice as stover has proven to be economically competitive with other forages.

The Renewable Fuel Standard[9] sets mandates for blending renewable biofuels into our transportation fuel supply stream. The mandate includes 16 billion gallons of biofuels sourced from cellulosic products such as corn stover by 2022. The first commercial cellulosic ethanol plants in the United States were commissioned in Iowa with corn stover as the primary feedstock.

There is interest in corn stover for other uses as well, including use as a fiber in building materials and for power generation. Other uses for corn stover include electricity production using microbial fuel cells and use of stover in the pharmaceutical industry as a feedstock that produces a pharmaceutical precursor called succinic acid. Succinic acid is used in the chemical, food and pharmaceutical industries[13]. It is becoming apparent that farmers will have multiple options in the future to market their corn stover in addition to their grain.

Pros and cons[3]

A large number of variables come into play when determining if stover harvest is right for a farming operation. Stover harvest may have not only benefits to an operation but also some negative effects. The decision whether to harvest stover depends on whether the advantages outweigh the disadvantages.

Advantages of removing stover:

- Excessive stover can make tillage difficult and may require multiple passes to adequately manage the residue. Removing some stover in these situations can reduce tillage trips, saving money, fuel, time and compaction. Reducing tillage can subsequently lead to a reduction in soil erosion.
- Excessive stover can physically interfere with planter units during planting and can reduce seed-to-soil contact, reducing emergence. Removal of stover may increase seed germination and emergence.
- Heavy residue can slow the drying and warming of soil in the spring. This is problematic in heavy, wet soils and can delay planting and emergence. Reducing the amount of stover may allow the soils to warm up and dry faster in the spring to facilitate planting.
- There is some evidence that corn residue has a detrimental effect on the yield of the following year's corn crop. This may be due to immobilized nitrogen, reduced emergence and survival, allelopathy or perhaps all three. In a continuous corn situation, reducing amounts of stover may have a positive effect on the yield of the following corn crop.
- Stover can be a source of pathogens, which may increase incidence of some diseases in the following corn crop. Reduced stover may improve health of the following crop.

Disadvantages of removing stover:

- Excessive removal of stover can expose soil to erosion.
- Stover contains nutrients that are removed with the stover. Nitrogen (N), phosphorus (P) and potassium (K) can be replaced through the addition of fertilizer but with added cost.
- Stover harvest incurs additional equipment, fuel and labor costs.
- Stover is a source of carbon (soil organic matter) for soils. Therefore, enough stover should be left in the field to prevent a net loss of soil organic matter each year that corn stover is removed.
- Harvesting stover requires more trips across the fields, which carries a cost and may also contribute to compaction, especially if done when fields are wet.
- On soils with poor water-holding capacity, surface residue can help maintain higher moisture content in the soils and prevent them from drying out. Removal of stover may lead to higher potential for yield loss under dry conditions on lighter (sandy) soils.
- Stover harvest can be delayed by weather, which may delay other field operations.
- Stover harvest is one more operation to fit into the busy fall season.
- Stover harvest may affect contracts for rented ground.

Factors affecting how much stover can be removed[3]

Rotation

Corn and soybeans differ greatly in the amount of carbon that they add back to the soil. Soybeans contribute much less carbon than a corn crop. A long-term corn-soybean rotation contributes less organic matter to the soil than a continuous corn rotation. Not surprisingly, the amount of corn stover that can be removed in a corn-soybean rotation is less than what can be removed with continuous corn to maintain soil organic matter levels. If stover removal is being considered, acreages under continuous corn would be the best candidate. Coupling continuous corn with no-till practices results in an excessive amount of stover, and stover removal is ideally suited to this scenario. Stover removal can assist in the management of residue without the concern for loss of soil organic matter that occurs when tillage and soybeans are added into the mix. Adding tillage or soybeans will decrease the amount of stover available for harvest.

Combining both intensive tillage and a soybean rotation results in the least amount of potentially harvestable stover and organic matter retention in the soil.

Slope

The more a field slopes, the more erosion control is necessary and, therefore, the more stover that should be left on the field. It is generally recommended that no stover be removed on parts of fields where slope exceeds 2 percent to 3 percent. Level fields are best for harvesting stover.

Yield Level

The amount of stover that must be left on a given field to control soil erosion and to build organic matter does not vary with corn yield. Therefore, with higher grain and thus higher stover yields, more stover is available for removal.

Cover Crops and Manure

Any practice that adds organic matter to soils will allow for a greater amount of stover removal. Such practices include use of cover crops and addition of manure to fields. Because preservation of soil organic matter is often the limiting factor for deciding how much stover can be removed from a field, the more organic matter that can be added through sources other than stover, the greater the amount of stover that can be removed without degrading the soil.

How much stover to remove?

Tools are available to help make informed decisions on appropriate amounts of stover to remove. The RUSLE2 is a soil conservation planning tool used by the NRCS. The SCI is a component of RUSLE2 and is a common method for determining whether given farming practices are increasing or decreasing soil carbon, which is an indication of soil organic matter content. It is not quantitative but rather indicates direction of change. A negative SCI indicates that soil carbon is being lost; a positive SCI indicates that soil carbon is increasing. RUSLE2 and SCI work well on highly erodible land (where slopes are steep). For land that is relatively flat (less than 6 percent slopes), there is a new tool, developed at Ohio State University, called the Lucas Soil Organic Matter Calculator. The calculator is more robust because it calculates the net balance of soil carbon. It provides a place to enter management practices including tillage type and depth, crop rotation, crop yields, residue harvest, cover crops and manure application. The calculator is based on research conducted at Michigan State University by Dr. Bob Lucas.

The most advanced tool to date that is available to farmers is the LEAF, developed collaboratively by the U.S. Department of Energy at Idaho National Laboratory, the U.S. Department of Agriculture Agricultural Research Service and Iowa State University. This tool calculates the amount of stover that can be sustainably harvested from any given part of a field. Cellulosic ethanol suppliers are currently using the LEAF tool to support sustainable stover removal practices. As the corn stover industry evolves, it can be expected that more such tools will become available to growers for making sustainable decisions on stover removal based on tillage, crop rotations, and field location and topography. These tools will likely be used to communicate with field equipment to automate variable-rate stover harvest.

A common recommendation is to harvest stover in a field every alternating corn year on the basis of the following assumptions: 150 bu (Michigan average corn crop) × 56 lb/bu × 0.845 (percent dry matter) = 7098 lb stover, or 3.5 dry tons, assuming roughly equal corn grain and stover weight. Shinners et al., in a thorough study at the University of Wisconsin, showed an average stover harvest efficiency of 30 percent using several common harvest methods over varying field conditions. Harvesting all the stover that can be mechanically picked up every other corn year is a good strategy for residue management and energy conservation.

Michigan Corn Stover Project

The Michigan Corn Stover Project was a collaborative effort at Michigan State University to investigate the uses of corn stover and potential impacts of stover harvest in Michigan. This effort was made up of on-farm and small-scale research conducted across lower Michigan. It included a cattle feeding study, integration of a cover crop, a bale storage study, harvest time evaluation and the impact of stover removal on yield of the subsequent crop. Funding for the multiyear project was obtained from the Michigan Corn Marketing Board and MSU's Project GREEN (Generating Research and Extension to meet Economic and Environmental Needs). The purpose of this project was to refine best management practices for farmers in Michigan who may be interested in harvesting corn stover.

Harvest

The objectives of the corn stover harvest study were: to determine whether harvesting stover would influence crop yield the following season; to estimate the amount of machine-harvested stover removed compared with non-harvested plots; and to quantify the amounts of nutrients (N, P and K) that would be removed per dry ton of stover. Three locations were chosen in 2014—two had been in a corn-corn rotation and one in a corn-soybean rotation. Sizes of the study fields ranged from 24 to 68 acres with plot widths of 24 to 72 rows. Corn was planted on 30-inch centers at corn-corn sites and 20-inch centers at the corn-soybean site. All fields were planted to corn in 2014, and stover was harvested from half of the plots, randomly ordered, at each site. The study was repeated in 2015 and 2016; because of crop rotation and weather-related harvest problems, however, stover was harvested in only two years at two of the sites.

Table 1. Crop yields (bushels/acre) in plots where stover was harvested (h) and not harvested (nh).

Site	Harvested (h)	Not harvested (nh)	% change (h-nh)/h)
A	154	140	9%
B	113	91	18%
C [a]	139	145	-6%
Average	135	125	7%

[a] Soybean planted in 2015 at site C

The impact of harvesting stover on grain yield the subsequent year is summarized in Table 1. Variability within fields, among sites and across years was high, and no significant statistical differences were detected between plots where stover had been harvested and where it had not. In stover-harvested plots, rotational crop yield was 7 percent higher than in non-harvested plots when averaged across locations and years. Previous studies have shown some evidence that reducing the amount of corn stover remaining can increase grain yields the following year. Although that was not found to be the case in this three-year study, the trend was higher yields the following year.

Table 2. Stover residue (percent of ground covered) following stover harvest operations in harvested (h) and non-harvested (nh) plots, averaged across years.

Site	Harvested (h)	Not harvested (nh)	Difference (h-nh)
A	78%	90%	-12% *
B	73%	92%	-19% *
C	90%	97%	-7%
Average	82%	95%	-13% *

* Difference is significant (α=0.10)

The amount of residue cover remaining after stover baling was 13 percent less than in strips where no stover was harvested when averaged over sites and years (Table 2). A Cornrower head was used to chop and windrow the stover at sites A and B. However, a stalk chopper/windrower was used at site C. This stalk chopper/windrower was not as efficient in collecting stover, so differences between plots could not be detected statistically. Farmers can adjust the amount of stover to remove by setting the height of the stalk chopper, if used, and the height of the stover baler. Though Shinners et al. estimated a stover harvest efficiency of 30 percent[12], the average harvest efficiency for this research was 48 percent (data not shown). This may be reflecting better than average harvest conditions, which could make our removal estimates somewhat conservative with regard to removing too much stover. How much stover to leave behind to avoid a reduction in soil carbon and unsustainable soil loss due to erosion will depend on many factors, such as soil type, slope, crop rotation and tillage practices.

On average, approximately 1 to 2 dry tons per acre of stover were removed from plots. The resulting amounts of macronutrients (N, P and K) removed are summarized in Table 3. When averaged over years and locations, 10, 3 and 24 lb of N, P_2O_5 and K_2O, respectively, were removed per dry ton of stover. This is lower than the values removed per dry ton of stover in previous research[12] – 22, 8 and 32 lb of N, P_2O_5 and K_2O, respectively. From a short-term perspective, Nitrogen removal is typically not factored in with stover removal because the N loss may be balanced with the reduction in N tie-up as a portion of the carbon-rich residue is removed. Farmers will need to sample their stover bales to better estimate the amount of additional fertilizer they will need to apply for the following crop, and to base fertilizer applications on soil test levels. Manure applications and the use of cover crops in a rotation can help offset some of the loss of nutrients when stover is removed from the field. Farmers will need to include the cost of these additional fertilizer inputs when deciding whether harvesting stover makes economic sense on their farms.

Table 3. Nutrients removed per dry ton of stover, averaged over all study years.

Site	Stover yield (dry tons per acre)	Nutrients removed (lb per dry ton stover)		
		N	P_2O_5	K_2O
A	2.0	11	3	30
B	1.2	8	3	20
C	1.8	13	3	22
Average	1.7	10	3	24

Recommendations:

1. A stover removal rate of 1 to 2 tons of dry matter per acre will not negatively influence subsequent crop yields on most soils.
2. Use available tools (RUSLE2 and SCI) to help make field-by-field determinations for stover removal rates.
3. Pull forage samples from stover each year to ensure that your stover price includes the cost of replacing nutrients removed that year. Make sure you use current fertilizer prices, application costs and soil test levels.

Storage

Bale storage will have an impact on stover dry matter content recovery, nutritional composition and ethanol yield. Moisture content of stover at the time of baling also has an impact. In our study, corn stover round bales were harvested at 45 percent (HM) or 22 percent (LM) moisture. Bales did retain moisture during transportation and storage prior to the start of the study. Corn stover moisture was affected by hybrid type, field location and harvest type. Bales were stored by one of three methods: outside uncovered, outside covered or inside (under a roof). Forage quality samples and bale weights were measured at 0, 30, 120, 240 and 360 days to determine forage composition and loss over time for each of the storage methods.

Corn stover baled for the bioenergy feedstock industry may need to remain in storage for up to 360 days and therefore should contain minimal moisture and ash to optimize ethanol yield and dry matter recovery. Results indicated that low-moisture bales kept their structural integrity and had the best results for ethanol production, including higher sugar content, higher ethanol yields and lower ash. In this study, storage method did not affect the tested quality parameters for the LM bales.

Initial moisture content and storage method affected high-moisture (HM) bales. These bales should be stored outside, away from buildings. With HM bales, there is some uncertainty about the risk of fire hazard, so just to be safe, keep them away from any structures. Uncovered high-moisture bales maintained nutrient and dry matter through 120 days; if stored longer, HM bales tended to degrade quickly. Therefore it is feasible to store bales of 45 percent moisture outdoors for no longer than 120 days.

Overall, LM bales showed better preservation in storage and higher ethanol yield but lower nutrient content (Table 4) compared with HM bales. The study showed no advantage to storing bales with moisture content of 30 percent or less indoors because the nutrient and dry matter contents were similar over time in storage. Higher moisture bales became very difficult to move after 120 days in storage because they lost structural integrity (Figure 1). Overall, bales with lower moisture performed better regardless of intended use or storage type.

Table 4. Protein, fiber, energy and mineral content of corn stover on day 0 for high moisture (HM) and low moisture (LM) bales

	HM	LM
DM, %	53 ± 2	64 ± 4
EtOH, %	18 ± 0.01	19 ± 0.01
NEg, Mcal/lb	0.3 ± 0.01	0.2 ± 0.03
NEm, Mcal/lb	0.53 ± 0.01	0.48 ± 0.03
	% DM	
OM	93 ± 0.02	95 ± 0.01
CP	5 ± 0.3	4 ± 0.3
CF	37 ± 0.3	42 ± 2
ADF	47 ± 0.4	52 ± 3
TDN	56 ± 0.3	52 ± 2
Ash	6 ± 1	4 ± 0.2
Ca	0.3 ± 0.02	0.5 ± 0.04
K	0.7 ± 0.1	0.6 ± 0.3

Dry matter (DM), ethanol content (EtOH) net energy for gain (NE_g), net energy for maintenance (NE_m), organic matter (OM), crude protein (CP), acid detergent fiber (ADF), crude fiber (CF), total digestible nutrient (TDN), crude fiber (CF), calcium (Ca), potassium (K)

Figure 1. Higher moisture bale (top) and lower moisture bales (bottom) at 360 days.

Recommendations:

1. Storing bales under cover (roof or plastic) reduces storage losses and provides opportunity for long-term storage (>120 days).
2. Storing bales outside uncovered works well through the winter, but when the weather warms up in the spring and summer, dry matter losses will increase significantly, particularly with high-moisture bales.

Feeding Cattle

The objective of the cattle feeding study was to evaluate the use of stover as an alternative forage. Bales were processed by a bale buster and fed as a percentage of the total mixed ration. One hundred and forty-four Holstein yearling steers (eight head to a pen) averaging 952 lb were fed 0 percent, 10 percent or 20 percent stover on a DM basis, with stover replacing a proportionate amount of corn silage. Nutrient composition and feedstuff composition of the rations are shown in Table 5.

Table 5. Total ration compositon for feeding study componenets (DM %).

	Control	10%	20%
Corn stover	0	10	20
Dry rolled corn	26	26	25
High moisture corn	20	20	20
Corn silage	20	10	0
Dry distiller's grains w/ solubles	30	30	31
Supplement[1]	4	4	4

[1] Contained monensin (667 g/ton), 15% crude protein, 3% crude fat, 16% crude fiber, 1416.8% Ca, 0.3% P, 6.5-7.8% salt, 0.1% K, 200,000 IU/kg vitamin A, 20,000 IU/kg vitamin D3 and 57.8 IU/kg vitamin E.

Feeding corn stover increased dry matter intake, but average daily gain and carcass characteristics were similar among treatments. The calculated net energy (NE_g) value for corn stover, derived from the feeding trial, was 0.19 Mcal/lb. Cattle were able to compensate for a lower energy diet containing less corn by increased intake when fed a 20 percent corn stover diet. The quality of the carcass was similar among treatments as measured by ribeye area, marbling, backfat, USDA calculated yield grade and USDA quality grade (Table 6). Average Choice was the overall quality grade.

Overall, the results indicated that feeding stover had a significant effect on DMI, but the carcass characteristics and weight gain remained similar among feeding treatments. Other management factors to consider include the cost of buying a bale buster, if using a total mixed ration, or allowing cattle to graze bales to eliminate processing costs. Corn stover is a viable alternative forage for livestock owners, making economic sense when the cost of hay or other forage surpasses the cost to harvest, store and feed stover.

Recommendations:

1. Finishing steers in a feedlot operation can be fed a ration with up to 20 percent corn stover on a dry matter basis without significantly affecting performance.
2. Ration balancing is critical when factoring stover into cattle diets. Farmers must ensure that proper energy, protein and minerals are provided to meet cattle nutrient requirements and performance goals.

Table 6. Effects of dietary corn stover on cattle performance.

	Control	10% stover	20% stover
Final weight, lb	1530	1532	1507
Average daily gain lb			
0-end	3.5	3.5	3.4
Dry matter intake, lb/d			
0-end	28^{A}	31^{B}	31^{B}
Corn intake	16^{A}	16^{A}	14^{B}
Gain/feed, lb gain/lb DMI			
0-end	0.12^{A}	0.11^{B}	0.11^{C}
Ration NE_m[4] (Mcal/lb)	1.02^{A}	0.94^{B}	0.89^{C}
Carcass Characteristics			
Hot carc. wt., lb	872	874	860
Ribeye area, in^2	13	13	13
Marbling[1]	616	602	586
Backfat, in	0.28	0.29	0.26
KPH[2], %	3.75^{A}	3.50^{A}	2.00^{B}
Quality grade[3]	20	20	19
Calc. yield grade	3.4	3.3	3.1

^{ABC} Means in a row with unlike superscripts differ, P=0.05

[1]Marbling score: 600=modest; 700=moderate

[2]KPH: Kidney, pelvic and heart fat

[3]Quality grade: 19=Choice; 20=average Choice

[4]net energy for maintenance (NEm)

Cover Crops

The cover crop integration study evaluated the yield and quality of mixed biomass feedstocks resulting from the addition of interseeded cereal rye (*Secale cereale* L.) or triticale (*Triticale hexaploide* Lart.) with corn stover.

Cropping systems evaluated were:

- Corn stover only, harvested in the fall.
- Corn stover only, harvested in the spring.
- Corn stover with a winter cereal cover crop harvested in the fall and spring (two-harvest system).
  - The fall-harvested feedstock was primarily corn stover because the time frame for growth of the fall-planted winter cereals was limited.
  - The spring harvest consisted primarily of winter annual cereal crop biomass because the stover fraction had been effectively removed during the fall harvest.
- Corn stover with a winter cereal cover crop harvested only in the spring
  - The feedstock was a mix of winter annual cereal crop biomass and corn stover biomass overwintered in the field from the previous corn crop.

The two-harvest system had greater dry matter, ethanol, crude protein and energy content compared with the spring one-harvest system. There may be no economic advantage, however, when the cost of the second harvest pass is factored in. If assuming the cost of the second

Pictures taken at fall harvest time of an interseeded plot with no harvest, an interseeded plot that was harvested and a stover-only plot that was harvested.

pass outweighed the nutritive advantage, a single corn stover fall harvest would have the greatest yield for ethanol production. If harvesting stover for cattle feed, a single pass harvest in the fall is recommended to avoid yield loss due to overwintering in the field. If harvesting in the spring is planned, a winter annual cover crop should be interseeded in the fall to offset the stover's overwinter decrease in yield, crude protein and digestibility. Although triticale's nutritive concentration was higher, its yield was lower, making the two cover crops we tested equally beneficial for cattle feeding.

Recommendations:

1. Addition of harvested winter cereal cover crops increases biomass and ethanol yields per acre.
2. Whether harvested or not, winter cereal cover crops provide several ecosystem services, such as additional ground cover, nutrient recycling and a reduction in soil erosion.
3. A two-harvest system (fall and spring) produced the highest yield. An analysis of the two-harvest system would need to be made on a farm-by-farm basis to determine if the second harvest is economically feasible.

Picture taken at spring harvest time of an interceded plot with corn stover harvested in the fall, stover-only plot and interceded plot with corn stover.

Table 7. Interaction of harvest time and treatment on feedstock content.

Treatment	Rye + Stover			Triticale + Stover			Stover - only	
Harvest Time	2x		1x	2x		1x	2x	
	Fall	Spring	Spring	Fall	Spring	Spring	Fall	Spring
DM, %	68^B	27^D	40^C	68^B	25^D	42^C	68^B	77^A
EtOH, %	16^C	15^D	17.5^B	16^C	15^D	18^B	16^C	20^A
Yield, DM ton/acre	2	1	1.5	2	0.7	1.4	2.2	1
NE_m, Mcal/lb	0.5^C	0.6^B	0.5^D	0.5^C	0.7^A	0.5^D	0.5^C	0.3^E
NE_g, Mcal/lb	0.3^C	0.3^B	0.2^D	0.3^C	0.4^A	0.2^D	0.3^C	0.1^E
% of DM								
CP	4.6^C	7.6^A	6.0A^B	4.4^C	8.5^A	6.0^{AB}	4.0^C	4.0^C
ADF	48^B	40^C	49^B	48^B	36^D	49^B	48^B	56^A
TDN	54^C	61^B	52^C	55^C	64^A	51^C	55^C	44^D
P	0.1	0.2	0.2	0.1	0.3	0.1	0.1	0.1
Ca	0.4^A	0.2^C	0.2^{AB}	0.4^A	0.2^B	0.2^{AB}	0.4^{AB}	0.3^{AB}

Ethanol content (EtOH); crude protein (CP); acid detergent fiber (ADF); total digestible nutrients (TDN); net energy for maintenance (NE_m); net energy for gain (NE_g); Phosphorus (P) and Calcium (Ca)

^{ABC}Means with unlike letters differ, P=0.05

Economics and Marketing

The value of corn stover depends on its end use and on the price and availability of other alternative feeds, bedding and feedstock sources. When determining the price of corn stover, farmers need to consider several factors, including feed or nutrient value, nutrient removal rates, harvest costs, transportation and storage costs.

Regardless of what stover is used for, the minimum value needs to account for nutrients removed when harvested – these nutrients will need to be replaced with fertilizer. In our study, stover removed 10, 3 and 24 pounds of N, P_2O_5 and K_2O per ton, respectively. Removal rates varied greatly from field to field and from year to year. Literature values for nutrient removal are also quite variable.

Therefore, we recommend that forage quality samples be taken each year to determine nutrient content, and then the stover price adjusted accordingly. If a third party harvests the corn stover, this recommendation should be included in the contract.

Harvest operations and equipment cost can be determined from cost of production worksheets or custom harvest rates from Michigan State University Extension[7] budget, cost of production and decision-making tools. Each of the equipment options for harvesting stover has its own unique costs. The corn stover harvest study used the Cornrower head to harvest grain and windrow stover in one pass. A round baler followed the combine. Additional cost is associated with using the Cornrower head rather than a standard head plus the baling operation. In one field, a standard grain head was used, followed by a stalkchopper/windrower and a round baler. Most on-farm forage harvesting equipment can be used to harvest stover.

Finally, there is a cost to remove the bales from the field and put them in storage. This cost will vary depending on what equipment is used, the type of storage and the distance to storage. In this report, $3.25 per bale was used for the cost of moving bales into storage.

This research demonstrated that stover could be used effectively in cattle finishing rations. When deciding whether to feed stover to cattle, producers need a cost comparison of stover to alternative forages. Comparisons will need to be made for energy, protein and dry matter. Additionally, corn stover properly supplemented into dry beef cow diets can significantly reduce feed cost, especially when forage prices are high.

Recommendations:

1. One of the key learning outcomes from our project was that weather conditions can make harvesting stover very challenging. Make sure you take harvest risk and storage options into account when deciding whether to harvest stover.
2. Use MSU Extension custom work rates or your own rates to determine stover harvest costs.
3. If you plan to feed stover to cattle, first determine your cost to harvest stover, and then add that cost into a ration-balancing program to see if stover provides the cheapest feed cost for your farm.

Budget for 4x6 round bale (1000 lb @20% moisture)

Harvest Operation	**Units**		
Baling	$/bale		12.25
Raking	$/bale		2.64
Transport to storage	$/bale		3.25
Nutrient removal			
	$/lb	lb removed	
N	$0.46	10	$ 4.60
P	$0.44	3	$ 1.32
K	$0.30	24	$ 7.12
per bale at 20% moisture			$ 31.18
per ton at 20% moisture			$ 62.37
per ton at 0% moisture			$ 77.96

Budget for 3x4x8 square bale (1200 lb @20% moisture)

Harvest Operation	**Units**		
Baling	$/bale		$13.75
Raking	$/bale		$2.64
Transport to storage	$/bale		$3.25
Nutrient removal			
	$/lb	lb removed	
N	$0.46	10	$ 4.60
P	$0.44	3	$ 1.32
K	$0.30	24	$ 7.12
per bale at 20% moisture			$32.68
per ton at 20% moisture			$54.47
per ton at 0% moisture			$68.09

Case Study – Siegler Farm, Lapeer County

The Siegler Farm is a family-owned and -operated dairy farm that milks cows and raises all of their replacement heifers as well as a few steers. The operators became involved in this project because they were looking for more research data on how to utilize corn stover in their rations. As a result, they committed to growing corn after corn for three years on a 32-acre field that they own. The field was divided into eight research plots where we collected grain yield, stover yield and residue cover data. A single-pass system was used, annually harvesting the same four 48-row-wide and field-length plots. The New Holland Cornrower head, developed by Jim Straeter, was used to combine the corn and windrow the stover. A John Deere 569 round baler followed the combine. In the four plots where stover was not harvested, we set the Cornrower head to chop and blew the stover back on the ground.

The field was located 2 miles southeast of Imlay City. Predominant soil types included Blount loam and Macomb sandy loam with 0.3 percent to 4 percent slopes. The majority of the field was somewhat poorly drained, with a few small areas of poorly drained soils. The Lucas Soil Organic Matter Calculator (SOM) was used to estimate the long-term effect of current and alternative farming practices on this field. The SOM calculator is a soil carbon accounting system that estimates soil levels on the basis of tillage practices, crop rotation, crop yield, and addition of OM from manure or cover crops. In this case, the base scenario is the current continuous corn rotation using conventional tillage to an 8-inch depth with no cover crop or manure being applied. The scenario is run for a 20-year period. The second scenario shows the effect of changing from conventional tillage to no-tillage. The third scenario is no-till plus adding a cereal rye cover crop each year after corn is harvested (see Table 1). On the basis of this information, 1.2 tons of stover per acre can be removed in a continuous corn rotation under conventional tillage without degrading the SOM. When no-till is adopted, SOM increases to 2.1 percent in 20 years. When you add a cereal rye cover crop in addition to no-till, SOM increases to 2.5 percent in 20 years. This shows that, with proper management, stover can be removed each year on this field while improving SOM.

Table 1 contains the grain yield, stover yield and residue cover data from this field for 2014-2016. Data is presented for the average of the four plots where stover

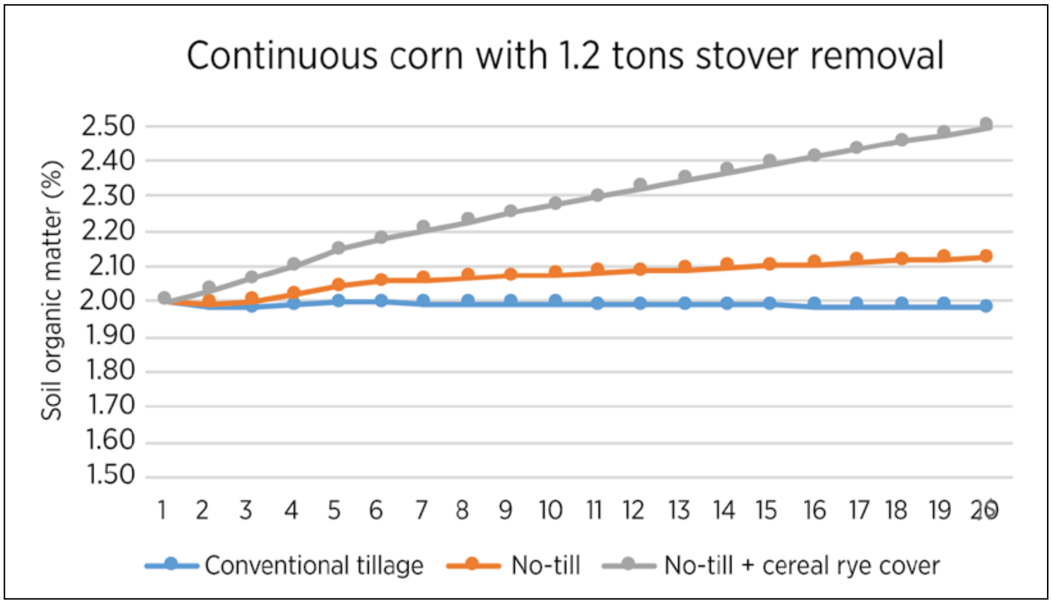

Figure 1. The effect of tillage and cover crop on SOM in a continuous corn rotation where 1.2 tons of stover is removed annually.

was removed and the four plots where stover was not removed. The purpose of this study was to determine if removing stover had deleterious effects on successive grain yields. In 2014 and 2015, grain yield was higher where stover was removed, but by 2016, there was virtually no difference in grain yield between plots where stover was removed and plots where it was not removed. Stover yield ranged from 1.1 to 1.4 tons of dry matter per acre. The Lucas SOM calculator indicated that harvesting this amount of stover is a sustainable practice on this farm.

Table 10. Selected research plot data from Siegler Dairy Farm.

Siegler Dairy Farm		**Stover Removed**	**Stover Not Removed**
2014	Corn grain yield (bu/acre)	125.5	110.8
	Corn stover yield (dry tons/acre)	1.39	---
	Ground residue cover (%)	64%	96%
2015	Corn grain yield (bu/acre)	123	82.3
	Corn stover yield (dry tons/acre)	1.18	---
	Ground residue cover (%)	79%	89%
2016	Corn grain yield (bu/acre)	102.5	100.3
	Corn stover yield (dry tons/acre)	1.11	---
	Ground residue cover (%)	77%	91%

To determine the value of the corn stover on this farm, we started with the nutrient removal rates. Forage samples were pulled from bales all three years. Data averaged for all three years found 8 lb nitrogen, 3 lb of P_2O_5 and 20 lb of K_2O per ton of stover. The Cornrower head requires more horsepower to operate the cutting and windrowing system for stover than a standard corn head, so an additional charge of $4 per ton was assessed for the head. A round baler cost of $12.25 per bale was used, based on the MSU Extension Custom Work Rates publication. For this farm, the cost per round bale was $30.50, which translates to $63.54 per ton on a dry matter basis. This cost needs to be compared with costs of other forage feedstuffs to determine if feeding stover at this price is the most profitable option.

Table 11. Budget for 4x6 round bale (1000 lb @20 percent moisture).

Harvest Operation	**Units**		
Baling	$/bale		$12.25
Cornrower	$/bale		$4.00
Transport to storage	$/bale		$3.25
Nutrient Removal			
	$/lb	lb removed	
N	$0.46	8	$3.68
P	$0.44	3	$1.32
K	$0.30	20	$6.00
per bale at 20% moisture			$30.50
per ton at 20% moisture			$50.83
per ton at 0% moisture			$63.54

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