Introduction
Corn stover is increasingly being harvested as a source of biomass for varied uses on and off the farm. Corn farmers with animals have harvested corn stover for bedding and are increasingly using it for feed. In Iowa, two cellulosic ethanol plants are being constructed that will use corn stover as a feedstock. In the future it can be anticipated that additional industries will move into Iowa to take advantage of this biomass treasure. These uses represent an economic benefit for a by-product of corn grain production. However, corn stover is a source of nutrients and organic matter which helps keep Iowa soils fertile and productive. This leads to questions about the effect that corn stover removal may have on soil fertility and quality.

This bulletin will address the issues related to harvesting corn stover. It will discuss the pros and cons of removing stover and the variables that need to be considered to determine if and how much stover can sustainably be removed from a field. It will also review harvest methods and some of the economic considerations of corn stover harvest. Because this is an emerging industry, there are still many unanswered questions dealing with stover harvest. This bulletin will provide a review of information currently available. More detailed information on this subject is available online at iowacorn.org/researchreports.

Uses of Corn Stover
Corn stover has been used as bedding and feed for cattle production and will continue to be used for this purpose. When used for bedding, the stover along with a portion of its organic matter eventually ends up back on the field applied with the manure. Corn stover is a handy source of bedding for corn farmers who produce cattle. It is readily available and can be harvested with existing equipment such as rakes and balers. The only cost is that required to harvest and transport the stover.

Cattle producers may feed corn stover as part of the ration. This has become a more common practice as the price of corn grain has increased and the increased availability of co-products from the ethanol industry such as dried distillers grains with solubles (DDGS) or syrup. These co-products can be added to stover to replace some of the grain in the ration.

Archer Daniels Midland (ADM) has developed a system to improve the feed value of corn stover fed to cattle. This method mixes hydrated lime, or calcium hydroxide, with corn stover. Within seven days, the calcium hydroxide breaks down chemical bonds in the stover making the cellulose more digestible for rumen microbes. Feeding studies conducted at the University of Nebraska showed improved digestibility of cornstalks by 43 percent with this chemical treatment. This increases the available energy content of the stover and allows for a greater percentage of stover in the feed ration. ADM is partnering with Monsanto to develop sustainable systems for harvest, treatment and feeding of this modified stover feed product.

Two cellulosic ethanol plants are currently under construction in Iowa, which will use corn stover as the feedstock. POET-DSM Advanced Biofuels is building a plant in Emmetsburg, Iowa, with operations planned to begin in 2014. The DuPont Nevada Site Cellulosic Ethanol Facility is an ethanol plant in Nevada, Iowa, with completion also scheduled for 2014. These facilities will purchase corn stover from a 30-50 mile radius around the plants. The stover will be converted to sugars and fermented into ethanol, which will qualify as a cellulosic biofuel under the Renewable Fuel Standard (RFS). Both companies are developing sustainable methods for harvesting, storing and transporting stover from field to the ethanol plant. Corn farmers will be compensated for their stover by these companies.

Corn stover offers a potential source of income for Iowa farmers but needs to be harvested in a sustainable manner.
There is interest in corn stover for other uses as well, including use as a fiber in building materials and for energy generation. It is becoming apparent that there will be multiple opportunities in the future for corn farmers to market their stover in addition to their grain.

Amount of Corn Stover Available for Harvest

Almost all of the industrial uses of corn, such as food, feed, chemicals and ethanol, are derived from corn grain, because it is readily available, affordable and has a desirable composition of starch, proteins and oil. But there is growing interest in using non-grain sources of biomass to help supply these commercial needs. Much research and development is being conducted to convert cellulosic biomass, such as stover, into useful feed, fibers and chemicals. These materials are sometimes viewed as waste products from the harvest of other economically important plant parts, such as grain and lumber. This residue includes not only corn stover but straw from small grains, bagasse from sugarcane production, and residue from forestry harvest and processing.

Cellulosic biomass is the fibrous plant material — such as stems and leaves — that do not have use as a human food. The Department of Energy (DOE) published a report in 2011 – the Billion Ton Update – which reviews the availability of biomass sources in the U.S. Of all the available sources of biomass, such as forest residue, grasses and crop residue, corn stover is expected to be the predominant source of biomass in the U.S. Because crop residues are a major source of biomass and corn stover is the primary source of biomass in this country, it should come as no surprise that Iowa is a leading source of biomass in the country.

As interest in biomass increases, Iowa will continue to be a focus of attention as estimates of the amount of corn stover produced are typically made by extrapolating from the grain yield. The harvest index is the ratio of grain yield to the above-ground vegetative portion of the plant. Harvest index ranges from 47 to 56 percent for corn, meaning that approximately half of the weight of the above-ground portion of the corn plant is the plant material (stover) and the other half is the grain. Harvest index is quite constant and has not changed much over the years as yields have increased.

As grain yields increase, the stover yield increases at a similar rate. Based on 2011 corn grain yields in Iowa, approximately 2.4 billion bushels were produced, which translates to 67 million tons of corn stover produced, assuming a harvest index of 50 percent. Even with only a fraction of this being available for removal, there is still a lot of stover available for harvesting. It is estimated that 75 million dry tons of stover can be sustainably harvested in the U.S. each year.

Obviously, the most corn stover is produced in areas where more corn grain is produced. The most sustainably harvestable corn stover is restricted to areas with relatively flat land, fertile soils and high yields. The areas having the most sustainably harvestable corn stover are found in prime corn growing areas, such as Iowa, southern Minnesota, Illinois and Nebraska.

Pros and Cons of Harvesting Stover

A large number of variables come into play when determining if stover harvest is right for a farming operation. Stover harvest may have benefits to an operation but also may have some negative effects. The decision whether to harvest stover depends on whether the advantages outweigh the disadvantages. Here is a listing of advantages and benefits and the disadvantages of harvesting stover.

Advantages/Benefits of Stover Harvest:

• 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 and save money, fuel, time and compaction.
• Excessive stover can interfere with planting operations and emergence. It can physically interfere with planter units during planting and can reduce good seed to soil contact, reducing emergence. Removal of stover may assist 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. It may be due to allelopathy, immobilized nitrogen, reduced stand and emergence, or perhaps all three. Having reduced amounts of stover may have a positive effect on the yield of the following corn crop in a continuous corn situation.
• Stover can be a source of pathogens, which may increase incidence of some diseases in the following corn crop. Reduced stover may improve plant health of the following corn crop.
• Removal of stover provides an economic benefit whether the stover is being used on-farm, such as feed or bedding, or if sold as an additional source of income from the corn crop.
• Reuse of the carbon in stover for other uses rather than allowing it to return to the atmosphere.

Disadvantages with Harvesting Stover

• Excessive removal of stover will expose soil to erosion.
• Stover contains nutrients which are removed with the stover. Nitrogen (N), phosphorus (P) and potassium (K) can be replaced through fertilizer but with added cost.
• Stover is a source of organic matter for soils. Therefore, enough stover should be left in the field to prevent loss of organic matter.
• Harvesting stover means 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 retention capacity, surface residue can help maintain higher moisture content in the soils and prevent them from drying out. Removal of stover may lead to drier soils and decreased yield on lighter soils.
• Costs and weather delays associated with stover harvest.
• Stover harvest is one more operation to fit into the busy fall season.
• Impact on contracts for rented ground.
Soil Quality Considerations with Harvesting Stover

A number of factors influence the quality of soil and need to be considered when it comes to deciding whether to harvest stover and the amount to harvest. Soil quality is determined by a variety of attributes including soil aggregation and aggregate stability, water infiltration, water-holding capacity, cation exchange capacity, organic matter, nutrient content, aeration, bulk density, resistance to compaction, and soil tilth.

Erosion

Corn stover remaining on the soil surface can reduce the amount of soil lost through wind and water erosion by creating a protective layer on the soil. The most protection occurs when all the stover is left on the surface of the fields in no-till situations. Tillage reduces this protective effect and exposes soil to greater erosion risk. Harvesting a portion of the corn stover can leave an adequate protective layer of residue on the soil surface but if normal tillage is done in combination with stover removal, there is a greater erosion risk. If corn stover is being removed, tillage should be adjusted to ensure adequate residue remains on the surface.

Soil Organic Matter

The crop productivity of soils is directly related to organic matter content. In most soils, organic matter is typically the limiting factor in determining the amount of stover that can be sustainably removed from fields. Leaving enough residue on the field to maintain soil organic matter typically provides adequate amounts to prevent significant erosion. Soil organic matter is in a constant state of flux. Every year some organic matter is decomposed while new organic matter is added from above-ground crop residue and the root tissue. When stover is harvested, less is available for formation of soil organic matter. However, it appears a majority of the new organic matter formed in soils comes from the roots. When tillage is performed, much of the above-ground residue decomposes and releases its carbon to the atmosphere as CO2 rather than being conserved as soil organic matter. From a carbon sequestration point of view, incorporating stalks into the soil with tillage and harvesting stover both result in a loss of carbon from the field. Because of this, tillage reduction should be considered when harvesting stover to avoid losing excessive amounts of organic matter from the field. Practices such as conservation tillage, no-till and strip tillage can reduce the amount of organic matter loss and allow for more stover to be harvested.

Compaction

Stover harvest may result in one to three extra passes across fields in the fall to harvest and transport stover bales. Extra passes increase compaction but the risk is greatest when the soil is wet. Care needs to be taken not to create compaction to the soil by driving across wet fields to harvest stover. To help offset risk of compaction, reduced tillage passes may be possible as there is less stover to manage in the fall.

Compaction

Strip till following stover harvest is a good combination to maintain soil organic matter.

Cover crops replace organic matter removed through stover harvest and protect against erosion.

Stover Nutrients

Corn stover contains significant quantities of the major plant nutrients, nitrogen (N), phosphorus (P) and potassium (K). When stover is removed, these nutrients are removed from the field with the stover. Depending on the soil fertility level and crops grown, some or all of these nutrients may need to be replaced. It’s difficult to provide specific recommendations on nutrient replacement resulting from harvesting stover. Nutrient content of stover varies depending on the proportion of stalks, leaves and cobs present in the harvested bales. Nutrient content can vary depending on the time of the season when harvest occurs, with potassium varying the most as it is water-soluble and leaches from stover the longer it is left in the field. Samples can be taken from bales, but sampling variability exists within a bale and from bale to bale.

Estimates are available on nutrient content of stover. Iowa State University estimates nutrient value of stover to be 3 pounds per ton for P₂O₅ and 19 pounds per ton for K₂O. There is still debate about the value of the nitrogen that is removed in harvested stover. While nitrogen is removed in stover, it may not be necessary to add it all back to the soil the following season. Soil microbes require nitrogen to decompose stover and, as a result, nitrogen is immobilized. Additional nitrogen needs to be added to accommodate for this immobilization. With removal of some stover, less nitrogen will be immobilized and this may offset the need to replace the nitrogen removed in the stover. More research is needed to fully understand the long-term impact of removing nitrogen through stover.

Soil Moisture

Removal of stover may have a positive or negative effect on soil moisture, depending on the situation. Stover creates an insulating layer over the soil surface. On heavy soils, removal of some of the stover may increase warming and drying of the soil prior to planting in a favorable manner. But on dry light soils, stover may provide protection from excessive drying of the soil during the following growing season.
Factors Impacting the Amount of Stover That Can Be Sustainably Harvested

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

Tillage
Tillage is used as a residue management tool, with getting rid of corn stover as a primary purpose. If heavy tillage is done, less stover can be harvested as it is needed in the field to provide erosion protection and because more of the stover will decompose faster with more aggressive tillage. However, if stover is removed, less tillage should be required because there is less residue to manage. No-till fields allow for the greatest amount of stover harvest.

Rotation
Soybeans leave behind considerably less residue and its residue decomposes more rapidly than residue from corn. A long term corn/soybean rotation contributes less soil organic matter than continuous corn. Continuous corn produces the greatest amount of stover and allows for more stover removal than a corn/soybean rotation. When continuous corn production is combined with reduced or no-till practices, stover removal is a viable method of residue management.

Yield Level
Because harvest index in corn is very close to 50 percent, the stover yield is just about equal to the grain yield in tons per acre. 180 bushels of corn grain is about 4.3 tons, meaning that 4.3 tons of stover are also produced. The amount of stover that must be left on a given field to control erosion and to build organic matter doesn’t vary with corn yield level. Therefore, with higher grain and stover yields, more stover is available for removal. Typically, in high-yielding fields managed with minimum or no-till practices, about 45 percent, or two tons per acre, of the stover can be sustainably removed following each corn crop. High-yielding fields are the best candidates for stover 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 stover removal, the more organic matter that can be added through sources other than stover increases the amount of stover that can be removed without harming the soil.

Calculating Corn Stover Removal Rates
There are some tools available to help make informed decisions on appropriate amounts of stover to remove. The Revised Universal Soil Loss Equation, Version 2 (RUSLE2) is a soil conservation planning tool used by NRCS. The Soil Conditioning Index (SCI) is a component of RUSLE2 and is a common method for determining whether given farming practices are increasing or decreasing soil carbon. It is not quantitative but rather indicates direction of change. A negative SCI indicates soil carbon is being lost while a positive SCI indicates soil building.

The most advanced tool to-date that is available to farmers is the Landscape Environmental Assessment Framework (LEAF) developed collaboratively by the US Department of Energy (DOE) at Idaho National Laboratory, USDA-ARS and Iowa State University. LEAF can be accessed at http://bioenergyidt.inl.gov. This tool calculates the amount of stover that can be sustainably harvested from any given part of a field. LEAF is currently being used by cellulosic ethanol supply chain developers to support sustainable removal practices.

Methods of Stover Harvest, Transport and Storage
One of the greatest obstacles to the realization of a viable corn stover industry may not lie in the technology required to convert biomass into feed, fuel or chemicals, but rather the ability to harvest and deliver stover in a timely fashion and to find enough area to store it for up to a year. For example, one large cellulosic ethanol plant will require the delivery of 80 bales (40 dry tons) of stover per hour, 24 hours per day, 365 days per year. Significant infrastructure will be required to harvest, bale, transport and store this volume of material.

Harvest
For best results, stover should contain 20 percent moisture or less at harvest. This could prove difficult if the fall is rainy. Harvesting stover when wet can increase the amount of decomposition and loss of biomass in the bales and decrease quality. Late grain harvest and wet weather can delay or even prevent harvest of stover.

There are several stover harvest systems being developed. A one-pass system is being developed where the combine tows a specially designed baler and bales the stover coming right out of the back of the combine and bales it without hitting the ground.
A one-pass system results in the cleanest stover with the lowest ash (dirt) content but requires additional equipment and may slow harvest speed of the combine. This system only retrieves the stover passing through the combine so much of the stover is not available for harvest.

A two-pass system is a simple method to harvest stover with existing equipment. The spreader on the combine is turned off allowing the stover coming out of the combine to fall in a windrow behind the combine. This system only retrieves the stover passing through the combine so much of the stover is not available for harvest.

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A second pass with a baler picks up the stover from these windrows. This system has the advantage of only requiring one additional pass to bale the stover. As with the one-pass system, the two-pass system only captures the stover that passes through the combine. These first two systems are limited to harvesting only about 30 percent of the stover from the field.

A three-pass system involves harvesting the corn with a combine, following with either a rake or flail windrower and then baling the windrows.

This method can harvest greater amounts of stover than the one- and two-pass systems. But it also has the tendency to bring in more dirt thus increasing the ash content of the stover.

Farmers most commonly own large round balers. These work for harvesting stover and many use them for harvesting stover for on-farm use. For large scale harvest for industrial uses such as cellulosic ethanol, square bales are preferred because they handle and stack better than round bales and more can fit onto trucks for transport.

For on-farm use, bales are often transported with a bale fork or spear, or on small bale trailers to move the bales from the field to other locations on the farm.

For industrial scale hauling, where large numbers of bales need to be hauled many miles, loading onto semi trucks will be required. Equipment to move the bales from the farm onto trucks will be required. It is likely that bales will be moved from the fields to temporary storage sites prior to being delivered to the ethanol plants.

Once the stover is harvested, the bales should be removed from the field and either stored at the edge of the field or some other central storage site. The best way to preserve stover quality is to store bales inside of a barn or shelter where they are kept dry. A more affordable alternative is to cover the bale piles with tarp. If bales get wet in storage, this can lead
to microbial activity, decomposition and loss of biomass. To prevent this, bales should be maintained at less than 20 percent moisture content. In uncovered stover bales, it is typical to see a 10 percent loss of dry matter by the following summer due to decomposition.

### Economics of Stover Harvest

Stover harvest needs to be economically as well as environmentally sustainable. A number of factors are involved in deciding whether it makes financial sense to harvest stover, most importantly the price or value of the harvested stover received versus the cost of harvesting. There are intangible values and costs to be considered as well.

#### Value/Price of Stover

There are a number of ways to calculate the value of harvested corn stover depending on use. For on-farm feeding or bedding use, the cost of harvesting stover needs to be weighed against the cost of purchasing stover from a neighbor or local hay auction. Iowa State University has developed an online calculator for estimating the feed value of corn stover. (www.extension.iastate.edu/agdm/crops/html/a1-70.html)

If industrial consumers of stover want to purchase stover, they will have an offering price, but a number of variables can affect the actual value to farmers. These variables include who will do the harvesting, transport and storage. In addition to the actual cost paid per ton of stover, a number of intangible costs must be considered. The benefits of stover harvest may include a reduction in tillage operations, fuel savings, improved seedbed and emergence conditions, improved soil temperature in spring and possibly fewer leaf diseases. Stover harvest may facilitate increased conservation tillage or no-till. Several studies show a yield increase in the following corn crop when some of the stover is removed the previous season.

#### Costs of Harvesting Stover

The tangible costs of harvesting stover include equipment, fuel, and labor. These vary greatly and are unique to each farm. Costs can range from $26 to $79 per ton to harvest, transport and store corn stover, with most estimates falling in the $40-$60 range. These wide ranges are due to the different methods used to harvest stover and the number of tons harvested per acre. If farmers have well-defined costs for various operations such as raking and baling, they should use their numbers. If those are not known, then custom rates could be used instead.

The Iowa State University custom rates are available at www.extension.iastate.edu/publications/FM1698.pdf. Nutrient replacement costs must also be factored in. It is estimated that the replacement cost of phosphorus and potassium is in the range of $15 to $20 per dry ton of stover removed.

In addition, there are intangible costs associated with stover harvest. Managing stover harvest is an additional step in the farm operation at a busy time in the fall. It requires additional time, labor and coordination with other post-harvest activities. It has the potential to delay fall fieldwork as well, especially with a wet fall. There may be the situation where a fall is too wet to allow for any stover harvest. This would result in no stover for either on-farm use or to fulfill a contract with a buyer. This situation needs to be anticipated when signing a contract to deliver stover to a third party. Extra trips across the field to harvest stover may cause additional compaction. Failure to replace nutrients or to maintain organic matter can impact the long-term productivity of fields.

One last consideration has to do with rented ground. If ground is rented for corn grain production, the grower should read the contract or ask the landlord as to whether stover can be removed as part of the land rental arrangement. It is likely that contracts in the future will specifically address stover removal as stover harvesting becomes more common.

### Conclusions

The decision whether to harvest corn stover is a complicated one involving consideration of a number of factors described in this bulletin. In most cases, these decisions will be unique to each farm, and in some cases, specific to each field. The corn farmer is encouraged to become as informed as possible when considering corn stover harvest. The decision to harvest stover should be based on sound financial and agronomic information.

In summary, here are some key points to think about when considering stover harvest:
- Select fields with the least amount of slope to reduce erosion potential.
- Select fields with the highest yield potential as they will produce the most stover.
- Give priority to fields that will be going back into corn the following year.
- Replace nutrients removed from stover harvest including P, K, and organic matter (manure, cover crops).
- Reduce tillage following stover harvest to leave more on the surface to protect runoff.
- Remove only the amount of stover that will provide erosion protection and maintenance of soil organic matter levels (typically no more than 30 percent of the stover, or 1-2 tons per acre).

Managing stover harvest is an additional step in the farm operation at a busy time in the fall. It requires additional time, labor and coordination with other post-harvest activities. It has the potential to delay fall fieldwork as well, especially with a wet fall. There may be the situation where a fall is too wet to allow for any stover harvest. This would result in no stover for either on-farm use or to fulfill a contract with a buyer. This situation needs to be anticipated when signing a contract to deliver stover to a third party. Extra trips across the field to harvest stover may cause additional compaction. Failure to replace nutrients or to maintain organic matter can impact the long-term productivity of fields.

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This brochure is produced by the Iowa Corn Promotion Board (ICPB). The ICPB works to develop and defend markets, fund research, and provide education about corn and corn products.

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