CROP INSIGHTS

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Sustainable Corn Stover Harvest for Biofuel Production

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Summary

- Corn stover is the most plentiful source of lignocellulosic biomass in the U.S. Sustainable utilization of corn stover as a feedstock for ethanol and other biofuels could help meet energy needs while delivering agronomic benefits.
- In fields where excess residue interferes with planting, impedes stand establishment, and ties up nitrogen, partial stover harvest can increase corn yields and potentially reduce production costs.
- Sustainable corn stover harvest requires that only a portion is removed from the field, leaving a sufficient amount behind to meet other critical needs, including mitigation of soil erosion, maintenance of soil organic matter, and sustained soil fertility.
- The amount of stover that can be sustainably harvested is generally most limited by the amount that must be left in the field to maintain soil organic matter levels.
- Crop nutrients, most notably potassium, are removed from the field when stover is harvested. Specific removal rates will vary according to soil nutrient levels, growing conditions, hybrid, and the time and method of harvest.

Introduction

Lignocellulose is a structural component of all plant matter. Because it is abundant in nature, has high energy value, and is not used directly for human consumption, this material holds great promise for renewable energy production. The primary plant materials being considered for large-scale cellulosic ethanol production include crop residues, "energy crops" developed specifically for fuel, and forest and wood processing residues. Of these, crop residues, and particularly those of corn, hold the greatest potential (U.S. Department of Energy, 2011).

Corn produces the highest volume of residue of all the major crops in the U.S., and this volume has increased in tandem with corn grain increases. Because of its abundance and even excess in some areas, several "second-generation" ethanol plants that use corn residue as a feedstock are planned for production in the U.S. Corn Belt. This will provide growers with the opportunity to get more value from their agricultural land by supplying corn stover to make biofuel.

Higher corn yields have been accompanied by increases in corn residue. Harvesting excess stover for ethanol production is a way to capture additional value from the crop while reducing residue management challenges.

Sustainable corn stover harvest must be done in such a way as to provide value to the grower and biofuel producer without negatively impacting the health and productivity of the soil. Stover removal is not an option for every field, particularly those subject to erosion or those with low average yields and low stover production. On the other hand, stover harvest may offer stand establishment and yield advantages for uniform, high yielding fields with high levels of corn residue that impede crop production. Weighing the crop production advantages versus the value of the residue removed can help growers make a profitable and sustainable decision for each field.

Value of corn stover in a cropping system

Corn residue plays several important roles in a cropping system. Its most obvious function, and the primary driver behind the historical trend toward reduced and no-tillage, is mitigating wind and water erosion. Return of corn residue to the soil is also important in maintaining soil organic matter, which in turn influences soil structure, fertility, and water holding capacity. Because of the value that corn residue provides in maintaining soil productivity and maximizing grain yields, a sustainable corn stover harvest program necessarily only removes a portion of the total corn stover, leaving a sufficient amount behind to meet critical needs (erosion control, fertility, soil carbon, etc.).

Corn residue higher, often excessive

The level of corn residue remaining in the spring has increased significantly in many fields as a result of the general trend for higher corn yields (Figure 1). Management of corn residues has become more difficult due to the use of foliar fungicides and *Bt* traits that result in stronger corn stalks that resist decomposition. Adoption of reduced tillage practices has also contributed to less residue breakdown in many areas. Corn produced in the U.S. Corn Belt has maintained a relatively stable harvest index of 0.5, meaning that increases in grain yield have been accompanied by corresponding increases in stover production (Lorenz et al. 2010).

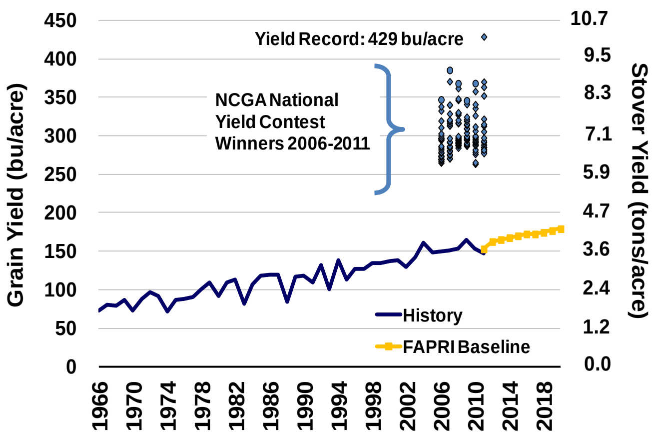

Figure 1. Average U.S. corn grain and stover yields and recent NCGA contest-winning yields. Estimates of corn stover yield are based on a harvest index of 0.5.

In many highly productive systems, particularly under continuous corn, corn stover production most often exceeds the minimum amounts needed to maintain soil health and productivity, making sustainable stover harvest a viable option. In systems where excessive residue levels have become a management challenge, removing a portion of the residue should have a positive impact on stand establishment, early growth and grain yield.

Advantages of removing excess residue

The primary advantage in reducing surface residue is preventing its interference with planting and stand establishment of the subsequent crop. In many high-yielding areas of the U.S. Corn Belt, residue accumulation has become an increasing problem. To counter this problem, many growers are chopping stalks during or after harvest and/or incorporating stalks into the soil through more aggressive tillage. Both practices increase microbial degradation of stalks with resulting loss of carbon through CO_2 release. From a carbon sequestration standpoint, managing excess residue by removing a portion for ethanol production is not substantially different than tilling the soil to increase decomposition (Al-Kaisi and Yin 2005).

In cases where management of excess residue is a driving factor in management decisions, partial stover harvest could potentially expand rotation and management options. For example, a reduction in excess residue could allow for increased production of corn following corn, particularly in the northern Corn Belt where residue decomposition tends to be slower. Tillage or other field operations currently done specifically to manage residue could potentially be eliminated, providing substantial production cost savings. Partial stover harvest could have secondary benefits as well, including reduction in inoculum levels for corn pathogens that overwinter in corn residue (e.g., anthracnose, gray leaf spot, Goss's wilt, and northern leaf blight) as well as reduced nitrogen immobilization.

Residue Management

Research conducted by the University of Missouri and Pioneer Hi-Bred compared several common methods of managing residue in no-till continuous corn including (1) use of row cleaners at planting, (2) fall nitrogen application, (3) fall stalk chopping and (4) baling and removing 50% of stover following grain harvest. Over the four year duration of the experiment, only the 50% stover removal treatment provided a significant yield advantage compared to no residue management (Figure 2). This outcome was partially explained by improved stand establishment following stover removal (data not shown), but was also likely due to reduced nitrogen immobilization and enhanced early corn growth.

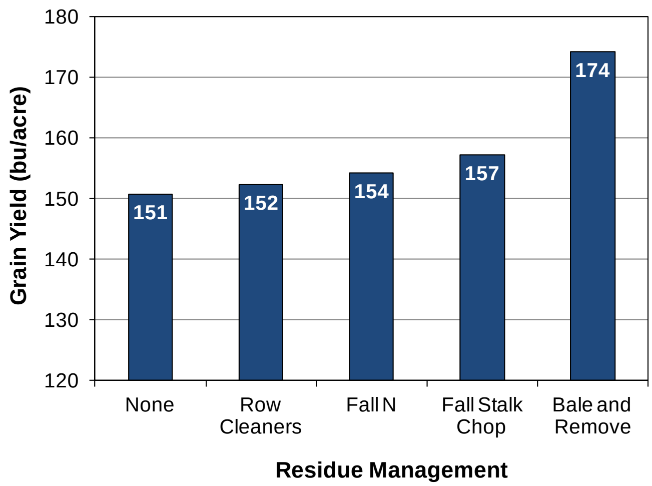

Figure 2. Effect of residue management practices on grain yield in no-till continuous corn (Wiebold, 2011).

Nitrogen Availability

One of the major impacts of excess corn residue is reduced nitrogen availability as a result of microbial uptake and immobilization. In order to break-down crop residues, soil microbes require a nitrogen source. While this immobilized nitrogen is later released back to the soil as microbial populations decline, it is unavailable during spring and early summer when crop nitrogen demands are highest. For residues that have a carbon-nitrogen (C:N) ratio less than 30, ample nitrogen for microbial decomposition is derived directly from the residue itself and no immobilization occurs. This is the case for soybean residues as well as for most animal manures. For residues and other organic amendments that have a C:N ratio greater than 30, additional nitrogen required for decomposition is derived from soil mineral nitrogen that would otherwise be available for crop uptake. Corn residues typically have a C:N ratio in the range of 50-75 and can immobilize large quantities of nitrogen, especially at high residue levels.

Research conducted at the University of Illinois demonstrated the value of corn stover harvest as means of reducing nitrogen immobilization and fertilizer nitrogen requirements in continuous corn production (Figure 3). Researchers determined optimum nitrogen fertilizer rates for continuous corn under chisel plow and no-till in a five-year study that included multiple field locations. Compared to no stover harvest, optimum nitrogen rate for the no-till system was reduced by 47 lb/acre when half of the stover was removed and 65 lb/acre when all of the stover was removed. For chisel plow, optimum nitrogen rate was reduced by 9 and 16 lb/acre, respectively, with half and complete stover removal. Under no-till, corn yield was also increased by 5 bu/acre when half of the stover was removed and 18 bu/acre when all of the stover was removed. Yields under chisel plow were similar across stover harvest treatments.

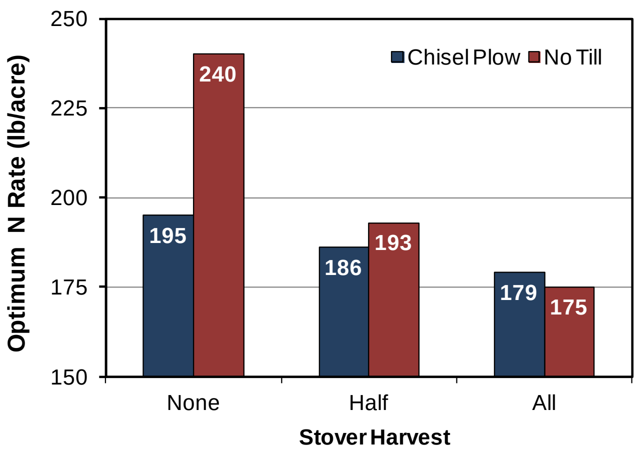

Figure 3. Effect of stover harvest and tillage system on fertilizer nitrogen requirements for continuous corn (Nafziger 2011).

Soil Moisture and Temperature

Reducing the amount of residue on the soil surface is generally associated with increased soil temperature in the spring and a faster rate of soil drying, which can be advantageous in many cases. Higher soil temperatures in the spring will almost always be positive, since soil temperatures at planting are often below the optimum levels for germination and emergence. Warmer soil temperatures can improve germination as well as subsequent root growth and nutrient uptake.

Faster soil drying is usually positive, especially in northern states and northern areas of central states where wet spring conditions often prevail. Faster drying soils allows growers to get into the field sooner for spring tillage, fertilizer application and planting. However, in moisture-limited environments such as the semiarid Plains states, reduced soil moisture associated with residue removal can have a negative impact on yield. Research conducted in Nebraska found significant yield reductions with residue removal, which was attributed primarily to reduced soil moisture (Wilhelm et al. 1986). In these chronically drought-stressed environments, corn stover harvest may not be feasible. The net effect of partial stover harvest on grain yield due to its influence on soil moisture will vary according to conditions, and is likely to have neutral or positive effects in most cases where available moisture is adequate.

How much residue can be harvested?

Excessive levels of corn residue in many fields make residue harvest a viable, sustainable option. In these fields, the important question is how much of the residue can be removed. That question can be best answered by examining the factors that control how much residue should remain. Those factors include soil erosion prevention, soil organic carbon maintenance, and soil fertility management.

Soil Erosion Mitigation

Soil erosion is a major consideration in determining the potential for sustainable corn stover removal. Any stover harvest program must leave enough residue on the soil to mitigate water and wind erosion, keeping soil loss within tolerable levels. Tools such as RUSLE2 (Revised Universal Soil Loss Equation, version 2) and WEPS (Wind Erosion Prediction System) are available to assist in developing a soil conservation plan.

The amount of corn residue needed to manage erosion can vary greatly according to field characteristics and management practices (Table 1), but is often considerably less than the total quantity produced (Figure 1). Factors such as soil type, slope, crop rotation, and tillage all influence the amount of residue needed to mitigate water and wind erosion. Consequently, the potential for sustainable stover harvest will also vary based on field characteristics, and will not be feasible in all situations. In some cases, changes to crop management practices (such as continuous corn, no-till, or rotational stover removal) may make it possible to accommodate partial stover harvest in a cropping system.

Table 1. Examples of residue levels needed to keep water erosion within tolerable limits as determined by RUSLE2 for several Midwestern sites using conservation tillage[1].

State	Soil	Slope	Corn-Corn	Corn-Soybean
		%	--- tons/acre ---	
IA	Kossuth silty clay loam	0-2	0.41	0.61
IL	Fox silt loam	2-4	0.60	0.80
IN	Morley-Glywood Complex loam	1-4	0.55	0.73
MI	Kalamazoo loam	0-6	0.37	0.37
MN	Port Bryon silt loam	2-6	0.03	0.04
MN	Hayden loam	2-6	0.04	0.04
NE	Holdrege silt loam	3-5	0.04	0.43
OH	Mermill loam	0-2	0.48	0.63
SD	Moody-Nora silty clay loam	2-6	0.03	0.03
WI	Dresden silt loam	2-6	0.36	0.60

[1] Wilhelm et al. 2007

Soil Organic Carbon Maintenance

Another major consideration in determining the potential for sustainable corn stover harvest is the need to maintain soil organic matter levels. Soil organic matter is important to soil structure, water-holding capacity and nutrient supply to plants. Soil organic matter levels are determined by the rate of loss through erosion and mineralization and the rate of gain through return of plant residue and other organic material. Corn stover harvest can potentially influence both the input and output of organic matter from the soil so it is important to determine how much can be safely removed without having a negative impact. Soil organic matter plays many critical roles in producing high grain yields, creating an economic incentive for ensuring that corn stover harvest is done in a sustainable manner.

Soil organic matter is frequently measured according to its carbon fraction, or soil organic carbon. Research indicates that maintenance of soil organic carbon is generally likely to be the most limiting factor on the amount of corn stover that can be sustainably removed; i.e., the amount of residue needed to maintain soil organic carbon will likely be greater than the amount needed to mitigate erosion (Figure 4).

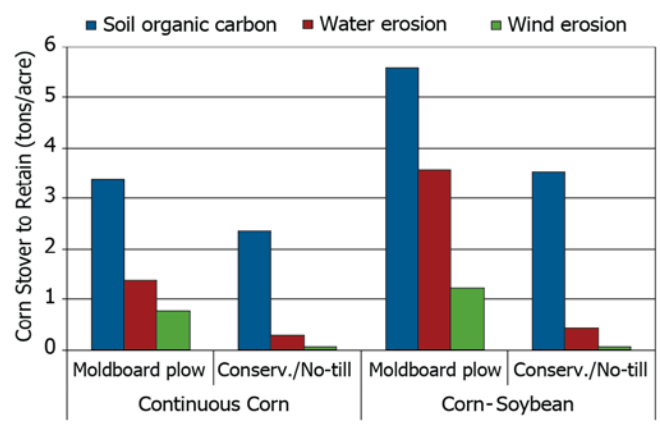

Figure 4. Average amounts of corn residue needed to maintain soil organic carbon (Johnson et al. 2006) and manage water and wind erosion (Wilhelm et al. 2007) across multiple sites.

Residue levels needed to maintain soil organic carbon will vary according to soil characteristics and management factors; therefore sustainable removal rates will need to be determined on a site-specific basis. Yield level and crop rotation both greatly influence the amount of residue needed to maintain soil organic carbon levels (Table 2); as does tillage (Figure 3). The Soil Conditioning Index (SCI) is a tool used to predict qualitative changes in soil organic matter based on management practices and has proven to be effective for estimating sustainable corn stover removal rates. Continued increases in corn grain yield will be accompanied by increases in stover production, which will expand opportunities for sustainable corn stover harvest.

Table 2. Effects of yield level and crop rotation on quantity of corn stover available for continual harvest while maintaining soil organic carbon. (Estimates based on data from multiple research sites; actual removal rates will vary).

Grain Yield	Stover Production[1]	Stover Available for Harvest	
		Continuous Corn[2]	Corn-Soybean[3]
bu/acre	------ dry matter tons/acre ------		
150	3.5	1.2	0.0
160	3.8	1.5	0.3
170	4.0	1.7	0.5
180	4.3	2.0	0.8
190	4.5	2.2	1.0
200	4.7	2.4	1.2
210	5.0	2.7	1.5
220	5.2	2.9	1.7
230	5.4	3.1	1.9
240	5.7	3.4	2.2
250	5.9	3.6	2.4

[1] Based on a harvest index of 0.5

[2] Estimated 2.3 tons/acre dry corn stover needed to maintain soil organic carbon under continuous corn with conservation or no-tillage (Johnson et al. 2006, Wilhelm et al. 2007).

[3] Estimated 3.5 tons/acre dry corn stover needed to maintain soil organic carbon under corn soybean rotation with conservation or no-tillage (Johnson et al. 2006, Wilhelm et al. 2007).

Soil Fertility Management

Stover harvest increases the total amount of plant material removed from a field, resulting in greater quantities of nutrients also being removed. Estimates of stover nutrient content are available in various state soil fertility extension publications (Table 3). Though these estimates are useful as a general guide, the actual impact of stover removal on soil fertility is a complex issue that can be affected by soil nutrient levels, growing conditions and hybrid, as well as the time and method of stover harvest.

Nutrient removal estimates based on silage harvest or for corn stover at physiological maturity typically overestimate the amount of nutrients actually removed by corn stover harvest. Generally, research has shown that the nutrient content of corn stover decreases between physiological maturity and grain harvest (Sawyer and Mallarino 2007, Johnson et al. 2010). Nutrient removal decreases further if stover harvest occurs days or weeks following grain harvest, particularly if the stover is rained on prior to collection. Rainfall can leach nutrients out of corn stover, particularly potassium, which exists in a soluble form in the plant (Figure 5).

Table 3. Estimates of the nutrient content of corn stover.

Source	N	P_2O_5	K_2O
	--- lbs/ton dry matter ---		
Iowa State[1]	15.0	5.9	25.0
Michigan State[2]	13.6	3.6	19.7
Univ. of Wisconsin[3]	12.1	3.3	35.7
Univ. of Illinois[4]	-	7.0	30.0
DuPont – rake and bale[5]	-	4.4	23.5
Iowa State – single-pass bale[6]	9.5	3.0	16.5

[1] Sawyer et al. 2011
[2] Gould 2007
[3] Bundy 1998 (based on 4.2 tons dry stover/acre at 150 bu/acre)
[4] Fernández 2007
[5] Iowa corn stover test harvest 2010
[6] Combine with integrated baler 2011

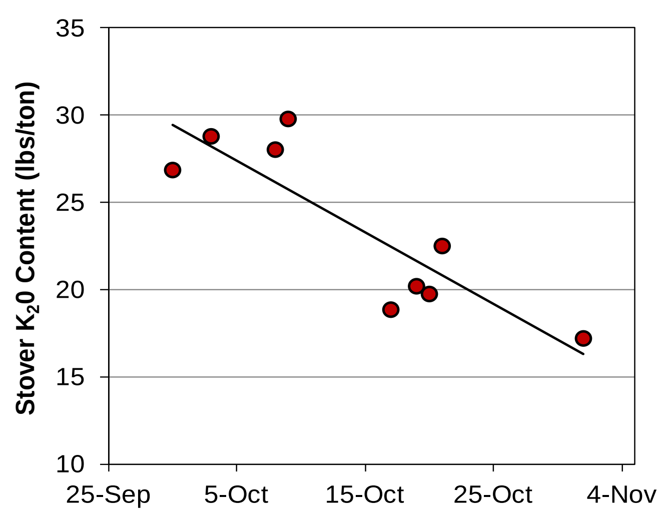

Figure 5. Decline in corn stover K_2O content observed during 2010 DuPont stover test harvest in Iowa. Each point represents average K_2O content of five large, square bales.

Partial stover harvest will increase the removal of plant nutrients; however, short and long term effects on soil fertility will vary for different nutrients. In general, growers should account for phosphorus and potassium removal in their fertility programs, keeping in mind that nutrient content values from university extension recommendations designed for silage harvest usually overestimate the amount actually removed - especially for potassium - depending on when and how stover is harvested. Long-term effects on nitrogen, sulfur, and other nutrients are not as readily apparent; but fertility should be monitored if partial stover harvest becomes a regular, long-term cropping practice.

Stover removal has compensating effects on nitrogen fertilizer needs. Stover harvest removes a small amount of nitrogen from the field, but also reduces the amount of nitrogen immobilized in the soil the following year. In corn-after-corn fields, growers must increase their nitrogen fertilizer rates (vs. corn after soybeans) to compensate for nitrogen immobilized for residue decomposition. Removing a portion of the corn stover can reduce the amount of additional nitrogen fertilizer required because less nitrogen is tied up in the spring by residue decomposition (Coulter and Nafziger 2008). It is unclear whether partial stover removal will reduce the amount of organic nitrogen available through mineralization over the long-term. It stands to reason that soil nitrogen supply capacity will depend upon maintaining organic matter levels through sustainable, partial stover harvest.

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