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DuPont cellulosic ethanol: Sustainable corn stover harvest for biofuel production

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DuPont has been developing technology to produce ethanol from cellulosic biomass for over a decade. In 2012, DuPont Industrial Biosciences will take the first steps to commercialize this revolutionary technology by commencing construction on a first-of-its-kind cellulosic biorefinery near Nevada, Iowa. This biorefinery, which is expected to begin operation in 2014, will produce 25 million gallons of ethanol annually from corn stover. All of the stover required to operate the biorefinery will be collected from within a 30-mile radius of the plant location.

To lead the way in meeting the feedstock needs of next generation of biofuels, DuPont partnered with Iowa State University in 2010 to initiate a corn stover supply chain research and development program in central Iowa. Over the past three years, this program has been working to develop and scale-up a cost-effective, high-quality and sustainable supply of corn stover biomass for the Nevada biorefinery. At full commercial capacity, DuPont's Nevada biorefinery will consume roughly 350, 000 tons of corn stover each year (Figure 1).

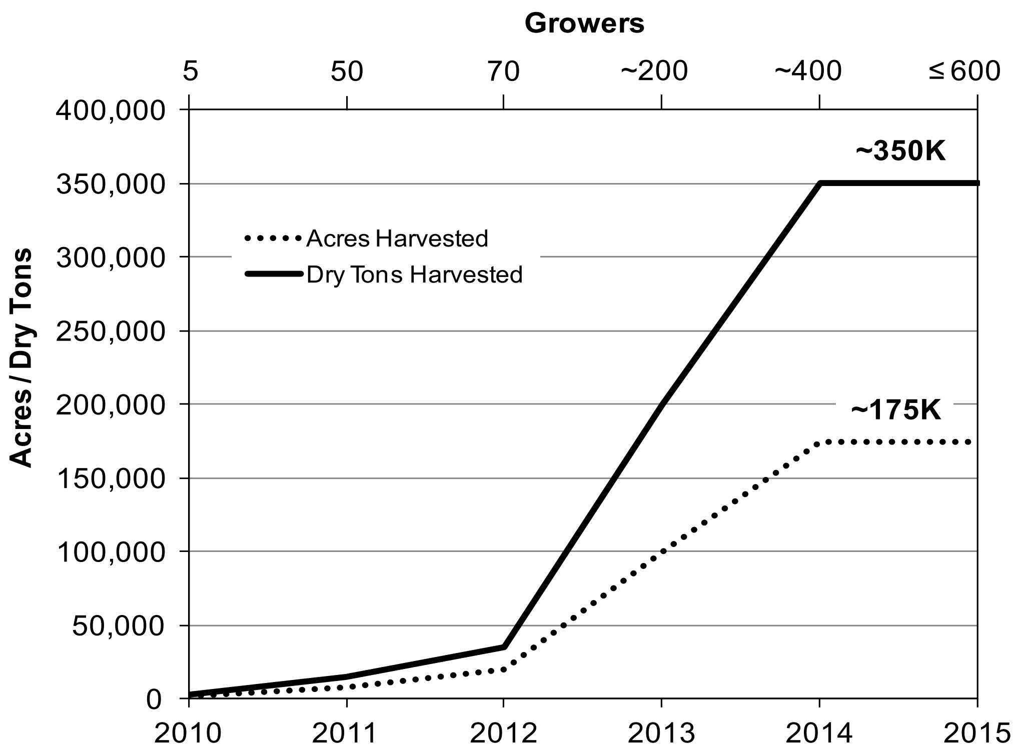

Figure 1. Anticipated corn stover supply chain scale-up for DuPont's Nevada, IA biorefinery.

Corn stover supply chain model

For the past three years, DuPont has been working to develop a corn stover supply chain that delivers high quality, cost-competitive feedstock, while also successfully integrating into, and adding sustainable value to, the farming operations of Iowa corn growers (Figure 2). Key features of the DuPont corn stover supply chain model include: (1) contracted access to corn fields following grain harvest; (2) third-party stover harvest; (3) packaging of stover as high density, large square bales; (4) temporary field-edge feedstock storage; (5) long-term, covered feedstock storage at distributed satellite locations; and (6) "just-in-time" delivery of feedstock to the biorefinery. Stover harvest is currently achieved using two field passes (shredder-windrower followed by baler), but the supply chain is designed to accommodate "single-pass" grain and stover harvest technology currently under development by several equipment manufactures.

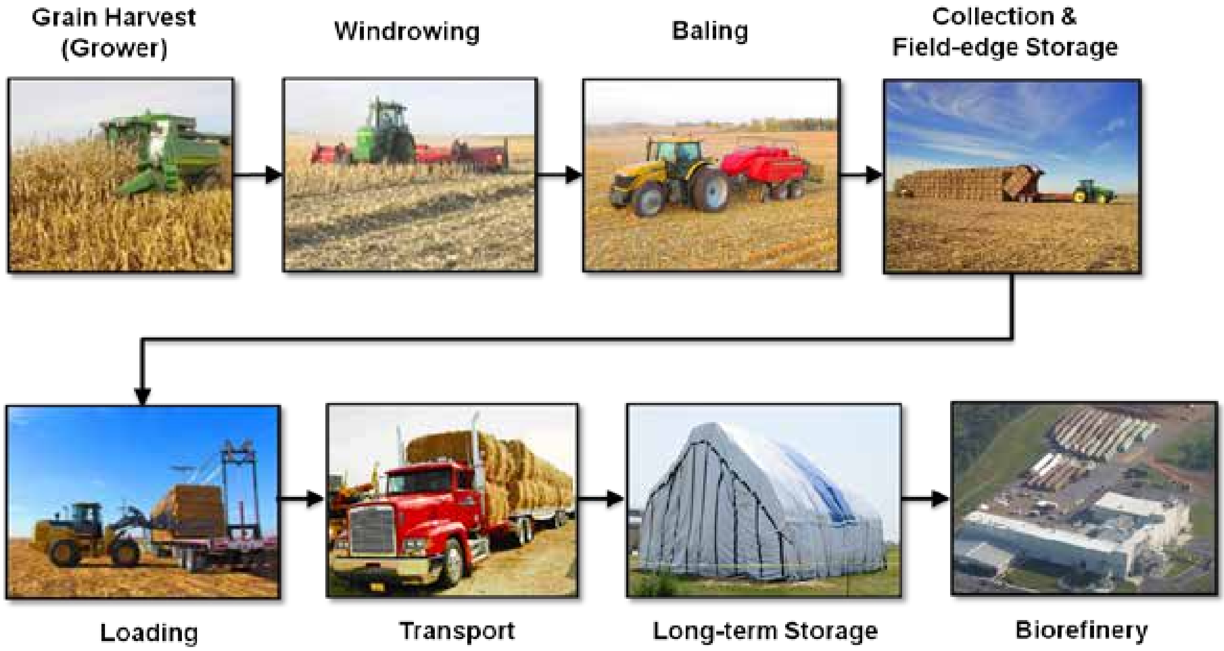

Figure 2. Corn stover supply chain model being developed for DuPont's Nevada, IA biorefinery

Agronomic impacts of corn stover harvest

Increasing corn yields have been accompanied by similar increases in the quantity of stover remaining in fields following grain harvest (Lorenz et al. 2010). The development of higher yielding hybrids with stronger stalks that delay the onset of decomposition, has contributed to residue management becoming a growing challenge for many growers. Corn stover also immobilizes soil nitrogen (Green and Blackmer, 1995), and serves as a source of incoculum for damaging corn diseases. Therefore, in addition to the direct value growers receive as payment for harvested stover, removing a portion of this material from fields has the potential to deliver additional agronomic value. Currently, limited information exists regarding the impacts of commercial corn stover harvest operations on crop production.

DuPont Pioneer corn stover harvest research trials

To better define the agronomic impacts of stover harvest, DuPont Pioneer partnered with Iowa State University in 2011 to establish eight on-farm stover harvest strip trials. Each strip trial is approximately 40 acres and includes two treatments, each replicated three times. In one treatment, a portion of corn stover is harvested in the fall using the same equipment and methods employed in DuPont's commercial harvest system (~50% stover removal). The second treatment consists of a control, where corn stover is not harvested. Corn stover harvest treatments were initiated in fall 2011, at which time extensive soil sampling was conducted at all trial locations to characterize background site characteristics for long-term monitoring of soil fertility and organic matter. All research locations were planted to corn in 2012. Crop establishment rates were assessed in spring 2012 and grain yields were determined in fall 2012.

Corn establishment and yield following partial stover harvest

Repeated stand counts indicated that early corn emergence was generally enhanced by partial stover harvest (Figure 3). Assessed 7-10 days after planting, corn emergence was significantly greater at six of eight locations ($P < 0.1$) and trended greater at the remaining two locations with partial stover harvest. Across locations, 68% of the planted population emerged 7-10 days after planting with partial stover harvest, compared to 54% without stover harvest. Though corn emergence was more rapid following partial stover harvest, final populations were similar for the two residue management treatments.

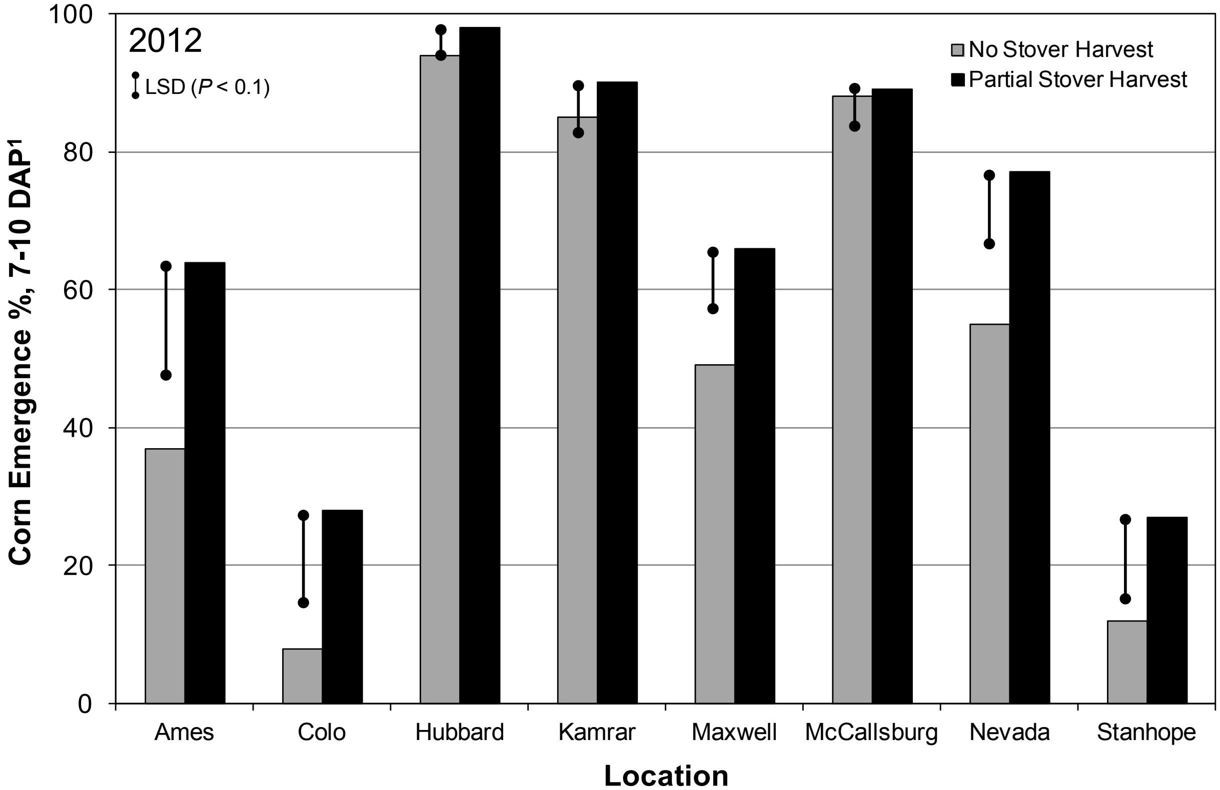

Figure 3. Corn emergence 7-10 days after planting (DAP) with and without partial stover harvest (~50% removal) at eight locations in central Iowa.

Partial stover harvest also enhanced corn grain yield at seven of eight locations (Figure 4). Averaged across locations, partial stover harvest increased corn yield by 3.3% compared to no stover harvest ($P < 0.01$). Increased corn yields were likely due to the positive effects of stover harvest on stand establishment and soil nitrogen (N) availability during vegetative growth (data not shown). Ongoing monitoring of DuPont's Pioneer's corn stover research trials will help to further define partial corn stover harvest impacts on crop performance and soil fertility.

Nutrient content of corn stover

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. Many extension sources report stover nutrient content for corn plants at physiological maturity. Nutrient removal estimates based on silage harvest or for corn stover at physiological maturity typically overestimate the amount of nutrients actually removed by commercial corn stover harvest.

DuPont and Iowa State analyzed the phosphate (P_2O_5) and potash (K_2O) content of approximately 300 large, square bales collected during commercial harvest operations in central Iowa in 2010 and 2011. Nitrogen content was also assessed for a subset of bales. From this analysis, the nutrient content of commercially harvested bales was confirmed to be less than that generally reported for corn stover by regional extension services (Figure 5). Reduced nutrient content for commercially harvested stover is believed to result from: (1) the reduction in potassium - which exists in stover in a soluble form - that occurs between plant physiological maturity and the time of stover harvest (Sawyer and Mallarino, 2007); and (2) the fact that commercial stover harvest disproportionately removes the upper portion of the corn plant, which typically has a lower nutrient content than the lower portion of the plant (Johnson et al., 2010).

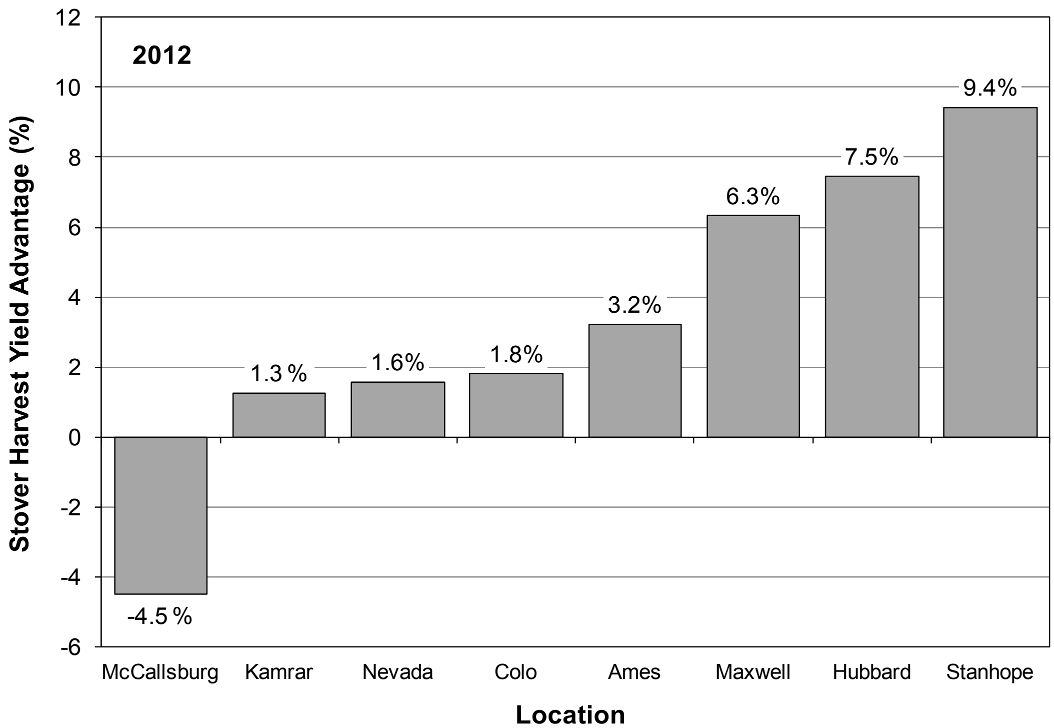

Figure 4. Corn yield advantage with partial stover harvest (~50% removal) at eight locations in central Iowa.

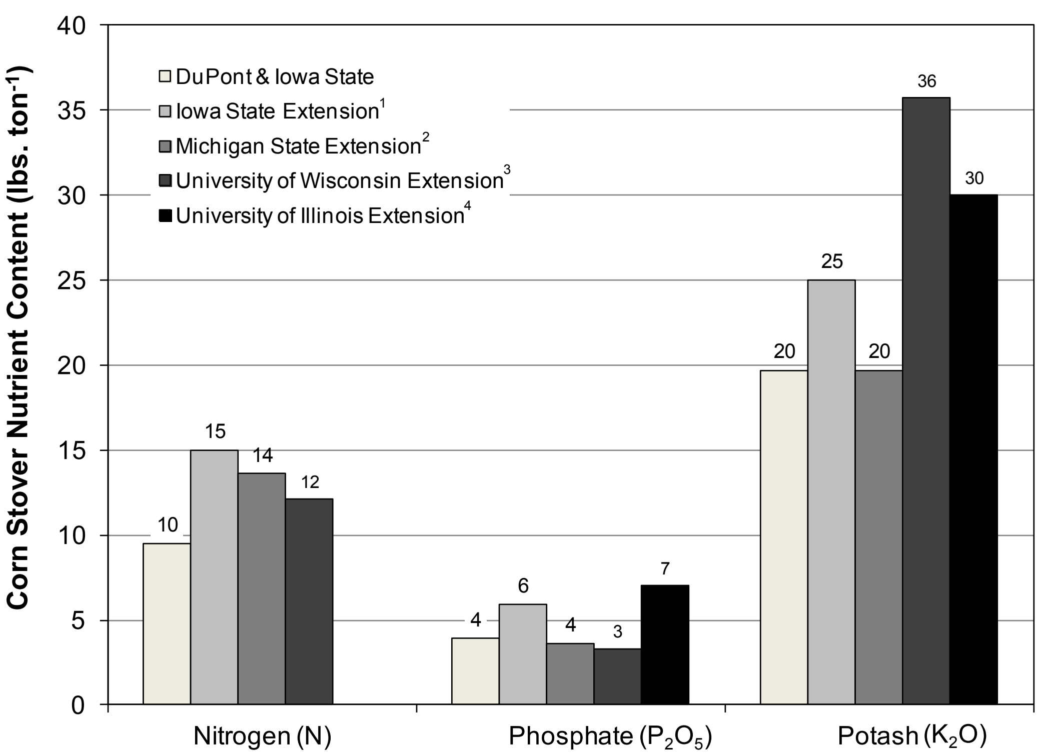

Figure 5. Nutrient (N, P_2O_5 and K_2O) content of corn stover baled by DuPont and Iowa State in 2010 and 2011, compared to that reported by four university extension services. References are: (1) Sawyer et al. 2011; (2) Gould 2007; (3) Bundy 1998; and (4) Fernández 2007.

Corn stover harvest sustainability

Corn stover plays several important roles in a cropping system, including mitigation of soil erosion and maintenance of soil organic matter. Because of the value that corn residues provide in maintaining soil productivity, a portion of corn stover must be retained in fields to meet critical soil quality needs. Research conducted by the USDA provides general guidelines for how much stover must be retained in fields to prevent soil erosion and maintain soil organic matter (Wilhelm et al. 2007). Tillage practices and crop rotation both affect sustainable stover rates, as does the productivity of the field. Regardless of management practices or productivity level, the need to maintain soil organic matter ultimately sets the limit for how much stover can be harvested in a sustainable manner.

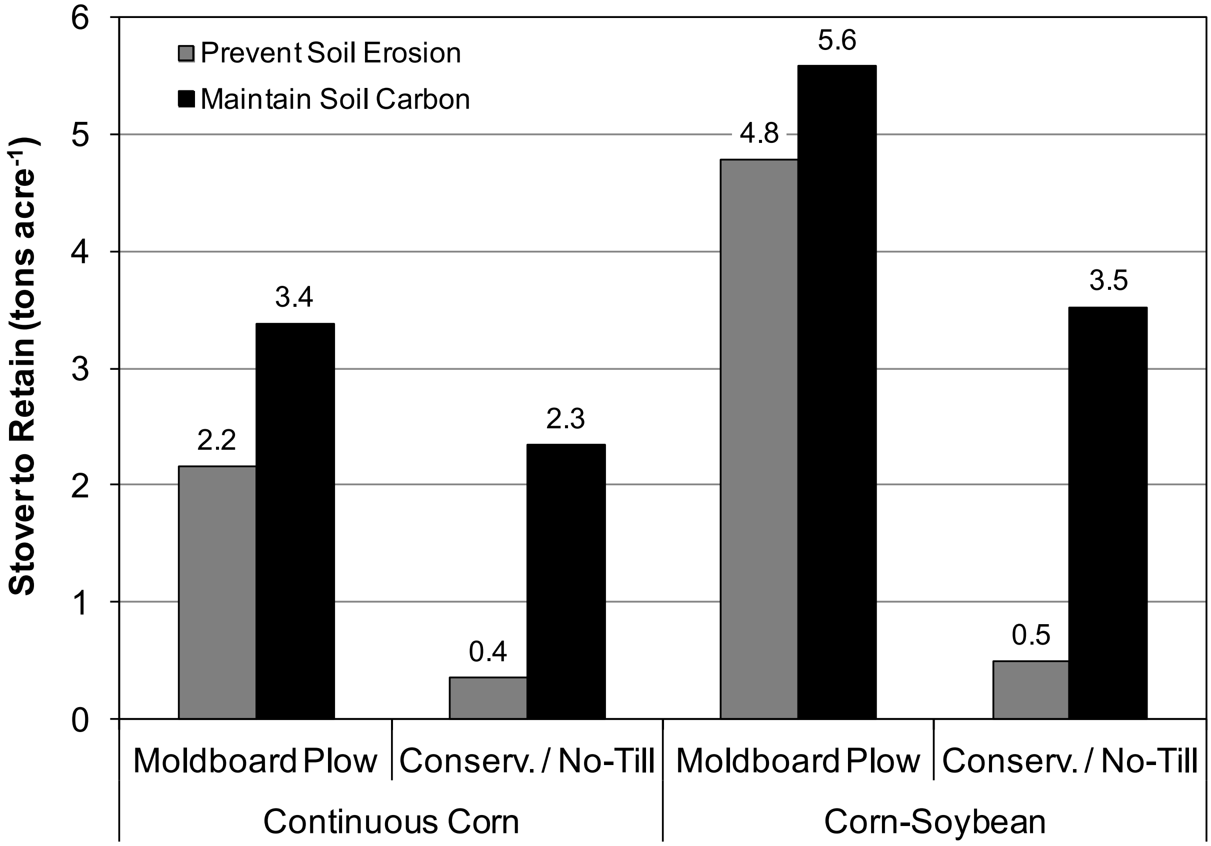

Figure 6. Quantity of corn stover that needs to be retained in the field to prevent soil erosion from exceeding tolerable (T) values established by the Natural Resource Conservation Service (NRCS), and to maintain soil carbon in steady state. Adapted from Wilhelm et al. 2007.

DuPont sustainable stover harvest recommendations

DuPont provides sustainable harvest recommendations to growers participating in its stover harvest program. These recommendations are based on guidelines established by USDA research (Wilhelm et al. 2007). In practice, DuPont's sustainable stover harvest recommendation has three key components:

1. Partial stover harvest – A portion of stover must be retained in fields to prevent soil erosion and sustain soil organic matter. DuPont limits stover harvest to a rate of two tons acre^{-1}, which is generally less than half of the total stover produced in harvested fields.
2. Field characteristics – Stover harvest is limited to appropriate fields. DuPont advises growers to only harvest stover from fields that have a recent yield history of 180 bushels acre^{-1} or greater and a slope of 4% or less. Additionally, DuPont positions stover harvest on fields that are managed with conservation or no-till practices.

3. Harvest frequency – Stover is not harvested off of the same field every year. For fields that are managed in continuous corn, DuPont advises that stover be harvested no more than three out of every four years. For fields in a corn-soybean rotation, it is recommended that stover harvest take place only two out of every five years that the field is in corn. Varying harvest frequency helps to insure that soil organic matter is maintained over the long term.

Stover harvest cropping considerations

Although DuPont has purposefully developed a stover harvest program that allows corn growers to participate with minimal or no changes to their current farming practices, stover harvest does create new crop production opportunities. Most obviously, growers participating in a stover harvest program do not need to perform fall residue management activities such stalk chopping and/or AMS application. In some cases, it may also be possible to eliminate tillage operations that are directed primarily toward residue management. Finally, because partial stover harvest provides some of the same benefits as rotation with soybean, certain management challenges associated with producing corn following corn can be potentially be avoided.

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