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Value and implications of corn stover removal from Virginia fields

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Introduction

There has recently been increased interest in the use of crop residues for different industrial uses in the US and the world. Corn residue is frequently cited as the most likely candidate for alternate industrial uses because of the large area of production and the relatively large amount of residue produced per acre. Among the potential alternate uses for corn stover, biofuel production has received the greatest attention. However, a diverse array of uses exists including:

a) Conversion of corn stover to sugars for the sweetener industry
b) Electricity generation using microbial fuel cells (MFCs) through either neutral or acid steam-exploded hydrolysis processes
c) Corn stover ensilage to both preserve and pretreat biomass feedstock for conversion into chemicals, fuels, and/or fiber products
d) Co-firing with coal for electricity production
e) Anaerobic co-digestion of manure and stover for biogas production
f) Livestock feed
g) Dissolved pulp for paper production and low-molecular weight lignin as a raw material for wood adhesive production

The U.S. is the major producer of corn grain with around 35% of the world's total production and so it is also likely the US can lead the world in production of bioethanol and other outputs from corn residues. Moreover, using corn residues, more commonly known as corn stover (i.e. part of the plant that stays on the field after grain harvesting: stalks, leaves, husks and tassels) to make biofuels, for example, instead of corn grain may help to address concerns about use of grain crops for fuel; concerns characterized by the "food vs. fuels" discussions. Typically, farmers in Virginia have either left all corn residue in the field or have collected a portion for animal feed or bedding.

Generating local information on the environmental and economic impacts of crop residue removal will be an important first step in determining whether harvesting additional stover can be a viable addition to Virginia's cropping system. To date, almost all the published information on stover produced in the US has been generated in the Corn Belt area, however extrapolating this information to Virginia is problematic because of differences in soils and climate. While development of any corn residue-based

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industry, other than livestock feed, in Virginia is still in the feasibility stage, research is being conducting to understand the implications of corn residue removal (among some other crops), under different crop rotations, soils and climatic conditions. Utilizing a portion of these residues could represent a valuable extra source of income for Virginia farmers provided that doing so will not negatively affect long-term sustainability. Factors such as soil quality parameters, greenhouse gases emissions, water availability and potential economic returns of the system will all affect the value of stover harvest for the farm operation.

The balance of stover removed to carbon returned, in the form of stover, to the fields must be considered due to increased erosion potential and decreased soil organic matter content with stover removal. As a result, not all of the stover produced will be available to use in the biofuel industry. Based on reported negative effects of corn stover removal on soil quality indicators such as soil organic matter, Corn Belt researchers have suggested that no more than 25% of corn crop residues can sustainably be removed from silt and clay loams soils ranging from 1-10% slopes. Other less conservative assessments indicate that 30 to 50% stover removal could be sustainable in the Corn Belt and in Europe.

Many field-specific variables such as tillage system and crop rotation impact the final effect of the amount of stover removed. Some researchers have previously recommended harvesting only about 30% under conventional tillage, while values up to 50% could be sustainably collected in no-till systems while others have estimated that up to 60% of corn stover could be sustainably removed. A 2014 Virginia Department of Mines Minerals and Energy report assumed that up to 35% of aboveground residues produced in Virginia, including corn, barley, oat, peanut, soybeans and wheat could be removed with no negative impact on soil health.

Example: the potential value for bioethanol production in Virginia

While grain yield data is generally available at the farm-level, stover yield data is not. To estimate stover production researchers have historically used the Harvest Index (HI) concept. Harvest index is a ratio of the amount of grain produced over the total amount of aboveground biomass generated by the crop (grain + stover or fodder biomass) in a weight basis, and is calculated as follows:

$$\textbf{Harvest Index (HI)} = \textbf{grain mass} / (\textbf{grain} + \textbf{stover})\ \textbf{mass} \qquad \text{[Equation 1]}$$

Harvest index is not a static value and varies based on environment and management. Wet or dry years and insects or diseases that negatively affect corn are all predisposing factors for reductions in the grain yield component, resulting in decreased HI. Improvements in crop grain yields through better genetics and more intensive management practices, for the same plant size, increase the HI. Under favorable crop growth conditions, the HI is generally around 0.50 which is the value most commonly used to estimate the ratio of corn grain to stover

Grain and stover dry matter (DM) yields in Virginia were investigated in different years in order to develop an initial corn stover feedstock assessment (i.e. 2005, n=36; 2006, n=24; 2012, n=10 and 2014, n=10). With this data, HI was calculated using Equation 1. In our analysis HI ranged from 0.16 to 0.75 in non-irrigated conditions, with an average value across years and locations of 0.43, a value within the range cited by others. Under irrigated conditions, data from three fields obtained in 2012 and 2014 shows a HI of 0.62, reflecting the increased grain component value over total biomass when compared with non-irrigated conditions. The highly variable nature of corn HI data collected in field experiments is in agreement with previous reports of others authors.

A second important concept is the theoretical yield for conversion of biomass into ethanol. And in this sense, available conversion techniques are improving this efficiency over time. In a 2010 study in Minnesota studying the effect of nitrogen fertilization on energy production and nutrient removal in harvest both for stover and cobs, Sheaffer et al. (2010) reported ethanol yields ranging between 80 to 100 gallons ethanol Ton of stover^{-1} and 108 to 114 gallons ethanol Ton of cob^{-1}. In this study, the authors analyzed the cob portion (usually considered as part of the "stover pool", as previously defined) separately from the rest of the stover. Current U.S. Department of Energy ethanol yields estimations for corn stover as a whole (i.e. no distinction between cobs and other aboveground stover) are on the order of 113 gallons of ethanol Ton of stover^{-1}.

With this information, we can evaluate potential scenarios of bioethanol production from corn stover in Virginia. For the sake of simplicity only two stover removal rates will be considered; 30 and 50%, representing the recommended maximum stover rates under conventional and no-till systems, respectively. Virginia's corn grain yields (138 bu acre^{-1}) and average harvested area (340,000 acres) for the last 5 years (period 2011-2016) and an approximated conversion rate of 113 gallons of ethanol Ton of stover^{-1} would be used in this example.

1) Assuming a HI of 0.43 for non-irrigated conditions in Virginia, the biomass other than corn grain (simply known as "corn stover") represents 57% of the overall plant weight. Multiplying the measured grain yield by the HI and then by 56 lb bu^{-1} results in an estimate of the total lb of corn stover per acre. In our example, the average corn stover biomass production in Virginia would be around 10,200 lb acre^{-1} or approximately 5.1 dry tons of stover acre^{-1} [Equation 2]

$$\textbf{Corn stover}\left(\frac{\text{lbs}}{\text{acre}}\right) = \frac{(1-\text{HI})}{\text{HI}} * \textbf{grain yield}\left(\frac{\text{bu}}{\text{acre}}\right) * 56\,\frac{\text{lbs}}{\text{bu}} \qquad \text{[Equation 2]}$$

$$\textbf{Corn stover} = \frac{(1-0.43)}{0.43} * 138\left(\frac{\cancel{\text{bu}}}{\text{acre}}\right) * 56\,\frac{\text{lbs}}{\cancel{\text{bu}}} = 10{,}244\,\frac{\text{lbs stover}}{\text{acre}} \cong 5.1\,\frac{\text{dry ton stover}}{\text{acre}}$$

2) Ethanol yield conversion for corn stover can then by expressed in terms of gallons of ethanol per lb of stover [Equation 3]

$$113\,\frac{\text{gallons of ethanol}}{\cancel{\text{dry ton of stover}}} * \frac{1}{2{,}000}\,\frac{\cancel{\text{dry ton}}}{\text{lbs}} = 0.0565\,\frac{\text{gallons ethanol}}{\text{lbs stover}} \qquad \text{[Equation 3]}$$

3) Ethanol production per acre

   i. At 30% stover removal rate

$$0.0565\ \frac{\text{gallons ethanol}}{\text{lbs stover}} * 10,244\ \frac{\text{lbs stover}}{\text{acre}} * 0.30 = 174\ \frac{\text{gallons ethanol}}{\text{acre}}$$ [Equation 4]

ii. At 50% stover removal rate

$$0.0565\ \frac{\text{gallons ethanol}}{\text{lbs stover}} * 10,244\ \frac{\text{lbs stover}}{\text{acre}} * 0.50 = 289\ \frac{\text{gallons ethanol}}{\text{acre}}$$ [Equation 5]

4) Total annual ethanol production from corn stover in Virginia:

i. At 30% stover removal rate

$$\text{Bioethanol production}\ \left(\frac{\text{gallons}}{\text{year}}\right) = 174\ \frac{\text{gallons ethanol}}{\text{acre}} * 340,000\ \text{acres}$$

$$\text{Bioethanol production} = 59,160,000\ \frac{\text{gallons}}{\text{year}}$$ [Equation 6]

ii. At 50% stover removal rate

$$\text{Bioethanol production}\ \left(\frac{\text{gallons}}{\text{year}}\right) = 289\ \frac{\text{gallons ethanol}}{\text{acre}} * 340,000\ \text{acres}$$

$$\text{Bioethanol production} = 98,260,000\ \frac{\text{gallons}}{\text{year}}$$ [Equation 7]

In our example, 30% and 50% stover removal represents harvesting approximately 1.5 and 2.5 dry tons of stover acre^{-1}, with average production of 174 (Equation 4) and 289 gallons ethanol acre^{-1} (Equation 5), respectively. These values are similar to the current values of 1.2 to 2 dry tons of stover per acre harvested by the ethanol companies using corn stover at industrial scale for ethanol production. As a result, Virginia's ethanol production resulting from corn stover could range from about 59 million gallons of ethanol per year at a 30% stover removal rate to about 98 million gallons of ethanol per year under a 50% removal rate scenario (Equation 7).

Wheat straw is also a potential crop residue feedstock for biofuel production in vast agricultural regions of the United States including Virginia. Ethanol production estimates range from 69 to 93 gallons ethanol ton of straw^{-1}. There is potential to increase these values to theoretical yields of 114 gallons ethanol ton of straw^{-1} if all the sugars could be recovered and converted to ethanol.

Following a similar approach to the earlier calculations shown for corn and considering a winter wheat average grain yield of 64 bu acre^{-1}and a HI for winter wheat in Virginia of 0.45 (i.e., 4,700 lb straw acre^{-1}) and a conversion rate of 93 gallons ethanol ton of straw^{-1}, straw removal rates of 30% and 50% would produce an average of 65 and 109 gallons of ethanol acre^{-1}, respectively. With approximately 236,000 acres of winter wheat harvested each year in Virginia, removal rates scenarios of 30% and 50% would potentially produce another 15.4 and 25.7 million gallons of ethanol per year, respectively. With an annual harvested area of about 1/6 to 1/7 of that for winter wheat, barley (Table 1) (assuming similar conversion rates and HI than in winter wheat) could supply another 4 million gallons of ethanol per year under a 50% removal rates scenario.

In summary, potential bioethanol production from corn and small grain residues in Virginia could generate 130 million gallons of ethanol using half of the corn, wheat and barley crop residues produced each year. Removal of corn residue may offer expanded revenue opportunities for Virginia farmers, especially if additional stover markets are developed in future years. However, the added costs of removing residues, including the potential for increased soil erosion and decreased soil quality over time should be carefully considered, factors that are currently being investigated in Virginia.

Literature cited

Sheaffer, C., J. Lamb and Rosen C. 2010. Corn stover: ethanol production and nutrient uptake. At: *http://www.mncorn.org/sites/mncorn.org/files/research/final-reports/201211/B6-CornStoverEthanolProduction_2.pdf* (accessed 14 Jan. 2017).