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Harvesting and nutrient replacement costs associated with corn stover removal in Virginia

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Use of crop residues for bioenergy has grown over the last decade as a result of government policies to create alternative energy sources and secure US fuel supplies (EISA-EPA, 2007). Even when second generation biofuels (i.e., those produced from annual crop residues) have the capacity to both increase and diversify farm income, and reduce fossil fuel use and greenhouse gas fluxes to the atmosphere (Wilhelm et al., 2004), there are also concerns about the broad impacts of these practices in our agroecosystems. The balance of stover removed to carbon returned to the fields must be thoroughly considered to address, at least, three important impacts:

1) Potential increases in soil erosion and decreases in soil organic matter content and other chemical, physical and chemical parameters of soil quality, with stover removal (i.e., environmental concerns).
2) Potential negative impacts in grain production (agronomic concerns).
3) Impacts on harvesting and nutrient replacement costs (economic concerns).

In this publication, we analyze the economic impacts resulting from both the harvest and nutrient replacement costs of corn stover for the bioethanol industry in Virginia.

Information about ethanol production and conversion efficiency may have an important value for entrepreneurs, people in the bioethanol industry, researchers and government parties, but certainly is not the main interest for the farmer. The main interest for the farmer is to know: a) methods for determining the price of stover, (delivery locations, in what form, and when); b) price value received per dry ton of stover; c) stover harvest costs; d) nutrient replacement costs; e) additional machinery costs; and finally, f) breakeven cost of corn stover harvesting for Virginia farmers.

a) Stover delivery locations for Virginia farmers is uncertain, as the bioethanol industry from corn stover (or any other crop residue) in the state has yet to be developed. Ethanol plants currently working with corn stover are fueled with corn stover harvested from an approximate 30 to 50-mile radius from the facility. Custom operations supported or provided by companies usually comprises the use of stalk shredders, rakes and balers to windrow stover and package as large, high density square bales weighing between 1,300-1,500 pounds that would yield about 1,000 pounds dry matter. Large square bales have proven to be the most safely and cost effective harvesting, transporting and storing method at present. Companies harvesting crews are also responsible for stacking all the bales on the field edge within 3 days after baling and removing the bales from the field by an agreed upon date.

b) Reported value of stover varies with demand and by region. Some values reported in the last three years in the Corn Belt suggest that bioethanol companies are willing to pay between \$72 and \$77 per dry ton (Grooms, 2014) with future price expectations ranging from \$45 to \$80 per ton for delivered corn stover (University of Missouri Extension, 2012; University of Wisconsin Extension, 2012; Iowa State University Extension and Outreach, 2014). However, this price can be considerable higher in drought years like 2012, when the prices for baled corn stover varied between \$60 and \$100 per ton of stover dry matter (University of Missouri Extension, 2012).

c) Graham et al. (2007) suggested that around 30% of the total corn stover produced in the US could be collected for less than \$30 ton^{-1} of dry matter. A report from the University of Minnesota concluded that corn stover would be the cheapest energy feedstock of a group of candidates that included grassland (i.e. Switchgrass) with high and low fertilization and a short-rotation woody crop of hybrid poplar. This study estimates the cost of corn stover production and transportation to be \$50 ton^{-1} to cover additional machinery costs to shred, rake, bale and transport 25 miles to a processing plant (Lazarus, 2008). However, an important consideration is the proportion of the overall corn production costs assigned to the corn stover. Khanna and Paulson (2016) recently calculated corn stover harvest costs in Illinois for different combinations of crop productivity, rotations and tillage systems. For high productivity levels [i.e., corn grain yields of 158 and 180 bu acre^{-1} for CC (continuous corn) and C/S (corn-soybean) rotations, respectively], total harvesting and storage costs were between 6% and 9% higher for CC rotations. Averaged across rotations, costs for conventional tillage were 32% higher than similar costs in no-till systems. Clearly, more sustainable systems involving a) two or more crop species within a rotation and, b) no-till systems with a higher amount of corn stover to be sustainably harvested (around 50% for no-till vs. 30% for conventional tillage), would result in greater harvested stover yields per unit area and thus, lower harvesting costs per ton of stover. Lower productivity levels (i.e., corn grain yields of 112 and 127 bu acre^{-1} for CC and C/S rotations, respectively) resulted in costs 19% to 26% higher for each combination of factors. Overall, costs in this assessment ranged from a lowest \$37.14 (high productivity, C/S rotation and no-till) to a highest \$66.64 ton^{-1} of dry matter (low productivity, CC rotation and conventional tillage). Recent data generated by the Department of Agricultural and Applied Economics and the Virginia Cooperative Extension at Virginia Tech (Eberly and Groover, 2007) for hay baling is shown in Tables 1 (variable costs) and 2 (fixed costs).

For the following economic assessment, we consider two different corn grain yield scenarios with two different stover removal (SR) rates each one [harvest index (HI) of 0.43 for all comparisons), as follows:

i. "State average productivity" scenario, corresponding to the statewide average corn grain yield for the period 2011-2015 (i.e., corn grain yields of 136 bu acre^{-1}and stover yields of approximately 5 tons stover dry matter acre^{-1}) under 30% and 50% SR rates.

ii. "High productivity scenario", corresponding to a corn grain yield of 180 bu acre^{-1} and stover yield of approximately 6.7 tons stover dry matter acre^{-1}, under 30% and 50% SR rates.

Under these assumptions, harvested stover yields for the "state average productivity" scenario are approximately 1.5- (30% SR) and 2.5 ton of stover $acre^{-1}$ (50% SR) (total available stover of approximately 5 tons $acre^{-1}$). Total variable costs (i.e., fuel, oil and lube + repair costs + harvest labor) are \$14.67 ton^{-1} for 50% SR and \$23.28 ton^{-1} for 30% SR (Table 1).

Harvested stover yields for the "high productivity" scenario represent approximately 2- (30% SR) and 3.35 ton of stover $acre^{-1}$ (50% SR) (total available stover of approximately 6.68 tons $acre^{-1}$). Total variable costs are \$11.42 ton^{-1} for 50% SR and \$17.86 ton^{-1} for 30% SR (Table 2). As a result, total variable costs are approximately 37% lower at each scenario when harvesting half of the total available stover in comparison with only harvesting 30%.

For both scenarios and stover removal rates, fixed or "ownership" costs (i.e., those that occur regardless of machine use) based on new machinery are \$26.05 ac^{-1} (Table 3).

Total baling costs (TBC) [Equation 1] are expressed in \$ $acre^{-1}$ in the final breakeven economic analysis (Table 5). To do so, variable costs were transformed from a \$ ton^{-1} to a \$ $acre^{-1}$ basis by multiplying the cost per ton by the tons produced per acre. An example illustrating this calculation for the "mowing" total cost (100HP+Rotary Mower-12 FT) with the state average productivity scenario and 30% SR is provided below.

$$\mathbf{TBC = (variable + fixed)\ costs} = \left(\mathbf{7.97}\ \frac{\$}{\cancel{\mathbf{ton}}} * \mathbf{1.5}\ \frac{\cancel{\mathbf{ton}}}{\mathbf{acre}}\right) + \mathbf{7.56}\ \frac{\$}{\mathbf{acre}} = \mathbf{19.52}\ \frac{\$}{\mathbf{acre}} \quad \text{[Equation 1]}$$

For all the calculations shown here, we are assuming that the farmer does not own the machinery listed in Table 3. In the case the farmer is already owning the needed machinery, the fixed costs are much lower and only include depreciation, interest (opportunity cost), taxes, insurance, and housing and maintenance facilities (Iowa State University Extension and Outreach, 2014). Custom hiring for baling is another possible scenario. In this case, Grooms (2014) points out that there is an average \$2-\$5 revenue advantage per ton for the farmers that decide to do the baling themselves. After the baling process is finished, most logistic systems used nowadays consist in moving bales to a central location at the edge of roadsides to facilitate pick up by semi-trailer trucks. Trucks, which typically work under separate contract with the companies, pick up these bales within days from harvesting and transport them to the biorefinery. Consequently, hauling, storage and transportation costs as well as storage losses are not considered in this budget.

d) Information regarding nutrient removal rates per unit of harvested corn grain is available for most regions in the US. However, this information is less readily available for corn stover. Also, current fertilization recommendations are based, among other things, on grain nutrient removal rates, but not from corn stover harvesting which could substantially increase nutrient removal. Data generated from IPNI (International Plant Nutrition Institute) (IPNI, 2008) in the US Northcentral region regarding nutrient removal rates (i.e., N, P_2O_5, K_2O and S) for corn stover is presented in Table 4. Nutrient removal rates resulting from corn stover harvesting are not negligible and need to be considered both for the system's environmental and financial sustainability. With this information and average fertilizer prices (Table 4), nutrient replacement costs can be estimated for different corn grain and stover productivity scenarios and different stover removal rates. Fertilizer prices were based on a 10-year average (2004-2013) calculated from data reported by USDA-ERS (2016). Economic analysis for this report do not consider the replacement costs of other nutrients (commonly known as "micronutrients") that would potentially be removed (manganese, zinc, boron, etc).

e) In our analysis, we consider the use of the following equipment for mowing, raking and baling with 2014 prices for new machinery (Eberly and Groover, 2007), as follows:

- A 12-ft rotary mower with a new estimated price of $12,000; this machinery is attached to a 100-HP tractor. A more economical alternative to this is a 9-ft rotary mower attached to a 75-HP tractor with a new estimated price of $10,450, although repair costs per acre for this machinery are 10% more expensive when compared with the first option. A second alternative, is a 9-ft mower-conditioner machine attached to a 75-HP tractor, with a higher price to new ($14,000) but lower (-53%) repair costs per acre than first option.
- An 18-ft wheel rake attached to a 75-HP tractor with a new estimated price of $4,500. An alternative to this is an 18-ft wheel rake attached to a 55-HP tractor with similar price to new, but repair cost per acre 24% lower than first option.
- A round baler PTO 1500# attached to a 100 MFWD tractor with a new estimated price of $37,500. An alternative to this machinery is a 16x18 square baler PTO Twine attached to an 80-HP tractor with lower new estimated price ($27,500) and repair costs per acre (-56%) than first option, but this option is less commonly used in Virginia.

f) Breakeven analysis (Table 5):

In our analysis, total costs per acre ranged from $105.79, with a scenario of low corn removal rates and state average productivity for corn, to $163.01 with higher removal rates and high corn productivity (Table 5). The nutrient replacement costs resulting only from corn stover removal for alternative uses represent between 40% (i.e., 30% SR and state average productivity) and 57% (i.e., 50% SR and high productivity) of the total costs in our projection. While removing more stover per acre increases the cost of replacing those nutrients, harvesting and storage costs, which change little among the different comparisons, diminish in a per acre basis as more and more residues are harvested, representing a 60% and a 40% of the total cost for the above comparisons, respectively.

The breakeven stover price in our comparisons (i.e., the price at which the farmer should sell the stover to cover his total costs related to the removal of corn stover for alternative uses), is calculated as the ratio between the total cost per acre ($ acre^{-1}) and the marketable stover (in tons dry matter acre^{-1}). As expected, removing more stover, even at the same farm, have noticeable implications in the final breakeven stover price. As an example, farmers with average and high corn productivity can reduce its corn stover breakeven price between 19% and 22%, for the same farm, by harvesting 50% instead of 30% of the available stover (Table 5).

Corn stover price has shown a lot of volatility over the last couple years (see point c). The absence of major players in this business, with an incipient industry that is developing in a scenario of historic low fossil-fuel prices, coupled with the more intense and frequent extreme weather episodes at a global scale, will likely determine more fluctuations in the corn stover prices in the years to come. In a scenario of low corn stover prices, for example $50 dry ton^{-1}, harvesting corn stover for alternative uses will only be (marginally) cost-effective in Virginia for farmers with high corn productivities and willing to remove at least 50% of their aboveground stover. With corn stover prices of $75 dry ton^{-1} (a price in the mid-range from those reported in the last years in the Corn Belt area) three out of the four situations in our analysis (i.e., 30% SR for state corn productivity; both SR for high corn productivity) will result in net profits at or greater than $15 acre^{-1}. With a high corn value of $90 dry ton^{-1}, a likely value in drought years and/or with higher feedstock demand from cellulosic bioethanol companies, productivity systems described here will generate a net profit exceeding the $20 acre^{-1} in all cases, with a maximum of $41.2 acre^{-1} net profit for the high productivity-high removal rate combination, a farmer profit similar to that claimed by the cellulosic companies working with farmers in the Corn Belt area.

Table 1. Harvest variable costs for corn stover baling in Virginia for state corn grain scenario and two stover removal (SR) rates (%) §

136 bu corn $acre^{-1}$					HARVEST VARIABLE COSTS								
	TIMES OVER	LABOR		MACHINE	FUEL, OIL & LUBE †‡¶		REPAIR COSTS		HARVEST LABOR		BALER TWINE	TOTAL	
					30 % SR	50 % SR	30 % SR	50 % SR	30 % SR	50 % SR		30 % SR	50 % SR
UNIT		Hrs ac^{-1}	\$ Hrs^{-1}	Hrs ac^{-1}	——————————\$ Ton^{-1} ——————————								
HARVEST													
100HP+Rotary Mower-12 FT	1	0.32	14.50	0.29	\$1.86	\$1.12	\$3.02	\$1.81	3.09	1.86		\$7.97	\$4.78
75HP+Wheel Rake-18 FT	1	0.12		0.11	\$0.53	\$0.32	\$0.33	\$0.20	1.16	0.70		\$2.01	\$1.21
100MFWD+Round Baler PTO 1500#	1	0.29		0.26	\$1.67	\$1.00	\$5.33	\$3.20	2.80	1.68	\$1.75	\$11.55	\$7.63
25% UNALLOCATED LABOR		0.18							1.74	1.04		\$1.74	\$1.04
TOTAL		0.91	14.50	0.66	4.06	2.43	8.67	5.20	8.80	5.28	\$1.75	**23.28**	**14.67**

Table 2. Harvest variable costs for corn stover baling in Virginia with high corn grain yield scenario and two stover removal (SR) rates (%) €

180 bu corn $acre^{-1}$					HARVEST VARIABLE COSTS								
	TIMES OVER	LABOR		MACHINE	FUEL, OIL & LUBE †‡¶		REPAIR COSTS		HARVEST LABOR		BALER TWINE	TOTAL	
					30 % SR	50 % SR	30 % SR	50 % SR	30 % SR	50 % SR		30 % SR	50 % SR
UNIT		Hrs ac^{-1}	\$ Hrs^{-1}	Hrs ac^{-1}	——————————\$ Ton^{-1} ——————————								
HARVEST													
100HP+Rotary Mower-12 FT	1	0.32	14.50	0.29	\$1.39	\$0.84	\$2.26	\$1.36	2.32	1.39		\$5.97	\$3.58
75HP+Wheel Rake-18 FT	1	0.12		0.11	\$0.40	\$0.24	\$0.24	\$0.15	0.87	0.52		\$1.51	\$0.90
100MFWD+Round Baler PTO 1500#	1	0.29		0.26	\$1.25	\$0.75	\$3.99	\$2.39	2.10	1.26	\$1.75	\$9.08	\$6.15
25% UNALLOCATED LABOR		0.18							1.30	0.78		\$1.30	\$0.78
TOTAL		0.91	14.50	0.66	3.03	1.82	6.49	3.89	6.58	3.95	\$1.75	**17.86**	**11.42**

§ Stover removal (SR) rates of 30% (i.e., 1.5-ton dry matter ac^{-1}) and 50% (i.e., 2.5-ton dry matter ac^{-1}) from total annual corn stover produced with 0.43 grain HI (i.e., 57% stover). Adapted from Groover (2014).

€ Stover removal (SR) rates of 30% (i.e., 2-ton dry matter ac^{-1}) and 50% (i.e., 3.3-ton dry matter ac^{-1}) from total annual corn stover produced with 0.43 grain HI (i.e., 57% stover). Adapted from Groover (2014).

† September 2015-February 2016 diesel fuel price average of $2.2525 per gallon adapted from "Weekly Lower Atlantic (PADD NC) No 2 Diesel Retail prices" category, according to the U.S. Energy Information Administration Independent Statistics & Analysis. At: http://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_r1z_w.htm

‡ Virginia federal and state road taxes of $0.5043 per gallon effective from January 1, 2016 are applicable and subtracted from retail price to get a farmer final value of $ 1.7482 per gallon. At: http://www.api.org/~/media/Files/Statistics/State-Motor-Fuel-Taxes-Report-January-2016.pdf?la=en

¶ Gallons of Diesel Fuel + 15% to cover Oil & Lube.

Table 3. Machinery fixed costs for corn stover baling in Virginia based on new equipment cost ¥

	FIXED COSTS ¥
UNIT	\$ ac^{-1}
HARVEST	
100HP+Rotary Mower-12 FT	\$7.56
75HP+Wheel Rake-18 FT	\$1.80
100MFWD+Round Baler PTO 1500#	\$16.69
TOTAL	**\$26.05**

¥ Estimated fixed costs of 12, 37.5 and 4.5 thousand of dollars for rotary mower, wheel rake and round baler new machinery, respectively (implement alone, excluding tractor). Adapted from Groover (2014).

Table 4. Average nutrient replacement cost and nutrient removal rates based on 10-year nutrient price averages (2004-2013) in the US and published rates of nutrient removal by corn stover

	\$ lb nutrient^{-1} ¶	Nutrient removal (lb nutrient ton stover^{-1}) §
Nitrogen (N)	0.50	16
Phosphorus (P_2O_5) †	0.48	5.8
Potassium (K_20) ‡	0.40	40
Sulfur (S) ¥	0.29	3

¶ USDA-ERS (2016).
§ IPNI (2008).
† To convert P_2O_5 to P multiply by 0.43646
‡ To convert K_2O to K multiply by 0.83013
¥ To convert SO_4 to S multiply by 0.3333

Table 5. Breakeven analysis for the state average and high productivity scenarios under two stover removal rates in Virginia.

	State average productivity		High productivity	
STOVER REMOVAL RATE	**30%SR**	**50%SR**	**30%SR**	**50%SR**
GRAIN AND STOVER YIELDS (dry basis)				
CORN YIELD (bu acre^{-1})	136		180	
STOVER YIELD (ton acre^{-1})	5.05		6.68	
STOVER HARVESTED (ton acre^{-1}) †	1.52	2.53	2.00	3.34
STORAGE LOSS (%)	0	0	0	0
MARKETABLE STOVER (ton acre^{-1}) ‡	1.52	2.53	2.00	3.34
EXPENSES				
NUTRIENT REMOVAL (Lb per ton stover)				
NUTRIENT REPLACEMENT	——————————$ acre^{-1} ——————————			
NITROGEN (N)	$12.12	$20.20	$16.03	$26.72
PHOSPHORUS (P_2O_5)	$4.22	$7.03	$5.58	$9.30
POTASSIUM (K_2O)	$24.24	$40.40	$32.06	$53.44
SULFUR (S)	$1.32	$2.20	$1.74	$2.91
TOTAL NUTRIENT REPLACEMENT	**$41.90**	**$69.83**	**$55.42**	**$92.36**
HARVESTING AND POST HARVESTING COSTS	——————————$ acre^{-1} ——————————			
Mowing	$19.52	$19.52	$19.52	$19.52
Raking	$4.82	$4.82	$4.82	$4.82
Baling	$34.01	$35.76	$34.89	$37.23
Storage	$0.00	$0.00	$0.00	$0.00
Staging and loading	$0.00	$0.00	$0.00	$0.00
Hauling and transportation	$0.00	$0.00	$0.00	$0.00
Unallocated labor	$2.61	$2.61	$2.61	$2.61
Interest ¶	$2.93	$4.89	$3.88	$6.47
TOTAL HARVESTING AND STORAGE	**$63.90**	**$67.60**	**$65.72**	**$70.65**
TOTAL COST	**$105.79**	**$137.43**	**$121.14**	**$163.01**
BREAKEVEN STOVER PRICE ($ dry ton^{-1}) §	**$69.83**	**$54.43**	**$60.45**	**$48.81**

† Calculated from corn grain yields using a harvest index of 0.43 and on a dry basis. Some budgets can present wet stover harvested and then discount the harvest moisture content (assumed to be 15% in most cases), to obtain the adjusted for zero moisture content harvested stover. If wet harvested stover is initially consider, the variable harvest and post-harvest costs are calculated on a wet stover yield basis. Dried basis collected stover is used to determine nutrient replacement needs according to corn stover nutrient content charts from IPNI (2008).
‡ Adjusted by storage losses (0% in this example). Value used to calculate breakeven stover prices.
¶ Interest rate of 7% charged to total cost of nutrient replacement.
§ Breakeven stover price is the minimum amount of stover needed to cover additional nutrient and stover harvesting and post-harvesting costs.

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