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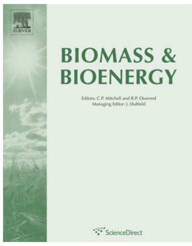

Corn stover for bioenergy production: Cost estimates and farmer supply response

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ABSTRACT

A lot of attention is being paid to potential use of corn stover as a feedstock for bioenergy production. In addition to meeting renewable energy goals, use of corn stover for energy production may provide a new source of income for corn growers. This study estimates the costs of corn stover harvest and supply, and then uses that information to estimate farm production decisions and changes to farm profit at varying corn stover prices. In this study, corn stover is collected in large round bales using a raking, baling, and staging method. Harvest cost includes payments for fuel, labor, equipment ownership and repair, net wrap, and nutrient replacement. Supply costs include storage, loading and unloading, and transport. The total cost of harvest and supply is estimated between 82.19 $ Mg^{-1} (dry) and 100.56 $ Mg^{-1} (dry). Costs will vary considerably from farm to farm and from year to year depending on weather conditions.

A linear programming model was used to estimate the willingness of corn growers to harvest corn stover at varying stover prices. Corn stover supply, farm profit, and land allocation was analyzed under multiple scenarios. At a price of 88.19 $ Mg^{-1}, farms in the base case harvested corn stover at a rate of 2.49 Mg ha^{-1} using a 33% removal rate. At this price, stover provided enough additional profit to entice farmers to shift to more continuous corn production. Future research is needed to determine the overall impacts of a viable stover market on corn and soybean production and price.

1. Introduction

Corn stover has significant potential for bioenergy production. It consists of the cobs, husks, stalks, leaves, and tassels of the corn plant, and is currently used in limited quantities for animal bedding [1], production of furfural [2], production of paper pulp [3], and as part of livestock feed rations [4]. Stover left in the field provides erosion control. Most corn stover, however, is not removed from the field.

As a byproduct of corn production, corn stover is already produced in significant quantities in the United States, with an estimated 68 Tg generated each year [5]. The process of harvesting and supplying corn stover to biorefineries is an essential first step to creating energy from the material. This study models the willingness of corn growers to harvest corn stover at varying stover prices. Stover supply, farm profit, and land allocation are analyzed under multiple scenarios.

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2. Material and methods

Corn stover harvest data was provided by a pilot harvest operation funded by John Deere, Archer Daniels Midland, and Monsanto Corporation (DAM). The DAM project has harvested corn stover near Cedar Rapids, IA for the 2008, 2009, and 2010 seasons and collected information on the land, equipment, inputs, timing, and bale characteristics. In this operation, stover is collected in large round bales (approximately 0.45 Mg dry weight) using a raking, baling, and staging method. These data were analyzed using Microsoft Excel and the Iowa State Machinery Cost Calculator [6] to estimate the cost ($ Mg^{-1}) of stover harvest. Section 3.1 explains the parameters used and the resulting estimates for harvest cost, storage cost, loading and unloading cost, and transport cost.

The cost estimates explained in Section 3.1 were generated without providing farm incentives. Even after all costs are met, it is possible that farms will not harvest corn stover due to higher benefits of other crop alternatives such as wheat, soybeans, or milo. Thus, a linear programming model seeking to maximize farm profit was used to estimate the willingness of farmers to supply corn stover at varying prices. The Purdue Crop/Livestock Linear Programming (PCLP) model [7] was chosen to simulate farm decisions. With data on land, labor, capital resources, crop yields, crop prices, and input costs, the model determines the most profitable combination of crops to grow and the optimal land area devoted to those crops. Section 3.2 explains the process used to predict farm decisions while Section 4 explains the resulting corn stover supply. The PCLP model or its precursors has been used for years by Midwest farmers in making investment and planning decisions. It reproduces current Indiana cropping patterns quite well.

3. Calculation

3.1. *Cost estimates*

The primary components of harvest cost are fuel, labor, equipment, nutrient replacement, and net wrap. Fuel and repair costs were estimated with the Iowa State Machinery Cost Calculator [6] using a fuel price of approximately 0.75 $ L^{-1} [8], a 59.66–111.85 kW (80–150 hp) tractor, and the efficiencies observed in the DAM data. Observed efficiencies were 18.02 $\mathrm{m}^2\ \mathrm{s}^{-1}$ for baling, 18.63 $\mathrm{m}^2\ \mathrm{s}^{-1}$ for raking, and 47.33 $\mathrm{m}^2\ \mathrm{s}^{-1}$ for staging. This resulted in a fuel cost of 3.37 $ Mg^{-1} (dry) of corn stover harvested. Labor was valued at 20.53 $ h^{-1} [9] with a labor hours to machine hours ratio of 1.1 [10] and resulted in a cost of 3.65 $ Mg^{-1} (dry). Equipment cost includes both ownership and repair costs for a round baler, a wheel rake, a round bale transporter, and a 59.66–111.85 kW (80–150 hp) tractor. Ownership cost was calculated using a 5 year ownership period for the baler and rake, a 10 year ownership period for the bale transporter and tractor, a 6% interest rate [11], a 40% salvage value for capital cost [6] and a 1% rate for taxes, housing, and insurance [10]. Repair costs were estimated using the Iowa State Machinery Cost Calculator [6]. Summing ownership and repair costs resulted in an equipment cost of 8.14 $ Mg^{-1} (dry).

Nutrient replacement was the largest component of harvest cost. This study calculated the cost of replacing the primary nutrients of phosphorus, potassium, and nitrogen; the secondary nutrients of calcium, magnesium, and sulfur; and the micronutrients of copper, iron, manganese, and zinc. The price for nitrogen, potassium, and phosphorus was based on fertilizer price trends observed in the 2000–2011 Iowa State crop budgets [12–23]. A trend line was fitted to the data and evaluated at the year 2010. The quantities for phosphorus, potassium, and nitrogen were based on averages from previous literature [4,24–29]. Replacement of secondary and micronutrients is valued at a cost of 2.00 $ Mg^{-1} (dry) [30]. The total cost of nutrient replacement is estimated at 24.17 $ Mg^{-1} (dry).

The final component included in harvest cost is net wrap, used to bind the round stover bales. In the DAM project, net wrap was purchased at a cost of 234 $ per 2134 m roll and was applied at a rate of 5.5 rounds per bale. While this rate may seem high, using less net wrap was found to result in bale breakage in the DAM experiments. Each bale is estimated to have a 5.33 m circumference, resulting in a net wrap cost of 3.22 $ per bale or 7.10 $ Mg^{-1} (dry). Summing these five cost components resulted in a total harvest cost of 46.43 $ Mg^{-1} (dry). The partition of estimated harvest cost is shown in Fig. 1. Clearly, the most sensitive cost component would be nutrient replacement cost, which represents 52% of the harvest cost. Nutrient prices were relatively high in 2010 and have come down since then, so a reduction in nutrient cost would reduce total harvest cost accordingly.

Storage cost was estimated assuming that large round bales are stored outdoors on a rock bed, under a tarp for up to 12 months. The rock bed acts to drain moisture away from the bales while the tarp covering will minimize the moisture entering the stack. Other storage techniques (using a sheet of plastic, placing the bales on the ground) were tried, and they resulted in much more bale deterioration during storage. Both the rock bed (2–3 inch rocks dumped on the strip to hold the bales) and the tarp were found necessary to maintain bale quality. Length of storage is dependent on the feedstock needs of the biorefinery. Since stover harvest typically occurs in a 5 week to 3 month window [31], storage may need to occur for up to 12 months to ensure a year-round supply to the biorefinery. Depending on weather, it is possible that even more than 12 months storage would be needed in some cases, but we used an average storage time of six months. Storage costs are estimated to be 20.88 $ Mg^{-1} (dry). The components included in this cost and their sources are summarized in Table 1. It is assumed that tarps can be used for three years and the rock bed can be used for five years. The costs of these capital investments were annualized using a 6% nominal interest rate [11].

Moving bales from farm storage to the biorefinery involves three steps: 1) loading the bales onto the transporting vehicle, 2) transporting the bales, and 3) unloading the bales at their destination. This analysis assumes bales are loaded onto a 16.15 m flatbed trailer using a front-end loader with an attached bale spear. Each trailer is expected to hold 26 large round bales of corn stover (the equivalent of 11.79 Mg, dry). The semi-truck is operated by a driver who is paid an hourly wage of $18.01 [9]. The hourly cost of the truck waiting during