Impact of Stover Collection on Iowa Land Use

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Abstract The study evaluates land use impacts of corn stover markets for the state of Iowa. To tie land use decisions to their economic basis, we use an economic model to simulate profit-maximizing choices of crop-tillage rotations and stover collection, and evaluate the impacts of the stover collection restrictions imposed on the land of lower productivity, as defined by the land with Corn Suitability Rating below 80. We find that stover collection is likely to lead to substantial shifts in rotations favoring continuous corn at stover prices above $50/ton. This crop rotation shift is accompanied by the changes in tillage rotations favoring both continuous conventional tillage and, to a lesser extent, continuous conservation tillage. The crop-rotation impacts of stover markets differ substantially between the restricted and unrestricted stover markets. This finding illustrates the importance of differentiating among the cropland of alternative soil quality when assessing the impacts of corn stover markets.

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1 Introduction

Advancements in cellulosic ethanol production technologies are expected to lead to the establishment of viable markets for corn residues (stover), which are comprised of corn stalks, cobs, and leaves left in the field after grain harvest. Recent research agrees that a large, viable market for stover is likely to significantly alter the profitability of corn relative to other traditional row crops and cropping patterns (Sarica and Tyner 2013; Dodder et al. 2015; USDOE 2016). However, large-scale analyses that commonly use relatively low-spatial-resolution models provide only limited insights on regional impacts. As soil and climatic conditions, cropping patterns, and farming practices differ across the U.S., the impacts of stover markets differ substantially between the states (Egbendewe-Mondzozo et al. 2011; Archer and Johnson 2012; Sesmero and Gramig 2013; Chen and Li 2016). Present study contributes to the literature on regional assessments of stover markets by evaluating the potential land use impacts for the state of Iowa.

Being a major U.S. corn producer, Iowa has been a subject of the economics of corn stover research (Kurkalova et al. 2010; Tyndall et al. 2011; Elobeid et al. 2013; Archer et al. 2014). Building on the models of Kurkalova et al. (2010) and Elobeid et al. (2013), we extend previous work by evaluating the impact of soil preservation restrictions on stover collection using a more realistic economic model of land use.

The land use model is extended in two important directions. First, we consider interactions between crop rotations and tillage. The crop rotation aspect is important because predominantly large fraction of Iowa cropland is in corn-soybean (CS) rotation (corn being yearly alternated with soybeans), with the rest of the land almost exclusively in continuous corn (CC) (corn planted every year) (Stern et al. 2008; Secchi et al. 2011b; Plourde et al. 2013). However, most previous economic analyses either focused on continuous corn (Archer et al. 2014), or have ignored crop rotations (USDOE 2016). Kurkalova et al. (2010) and Elobeid et al. (2013) model crop rotations, but under an assumption that tillage systems do not differ within any given crop rotation. Here we allow for more realistic choices, where tillage systems could alternate within crop rotations. Recent research suggests that such alternation is a wide-spread practice in Iowa (Kurkalova and Tran 2017).

Secondly, we relax the restriction that has been commonly imposed in previous analyses of Iowa crop production on the highly erodible land (HEL).[1] Kurkalova et al. (2010) and Secchi et al. (2011b) assumed that HEL is only farmed using notill

[1] USDA Natural Resource Conservation Service classifies cropland as HEL if the potential of a soil to erode, considering the physical and chemical properties of the soil and climatic conditions where it is located, is eight times or more the rate at which the soil can sustain productivity (https://prod. nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_007707.pdf, accessed September 2017).

(NT), which is the tillage system that disturbs soils the least. That restriction is commonly imposed because the HEL designation requires farmers to implement conservation plans to remain eligible for payments from Federal agricultural programs (Claassen et al. 2014). However, monitoring of conservation compliance is not universal and the conservation plans may not include NT. For Iowa specifically, field surveys suggest that some HEL, especially of higher productivity, is not farmed using NT as often as the non-HEL (Schilling et al. 2007; Tomer et al. 2008).

Large and growing body of agronomic literature is warning against the perception that stover can be collected without much productivity and environmental impact. Leaving the corn stover on the fields not only reduces soil erosion, but also maintains soil organic matter, thus contributing to overall soil sustainability for agricultural production (Blanco-Canqui and Lal 2007; Wilhelm et al. 2004, 2007; Karlen et al. 2011) and water quality (Cruse and Herndl 2009; Thomas et al. 2011; Demissie et al. 2012). Most technical analyses of the stover production potential incorporate soil preservation restrictions (Graham et al. 2007), yet the impact of the restrictions on the economically viable land use and stover collection remains understudied. We fill this gap by comparing and contrasting the economically profitable land use choices under unrestricted stover collection versus the case when stover collection is not allowed on a lower soil quality land.

In the following section we present our data and methods. After describing the economic model, we evaluate the impacts of environmental restrictions under alternative stover prices. We summarize the results and outline the directions for future research in the last section.

2 Methods

2.1 Data

Farmers' choices are simulated for Iowa cropland that was in production in 2009. The GIS representation of the cropland comes from the U.S. Department of Agriculture National Agricultural Statistical Service GIS-based remote-sensing cropland data layer (CDL) (Johnson and Mueller 2010). Soil productivity is measured by the Corn Suitability Rating (*CSR*), an index from 0 to 100 with the higher *CSR* values corresponding to the higher land's productivity in crop production. For each CDL grid unit, the *CSR* value and HEL designation come from the Iowa Soil Properties and Interpretations Database (ISPAID) GIS soil data layer (ISU 2004) (Secchi et al. 2009, 2011b). The resulting data covers approximately 96% of the state's 2009 crop land (Kurkalova and Carter 2017). The distribution of Iowa land by *CSR* and HEL is shown in Fig. 1.

2.2 Farmers' Choices

Our model simulates two choices: crop-tillage rotation and stover collection (Fig. 2). We assume that farmers choose between the two crop rotations, CC and CS. Each year of rotation they choose among three tillage systems: conventional tillage (VT),

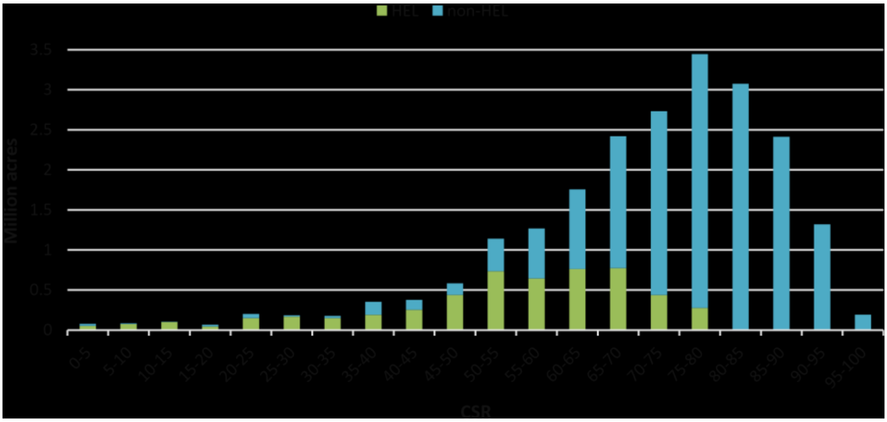

Fig. 1 Distribution of Iowa land by land quality and HEL status

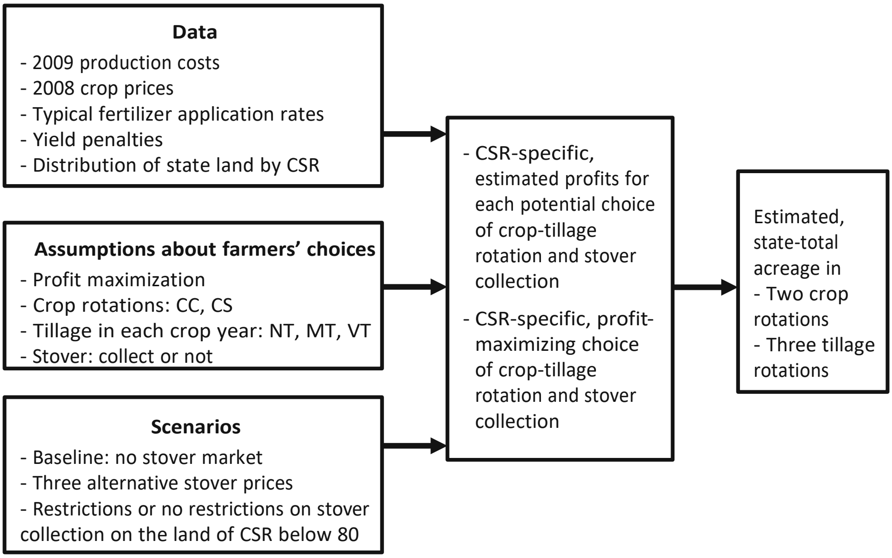

Fig. 2 Overview of the study's modeling approach

mulch till (MT), and NT. Any tillage system that leaves less than 30% residue on soil surface after planting is VT (CTIC 2017). All tillage practices that are not VT are referred to as conservation tillage (CT). Our model distinguishes between two versions of CT, MT and NT. MT disturbs the entire soil surface and involves up to three tillage passes from the harvest of previous crop to the planting of the current crop. NT is an umbrella term used for the tillage systems such as striptill, vertical tillage, and fluffing harrows, which disturb only the minimal amount of soil (CTIC 2017). Farming operations assumed under specific tillage systems and cropping sequences are based on the typical practices documented by the Iowa State University's Extension (Duffy and Smith 2009). In total, we allow for 9 croptillage rotations for CS (both corn and soybean could use one of the three tillage systems). For CC we consider only 6 different crop-tillage rotations, because the order of tillage choices within this rotation does not matter: e.g., we treat corn MT followed by corn NT as equivalent to corn NT followed by corn MT. In contrast, previous studies that explicitly considered crop rotations have restricted tillage to be the same within a rotation, thus allowing for only 3 different crop-tillage rotations for CS and 3 – for CC (Kurkalova et al. 2010; Elobeid et al. 2013).

For each crop-tillage rotation, we model the farmer's choice on whether to collect or not corn stover in the corn production years. Total available stover is equal the corn grain mass produced, but for technological reasons only a fraction of stover is collectable (Graham et al. 2007; USDOE 2016). Following Graham et al. (2007) findings for Iowa, we assume a rate of 67.7% of collection of the total available stover.

The model assumes that production exhibits constant returns to land of any given quality, and that farmers make their choices to maximize 2-year average expected net returns. We treat production input, crop, and stover prices as exogenous; estimate CSR-specific expected net returns under the alternative farmers' choices; and identify the combination of crop-tillage rotation and stover collection choices that maximizes net returns. The crop-tillage rotation component of the model closely follows Kurkalova and Carter (2017), and the stover collection component – that of Kurkalova et al. (2010).

2.3 Model

Expected net returns are the sum of those from (traditional) crop production and those from stove collection.

Expected net returns from crop production are the difference between revenues, which are the product of expected crop price and expected yield, and costs. The 2009 expected prices are assumed equal the prices received at the time of previous year harvest, October 2008 (USDA/NASS 2010): 4.48 \$/bu. for corn and 10.4 \$/bu. for soybeans (Johanns 2017). Crop yield is the maximum potential crop yield adjusted for previous crop and/or tillage system. Following ISPAID, we model the maximum potential yields in 2009 as 80 + 1.6 *CSR* for corn and 23.2 + 0.464 *CSR* for soybeans.

Using NT or MT often lowers grain yields relative to VT. We use the data based on multiple long-term agronomic studies in Iowa (Yin and Al-Kaisi 2004; Al-Kaisi et al. 2005, 2015, 2016) to estimate the NT and MT yield penalties. Corn after soybeans yields are equal the maximum potential yield, for both VT and MT, and soybeans after corn yields are equal the maximum potential yield under VT. The remaining six crop-tillage combinations result in yield penalties. Mean corn yield penalties are: 92% of the maximum potential yield for corn NT after soybeans NT, and 81%, 87%, and 90% of the maximum potential yield for corn NT, MT, and VT, respectively, after corn. Mean soybean yield penalties are 94% and 95% of the maximum potential yields under NT and MT, respectively. To account for the potential variability of yield penalty across state, we consider four possible values for each yield penalty, equally spaced between the mean minus two standard deviations and the mean plus one standard deviation. We simulate optimal farmers' choices for each of the possible combination of yield penalties, and then summarize the results as the average over 4096 simulations ($4^6 = 4096$).

The costs of production, by crop, previous crop and tillage are based on 2009 typical production budgets developed by Duffy and Smith (2009), from which we separate the yield-dependent components, to account for the effect of the crop yields varying with innate soil productivity (*CSR*). We maintain most of Duffy and Smith (2009)'s input use and input price values except nitrogen fertilizer application rates and nitrogen and phosphate fertilizer prices. We estimate typical profit-maximizing nitrogen fertilizer rates based on the prices for nitrogen and corn using Corn Nitrogen Rate Calculator (ISU 2004) as 199 lb./ac for corn. While these rates are higher than those reported in Duffy and Smith (2009), we surmise that the actual application rates could be even higher: literature agrees that farmers often overuse fertilizer relative to agronomically recommended rates to avoid potential loss in yield associated with uncertainty in weather and soil nutrients levels (Sheriff 2005). We replace nitrogen and phosphate fertilizer prices of Duffy and Smith (2009), which are significantly higher than the year averages, with the ones estimated by applying agricultural producer price index (https://www.ers.usda.gov/data-products/fertilizeruse-and-price.aspx, Accessed September 2017) to the corresponding 2009 prices (Edwards et al. 2009). The resulting prices are equal 0.35 $/lb. for both nitrogen and phosphate.

Expected net returns from stover collection are the difference between stover collection revenues and costs. The revenues are the product of expected stover price, amount of available stover, and the proportion of stover removed. As explained earlier, we set the proportion of stover removal to 67.7%, where the total available stover is in one-to-one ratio to the grain weigh. To covert the corn production estimates reported in bushels to the stover production estimates reported in metric units, we assume that a bushel of corn has the dry mass of 21.5 kg (56 lb. at 15.5% moisture) (Graham et al. 2007).

Following common approach (Edwards 2011; Dumortier 2016; Chen and Li 2016; USDOE 2016), the cost of corn stover removal includes the cost of chopping and raking corn stalks, baling the stover, and replacing lost crop nutrients. In estimating these costs, we follow the approach outlined in Kurkalova et al. (2010).

Our estimates of the costs are based on Edwards (2011), adjusted to reflect the yields that vary by *CSR* and crop-tillage rotation, and the 2009 production input prices.

2.4 Simulation Scenarios

We evaluate a total of seven scenarios: one baseline corresponding to the 2009 economic conditions and assuming no stover market, and six scenarios corresponding to three alternative stover prices and two restrictions on stover collection.

Following previous research, which reported a wide range of corn stover prices (Archer et al. 2014; Chen and Li 2016; USDOE 2016), we consider three potential stover prices: \$50, \$75, and \$100 per ton. Each of the potential stover prices is considered with and without stover collection restrictions.

The levels of stover removal that do not have long-term soil quality effects could vary by numerous factors including soil type, cropping history, and tillage system (Wilhelm et al. 2004; USDOE 2016). Most previous stover assessments assume no stover collection on soils of high erodibility and/or where harvesting stover is likely to impede sustainable crop production. We follow Graham et al. (2007), who argues that the no-stover-collection restriction is commonly needed on the lowest quality soils, and allow for stover collection only on the land of *CSR* 80 and above. The threshold of 80 was chosen based on estimated baseline: the land with *CSR* of 80 and above makes up approximately 36% of Iowa land, but being of higher productivity, produces approximately 40% of all Iowa corn stover, which is in line with Graham et al. (2007) finding that roughly 38% of Iowa-produced stover could be collected safely. Additionally, the threshold of *CSR* 80 also implies that virtually no stover collection would be allowed on the HEL (Fig. 1). To evaluate how our results are sensitive to the *CSR* threshold choice, we considered two additional sets of scenarios, with the thresholds at *CSR* 78 and above, and *CSR* 82 and above. Such thresholds result in 46% and 33% of the total Iowa corn production, respectively.

3 Results and Discussion

With the focus of this study on the land-use changes of stover collection, the key outputs of the model are the simulated average crop and tillage rotations. Predicted crop rotations are summarized in Fig. 3. We summarize tillage rotations by focusing on three categories: continuous VT (CVT), continuous CT (CCT), and rotational CT, which refers to the system when VT was practiced in one of the years, with MT or NT in the other year of the rotation (Fig. 4).

The baseline simulated is reasonably close to the observed 2009 crop rotation data. According to the CDL data (https://nassgeodata.gmu.edu/CropScape/, accessed September 2017), the share of cropland in CC rotation was 18.9%, which is close to our estimate of 18.6%.

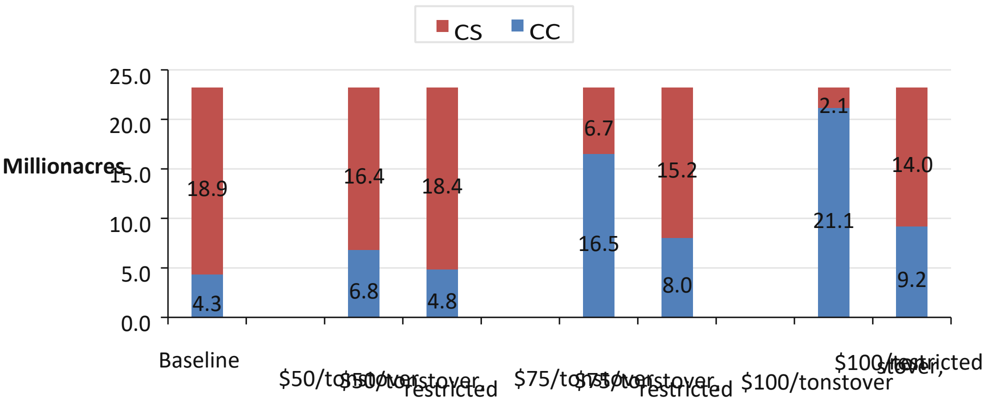

Fig. 3 Crop rotation effect of stover collection. Note: Restricted scenarios assume no stover collection at *CSR* below 80

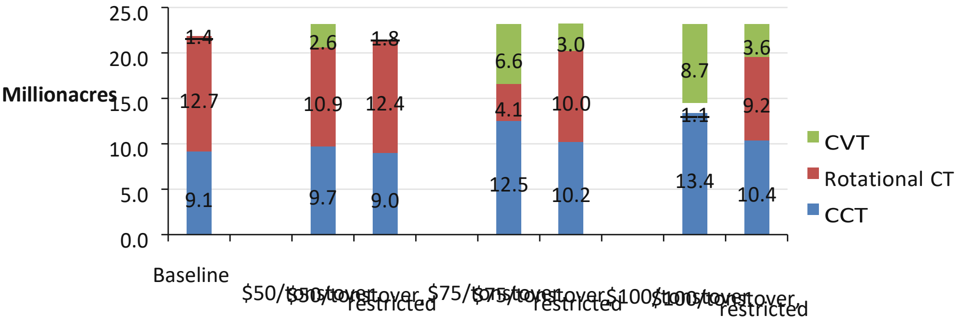

Fig. 4 Tillage rotation effect of stover collection. Notes: Restricted scenarios assume no stover collection at *CSR* below 80. CVT denotes continuous VT, i.e., VT practice in both years of rotation; CCT denotes continuous conservation tillage, i.e., MT or NT practiced in both years of rotation; and Rotational CT means that VT was practiced in one of the years, with MT or NT in the other year of the rotation

We estimate that without stover markets 39% of land is in CCT, 6% is in CVT, and the rest in rotational CT (Fig. 3). The tillage rotation data for comparison with our baseline are not readily available, because such data are rarely collected. A national survey of famers growing corn, soybeans and wheat in the U.S. in 2009 and 2010 found that out of 622 farmers surveyed in the Corn Belt, which includes Illinois, Indiana, Iowa, Missouri, and Ohio, some 55% were in CCT and 14% were in CVT (Andrews et al. 2013). Our estimates imply a single-year CT rate of 66.5%

(39% of CCT plus a half of the 55% of the rotational CT). This is close to the 2012 Census of Agriculture estimates, according to which 67% of Iowa cropland uses CT (https://www.agcensus.usda.gov/, accessed September 2017).

Overall, the impact of unrestricted stover collection on land use is minimal at the lowest stover price we consider, $50/ton, but is noticeable at $75/ton. These findings are consistent with the data on limited sales of corn stover bales at hay auctions in Iowa reported by Edwards (2011), who notes that 0.6-ton bales of corn stover have been sold at the prices from $30 to as high as $45 per bale, i.e., at a price range from $50 to $75 per ton.

The unrestricted stover collection predictably increases the share of land in continuous corn from 19% in the baseline to the estimated 29%, 71%, and 91% under $50, $75, and $100 per ton stover prices, respectively (Fig. 3). Overall, the impact of the stover collection restriction on profit-maximizing crop rotations is remarkable: the prohibition of stover collection on the land below *CSR* 80 affects 9%, 36%, and 52% of the land under $50, $75, and $100 per ton stover prices, respectively.

In the baseline, CC is more prevalent at the higher quality land: only 18.6% of land is in CC at the *CSR* below 80, as opposed to 63% at the *CSR* 80 and above. The comparison between the baseline and the restricted and the unrestricted stover collection scenarios shows that a higher share of the increase in CC comes from the lower quality land. For example, the $75/ton stover price increases CC on some 3.7 million ac of the higher quality land (4.3 vs 8.0 million ac, Fig. 3), and on some 8.5 million ac of the lower quality land (8.0 vs. 16.5 million ac).

Similar to the crop rotations, tillage rotations differ between the higher and the lower quality land. In the baseline, 24% and 1% were in CVT and CCT on the lower quality land, as opposed to 15% and 5% in CVT and CCT on the higher quality land, respectively. Overall, we find that the possibility of selling stover increases CVT and, to a smaller extent, CCT, and as with crop rotations, most of changes in the unrestricted case come from the lower quality land. For example, the $75/ton stover price increases CVT on some 1.6 million ac of the higher quality land (3.0 vs 1.4 million ac, Fig. 4) and on some 3.6 million ac of the lower quality land (3.0 vs. 6.6 million ac). Under the same price, the CCT increases on some 1.1 million ac of the higher quality land (9.1 vs 10.2 million ac) and on some 2.3 million ac of the lower quality land (12.5 vs 10.2 ac). The increase in CVT attributable to the switch from CS rotations to CC has been discussed in the literature as attributable to heavier and sturdier residue that corn has when compared to soybeans, and the subsequent need to more intensive tillage to prepare soils for planting next year crop – to prevent a significant drop in yields (Secchi et al. 2011a). The increase in CCT that we find suggests that the CCT yield loss could be outweigh by the economic benefit of higher net return resulting from growing more corn and lower CT input costs such machinery costs.

Sensitivity analysis reveals that qualitative results are not sensitive to the value of *CSR* below which stover collection is prohibited (Table 1). As discussed above, relatively little land use changes occur at the stover price of $50/ton. In fact, at this stover price, tillage rotations do not change on the higher quality land for all the threshold ranges considered.

Table 1 Crop and tillage rotations under alternative stover collection restrictions

Scenario considered	Crop rotation	Tillage rotation		
	CC (%)	CCT (%)	Rotational CT (%)	CVT (%)
Baseline	19	39	55	6
$50/ton stover	29	42	47	11
$50/ton stover, restricted at CSR below 78	22	39	53	8
$50/ton stover, restricted at CSR below 80	21	39	54	8
$50/ton stover, restricted at CSR below 82	20	39	54	7
$75/ton stover	71	54	18	28
$75/ton stover, restricted at CSR below 78	38	45	41	14
$75/ton stover, restricted at CSR below 80	35	44	43	13
$75/ton stover, restricted at CSR below 82	31	43	46	11
$100/ton stover	91	58	5	37
$100/ton stover, restricted at CSR below 78	43	46	37	17
$100/ton stover, restricted at CSR below 80	39	45	40	16
$100/ton stover, restricted at CSR below 82	35	44	43	14

4 Concluding Comments

Our study complements the growing literature on spatially-explicit, economic rather than only technical, regional assessments of corn stover production in the U.S., such as those for Minnesota (Archer and Johnson 2012), Michigan (EgbendeweMondzozo et al. 2011), Indiana (Sesmero and Gramig 2013), and Illinois (Chen and Li 2016). We extend previous assessments for Iowa (Kurkalova et al. 2010; Secchi et al. 2011b; Archer et al. 2014) by advancing the understanding of the interconnection between economically-viable stover collection, crop-tillage rotation, and soil protection restrictions imposed on lower quality land.

We find that if farmers are allowed to participate freely in the stover market, profit maximization is likely to shift cropping patterns towards continuous corn. The effect is accompanied by significant changes in tillage rotations. A notable increase in continuous conventional tillage paired with stover collection is likely to negatively affect the environmental outcomes of crop production such as soil carbon sequestration, soil erosion, nutrient runoff, and in consequence, water quality. We find a smaller potential increase in the use of continuous conservation tillage, but the environmental implications of this change are harder to predict. An increase in conservation tillage is generally associated with improved environmental outcomes, but not in the case when less intensive tillage is paired with stover removal. Investigating the environmental effects of the land use changes presented in this study constitutes a fascinating topic for future research.

We find that imposing restrictions on stover collection on lower quality land alters the land use decisions significantly. From the economic point of view, that means that the restrictions impose a cost on the farmers working lower quality land. Subsequent analyses could quantify the magnitudes of the opportunity costs, i.e., the potential profits lost for this portion of land managers due to these restrictions. Subsequent analyses could investigate how these costs change with alternative forms of restrictions.

Another possible extension of the current research is to extend the modeling to account for farmers' willingness to participate in the corn stover markets. Recent surveys (Tyndall et al. 2011) indicate that farmers' intent to participate in the stover market may be limited until stover market infrastructure develops and more information on the environmental impacts of stover collection becomes available.

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