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Corn stover as a biofuel feedstock in Iowa's bio-economy: An Iowa farmer survey

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ABSTRACT

The state of Iowa possesses the largest quantity of corn stover in the United States. With a representative survey we examine what Iowa crop farmers think about harvesting and selling corn stover and to what degree they may be interested in providing stover to a biorefinery. Iowa farmers are in an overall learning phase regarding corn stover yet believe that harvesting stover will require an increase in capital investment, additional managerial knowledge and a well-developed support infrastructure. The data suggests some degree of farmer ambivalence regarding what institutional support would be needed to facilitate market entry. Statewide, only 17% of Iowa's farmers currently express interest in harvesting their stover; though 37% are undecided. The farmers who are interested in marketing stover tend to be: younger, will be farming in 10 years, are at least somewhat knowledgeable about stover, manage large amounts of land and have hectares currently in continuous corn rotations. Regionally, farmers in North Central, IA–the Iowa region with the highest capacity to produce corn stover–tended to be more interested in harvesting stover. Environmental concerns that appear to be important stover supply barriers as farmers who anticipate the negative impacts of corn stover removal on environmental quality tend to be less interested in harvesting corn stover. Overall, the results of this study strongly suggest that future supply assessments consider farmer participation more explicitly and forego arbitrary assumptions regarding farmer behavior as previous supply analyses may have overstated the proportion of farmers interested in harvesting stover.

1. Introduction

The United States is the largest producer of bioethanol globally, producing 40.2 hm^3 in 2008 or 52% of global ethanol output [1]. Within the United States, Iowa is the leading ethanol producing state with a production capacity of 12.5 hm^3 representing almost a third of US ethanol capacity (over 2.5 times more production capacity than the number two domestic producer, Nebraska) [2]. Roughly 96% of the ethanol currently produced in the US is corn grain based; over 99% of Iowa's ethanol production is derived from corn grain [2]. The future of US biofuel production however is clearly entering a new era that will be characterized by a dramatic increase in the quantity of bioethanol produced as well as increasing reliance on non-grain feedstocks. The 2007 US Energy Independence and Security Act (EISA), among other purposes, enhanced the Renewable Fuel Standard (RFS) that will require liquid fuel producers to blend at least 136.27 hm^3 of biofuel by 2022. Ambitiously, EISA stipulates that 60.56 hm^3 of total US bioethanol output must be cellulosic ethanol made

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from biomass (ligno-cellulosic) feedstocks [3]. EISA also stipulates that cellulosic-based fuels must contribute a 60% reduction in greenhouse gas production (compared to a fossil fuel baseline) as determined by Life Cycle Analysis [4]. As of summer 2009, however, US cellulosic ethanol production was minimal with a capacity of roughly 1 hm^3 [1,2].

The legislated optimism of the US RFS is largely based on the theoretical promise of biomass feedstock options available to cellulosic ethanol as articulated in the so-called "Billion Ton Study" which calculated a annual US biomass inventory of roughly 1.42 G dry Mt of biomass potential–20% in the form of presumed readily available corn stover (e.g., stalk, leaf, husk, and cob remaining in the field following the harvest of corn grain) [5]. Several studies suggest that Iowa's share of the nation's collectable corn stover (based on measures of economic, technologic and long-term soil quality feasibility) ranges between 20 and 24% of the US total [6,7]. Recent estimates suggest that upwards of 13.7 M dry Mt of corn stover could be sustainably harvested from Iowa with existing technology [7]; this translates roughly into 5.8 hm^3 of cellulosic ethanol [8]. Therefore a large quantity of corn stover within the state of Iowa is expected to be committed to help US cellulosic ethanol goals reach fruition.

Nevertheless, because the current cellulosic ethanol refinement industry is largely pilot scale, future US locations for producing large quantities of cellulosic ethanol remain in question [9,10]. Since feedstock transportation and handling comprise roughly 50% of cellulosic ethanol production costs [11], it will be cost effective for refineries to locate where required feedstock is most abundant. Because of the myriad economic and social advantages possessed by the state of Iowa for producing and transporting ethanol (e.g., total ethanol infrastructure), in theory, Iowa appears to be strongly positioned to be a major contributor to the US's cellulosic ethanol goals [9]. It must be acknowledged, however, that despite legislated production quotas, the feasibility of corn stover as a feedstock ultimately rests with the decisions of farmers–particularly Iowa's farmers. As discussed in the literature review below recent studies suggest that Iowa's farmers have reservations about harvesting and selling stover [12,13] potentially calling into question the viability of Iowa corn stover as a feedstock. As such continued comprehensive examination of Iowa farmers' opinions, concerns, and intentions regarding corn stover harvesting and sale is particularly warranted [14]. Understanding what Iowa farmers think about harvesting corn stover and what factors influence farmers' harvest interest will be informative across the rest of the US Cornbelt and to some degree international contexts as well [15].

2. Literature review

2.1. *A closer look at corn stover*

There is little debate about the energy potential of corn stover as stover based ethanol has positive net energy values almost 4 times that of corn grain ethanol [16]. Net Energy Value is the difference of the energy content of ethanol minus the non-renewable energy consumed in the entire production system (from raw material extraction to processing) plus any non-renewable energy consumed in alternative product systems [16]. Additionally a series of LCA assessments performed by the US Environmental Protection Agency point to potential stover ethanol greenhouse gas reductions (as compared to fossil fuel equivalents) of over 100% [4]. There is, however, research that presents skepticism about the overall GHG benefits of stover ethanol; concerns are in regard to increased carbon release due to soil erosion [17]. Nevertheless, corn stover continues to be considered a key biofuel feedstock in the US and globally [18].

Despite the feedstock potential of stover from industrial and policy perspectives, there are considerable environmental and agronomic concerns coupled to stover field removal. Regional assessments clearly show that residue removal can lead to considerable increases in soil erosion, surface runoff, sedimentation and nutrient loss [19,20]. Which in turn lead to regional environmental impairments including loss of carbon sequestration capacity [17], impaired water quality [21,22] and an overall diminished capacity to produce food, fiber and fuel stock [23,24]. Also of concern is the fact that various wildlife species, particularly ground-feeding birds, such as sharp-tailed grouse (*Tympanuchus phasianellus*), pheasants (*Phasianinae* (Horsfield, 1821)), mourning doves (*Zenaida macroura*) and wild turkey (*Meleagris gallopavo*) depend on crop residues for food and cover [25]. Many of the consequences of ecosystem impairment subsequently end up being passed on to society as costly externalities that are increasingly being experienced at multiple spatial and temporal scales [26]. These concerns are not specific to the US but are relevant to cropping systems worldwide [27,28].

There are also potential in-field agronomic consequences, ranging from loss of soil organic matter [20], diminished soil structure/stability [29,30], reduced soil moisture [31], and removal of crop nutrients [21,32]. Any one of these outcomes can effectively hinder short term crop growth yet what has agronomists worldwide notably concerned is the negative long-term impact that diminished soil organic matter has on soil fertility [27,32]. Management approaches to mitigate many of these negative impacts exist in the form of best management practices including increased use of cover crops, green manures, compost, and precision nitrogen management [17,33]. Nevertheless, to maintain soil carbon, depending on soil types, tillage practices and crop rotations, upwards of 70% residue cover may be required [32].

2.2. *A closer look at corn stover market availability*

Ultimately, the availability of corn stover to a biofuel market goes well beyond industrial promise and physical abundance. Various studies describe corn stover supply as a matter of hierarchical scaling factors starting with a theoretical upper bound stover yield; this being an aggregate function of the number of hectares of corn, variable corn yield, variable tillage practices, and seasonal climate effects on crop yield [7,34]. This theoretical amount of stover is then scaled to technically feasible amounts of stover that could be marketed; in other words the harvestable fraction. Technological, policy, environmental, economic and social considerations ultimately define the harvestable fraction. This fraction is a dynamic function of the following factors: (a) harvest efficiency of available technology [35]; (b) policy requirements, e.g., commodity program conservation compliance for erosion prevention requires a minimum of 30% stover in conservation tillage systems [36]; (c) volunteer environmental constraints (e.g., to maintain SOC) (d) weather conditions during the stover harvest window [35]; and (e) overall cost of feedstock harvest and initial processing including payments to producers as well as transportation and storage costs [8,36]. The final key scaling factor defining the fraction of stover that can be collected is the proportion of farmers willing to harvest stover. To date, very little work has been done to comprehensively examine what corn farmers think about stover collection and marketing, and to what degree farmers are interested in supplying stover.

There are recent comprehensive regional analyses of farmer interest in perennial biomass production specifically examining miscanthus (*Miscanthus species*) and switchgrass (*Panicum virgatum*) [37–39]. It may, however, be difficult to glean much from these various studies in terms of farmer decision making because, unlike utilizing crop residues, the production of perennial feedstock (i.e., dedicated energy crops) requires a fundamental land-use change with a relatively long establishment phase (e.g., both miscanthus and switchgrass may take at least three years to become established and harvestable at full volume). In the US Cornbelt, dedicated energy crop systems have largely been examined in the context of alternative use for marginal cropland and conservation areas [40]. While there may be some similarities between corn stover and dedicated energy crops in terms of equipment requirements and marketing terms, the contextual differences between these feedstock systems suggest that corn stover should be singularly examined. Simply put, the estimation of the proportion of farmers who are willing to harvest and prepare stover for sale is one of the least understood factors in stover supply literature. Thus far, available supply assessments have either made broad assumptions about acceptable profit margins that would entice farmers [41,42], or have used arbitrary, simplifying assumptions to estimate producer participation rates (i.e., 50% of the stover producers in a defined supply shed will participate) [8]. In order for accurate assessments of corn stover supplies from Iowa to be developed, the opinions and current intentions that Iowa farmer's have regarding stover must be analyzed comprehensively [14,43]. As such, farmer interest in harvesting and marketing corn stover is likely a function of producer opinions and beliefs about the process, level of needed capitalization, farm-level financial factors (e.g., costs of production and concomitant profit thresholds), transaction costs, price of predicate crop (corn), confidence in the market and farm-level agronomic and environmental concerns [44]. Further, financial motivations are often mediated by contractual incentives that may be offered by processing facilities in order to minimize risk for both farmers and the facilities [45].

It has long been recognized that farmers in general are relatively heterogeneous, that is, farmers vary tremendously in land base, access to capital, skills, education, time availability, access to information, behavior towards risk, attitudes toward stewardship and so on [46]. Farm-level decision making is ultimately a complex socio-demographic and farm finance process [47]. While economic factors universally exert influence on farm-level decisions, those factors are very often layered in extra-economic concerns. For example, research points out that many farmers are willing to forgo profit in order to protect the environment [48]. In Iowa, concern for the environment is among the most important extra-economic layers that farmers factor into their decision process e.g. refs. [49,50], particularly as it relates to biomass production [39].

In 2001 the US National Renewable Energy Lab sponsored a "concept" study to explore corn farmer opinions regarding expanded bioethonol production with a specific examination of farmer interest in stover based cellulosic ethanol. This 2001 farmer survey [44] found that 74% of the survey respondents (across 12 corn producing states; $n = 400$) would likely sell at least some stover if it were "reasonably" profitable. For these farmers, the possibility of added income was the main motivation. Their primary concerns associated with harvesting stover included, in order of importance: inability to transport stover, amount of work likely involved, loss of nutrients, the need for additional equipment and increased soil erosion. More recently the Iowa Rural Farm Poll [12] ($n = 1203$) asked a few questions about stover harvest and found that in 2005, 51% of Iowa's farmers strongly agreed they would sell crop residue as a bio-refinement feedstock; 35% were uncertain. Interestingly, in the 2007 Iowa Rural Farm Poll ($n = 1095$) [13], Iowa farmer opinions regarding stover harvest had distinctly shifted and reactions to corn stover harvest had become largely negative. Only 5% of the respondents indicated that they would sell stover at some point within the next five years (26% were undecided). The potential for increased soil erosion was the chief concern discussed. While these studies did not analyze directly why Iowa farmer corn stover opinions changed (e.g., a 46% reduction over a 2 year period in the number of farmers interested in harvesting stover), it appears that as US (and Iowa) grain based ethanol production continues to expand and cellulosic ethanol production comes closer to reality at commercial scales important questions remain about the viability of Iowa corn stover as a cellulosic feedstock.

3. Study objectives

Because of the apparent social, environmental, and technological complexity involved in farmers' decisions toward stover management we chose a survey-based exploratory approach to characterize what Iowa farmers think about and the degree to which they might be interested in harvesting and selling corn stover as feedstock for bio-refinement. Specifically our survey sought to characterize what Iowa farmers believe regarding: 1) required equipment and other farm-infrastructure needed to harvest and prepare corn stover for sale; 2) the marketing institution that would facilitate their entry into a biomass market; and 3) the potential agronomic and environmental consequences of removing certain percentages of stover from their fields. Additionally we assess the degree to which Iowa's farmers are interested in harvesting corn stover and we identify and characterize key farm characteristics, demographic factors, and farmer beliefs that are associated with farmer interest in harvesting and selling stover.

4. Survey methods

Our Iowa crop farmer survey was conducted during Fall 2006 (post-corn harvest). The price of corn at the time of data collection ranged from $3.50–$3.75 per bushel [51]. The survey was conducted by mail and followed Dillman's tailored design survey protocols [52]. The sampling frame of 13,525 Iowa corn farmers was derived from a USDA Farm Service Agency database of Iowa corn (and in rotation, soybean) farmers. As displayed in Fig. 1 Iowa was stratified into four regions (Western, North Central, North Eastern, and South Eastern Iowa). The regional stratification was created by consolidating Iowa geologic landform regions by average county level Corn Suitability Rating (CSR) which is a farmland productivity index based on soils. As a result, the corn yield capacity is fairly uniform within each region and varies among the regions; North Central Iowa has the highest CSR and South east Iowa the lowest. A stratified random sample of 1500 corn farmers was drawn. The sample size in each region was proportional to the total number of farms in the region. After eliminating ineligible farmers, the total sample size was 1245. Response rates were calculated as ratios of completed surveys to the number eligible in the sample. Response rates were fairly constant across the four Iowa regions, ranging from 46% in South Central/Eastern Iowa to 51% in North Central Iowa. A total of 602 farmers completed surveys, yielding an overall response rate of 49%. Because 51% of the sample chose not to take the survey, testing for potential non-response bias was required to justify generalizations to the 2006 population of Iowa farmers. Non-response bias occurs when members of the intended study population do not respond to a survey and those who do are not representative of the entire study population [53]. One way to test for non-response bias is to compare respondents who are among the last to reply to survey requests ("late" responders) to early respondents on important population statistics [54]. Sample *t*-tests produced no evidence of significant differences between early and late respondents in the mean responses to several key farm/farmer variables (e.g., total crop hectares, land tenure, number of years farming and age of respondent). Another way to test for non-response bias is to compare characteristics of the sample to agricultural census data for the whole state. Sample *t*-tests produced no evidence of significant differences between the sample and the population of Iowa farmers for several characteristics including the mean age, the mean education level, and the proportions of farmers engaged in various land use activities. The results of the non-response tests provide grounds for generalizing inferences based on the sample to the entire population [55].

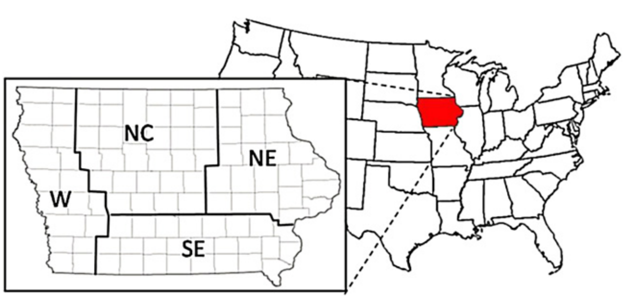

Fig. 1 – Map of Iowa relative to the United States. Survey stratification delineated Western, North Central, North Eastern, and South Eastern Iowa. NC = Corn Suitability Rating (CSR)70 and a 10 year average corn yield of 159 bu/acre; NE = CSR 64, 10 year average corn yield of 155 bu/acre of corn; W = CSR 61, 10 year average corn yield of 151 bu/acre of corn; and SE = CSR 51 10 year average corn yield of 141 bu/acre of corn. Data compiled from Iowa State University Agronomy Extension.

5. Farmer characteristics, opinions and interests regarding corn stover

5.1. *Descriptive data analysis methods*

Descriptive statistics were used to characterize the survey respondents and assess general trends in farmer beliefs. Because the realized sample sizes in the regions are roughly proportional to the number of farmers in each region, the usual formulas for *p*-values and standard errors are appropriate. ANOVA and Chi-square tests were conducted to explore how Iowa farmer beliefs regarding harvesting and marketing corn stover, opinions about agronomic and environmental consequences of stover harvesting, and interest in harvesting and selling stover vary across different farm and farmer characteristics. We explore relationships between ordinal farmer characteristics and farmer interest in supplying stover using a measure, *gamma*, which quantifies the degree of association between two ordinal characteristics. This association measure respects the ordering of the categories without assuming an interval separation. Because *gamma* is defined for two ordinal characteristics, we group continuous characteristics into four categories based on quartiles. Both SPSS 16.0 and SAS 9.1 were used to perform the analysis.

5.2. *Respondent farm characteristics*

The vast majority (90%) of farmers interviewed had been farming for over 20 years in 2006 (80% full-time) and 64% planned to continue farming for at least the next 10 years, though 21% were undecided about their future in farming. On average the respondents were 58 years old and 98% of farmers were male. Over half of the farmers (55%) have at least a high school education with 20% holding a college degree.

On average these farmers managed 287 ha in 2006, 60% of which were rented. The majority of the land farmed was in corn and soybean (C/S) rotations with an average 231 ha. Continuous corn rotations were limited to an average of 23 ha per farm. In addition to producing crops, a fair number of farmers also operated mixed production systems and raised livestock in 2006, with an estimated 36% raising beef cattle and 14% producing hogs.

In terms of tillage practices, just over half (51%) of the farmers in the 2006 population used reduced (or conservation) tillage on their primary corn ground; 21% used conventional tillage, 18% practiced no-till while the remaining 10% claimed a mix of practices. Estimating the typical residue management practices of Iowa farmers is somewhat difficult because, as the number of farmers indicated an open ended probe question, residue management "depends on the field." Nonetheless, an estimated 28% of the farmers left 15–30% residue on their primary corn ground. A third of farmers left about 50% residue, and 28% left about 70% residue on the ground. Table A1 in the appendix summarizes all respondent characteristics.

5.3. *Farmer opinions regarding corn stover harvesting and marketing*

Absent a broad market for corn stover, currently an estimated 6% of corn stover in the US is collected, largely for use as animal feed and bedding [56]. If corn stover harvest is expected to expand it seems likely that for many farmers, these activities may variably require additional harvesting and baling equipment, modifications to existing equipment, sorting and storage facilities, additional management skills and, in some cases cooperation among regional suppliers [8,34,35,56]. Therefore, it is important to understand the degree to which farmers would require outside services or need to enhance/expand their operations in order to harvest their stover. A question likewise emerges: if harvesting corn stover requires additional capital and dependence upon feedstock service providers in order to bring stover to market, how do Iowa farmers think the market institution should function to reduce risk and ultimately support their entry?

Currently, it seems that many Iowa farmers are in the learning phase of this potential biomass market. We asked how knowledgeable farmers were about harvesting and marketing corn stover. Forty-one percent of the farmers said they were "not knowledgeable at all", 28% were "a little" knowledgeable, and 20% felt as though they were "somewhat knowledgeable". Only 4% felt very well-informed.

In order to characterize Iowa farmers' beliefs about the process involved in corn stover harvesting and sale, the survey asked farmers to agree or disagree to a two-part series of 5-point Likert-scaled statements using the following scale: (1) strongly disagree, (2) do not agree, (3) neither agree nor disagree, (4) agree, and (5) strongly agree. Five-point Likert scale response choices are a form of intensity scale commonly used in assessing farmer opinions [57]. The first group of statements involved beliefs about possible equipment and management requirements needed to facilitate the physical collection of corn stover and on-site primary processing prior to transportation. The second group of statements involved beliefs about the required marketing infrastructure to facilitate the sale of stover.

Within the context of their current operations, in order to harvest stover the vast majority of the farmers would variably need increased access to various services, add equipment, improve their management skills and increase on-farm infrastructure. Eighty-four percent of the farmers either "agreed" or "strongly agreed" that they would require increased availability of custom baling services to help them collect stover from their fields. Seventy-six percent of the farmers "agreed" or "strongly agreed" that they would need more on-farm equipment and 67% "agreed" or "strongly agreed" that they would need to acquire specialized management skills to ensure stover quality. Fewer farmers, however, believe that there is a need for more clean storage areas (60% "agreed" or "strongly agreed"). In contrast, 51% of the respondents agreed that there would be an increased need for joint ownership of balers.

Table 1 below displays the mean scores for farmer beliefs about equipment and management. These beliefs are regionally consistent, except for the belief about equipment needs, which is significantly stronger in NC Iowa than in W or SE Iowa ($p = 0.05$). Additional F-tests and Chi-square tests were used to search for differences in farmer opinions about needs for new harvesting infrastructure across farm/farmer characteristics; no significant differences were found.

With regard to requirements for facilitating corn stover marketing, farmers tended to believe that a long-term (3–5 year) contract (as opposed to a short term, 1–2 year contract) would be needed to reduce market risk. Slightly more farmers agree than disagree that a co-op would be required to facilitate delivery of stover. Interestingly, more farmers disagreed than

Table 1 – Iowa crop farmer beliefs about equipment and management needs for harvesting corn stover and beliefs about marketing requirements, 2006.

Harvesting corn stover from fields will	N	Mean Belief Score[a]	Selling corn stover to bio-refineries would require	N	Mean Belief Score[a]
increase the need for custom baling.	536	4.07 [0.041]	a long-term contract (3–5 years) with the biorefinery.	457	3.35 [0.09]
increase the need for clean storage areas.	485	3.86 [0.040]	using a coop to handle delivery arrangements.	464	3.03 [0.050]
increase equipment needs.	537	3.85 [0.045]	a short term contract (1–2 years) with the biorefinery.	453	2.94 [0.050]
increase the need for specialized management to ensure the quality of stover.	493	3.70 [0.045]	bank financing.	461	2.89 [0.050]
increase the need for joint ownership of balers.	491	3.44 [0.047]	special insurance to lower risk.	437	2.75 [0.051]
			government subsidies.	449	2.61 [0.056]

a (1) strongly disagree, (2) do not agree, (3) neither agree nor disagree, (4) agree, and (5) strongly agree, [ ] = Standard error of estimates.

agreed that government subsidies (43% disagree/strongly disagree; 22% agree/strongly agree), special insurance (39% disagree/strongly disagree; 23% agree/strongly agree) or bank financing (31% disagree/strongly disagree; 28% agree/strongly agree) would be needed. *F*-tests and Chi-square tests did not find significant differences in marketing beliefs across regions or farm/farmer characteristics.

5.4. *Corn stover and environmental issues*

Literature has shown that localized environmental and agronomic impacts of stover removal differs according to soil types, topography, tillage practices, rotation patterns, degree of stover removal and seasonal weather conditions [20]. While the reality of these potential impacts varies, in order to gauge how these beliefs might influence decision making, it is instructive to understand Iowa farmer perceptions of these impacts. As noted earlier, many farmers are willing to give-up potential profits in order to protect or enhance environmental conditions within their systems [48].

The farmers were asked a series of questions about potential agronomic and environmental impacts due to removal of 50% of the stover, followed by an analogous series of questions about the potential impacts of 70% removal. They were asked whether they thought an agronomic/environmental outcome would increase, decrease or stay the same. With 50% of stover removal, a majority of farmers believed that both soil erosion and nutrient loss would increase (58% and 79%, respectively). Over half of the farmers believed that soil carbon would decrease (though soil carbon was the least understood environmental characteristic, since 26% were unsure). Almost half (47%) of the farmers believed that in-field moisture would decrease and just over half (53%) believed that in-field wildlife habitat would decrease. An estimated 33% believed water quality would decrease. Still, many farmers did not believe that 50% stover removal would lead to substantial environmental impacts. One-third believed there would be no change to soil erosion rates; just about half of farmers (49%) anticipated no change to water quality, and just over one-third believed there would be no change to in-field soil moisture and in-field wildlife habitat.

The proportions of farmers who anticipate negative environmental and agronomic consequences of stover removal are consistently higher at the 70% level than at the 50% level. The test statistic used to evaluate whether the observed differences in proportions are statistically significant accounts for dependence between two responses (one for the 50% level and one for the 70% level) from the same farmer. Test statistics are standardized differences between the proportions who think the feature will worsen at 50% and 70% removal. Mathematically, the test statistic is $602(p_{50}-p_{70})^2/(p_{50}+p_{70}-2p_{50,70})$; p_{50} *and* p_{70} are the proportions who think the characteristic will worsen after 50% and 70% removal, respectively, and $p_{50,70}$ is the proportion who think the characteristic will worsen after both 50% and 70% removal. *P*-values are from a chi-squared reference distribution with 1 degree of freedom. The estimated opinion differences between the 50% and 70% levels are statistically significant (Table 2, $p<0.01$). The most dramatic opinion shifts from 50% to 70% removal are as follows: 24% more farmers think soil erosion will increase; 16% more farmers think water quality will decrease; 11% more farmers think in-field wildlife habitat will decrease; and 10% more farmers think wildlife habitat in adjacent fields will decrease. The fraction of farmers who think that loss of soil nutrients will result from corn stover removal is high at both the 50% and 70% levels, increasing from 78% at the 50% level to 82% at the 70% level. Farmers are therefore keenly aware of potential negative environmental consequences of high rates of stover removal. Table 2 summarizes these farmer responses.

5.5. *Iowa farmer interest in harvesting and marketing stover*

To analyze the degree to which Iowa's farmers were interested in marketing their stover, we asked, "Thinking of your whole operation, how interested are you in actually marketing corn stover from your fields?" Responses were categorized on a 5-point Likert scale: (1) not at all interested, (2) not interested, (3) unsure, (4) interested, and (5) very interested.

Table 2 – Iowa farmer beliefs about potential agronomic and environmental consequences of removing 50% or 70% of corn stover from their crop fields[a] ($n = 602$).

	50% stover removal				70% stover removal				
Issue	Increase	Stay the same	Decrease	Don't know[b]	Increase	Stay the same	Decrease	Don't know[b]	*p*-value[c]
Soil erosion will	58%	33%	1%	10%	82%	7%	1%	10%	<0.001
Loss of nutrients (P, N, K) will	78%	7%	5%	10%	82%	2%	5%	11%	0.009
Soil organic carbon will	11%	9%	54%	26%	10%	4%	59%	27%	0.001
Water quality will	2%	49%	33%	15%	4%	30%	49%	18%	<0.001
In-field soil moisture will	3%	35%	47%	15%	4%	23%	56%	17%	<0.001
In-field wildlife habitat will	1%	34%	53%	12%	2%	20%	64%	14%	<0.001
Adjacent wildlife habitat will	14%	48%	22%	16%	14%	36%	32%	18%	<0.0

a Farmers were to assume the field rotates between corn and soybeans.
b Don't know includes missing.
c The null hypothesis is that the proportion of farmers who think an environmental/agronomic feature will worsen is the same for 50% and 70% removal.

Table 3 – Regional and statewide Iowa farmer interest levels in marketing corn stover, 2006 ($n = 594$).

Interest in harvesting & selling corn stover (Likert Scale)	Western Iowa ($n = 131$)	North Central Iowa ($n = 185$)	North East Iowa ($n = 187$)	South East Iowa ($n = 91$)	Statewide Distribution ($n = 594$)
% Very Interested	5	9	3	8	6
% Interested	12	14	8	11	11
% Undecided	34	41	37	29	37
% Not Interested	22	22	27	26	24
% Not at all Interested	27	14	25	26	22
Mean Interest in Harvesting and Selling Stover	2.46	2.83	2.37	2.47	2.55

Statewide, 17% of the farmers expressed interest in supplying corn stover (6% are "very interested", 11% are "interested"); 37% are undecided. Table 3 displays statewide and regional distributions of expressed interest. Because the North Central region has the greatest capacity for stover production, it is important to note that the mean interest level among farmers in the North Central region is significantly higher than the mean interest level among farmers in any other region (Student's t-test at $p < 0.01$).

To identify potential drivers and barriers to corn stover production, we quantify the degree of association between several farm/farmer characteristics and farmer interest in supplying stover. Table 4 displays estimates and standard errors of the association measure *gamma*. A positive estimate indicates a positive association between the characteristic and farmer interest in supplying stover.

Younger farmers and farmers who planned to continue farming in the next 10 years are estimated to have greater interest in marketing stover than older farmers and farmers who did not plan to continue farming. Twenty-five percent of farmers in the sample are at most 50 years old, the median age is 57 years, and the seventy-fifth percentile is 65 years. Four age groups based on these quartiles were formed to compute the association measure in the first row of Table 4. The negative estimate indicates that younger farmers tend to have greater interest in marketing stover than older farmers. In concert, the positive estimate in the second row of Table 4 indicates that farmers who planned to continue farming in the next 10 years tended to have greater interest in harvesting stover.

Farmer interest is estimated to be positively associated with farm size. The number of hectares farmers owned and the number of hectares farmers rented were each grouped into four categories based on quartiles. Farmers who owned more land tended to be more interested in marketing stover, as did farmers who rented more land. Likewise the positive estimate associated with hectares in continuous corn indicates that farmers with more land in continuous corn tended to have greater interest in marketing stover.

Farmers who expressed greater knowledge about corn stover harvesting and marketing processes tended to be more interested in marketing stover. Farmer interest was also positively associated with interest in payment via shares of a processing plant. Estimates for farmer opinions about marketing characteristics (not shown) are consistent with positive associations between the degree to which farmers agreed that a certain marketing infrastructure would be needed and farmer interest; however, none of the estimates differ significantly from zero.

Based on the estimates in Table 4, concerns about negative environmental and agronomic consequences of 50% removal

Table 4 – Measures of association between farmer interest in marketing corn stover and farm/farmer characteristics.

Farm/Farmer Characteristic	Measure of Association[a]	Standard Error	Effect of 50% stover removal on[f]	Measure of Association[a]	Standard Error
Age[b]	−0.207	0.044	Soil erosion	−0.319	0.062
Farm in next 10 years 1 = No, 2 = May be, 3 = Yes	0.254	0.053	Loss of soil nutrients	−0.240	0.086
Hectares owned[c]	0.130	0.045	Soil organic carbon	0.159	0.071
Hectares rented[d]	0.161	0.045	Water quality	0.436	0.056
Hectares in continuous corn[e]	0.134	0.065	Field moisture	0.224	0.062
Knowledge of stover production (1-5 scale)	0.249	0.049	Adjacent field wildlife habitat	0.207	0.059
Interest in payment in shares of a processing plant (1-5 scale)	0.212	0.048			

a The measure, *gamma*, quantifies the degree of monotone association between two ordinal characteristics. Two farmers are concordant if the farmer with a larger value of one variable also has a larger value of the second characteristic; *gamma* is the difference between the fractions of concordant and discordant farmers out of the farmers who are not tied on either of the two characteristics.

b Four categories: less than or equal to 50 years, 51–57, 58–65, >65 years.

c Four categories: less than or equal to 36 ha, 37–81, 82–152, >152 ha.

d Four categories: less than or equal to 11 ha, 12–105, 105–223, >223 ha.

e Five categories: 0 ha, 1–20, 21–40, 41–83, >83 ha.

f Three categories: 1 = decrease, 2 = stay the same, 3 = increase. Individuals who did not know or did not provide a response were omitted.

pose potential barriers to the development of a large-scale corn stover market. Farmers who thought that soil erosion and loss of nutrients will result from 50% removal tended to have lower interest in marketing stover. Likewise, farmers who thought that reductions in soil organic carbon, water quality, field moisture, and adjacent field wildlife habitat will result from 50% removal are estimated to have lower interest in marketing stover.

6. Discussion and conclusions

As noted in other biofuel feedstock assessments, barriers to national and regional biofuel target goals should be identified early in the development of the emerging industry [15]. Increased biofuel production depends on technological advancement, expanded infrastructure, facilitory policy, and market accessibility, but it is also heavily reliant on farmers' farm-level decisions [15,43]. Based on the overall results of this study, the involvement of Iowa farmers in supplying corn stover can be understood as a complex socio-environmental issue which strongly suggests that future supply assessments must consider farmer participation more explicitly and forego arbitrary assumptions regarding farmer behavior as previous supply analyses may have overstated the proportion of farmers interested in harvesting stover.

Overall, only 17% of our representative farmers expressed interest in harvesting their stover; though 37% are undecided. Yet the farmers who are interested tend to be younger farmers who will be farming in 10 years (at least until 2016). These farmers also tend to manage large amounts of land and have more hectares currently in continuous corn rotations. Farmers in North Central, IA tended to be more likely to be interested in harvesting stover. This region has the highest capacity in Iowa to produce corn stover based on corn suitability ratings and also has the lowest percentage of Highly Erodible Land [58]. This outcome has important implications in that interested farmers tend to have lower environmental concerns about stover harvest. There may be perceptions that higher rates of corn stover removal in this region may be less of an overall concern compared to Western, North eastern, and South eastern Iowa where inherent topography and soils are more prone to erosion under crop conditions. Yet in the whole, there is evidence that increased crop prices, due in large part to expanding bioeconomic demand for corn, has contributed to increased environmental vulnerability throughout the whole US Cornbelt as evidenced by recent Conservation Reserve Program hectares returning to production [58,59]. Increases in off-farm movement of sediment, N, and P, along with reductions in sequestered carbon and wildlife habitat have been predicted as a consequence of increased production of corn let alone in conjunction with stover removal [58]. Regardless of region, if interested farmers are to participate in large-scale corn stover harvest, the extent of stover removal will need to be carefully controlled so that adverse environmental and agronomic consequences are minimized. Concerns that farmers have for the environment are important barriers to the use of corn stover as a feedstock. Farmers who anticipate the negative impacts of corn stover removal on environmental quality tend to be less interested in harvesting corn stover. All in all, inherent in recent calls for sustainable cellulosic biofuel policy in the US, there is recognition that overall crop management practices, intensity of inputs and harvesting strategy, and expanded use of conservation practices will have strong influence on the environmental viability of cellulosic feedstock [43,60]. In international contexts it has been suggested that certification of biomass resources including crop residues may be one way to prevent negative environmental side-effects. Certification would include protocols for setting minimum ecological standards associated with biomass supply chains along with the capacity to trace biomass from production to end-use [61].

Overall knowledge about stover harvesting/marketing plays a role in intentions that lean toward supplying stover and currently Iowa farmers are, by and large, in a learning phase. Farmer education programs about stover harvesting are expanding e.g. in ref. [62]; yet appear to be limited with regard to providing explicit marketing advice [63]. Farmers who look toward institutional safeguards to manage risk, draw capital and physically support the sale process (e.g., bank financing and co-op deliveries) tend to be more interested in selling stover. Additionally, the findings support that farmers interested in owning shares in a biorefinery have greater interest in supplying corn stover. A potential implication of this finding is that interested farmers are looking to make a commitment to harvest stover for an extended duration, with the particular view of "buying-in" to the process (e.g., owning shares). Such an outcome can have broader implications on regional communities as it has been put forth that local ownership in biofuel production can increase rural economic development by helping to offset risk associated with crop price volatility and by enhancing local cashflow [64]; such outcomes remain to be seen however, and contrary research suggests that local ownership really means implicit ownership of potential profit and explicit ownership in biofuel market risk [64]. Evolving policy should therefore focus on risk management from the growers perspective as well as facilitating the evolution of marketing co-ops that link farmers in ways that promote farmer-to-farmer learning, supply chain cooperation and risk management [45,65]. Since this study, new US farm bill policy [66] has significantly expanded existing programs promoting biofuel development, and a number of new programs aim to further motivate and connect farmers with bio-refineries. For example, the Biomass Crop Assistance Program is a cost share and land payment program, incentivizing the production of energy crops and partnering producers directly with area biomass conversion facilities [66]. However, available incentive programming for producers looking to utilize crop residues is lacking.

To suggest implications of current farmer interest in corn stover supply, as a simple example we estimate available stover in the North Central region of Iowa based on physical stover yield scaled by: 1) NC Iowa farmer interest in providing stover, and 2) recommended removal rates to maintain SOC levels [32]. To calculate potential supply based on this scenario we created a weighted "representation factor" for each respondent by using US Department of Agriculture estimates of 2006 Iowa corn hectares per county and dividing by the sum of corn hectares reported by respondents per county. Then following the general stover yield methodology of Perlack and Turhollow [34] the density of Iowa corn production in 2006 was verified with USDA agriculture census data for the state of Iowa. Corn yield in dry Mt per hectare was determined by taking a 10 year average corn yield (dry tonnes/hectare) per county as reported by Iowa State University Extension and assuming a corn dry weight of 0.254 dry tones. Corn stover yield was estimated using a 1:1 corn grain to stover ratio [7]. The fraction of stover in the north central region that interested farmers would have hypothetically made available to a market in 2006 was calculated to be 1.23 million dry Mt of stover which in turn could be converted into roughly 0.478 hm^3 of ethanol; undecided farmers controled an additional 2.2 million dry Mt of stover. Thus the region in Iowa with the highest stover yields and shows the highest degree of and potential for farmer interest in stover harvest might be able to offer about 9% of the state's sustainable harvest yield as calculated by Graham et al. [7]; this could increase to ≈25% if all the undecided farmers in NC Iowa decided to supply stover. It is difficult to speculate on the ultimate implications of this stover supply on cellulosic ethanol production in Iowa, but it should be recognized that once converted into ethanol this quantity would be added to the state total infrastructural capacity to distribute ethanol to national markets. An infrastructure that has shown some signs of strain particularly in the form of rail car capacity to transport ethanol to west coast and Gulf port markets [67]. Additionally, there are still questions associated with spatial location of available stover and the ability to schedule feedstock pick up [14].

Ultimately it is unlikely that a single biomass feedstock will best suit all the needs of an evolving biomass energy market in the US Cornbelt region in general and Iowa specifically; as such, a portfolio approach to bioenergy feedstock production will likely be needed. Indeed the future of energy in general and ethanol in particular very likely will involve production sites that are capable of processing multiple feedstocks (integrated feedstock systems) such as the POET biorefinery in Emmetsburg, Iowa (North Central region) which has implemented "bolt-on" technology to produce ethanol from both corn grain and from cellulosic materials (corn cobs) [9]. As this study indicates, the total amount of stover that may make its way to a cellulosic market today could be considerably lower than the theoretical total outlined in the "Billion ton study" [5]; but perhaps more than enough to fulfill feedstock portfolio perspectives. Ultimately, the type of study outlined in this research should be an integral and longitudinally-repeated part of all biomass feedstock research programs whose purpose is 1) to track how farmer beliefs, interests and concerns regarding the cellulosic biofuel system change over time and 2) to provide further assessment of how these factors predict farmers' intentions and actual behavior toward providing biofuel feedstocks.

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Appendix. Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.biombioe.2010.08.049.

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