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Biomass from Marginal Cropland: Willingness of North Central US Farmers to Produce Switchgrass on Their Least Productive Fields

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Abstract: If the US mandates for the use of cellulosic biofuels are ultimately enforced, cellulosic feedstock will be demanded. Native switchgrass is a cellulosic feedstock that has been of substantial interest for this purpose because it is widely grown across the USA, it can be grown on marginal cropland and thus compete minimally with food supplies, it has a low carbon footprint, and in many ways, it is a sustainable source of energy. The purpose of the research reported here is to quantify the potential willingness of producers across 358 counties in a 10-state area in North Central USA to produce this biomass. We conducted a contingent valuation survey of randomly selected farm operators in this area. From the more than 1100 responses, we found that the mean reservation price at which respondents were willing to supply switchgrass from their least productive field is a return of about $228 per acre, which translates to about $82 per dry ton. Respondents were somewhat less willing to lease out their land for this purpose, requiring an additional $3.50 per dry ton to be willing to lease. In sub-regions of counties grouped by opportunity cost, mean reservation prices are equivalent to $75 per ton, $82 per ton, and $99 per ton, very close in the first two subregions to the Department of Energy goal of $84 per dry ton delivered to the biorefinery. Thus, prospects appear favorable that substantial fractions of farmers would be willing to supply switchgrass in this area, particularly in the sub-areas with lower land costs. © 2017 Society of Chemical Industry and John Wiley & Sons, Ltd

Keywords: cellulosic feedstock; switchgrass; willingness to accept; biomass supply

Introduction

US energy policy, as expressed in the Energy Independence and Security Act (EISA) of 2007,[1] mandates that the national highway fuel supply include biofuels made from cellulosic materials. Compared to biofuels made from corn starch (corn ethanol), cellulosic ethanol has a lower carbon footprint and is less competitive with the food supply. Dedicated cellulosic crops such as grasses, however, compete with the food supply, but less so if they are grown on marginal cropland. The research reported here examines the willingness of

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farmers across the North Central USA to devote their least productive fields to the production of switchgrass as a biomass crop.

The quantities of various types of renewable fuels mandated by EISA are collectively known as the Renewable Fuel Standard (RFS2). The mandated volumes of cellulosic biofuels started in 2010, reached 4.25 billion gallons per year (bgy) by 2016, and 16 bgy by 2022. But cellulosic fuel production has been a failure to date: production has not been forthcoming and the Environmental Protection Agency (EPA)[2] has consequently reduced the mandate from 4.25 bgy to 0.23 bgy in 2016. But the government remains committed to developing a cost-competitive cellulosic fuel industry. The Department of Energy (DOE) maintains a commitment to developing cellulosic biofuel pathways that deliver cellulosic material at a cost of $84 per dry ton and ethanol at $2.65 per gallon.[3] Massive quantities of cellulosic feedstock may yet be required. This study compares the average reservation prices expressed by farmers across a broad region, with the $84 per ton DOE objective.

The federal government established the Biomass Crop Assistance Program (BCAP) in the 2008 Farm Bill to provide assistance in bringing together producers and processors at scale to produce cellulosic ethanol from biomass crops. BCAP has suffered from issues related to eligibility and congressional funding, but some grass-oriented BCAP projects have had difficulty signing up the intended number of acres, in part because of the difficulty of negotiating individual production contracts between the processor and the 100–200 individual producers needed. It is our conjecture that the substantial transaction costs that impede the organization of biomass supply and processing networks can be reduced if processors lease land to produce and harvest the crop themselves. In this way, they could simply post a lease rate at a sufficient level to attract the quantities needed. Hence this research examines the differences between farmers' willingness to produce switchgrass and their willingness to lease land for the processor to produce.

Previous research on farmer willingness to supply switchgrass

Four basic approaches have been used to determine the potential supply of biomass for energy. The acreage assessment approach, such as is followed by the Billion-Ton Study,[4] simply assesses the current acreage and production of various crops and crop residues and then makes educated assumptions about what fraction of these sources could be available as feedstock, with little attention to incentives. The budgeting approach uses engineering-assessment data to identify likely breakeven prices. The simulation approach combines budget and resource data of various types, along with economic optimization algorithms, to estimate the total quantities that might be forthcoming from farms in a given area. Finally, the contingent valuation (c.v.) approach, as we use in this study, solicits information about potential farmer response through surveys.

The acreage assessment approach does not consider the managers' choice to produce a crop, and thus the supply estimates from this approach tend to identify an upper bound, at best. Budgets provide estimates of cost of production, but they may not reflect prices and technology that farmers perceive, and they provide no sense of how variability among producers might lead to response to prices. The simulation approach is limited first by the analyst's ability to estimate technological relationships that are appropriate to farmers' circumstances (experimental data and engineering cost estimates are normally used). A second challenge to the simulation approach lies in positing an optimization algorithm that adequately represents farmers' preferences, especially considering uncertainty and non-pecuniary aspects of the choices available. Surveys directly address what choices a producer would make on their own farm in various circumstances. But they, too, have limitations, the most important of which is the difficulty of eliciting the choices that farmers would actually commit to, given that in a survey the respondent has little at stake, little information, and may devote little thought to the response.[1]

Debnath *et al.*[6] provide a useful summary of several breakeven price studies of switchgrass supplies, including their own estimate of a $50 per ton breakeven price in Oklahoma. They report other estimates of farm-gate breakeven prices ranging from $45 to 62 per ton in Tennessee, $55 per ton in Oklahoma, and $40 to 90 per ton in Illinois. Other comparable estimates are those for Tennessee[7] at about $50 per ton, for Massachusetts[8] starting at about $90 per ton, for Nebraska[9] starting at about $75 per ton, and for an unspecified area in the Midwest[10] an estimate of $66 per ton. Khanna, *et al.*[11] provide an example of simulation studies, in which optimization algorithms are used to simulate farmers' choices among various crops in 295 Crop Reporting Districts. They conclude that while supplies of grass crops

[1]The National Oceanic and Atmospheric Administration (NOAA) appointed a panel of leading social scientists to advise them on valuation of non-market goods using contingent valuation surveys (Carson, *et al.*[5]). The panel cautiously endorsed the c.v. method if several recommendations were followed. One of these was that a referendum approach such as the one here be used.

could be initiated at $40 per ton, a price of $140 per ton would be necessary to supply sufficient quantities of grasses (mostly Miscanthus, some switchgrass) to maintain a cellulosic ethanol industry. A similar study based on experimental plot yields in Michigan[12] estimates that a switchgrass price of $642 per ton would be necessary to break even with corn production with corn priced at $4 per bushel.

These results can be compared with actual on-farm production costs during 2000–2004, on 20-acre fields of a panel of collaborating farmers in Nebraska and the Dakotas.[13] This study reports breakeven costs averaging about $60 per ton, but ranging from $37 to $97 per ton across farms.

In Table 1 we provide a summary of results of seven previous c.v. surveys of farmers' willingness to produce switchgrass, giving here no attention to the details of methods used to obtain those responses. In these studies, the c.v. question has been framed in terms of various remuneration scenarios: as an acceptable price per ton, an acceptable net revenue per acre, or an acceptable rental rate for someone else to produce. In Table 1 we show conversions from one concept to the other, based in all but the last case on an assumed average yield of 4 tons per acre and production cost of $100 per acre.

In the context of c.v. studies, Willingness to Accept (WTA) can be thought of as a reservation price – the minimum price at which the individual would be just indifferent between producing or not producing. The range of estimated WTAs in these studies is notable. The *lowest* net revenue values acceptable to only the most willing of producers range from $15 per acre in the northern tier of Michigan and Wisconsin[19] to $100 per acre in SW Wisconsin.[16] These values translate roughly to $29 per ton and $50 per ton, which are at the low end of breakeven price estimates cited earlier. Bid offers in these c.v. studies were not, in general, high enough to be acceptable to 50% of producers (i.e., the median WTA), although $380 per acre ($120 per ton) was acceptable to 53% of producers in the South[17] and the Massachusetts study[20] estimated the median WTA to be $130 per acre ($134 per ton).

The methods and regions differ across these studies, so it is difficult to generalize from them what returns to land or biomass price would be sufficient to entice a significant fraction of Midwest farmers to either produce switchgrass or to rent their land out for that purpose. The study reported here is designed to address that information gap.

Farmer willingness to accept switchgrass production may depend upon whether the farmer produces the crop himself versus leasing out the land to another party to produce the crop. This is potentially an important issue in determining the strategy used to gain farmer commitments to produce for a potential processing facility. The bid strategy used by the US Department of Agriculture (USDA) Conservation Reserve Program (CRP), for example, simply asks farmers to submit a bid for their acceptable lease rate for a particular field, and the program administrators can the select the bid level that would result in the desired total acreage. Strategies used within BCAP projects of have generally involved negotiations with individual farmers to identify

Table 1. Summary of survey estimates of willingness to supply grassy crops for biomass.

Reference	Year of survey	Region	Number of responses	Crop(s)	Willingness to accept (cumulative fraction in parentheses)[a]			
					in $ per acre		in $ per ton	
					Low price	Higher price	Low price	Higher price
Altman[14b]	2007 2009	Illinois Missouri	960 600	hay hay	$120(3%) $120(6%)	$140(10%) $140(15%)	**$35(3%)** **$35(6%)**	**$40(10%)** **$40(15%)**
Fewell *et al*.[15]	2010-11	Central Kansas	290	switchgrass	**$50(~1-5%)**	**$60(~7-20%)**	~$37(~1-5%)	~$40(~7-20%)
Mooney *et al*.[16]	2011	SW Wisconsin	248	switchgrass	$100(3-5%)	$200(18%)	**$50(3-5%)**	**$75(18%)**
Quals *et al*.[17]	2009	12 S. states	760	switchgrass	$60(44%)	$380(53%)	**$40(44%)**	**$120(53%)**
Skevas *et al*.[18]	2012	S. Michigan	599	switchgrass (rent out for)	**$50(6-13%)**	**$300 (33-75%)**	$38(6-13%)	$100(33-75%)
Skevas *et al*.[12]	2014-15	N. Michigan & Wisconsin	1107	switchgrass (rent out for)	**$15(9%)**	**$60(20%)**	$29(9%)	$40(20%)
Timmons[8]	Not stated	Massachusetts	192	grass biomass		**$130(50%)**		$134(50%)

[a]Reported WTA in bold characters, conversions calculated here based on average cost of $100/acre, yield of 4 tons per acre. Cumulative fraction of producer WTA shown in parentheses.
[b]Reported as WTA per ton for a standing crop of hay. We have added $20/t to approximate farm gate price.

contract provisions for each that would entice participation, a time-consuming process. Hence, we wish to identify the difference, if any, between the price required for a farmer to grow switchgrass versus that required to lease land for switchgrass production.

We have not found any studies that have attempted to quantify the difference in willingness to produce on their land vs. willingness to lease out to others. Some studies have examined the willingness of an owner to rent out land for switchgrass production[12,18,19] while others have examined farmers' willingness to produce themselves,[7,8,14,15,17,20] but none of these studies address the question of whether the farmer would prefer to produce switchgrass himself or lease out his land for others to do so.

Theoretical framework and estimation technique

The objective of this study is to obtain a measure of the willingness to supply switchgrass by farmers across a wide range of the US Midwest. We seek a measure of the minimum WTA, or reservation price, across the population of producers. The WTA is generally defined as the minimum amount the individual would be willing to accept to undergo an economic change. It is a money-metric measure of welfare change due to a change in the status quo and it is equivalent to Hicks' compensating variation (CV).[21]

If the producer agrees to supply switchgrass on the terms proposed, then the utility he anticipates is $u^1(x;s)$, and if he does not it is $u^0(x';s)$, where x are goods and services consumed or provided and s is a vector of producers' characteristics. The producer's indirect utility function is $v^h(x(p,m);s)$, where $h=\{0,1\}$, p are prices and m is income.

Using the producer's indirect utility function, their willingness to supply switchgrass (their WTA, or CV) is the minimum increase in income that would make them indifferent between the status quo and switchgrass production, or

$$v^0(p,m;s) = v^1(p,m + WTA;s) = u^0(x(p,m);s) \quad (1)$$

In Eqn (1), the producer's utility if supplying switchgrass is the same as when not supplying it only after their income is increased by \$WTA. Note that $v(p, e(p,u);s) = u$ is the maximum utility from income $e(p, v(p,m);s)$ and that this is the minimum expenditure necessary to reach utility u. Then $m = e^0(p,u^0)$ and $m + WTA = e^1(p,u^0)$the minimum amount necessary to induce the supply of switchgrass is

$$WTA = e^1[p,u^0] - m = CV \quad (2)$$

The next question is how to obtain a measure of this WTA, using information from a contingent valuation survey. From the econometrician's perspective, u^0 and u^1 are unknown outcomes of variables that are random (given that they are unknown to the analyst) with a postulated probability distribution with means equal to $v^0(p,m;s)$ and $v^1(p,m;s)$ or

$$u(x(p,m);s) = v(p,m;s) + \varepsilon \quad (3)$$

where ε is an i.i.d. random variable with zero mean. When offered an amount of money \$A to supply switchgrass, the individual will accept the offer if

$$u^0 = v^0(p, m;s) + \varepsilon_0 \le v^1(p, m + A;s) + \varepsilon_1 = u^1 \quad (4)$$

Using Eqn (2) and Eqn (4) we obtain

$$WTA = e^1(p, v^0(p, m;s) + (\varepsilon_0 - \varepsilon_1)) - m \quad (5)$$

For the analyst, the individual's binary choice to accept or reject is a random variable whose probability distribution is

$$P_1 \equiv \Pr\{v^0(p, m;s) + \varepsilon_0 \le v^1(p, m + A;s) + \varepsilon_1\} = F(\Delta v) \quad (6)$$

where F is a cumulative density function (c.d.f.), P_1 represents the probability that the individual is willing to supply switchgrass and $(1\text{-}P_1) = P_0$ is the probability that she would not be willing to supply switchgrass. P_1 is the c.d.f. of the change in $v(.)$ or equivalently the c.d.f. of $(\varepsilon_0 - \varepsilon_1)$ and of the WTA in Eqn (5). With a specific functional form for the indirect utility function[2] and assuming that the change in indirect utility is distributed as a normal or logistic, the willingness to supply will be a function of the specific parameters of the indirect utility function and will have the same distribution. In this way Hanemann[21] makes it obvious that the binary choice model can be interpreted as the outcome of a utility-maximizing choice.

Alternatively, we could obtain the same result by specifying directly the WTA in Eqn (5), assuming that it is consistent with some expenditure function representing optimizing behavior.[22] Then

$$WTA_i = x_i\beta + u_i \quad (7)$$

where $u_i \sim N(0, s)$. As the WTA is unobserved it is manifested through an indicator variable, I_i that assumes values

[2]Hanemann[21] assumes indirect utility functions linear in income or in the logarithm of income. For $v(p, q, m;s) = \alpha + \beta m$, $WTA = [(\alpha_0 - a_1) + (\varepsilon_0 - \varepsilon_1)]/\beta$. With a more complex specification for the indirect utility function it might not be possible to find a simple, or a closed solution, for the corresponding WTA.

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of 0 and 1. It will be 1 when the true WTA is bigger than a threshold value bid_i offered. Then the probability that producer *i* will supply switchgrass is:

$$\Pr(WTA_i > bid_i|x) = \Pr(u_i/\sigma > (bid_i - x'_i\beta)/\sigma|x) = \Pr(\phi_i < (x'_i\beta - bid_i)/\sigma) = \Phi(z'_i\gamma) \quad (8)$$

where, $z'_i = (bid_i, x'_i)$ and $\gamma = \left(-\frac{1}{\sigma}, \frac{\beta}{\sigma}\right)'$, $\phi_i \sim N(0, 1)$ and Φ is a cumulative density function.[3] This is evaluated by estimating the following equation:

$$I_i = -\left(\frac{1}{\sigma}\right) bid_i + \left(\frac{1}{\sigma}\right) x'_i\beta + \phi_i = bid_i(\gamma_{did}) + x_i\gamma + \phi i \quad (9)$$

and obtaining the probabilities for each estimated index value using the c.d.f. of a standard normal. The parameters of Eqn (7) are then recovered from estimates of Eqn (9).[4]

For the probit and logit estimators, the mean and median WTA for respondent *i* is $x_i\hat{\beta}$, and the sample mean of the expected WTA is $\bar{x}\hat{\beta}$, where $\bar{x}$ is the sample mean of the covariates. For the exponential model, mean WTA for respondent *i* is *mean* $\ln WTA_i = x_i\hat{\beta} + \frac{\hat{\sigma}^2}{2}$, while *median* $WTA_i = x_i\hat{\beta}$.[5]

Questionnaire development

Following the guidelines of the NOAA panel of 1993,[5] we utilize a simple referendum approach (yes, no) for the questionnaire. (The questionnaire is attached as Appendix A.) We frame the referendum question by explaining the nature of the crop, our estimates of costs for establishment, maintenance, and harvest (both averages and ranges) and an approximate biomass price. While this information no doubt provides an anchoring effect that conditions responses, it is important that respondents be provided some such information. Given that it is based on the best unbiased data available, the conditioning should impart minimal bias relative to what the respondent would decide after becoming more informed. We then asked, for this range of outcomes, if the respondent would plant 'this operation's least productive field of 10 acres or more to switchgrass for the next five years if the average net revenue were \$A per acre', where \$A was a randomly chosen 'bid value' from a set of three values that differed by region. We then asked if the respondent would lease that field to a reputable company for the next five years at the same rate. The answer to the first question we coded as *YProd* = 1 if yes, and =0 if no. The answer to the second question we coded as *YLease* = 1 if yes, willing to lease, = 0 if no.

Special attention was given to selecting bid values because opportunity costs for land vary considerably across the North Central region. The region is defined primarily by crop management zones 1, 4, and 16 as defined by the US Department of Agriculture[23] so we obtained for counties in those zones the average CRP rental rates on which to base our bid values (Fig. 1). The federal CRP pays farmers to establish a grass crop on suitable marginal cropland for ten years, following prescribed practices for maintenance, but not harvesting or grazing it. Farmers are invited to bid a rate that they would accept for particular fields; then the USDA accepts those that provide the CRP targets at lowest cost. There were 553 counties in the region that reported county-average CRP rates in the 2013 sign-up period. We grouped these into low-rate, medium-rate, and high-rate counties, with corresponding average county rates of \$97 per acre, in Region 1, \$127 in Region 2, and \$199 per acre in Region 3 (note that these do not correspond to geographical regions). Based on this information, we set the three bid values to be offered to producers in Region 1 at \$25, \$100, and \$180 per acre. Region 2 bids were \$50, \$130, and \$225 per acre, while Region 3 bids were \$85, \$150, and \$260 per acre.

Apart from soliciting yes or no answers for producing switchgrass or leasing for switchgrass production, we limited other questions to a minimum to avoid discouraging respondents. We did inquire about the acreage of various crops on the operation as a whole, and with respect to the least productive field that the respondent selected for consideration we posed three questions that might reflect opportunity cost: what are the producer's estimates of the market rental rate for that field, what are the producer's estimates of the market sale value for that field, and what net revenue do they expect for the current land use. Responses to the last question were unfortunately of limited usefulness because instead of posing an open question, we asked them to check a box indicating the appropriate interval. We also inquired whether the field was owned or rented, what crop was planted this year, and what yield was obtained or expected.

Survey results

We contracted with the National Agricultural Statistics Service of USDA (NASS) to draw samples of farmers, send

[3]To estimate this cumulative density function with a conditional maximum likelihood estimator (MLE), the log-likelihood function for each individual *i* is needed. The MLE of ß and s maximize the sum of log likelihoods across all *i*'s.

[4]If ϕi is distributed as a Normal variable it is the probit estimating equation, if ϕi is distributed as the Logistic it is the logit estimating equation, and if bid_i is replaced with $lnbid_i$ it is the exponential probit or logit.

[5]Refer to Chapter 2 in StataCorp[25] for more details.

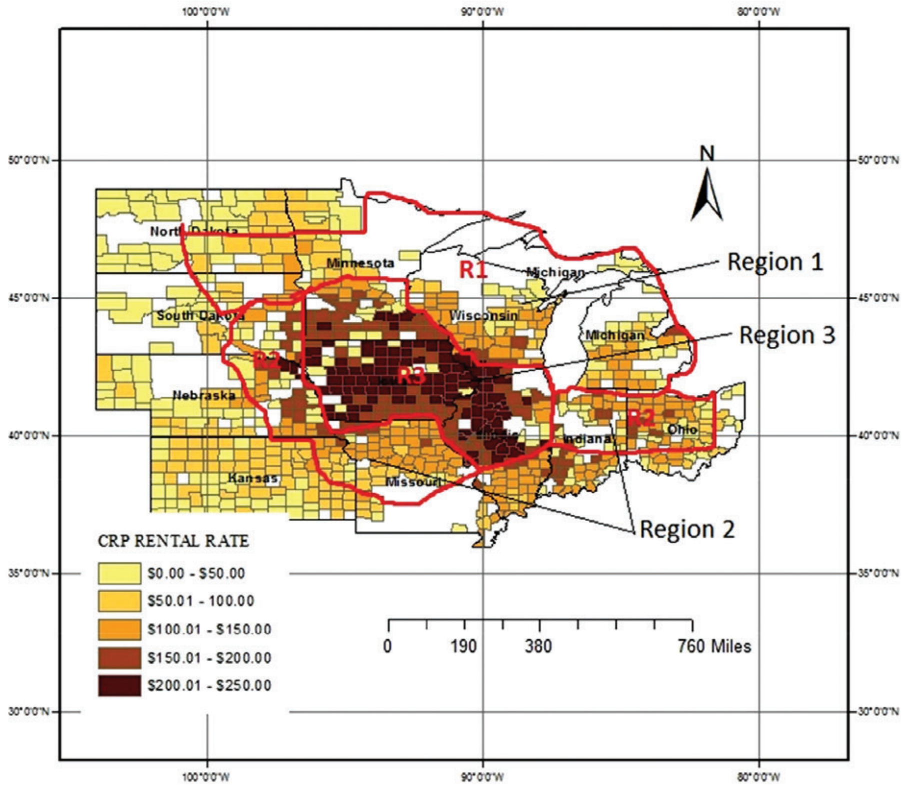

Figure 1. The survey regions.

the questionnaires, make up to eight telephone contacts with late responders to insure a good response, tabulate the data, and provide it to the authors in spreadsheet format. NASS drew a probability survey of 2100 cropland operators from a list of those with 40 acres or more of cropland in the study counties. Questionnaires were distributed during fall and winter, 2014/2015, and tabulated in the spring of 2015.

Responses were received from 1124 farmers, a 54% response rate, though not all questionnaires had a sufficient number of answers completed to be useful. The number and fraction of 'yes' responses are reported in Table 2 and depicted in Fig. 2. The percentages in Fig 2 correspond approximately to an empirical cumulative distribution of WTA. While these distributions do not at first appear monotonic here, they are monotonic within each region (compare responses from Region 1, for example, at bids of $25, $100, and $180). The low bids across these three regions ($25, $50, and $85) resulted in roughly similar fractions of 'yes' responses, reflecting differences in opportunity costs as we intended.

Descriptive statistics for each variable are presented by region in Table 3 and for the entire region in Table 4. With respect to the entire operation of the respondent: *crpacres* is the number of acres of CRP land on the operation (land committed to the conservation reserve program); *grasshayacres*, the acres in grass for hay; *pastureacres*, the acres in pasture; and *cropacres* is the acres in corn, soybeans,

Table 2. Percentage of yes responses by bid levels offered.

Bid ($ per acre)	Number of bids assigned	Number of responses	% of respondents who said 'yes'	
			Produce	Lease
Region 1				
25	122	116	22%	10%
100	136	125	27%	30%
180	128	122	39%	39%
Region 2				
50	198	192	19%	14%
130	180	167	32%	23%
225	179	158	43%	37%
Region 3				
85	53	51	20%	6%
150	64	58	26%	19%
260	64	59	46%	34%

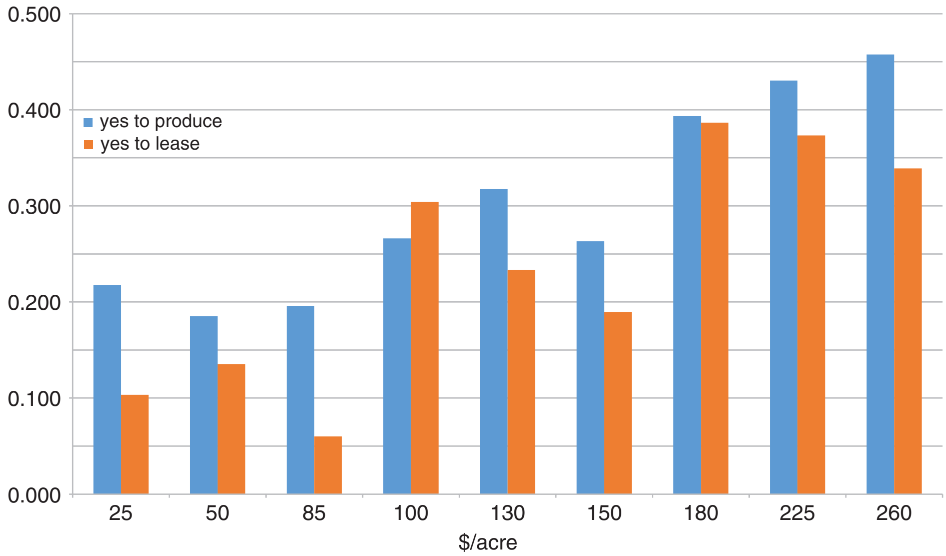

Figure 2. Fraction of yes answers by bid level.

and small grains. With respect to the field selected by the respondent for consideration: *fieldsize* is the number of acres in that field; *fieldowned* is 1 if the field is owned, 0 if not; *cropgrown* is 1 if pasture or grazing land, 0 otherwise; *landprice* is respondent's estimate of sale value per acre; and *rentalrate* is the respondent's estimate of the current market rental rate.

Analysis of respondents' willingness to accept switchgrass production

Our sequence of econometric tests is to use the YProd choice variable to examine alternative specifications and variables for estimating Eqn (10), to examine regional differences, and finally to use these results to consider whether there is any difference between response to the opportunity to produce (YProd) versus to lease out for production (YLease).

Table 5 presents results from estimating Eqn (9) with all variables, but with three different specifications.[6] There were 563 respondents who provided responses to all the variables shown.

Regarding the choice of structure, we are concerned about the statistical fit, but also how well the models predict the mean WTA. For each model estimated, we therefore show at the bottom of the table the mean value of expected WTA as calculated and averaged across the entire sample. By way of comparison, the raw response data of Table 2 and Fig. 2 indicate that 20% of the sample were willing to produce at net revenue bids in the range of $25–85 per acre, and that a bid of $226 per acre is acceptable to about 45% of the sample. The estimated mean WTA from the probit and logit models (5A and 5B in Table 5) are $203 and $202 per acre, reasonably consistent with this pattern.

The first two models in Table 5 are quite similar, though the probit (model 5A) had a slightly higher chi-square measure of fit. The exponential model (5C) provides totally unrealistic estimates, with a mean WTA of $4539 per acre. The probit model (5A), is the simpler and more traditional model, and given its slightly better fit, we will use that structure to examine subsequent questions below. With respect to important variables to be considered, it is evident that *fieldsize*, *cropgrown*, *crpacres* and *grasshayacres* are not significant in determining respondents' willingness to produce, regardless of the specification for Eqn (9), so we do not consider them further.[7] We also estimated the probit structure for data from each of the regions separately, but could not reject the hypothesis that the coefficients were the same for the three regions.[8]

In Table 6, we test one of the particular issues of interest for this study, the hypothesis that operators' responses are the same for the opportunity to produce (*YProd*) as for the opportunity to lease their land to someone else for switchgrass production (*YLease*). We confine this test to

[6]Estimations use StataCorp.[24]

[7]This conclusion was also supported by a process of stepwise downward selection using Likelihood Ratio tests.

[8]Chi-square=9.91, Prob > chi-square=0.62

Table 3. Descriptive statistics by region (based on all 1124 respondents).

Variable	Units	Region 1 Obs.	Region 1 Mean	Region 1 Std. Dev.	Region 1 Min	Region 1 Max	Region 2 Obs.	Region 2 Mean	Region 2 Std. Dev.	Region 2 Min	Region 2 Max	Region 3 Obs.	Region 3 Mean	Region 3 Std. Dev.	Region 3 Min	Region 3 Max
bid	$/acre	386	102.8	62.5	25	180	557	132.1	71.9	50	225	181	169.9	71.8	85	260
YProd	0,1	361	0.29	0.47	0	1	515	0.3	0.46	0	1	167	0.31	0.46	0	1
YLease	0,1	360	0.27	0.44	0	1	518	0.24	0.43	0	1	167	0.2	0.4	0	1
crpacres	acres	378	30.3	94.9	0	1200	535	40.5	306.6	0	5000	173	15.6	36.6	0	263
grasshayacres	acres	374	24.4	58.9	0	450	527	66.2	195.1	0	3000	173	15.9	57.9	0	600
pastureacres	acres	374	70.3	222	0	2500	518	339.4	1345.1	0	25000	171	42.1	98.3	0	600
cropacres	acres	365	417.8	966	0	12000	516	483.9	1312.3	0	22600	169	546.7	631.8	0	4000
fieldsize	acres	343	39.6	76.9	0	1200	463	58.4	142.9	0	1920	138	37.9	65.8	0	500
fieldowned	0,1	368	0.75	0.43	0	1	531	0.75	0.43	0	1	167	0.71	0.46	0	1
cropgrown	0,1	349	0.11	0.32	0	1	483	0.16	0.37	0	1	155	0.07	0.26	0	1
rentalrate	$/acre	289	103	57.9	0	300	348	138.2	85.1	0	500	135	223.7	86.7	0	450
landprice	$/acre	268	3829.7	2766	13	20000	366	4657	3175.2	0	23000	132	6962	3340.4	120	15000

Table 4. Descriptive statistics for the pooled data (based on all 1124 respondents).

Variable	Units	Obs.	Mean	Std. Dev.	Min	Max
bid	$/acre	1124	128.1	72.36	25	260
YProd	0,1	1043	0.3	0.46	0	1
YLease	0,1	1045	0.24	43	0	1
crpacres	acres	1086	33	222.9	0	5000
grasshayacres	acres	1074	43.5	144.62	0	3000
pastureacres	acres	1063	196.9	958.7	0	25000
cropacres	acres	1050	471	1111.3	0	22600
fieldsize	acres	944	48.6	113.5	0	1920
fieldowned	0,1	1066	0.74	0.44	0	1
cropgrown	0,1	987	0.13	0.34	0	1
landprice	$/acre	766	4764.9	3246	0	23000
rentalrate	$/acre	772	140	86.9	0	500

respondents who owned the field nominated, given that renters are unlikely to be allowed to sub-let to someone else. The Chi-square test value for equal parameter estimates for *Yprod* and *Ylease* is 11.92, which is significant at the 5% level, so we reject the hypothesis. This is completely consistent with the results from the raw data in Table 1, where in all but one of the nine bid scenarios, respondents were less willing to accept the bid as a lease rate than as an average net return when producing themselves. Our original expectations were that respondents would prefer a fairly certain stream of income from leasing to an uncertain stream of net revenue with the same average value. Clearly this expectation was incorrect. Respondents in Swinton, *et al.*[19] provided several reasons why farmers are reluctant to rent land out, such as potential liabilities, the nuisance of having others making cropping decisions, and the inflexibility imposed by long-term leasing. While the responses for leasing versus producing are significantly different, the mean WTAs are not very different ($228 per acre for producing, $238 per acre for leasing, equivalent to a difference of about $2.50 per ton).

The preceding paragraph considers whether field owners would be more likely to produce or rent out for others to produce switchgrass. We are also interested in whether farmers who owned the land are more likely to produce switchgrass than farmers who rented the land. One test of this hypothesis was to add *fieldowned*, a 0–1 indicator variable, to model 5A in Table 5. The coefficient was barely significant at the 10% level. We conducted a second test by estimating Model 5A separately for owners versus renters. The estimated mean WTAs were $199 for renters versus

Table 5. Alternative structures for the probability equation (dependent variable *Yprod*, standard errors in parentheses).

Variable	Specification		
	5A. probit	5B. logit	5C. exponential probit
	Parameter estimate	Parameter estimate	Parameter estimate
bid	0.00497***	0.00814***	0.47719***
	(0.0008)	(0.0014)	(0.0843)
rentalrate	-0.0026***	-0.00428***	-0.00252***
	(0.00086)	(0.0015)	(0.0008)
landprice	-0.00004*	-0.00007*	-0.00004*
	(0.00002)	(0.00004)	(0.00002)
fieldowned	-0.2226*	-0.36168*	-0.23023*
	(0.1251)	(0.2091)	(0.1246)
fieldsize	-0.00105	-0.0017	-0.00104
	(0.0007)	(0.0015)	(0.0007)
cropgrown	0.22892	0.35064	0.2433
	(0.1891)	(0.3160)	(0.1881)
pastureacres	-0.00016*	-0.00026*	-0.00017*
	(0.00009)	(0.00015)	(0.0001)
crpacres	0.001	0.00165	0.00111
	(0.0008)	(0.0014)	(0.0008)
grasshayacres	0.00095	0.00165	0.00094
	(0.0007)	(0.0013)	(0.0007)
cropacres	0.00014	0.00022**	0.00013**
	(0.00007)	(0.00011)	(0.00006)
_cons	-0.40005**	-0.66276**	-1.98367***
	(0.1801)	(0.3018)	(0.4172)
No. of obs	563	563	563
Mean WTA	203	202	4539

***1%, **5%, *10% significance level

Table 6. Willingness to produce vs. willingness to lease by landowners (standard errors in parentheses).

	Owners (*Yprod*)		Owners (*Ylease*)	
Variable	Parameter estimate	Marginal Effects^	Parameter estimate	Marginal Effects^
bid	0.005***	0.001725***	0.00595***	0.001872***
	(0.0010)	(0.0003)	(0.0010)	(0.00031)
rentalrate	-0.00242**	-0.000834**	-0.00532***	-0.001675***
	(0.0011)	(0.0004)	(0.0012)	(0.00037)
landprice	-0.00007**	-0.000023**	0.00001	2.78E-06
	(0.00003)	(0.00001)	(0.00003)	(0.000009)
pastureac	-0.00006	-0.00002	-0.00025**	-0.0000773**
	(0.00009)	(0.00003)	(0.0001)	(0.00004)
cropacres	0.00013	0.000044	0.00009	0.0000278
	(0.00009)	(0.00003)	(0.00007)	(0.00002)
_cons	-0.54263***		-0.69772***	
	(0.1713)		(0.1771)	
No. obs	418		418	
Mean WTA	228		238	

^at mean of covariates, ***1%, **5%, *10% significance levels

Table 7. Parameters for owners WTA to produce vs lease (standard errors in parentheses).

	(*Yprod*)	(*Ylease*)
Variable	Parameter estimate	Parameter estimate
rentalrate	0.4836**	0.8946***
	(0.2229)	(0.2271)
landprice	0.0133**	-0.0015
	(0.0062)	(0.0048)
pastureacres	0.0119	0.0413**
	(0.0191)	(0.0204)
cropacres	-0.0256	-0.0148
	(0.0192)	(0.1133)
_cons	108.44***	117.31***
	(27.878)	(25.104)
Mean WTA	228	238

$228 for field owners, but a Chi square test of the hypothesis that response coefficients are the same for owners and renters could not be rejected (the Chi square value of 2.25 has a p-value of 0.8). Hence, we concluded that operators who owned the field in question did not respond differently than those who rented the field, when presented the opportunity to grow switchgrass.

The tests we have described above suggest that the regionally-pooled models for owners to produce and owners to lease out for production (Table 6) are the most useful of those we examined. We therefore include in Table 6 the marginal probability effects associated with each estimated coefficient, and in Table 7 we show the implied WTA parameters (Eqn (7)) from these coefficients. *Rentalrate* and *landprice* are both proxy variables for the opportunity costs of using these fields for switchgrass production. They both are significant in the equations shown here, and in regressions not shown, their coefficients did not change substantially when the other variable was eliminated. We conclude that the two variables include different and independently useful information about opportunity costs that farmers face. The rental rate may reflect a more short-term view of opportunity cost, while land price reflects a longer-term evaluation. In Table 7, we see that WTA rises just $0.48 per acre for each $1.00 per acre increase in estimated rental rate, perhaps reflecting a strong preference for producing switchgrass rather than renting the field out at the going rental rate. The land price coefficient, 0.013, similarly suggests that these landowners are willing to accept a lower earnings/price ratio from switchgrass than the 0.04–0.05 that is more typical for farm land.

We had expected that more pasture acres on an operation would familiarize the operator with growing switchgrass, and thus increase willingness to produce. We found this *not* to be the case however, with probability of acceptance decreasing very slightly with each additional acre of pasture (the coefficients of *pastureacres* in Table 6). Apparently, our respondents felt that growing switchgrass is competitive with pasture, rather than complementary as we had anticipated. We similarly had expected that the probability of agreeing to produce switchgrass would fall with increased acreage of grain crops, but we found instead that it increases with each additional acre of such crops. Respondents felt that the potential for complementarity of switchgrass with grain crops exceeds the potential for competition for resources.

The average of expected owners' WTAs to produce across the region, calculated from Table 7, first column, is $228 per acre, or about $82 per ton. The owners' WTAs to *lease out* land for production, from Table 7 second column, result in a mean WTA of $238 per acre, about $86 per ton. These central tendencies imply that North Central farmers are even less willing to supply switchgrass than reported by other studies in that region summarized in Table 1. In the North Central states studies, prices in the vicinity of $40–50 per ton elicit positive responses from no more than about 20% of producers, whereas with our econometric analyses, bids in this range result in less than 10% of positive responses. (Farmers across the south are much more willing to produce switchgrass, as revealed by a 12-state study,[17] where nearly half indicated a willingness to accept a price of $40/t.) The raw data of Fig. 2 suggest that perhaps 15% or so would respond positively to prices of $40–50/t. Furthermore, the mean WTAs are somewhat higher than most of the breakeven cost studies reported above, and about a third higher than average breakeven cost from on-farm trials in eastern Nebraska and the Dakotas,[12] where average breakeven cost was about $60 per ton.

However, there is considerable heterogeneity in the willingness of farmers to supply switchgrass. Evaluating WTAs at the regional means of the variables, we obtain mean WTAs for producing in the three regions as $199 per acre, $229 per acre, and $296 per acre, which correspond to $75 per ton, $82 per ton, and $99 per ton. Corresponding mean WTAs for leasing are $207 per acre, $248 per acre and $309 per acre or $77 per ton, $87 per ton and $102 per ton. We conclude that average producers in Regions 1 and 2 are willing to produce switchgrass on their least productive fields at rates below or close to the DOE goal of $84 per ton, though the average producer in Region 3 would not be willing to do so.

The acreage of the least productive fields reported by respondents totaled 45,846 acres, or a bit over 5% of the 848,907 acres of farm land reported. Five percent of farmland in the North Central region represents a substantial amount of prospective biomass production. Hay, pasture, or other non-row crop was reported as the crop currently being grown on 46% of the fields identified as least productive, indicating that switchgrass production on these fields would be 'marginal land' in the sense that they would not compete with food production. The remaining fields would presumably be close to marginal in that sense, given that they were drawn from the same population of farms, but their conversion to switchgrass would imply some reduction in food production, nonetheless.

Conclusions

In this study, we employed a contingent valuation survey to learn about the potential for farmers across the North Central region to supply switchgrass as a biomass crop. We received responses from 1124 producers in the region, which we analyzed using standard econometric techniques for estimating willingness to accept (WTA – also interpreted as reservation price). Producers were asked if they would be willing to produce switchgrass on their least productive field for five years at a given average net return (in $ per acre), and if they would be willing to lease it to someone else for that purpose at that rate. Relative to similar survey studies in this region, our mail survey covers a larger geographic area and employs a simpler questionnaire which helped to minimize non-respondent biases. We were also able to compare reservation prices for producing switchgrass versus leasing land out for switchgrass production, an issue not posed by others.

Perhaps most importantly, we found that the estimated mean reservation price (WTA) for all respondents across the region is about $228 per acre, which at an average production cost of $100 per acre and yield of 4 tons per acre, translates to about $82 per ton. This is a higher average reservation price than comparable estimates from other survey studies in the area, and about a third higher than the breakeven costs from on-farm trials in this region from a decade earlier. Given average transportation and handling costs of $7–10 per ton to deliver from the farm gate to the biorefinery, this suggests that the price at which the average farmer in this region would enter production would be close to, but somewhat higher than, the DOE delivered cost goal of $84 per ton.

However, individual farmers' reservation prices for production ranged considerably around the mean values, as revealed clearly by the role of rental rates and land prices, both of which affect WTA. For example, while we could not reject the hypothesis that the response coefficients differed by regions, mean WTAs to produce by region are, $199 per acre ($75 per ton) for Region 1, $229 per acre ($82 per ton) for Region 2, and $296 per acre ($99 per ton) for Region 3. Adding $7–10 for delivery, low rental rate counties' (Region 1) mean WTA is sufficiently low to meet the $84 per ton DOE goal, mean WTA is close in Region 2, but mean WTA for the high rental rate counties in Region 3 is far above that goal.

The total acreage in the least productive fields on these farms was 45 846 aces, representing a bit more than 5% of the agricultural land in the respondent farms and a significant amount of potential regional biomass production at the $82 per ton average reservation price. In close to half of this area (46%), the crop currently grown on the least productive field was hay, pasture, or other non-grain crop. Thus, these fields represent 'marginal lands' in the sense of lands not sown to row crops, and therefore not directly competitive with food crops, or only marginally so. It seems likely that the other 54% of least productive fields were also sufficiently unproductive to be minimally competitive with food crops, as well. A field that a farmer perceives to be their least productive would not necessarily be classified as a marginal field using a definition of the term as is needed to classify marginal lands from biophysical characteristics.[18,26]

Another important finding is that parcel owners are significantly more willing to produce switchgrass themselves, rather than to lease the land out to others for the same purpose, although requiring at the mean a premium of only about $3.50 per ton to be willing to lease out rather than produce themselves. This is an important consideration for the transaction costs required to supply the processing plant. Leasing may increase required payments to the average farmer by $14 per acre ($3.50 per ton), but it is much simpler to post a lease rate high enough to attract a sufficient number of producer fields, than it is to negotiate production and delivery costs separately with the 100–150 producers needed to supply the plant. The transaction cost savings from simple lease bids, along with scale economies in production, could very well offset the extra payments to producers. We also found it interesting that respondents indicated a willingness to accept only an additional $0.48 earnings from switchgrass for each $1.00 increase they could have earned by renting out their least productive fields.

In addition to the general limitations of the hypothetical nature of questions posed to our respondents, one limitation of this study is that the questionnaire only asked about willingness of respondents to supply their least productive field of 10 acres or more. Thus, there was no opportunity to examine increased acreage that might be offered at higher prices (increases in supply at the intensive margin), only increases in the number of farmers willing to commit their least productive field (the extensive margin).

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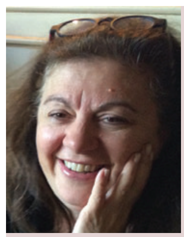

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Appendix A. The survey questionnaire

SWITCHGRASS PRODUCTION SURVEY - 2014

[redacted]

Please make corrections to name, address and ZIP Code, if necessary

You have been randomly selected to participate in a survey being conducted by the University of Nebraska-Lincoln (UNL). The purpose of this survey is to estimate the potential for commercial production of switchgrass as a biomass crop in your area. You are not required by anyone to respond to this request, but your answers to these questions will be very helpful to us in understanding producers' reactions to switchgrass opportunities. You have our assurance that your answers and information will be kept **strictly confidential**, and shared with no one other than the research team of four persons.

The survey should take about 15 minutes to complete. When you have finished, please return it to us in the enclosed postage-paid envelope. We will appreciate very much your taking the time to help us with this effort. Please respond within one week of receiving this request.

Section 1 – Acreage in 2014

	None	Acres
1. In 2014, how many acres of the following crops will this operation harvest?		
a. Corn.	☐	100
b. Soybeans.	☐	101
c. Small grains.	☐	102
d. Alfalfa hay.	☐	103
e. Grass hay.	☐	104
f. Other (Specify: 1000 ______________________)	☐	105
2. In 2014, how many acres of pasture or grazing land were on this operation?.	☐	106
3. In 2014, how many acres on this operation were enrolled in a government conservation program such as the Conservation Reserve Program (CRP)?.	☐	107

Section 2 – Selected Field

	Acres
1. Now think of this operation's **least productive field of 10 or more acres** in 2014. How many acres is this field?	108

2. What was this field's primary crop or land use in 2014? (Check one)

109
- 1 ☐ Corn
- 2 ☐ Soybeans
- 3 ☐ Small grains
- 4 ☐ Alfalfa hay
- 5 ☐ Grass hay
- 6 ☐ Pasture or grazing land
- 7 ☐ Other (Specify: 1001 ______________________)

(OVER)

Appendix A. Continued

3. What yield do you expect from this field in 2014? Please report in either bushels, tons, or pounds per acre. Report tons to the nearest tenth. Check the N/A box if this field will not be harvested in 2014.

N/A if not harvested	Bushels per Acre		Tons per Acre		Pounds per Acre
110 ☐	111	OR	112 . ___	OR	113

4. What net revenue per acre (receipts minus costs) do you expect from this field in 2014? (Check one)
   114
   - 1 ☐ Less than $150 per acre
   - 2 ☐ $150 - $300 per acre
   - 3 ☐ $301 - $500 per acre
   - 4 ☐ More than $500 per acre

5. Did you own, cash-rent, or share-rent this field in 2014? (Check one)
   115
   - 1 ☐ Own
   - 2 ☐ Cash-rent
   - 3 ☐ Share-rent
   - 4 ☐ Other arrangement (Specify: 1002 ______________________________)

	Dollars per Acre
6. What was, or do you expect would be, the **cash rental rate per acre** of this field in 2014?	116
7. What do you expect would be the **sale price per acre** of this field in 2014?	117

Section 3 - Your Willingness to Grow Switchgrass as a Biomass Crop:

Switchgrass is a perennial native prairie grass that usually takes about two years to become established, although about 20% of the time the establishment fails and it must be reseeded. Once established, annual production can range from 1.5 tons/acre to 6 tons/acre of biomass (hay, essentially, harvested once per year). The cost of establishment is $200 to $250 per acre, annual fertilizer cost is about $30/acre, and the value of baled biomass is about $70/ton.

For the average farm circumstances over a five-year period, average annual revenue should be about $225/acre, with average annual maintenance and harvest costs of about $100/acre, for average annual net revenue of $125/acre. For the range of outcomes above, the range in annual net revenue could be from $50/acre to $450/acre.

1. Would you be willing to plant this operation's least productive field of 10 acres or more to switchgrass for the next five years, if the average net revenue were $VALUE per acre?
   118 1☐Yes 3☐No
2. Would you be willing to lease this operation's least productive field of 10 acres or more to a reputable company for the purpose of switchgrass production for the next five years, at a rate of $VALUE per acre?
   119 1☐Yes 3☐No

Respondent Name: ___________________________	9911 Phone: (_____) _____-- __________	9910 MM DD YY Date: __ __ __ __ __ __

This completes the survey. Thank you for your help.

Office Use Only

Response		Respondent		Mode		Enum.	Eval.	Change	Office Use for POID			
1-Comp 2-R 3-Inac 4-Office Hold 5-R – Est 6-Inac – Est 7-Off Hold – Est	9901	1-Op/Mgr 2-Sp 3-Acct/Bkpr 4-Partner 9-Oth	9902	1-Mail 2-Tel 3-Face-to-Face 4-CATI 5-Web 6-e-mail 7-Fax 8-CAPI 19-Other	9903	9998	9900	R. Unit 9921	Optional Use 9907	9908	9906	9916
S/E Name												

  | *Biofuels, Bioprod. Bioref.* (2016); DOI: 10.1002/bbb