Adopting Bio-Energy Crops: Does Farmers' Attitude toward Loss Matter?

Mohit Anand, Dr. Ruiqing Miao and Dr. Madhu Khanna

Contact Information:

- **Mohit Anand**
  Department of Agricultural Economics and Rural Sociology

  306 Comer Hall Auburn University, Auburn, AL 36849

  Work: 334-246-9090 mza0066@auburn.edu

- **Dr. Ruiqing Miao**
  Assistant Professor, Agricultural Economics and Rural Sociology

  208B Comer Hall Auburn University, Auburn, AL 36849

  Work: 334-844-3273 rzm0050@auburn.edu

- **Dr. Madhu Khanna**
  ACES Distinguished Professor, Agricultural and Consumer Economics

  1301, W. Gregory Drive, University of Illinois at Urbana-Champaign, Urbana, IL 61801

  Work: 217-333-5176 Fax: 217-333-5538 khanna1@illinois.edu

Selected Paper prepared for presentation at the 2018 Southern Agricultural Economics Association Annual Meeting, February 3-6, Jacksonville, Florida

Adopting Bio-Energy Crops: Does Farmers' Attitude toward Loss Matter?

Abstract: This paper investigates farmers' willingness to grow bio-energy crops (namely, miscanthus and switchgrass) while accounting for their preferences toward loss. We model a representative farmer's optimal land allocation problem between conventional crops and bio-energy crops by employing the prospect theory. Numerical simulation is conducted for 1,919 U.S. counties east of the 100th Meridian that have yield data for corn and for at least one bio-energy crop. Results show that all else equal, if farmers are credit constrained then accounting for loss aversion will decrease the miscanthus production but increase switchgrass production. If farmers are not credit constrained, however, then accounting for loss aversion only has small impact on bio-energy crop production, indicating that the availability of credit mitigates the effect of farmers' loss preferences. We also find that biomass production on marginal land is less sensitive to farmers' loss aversion than production on high quality land is, which underscores the importance of marginal land in providing biomass for the bio-energy and bio-product sector. Moreover, results show that impact of loss aversion is smaller when interest rate is low as compare to scenarios under which interest rate is high. Geographical configuration of biomass production under various loss aversion, credit constraint, and interest rate scenarios are examined as well.

Keywords: Adoption, Bio-Energy Crops, Loss Aversion, Miscanthus, Prospect Theory, Switchgrass

JEL codes: D81, Q15, Q16

Adopting Bio-Energy Crops: Does Farmers' Attitude toward Loss Matter?

1. Introduction

The emerging cellulosic biofuel and bio-product industry requires the development of biomass markets. In these markets, however, technological and demand uncertainty is high and moreover, economic and policy challenges need to be overcome for farmers to successfully engage as viable suppliers of biomass. Large scale biomass production, as envisioned by the Billion-ton study (USDOE 2016), is anticipated to significantly rely on high yielding dedicated bio-energy crops in order to avoid competition with food/feed production. Perennial bio-energy crops such as miscanthus (Miscanthus × giganteus) and switchgrass (Panicum virgatum) are promising and can provide a range of environmental benefits (Hudiburg *et al*. 2016). The commercial scale production of these perennial bio-energy crops has not commenced yet due to, in part, farmers' lack of information about these crops' profit profiles, particularly in risk dimension (Miao and Khanna 2014, 2017a,b).

Simply comparing average profit from a perennial bio-energy crop with that of a conventional crop cannot assist farmers in making decisive crop choice decisions because a large literature has shown that most people are not only risk averse but also loss averse (e.g., Kahneman and Tversky, 1979; Tversky and Kahneman, 1992; Barberis, 2013). Bio-energy crop adoption involves a large amount of upfront investment, long-term commitment of land, and potential crop failure which may induce significant losses for farmers (Khanna, Louviere, and Yang, 2017). A survey conducted by Smith *et al*. (2011) reports that the fear of establishment failure or biorefinery shutdown that will cause extreme losses in returns is a significant barrier in adopting dedicated bio-energy crops. Therefore, the attitude toward loss is expected to be an important factor that will influence farmers' decision to grow these perennial bio-energy crops. However, there is a dearth of research in this regard.

A few studies have examined breakeven prices of bio-energy crops against conventional crops as a measure of bio-energy crop profitability (e.g., Miao and Khanna, 2014). Anand *et al*. (2017) investigate bio-energy crop profitability by examining the returns on investment in these crops. Dolginow *et al*. (2014) compare risk of miscanthus, switchgrass, and corn in north-eastern Missouri by using second-order stochastic dominance whereas Skevas *et al*. (2016) explore the risk of bio-energy crop returns in the southern Great Lakes region based on an expected utility theory framework. Miao and Khanna (2017a,b) investigate the impacts of policy instruments such as insurance for bio-energy crops, establishment cost subsidies, and the Biomass Crop Assistance Program on the production of bioenergy crops under an expected utility theory framework. However, none of these studies account for farmers' loss aversion when examining their adoption decisions. The present study aims to fill this gap by employing the prospect theory that explicitly incorporates decision makers' loss preferences.

Numerous studies have shown that prospect theory provides better predictions of people's decision making under risk and uncertainty than does the expected utility theory. Prospect theory has been widely applied in finance, insurance, industrial organization, and many other fields of economics (see a comprehensive review by Barberis, 2013), but applications of prospect theory to farmers' crop-adoption decisions are few. Based on a field experiment, Liu (2013) examines 320 Chinese farmers' adoption decisions on a new cotton variety. Bocquého (2012) surveys 102 farmers in the eastern France and finds that farmers who are more sensitive to losses are less willing to adopt miscanthus. Our study significantly differs from Bocquého (2012) in terms of both methodology and data. We employ a numerical simulation approach to examine the county-level bio-energy crop adoption and production in the rainfed region of United States under various loss preference parameters, credit availability, biomass prices, and interest rates. Bocquého (2012), however, utilizes a survey approach focusing on a small number of French farmers.

We first develop a conceptual framework that models a representative farmer's optimal land allocation problem between conventional crops (corn rotated with soybeans in this study) and bio-energy crops (miscanthus and switchgrass in this study) based on prospect theory. We then conduct numerical simulation for 1,919 U.S. counties east of the 100th Meridian that have yield data for corn and for at least one bio-energy crop, miscanthus or switchgrass, on high or low quality land. The analysis is of practical importance because it a) facilitates farmers' bio-energy crop adoption decisions by providing them with a reference regarding the profile of bio-energy crops' profits; and b) assists potential cellulosic biorefinery investors in their plant location decisions by providing them with geographical configuration of areas where the perennial bio-energy crop production is most viable. The analysis also sheds light on how accounting for farmers' loss aversion may affect predictions on farmers' adoption behavior. To our best knowledge, the study is the first that takes into account farmers' loss preference when modeling farmers' adoption of bio-energy crops in the rainfed region of the United States. Thus it extends the previous studies that are based on expected utility theory and deepens our understanding of farmers' behavior toward adoption of bio-energy crops.

Our results show that ignoring farmer's loss aversion may over-estimate miscanthus production and under-estimate switchgrass production. Our results also indicate that bio-energy crop production on marginal land is more resilient to accounting for farmers' loss aversion. Therefore, the results lend support to possible policy interventions that encourage biomass production on marginal land, for example, interventions allowing biomass harvesting on land in the Conservation Reserve Program (CRP) without imposing a program payment reduction.[1] We find that when farmers are credit constrained, biomass production from bio-energy crops is more sensitive to farmers' loss aversion than when farmers are not credit constrained.[2] This indicates that the availability of credit to farmers mitigates the effect of their loss preferences for bio-energy crop production. Results also show that impact of loss aversion under high interest rate is larger as compared to that under scenario with low interest rate. Moreover, geographical configuration of miscanthus and switchgrass adoption may differ significantly when farmers' loss aversion parameters, credit constraint status, and interest rates change. Our analysis highlights the importance of policy intervention that may mitigate the loss prospect of bio-energy crops, such as financial supports from the Biomass Crop Assistance Program and bio-energy crop insurance program.

2. Conceptual framework

In this section we first discuss the key components of prospect theory and then display a representative farmer's optimal land allocation decision problem under prospect theory. In addition to reflecting disutility from income volatility, prospect theory considers a few more features regarding people's preferences toward risky enterprise.

---

[1] As of 2017, CRP participants who harvest biomass on CRP land receive a 25% payment reduction. We refer readers to Anderson et al. (2016) for a study regarding using CRP land as a potential source of biomass production.

[2] Credit constraint is relevant to bio-energy crop adoption because the establishment of bio-energy crops will incur large costs and potential adopters may have difficulties to obtain loans to finance such establishment. Kirwan (2014) states that ". . . 6.2% of large commercial farms with over $500,000 in sales reported having been turned down for a loan." Since potential adopters for bio-energy crops are more likely to be young and beginning farmers (Gedikoglu 2015), we expect that credit constraint may be more of an issue for these farmers.

First, unlike expected utility theory, when evaluating returns prospect theory differentiates gains from losses relative to a reference point of return. Returns higher than the reference point are gains whereas returns lower than the reference point are losses. For a loss averse decision maker, the magnitude of disutility from a certain amount of loss is larger than the magnitude of utility from the same amount of gain. This feature is reflected in prospect theory's value function. Suppose that there are $m+n$ possible realizations for an enterprise's random profit π, where *m* and *n* are the number of losses and gains, respectively. Let π_k be a realization of π, where $k \in \Omega \equiv \{-m, 1-m, ..., -1, 1, ..., n\}$. We sort the realizations in ascending order so that $\pi_k \le \pi_{k'}$ if and only if $k \le k'$. The probability that π_k occurs is q_k. Following Tversky and Kahneman (1992), the value function for a profit realization π_k is specified as

$$v(\pi_k) = \begin{cases} (\pi_k - R)^\alpha & \text{if } \pi_k \ge R \\ -\lambda[-(\pi_k - R)]^\alpha & \text{if } \pi_k < R, \end{cases} \tag{1}$$

where R is the reference point, λ is the loss aversion parameter, and α is the risk aversion parameter. When $\lambda > 1$ (respectively, $\lambda = 1$ or $\lambda < 1$) then the farmer is loss averse (respectively, loss neutral or loss loving). Similarly, when $\alpha < 1$ (respectively, $\alpha = 1$ or $\alpha > 1$) then the farmer is risk averse (respectively, risk neutral or risk loving).

Second, prospect theory accounts for experimental observations that decision makers tend to overweight events with small probabilities but underweight events with large probabilities (Kahneman and Tversky, 1979). This feature is reflected by a probability weighting function. Following Tversky and Kahneman (1992), the probability weighting functions can be specified as:

$$\begin{cases} w^{+}(\phi_k) = \dfrac{\phi_k^{\gamma}}{(\phi_k^{\gamma} + (1-\phi_k)^{\gamma})^{1/\gamma}}, & \text{for gains} \\ w^{-}(\phi_k) = \dfrac{\phi_k^{\delta}}{(\phi_k^{\delta} + (1-\phi_k)^{\delta})^{1/\delta}}, & \text{for losses,} \end{cases} \tag{2}$$

where ϕ_k is the accumulative probability of profit realization π_k; γ and δ are non-stochastic parameters. If $\pi_k \geq R$ then $\phi_k = \Pr\{\pi \geq \pi_k\}$ whereas if $\pi_k < R$ then $\phi_k = \Pr\{\pi \leq \pi_k\}$. It is readily checked that $w^{+}(\cdot)$ and $w^{-}(\cdot)$ are strictly increasing functions with both domain and range as [0, 1], such that $w^{+}(0) = w^{-}(0) = 0$ and $w^{+}(1) = w^{-}(1) = 1$. The decision weight for profit realization π_k is then specified as:

$$d_k = \begin{cases} w^{+}(q_n) & \text{if } k = n, \\ w^{+}(\phi_k) - w^{+}(\phi_{k+1}) & \text{if } 1 \leq k < n, \\ w^{-}(\phi_k) - w^{-}(\phi_{k-1}) & \text{if } -m < k \leq -1, \\ w^{-}(q_{-m}) & \text{if } k = -m. \end{cases} \tag{3}$$

Unlike sum of probabilities being equal to 1, sum of decision weights is not necessarily equal to 1. Based on equations (1) and (3), the enterprise's prospective value to the decision maker is $\sum_{k \in \Omega} d_k v(\pi_k)$.

Based on prospect theory, we then consider a representative farmer who is optimally allocating a unit of land between conventional crops and a bio-energy crop to maximize her prospective value from her land. Corn stover, as a by-product of corn, may be harvested for biomass. The farmer's land is normalized to 1 unit. It consists of two types of land: high quality land at portion s^h and low quality land at portion $s^l = 1 - s^h$, where superscripts *h* and *l* stand for high and low quality land, respectively. For high quality land, the farmer decides the optimal land division between two uses: growing conventional crops (labeled as *c*) and growing an energy crop (labeled as *e*). For low quality land, the farmer decides the optimal land division among three uses: keeping under original use (labeled as *o*) such as idle or pasture, growing conventional crops, and growing an energy crop.

Let x^{ij} denote land acreage under use $i \in \{c,e,o\}$ and quality type $j \in \{h,l\}$.[3] Clearly, we have $x^{ch} + x^{eh} = s^h$ and $x^{ol} + x^{cl} + x^{el} = s^l$. Furthermore, let π^{ij} be the profit per unit of land with use *i* and quality *j*. Therefore, for a given set of land-use allocation, x^{ij}, the farmer's profit from her land is:

$$\pi = \sum_i \sum_j x^{ij} \pi^{ij}. \tag{4}$$

Let y_t^{ij} denote the stochastic yield of crop $i \in \{c,e\}$ in year *t* on land with quality type $j \in \{h,l\}$. Price of crop *i* in year *t* is represented by p_t^i. The price of the conventional crop is a stochastic variable, whose distribution is known to the farmer. For bio-energy crops, production is assumed to occur under a long term fixed price contract between the farmer and a biorefinery to ensure certainty of supply of biomass for the biorefinery (Yang, Paulson, and Khanna, 2016). Under such a contract, biomass price is fixed at p_t^e over its lifespan and we assume that this price is the same for miscanthus, switchgrass, and corn stover. The fixed and variable costs of producing crop *i* in year *t* are represented by f_t^i per unit of land and v_t^i per unit of yield, respectively. Because more than 80% of major crops' acreage is covered under federal crop insurance in the United States (Shields, 2015), we include indemnity payments provided by crop insurance in farmer's profits from conventional crops. In this study we consider revenue insurance which is widely used for conventional crops by US farmers (Shields 2015). The

---

[3] Based on the land-use assumption on high quality land, we have $x^{oh} = 0$.

indemnity payment per unit land in year *t* and on land type $j \in \{h, l\}$ for a conventional crop is specified as

$$\iota_t^{cj} = \max\{\theta^c \mathrm{E}(y_t^{cj}) \max[p_t^{\mathrm{proj}}, p_t^{\mathrm{harv}}] - p_t^{\mathrm{harv}} y_t^{cj}, 0\}, \tag{5}$$

where θ^c is insurance coverage level for the conventional crop; $\mathrm{E}(\cdot)$ is the expectation operator; p_t^{proj} and p_t^{harv} are respectively projected price and harvest price established by Risk Management Agency (RMA) (2011) of U.S. Department of Agriculture (USDA). The profit per unit of land for the conventional crop in year *t* on land with quality type *j* can then be written as

$$\pi_t^{cj} = (p_t^c - v_t^{cj}) y_t^{cj} - f_t^{cj} + \iota_t^{cj} - (1-\rho)\mathrm{E}[\iota_t^{cj}], \tag{6}$$

where ρ is insurance premium subsidy rate for the conventional crop.

Yield of the energy crop depends on the crop's age. Assuming a *T*-year lifespan, we define the first $\tau < T$ years in the lifespan as the establishment period and years $\tau + 1$ to *T* is the mature period. Since we are also interested in how credit constraint will affect biomass production, we consider the profit of growing bio-energy crops over the lifespan with and without credit constraint. When there is no credit constraint, then the farmer can obtain a loan to finance the establishment cost of bio-energy crops and then payback the loan in mature years with an annuity. When there is credit constraint, however, then such a loan is not available. Let *I* be a credit constraint indicator which equals 0 if there is no credit constraint and 1 if there is. The energy crop's profit in *t*th year of a lifespan on land with quality type *j* can be specified as

$$\pi_t^{ej} = \begin{cases} (p_t^e - v_t^{ej}) y_t^{ej} - f_t^{ej} I, & t \in \{1, \ldots, \tau\} \\ (p_t^e - v_t^{ej}) y_t^{ej} - f_t^{ej} - (1-I) A(f_1^{ej}, \ldots, f_\tau^{ej}, r), & t \in \{\tau + 1, \ldots, T\}, \end{cases} \tag{7}$$

where $A(f_1^{ej}, \ldots, f_\tau^{ej}, r)$ is the annuity the farmer needs to pay back due to the loan for establishment cost. By inserting equations (6) and (7) into equation (4) we obtain the total profit the farmer obtains from her land under a given set of land allocation x^{ij}.

Since the farmer's problem is to decide how much land should be allocated to the energy crop, a natural reference point to be used to differentiate gains and losses is the expected profit from original land use when energy crop is absent. Therefore, we set the reference point to be the expected profit from devoting all high quality land to conventional crop and keeping all low quality land under its original use such as idle or pasture. That is, we have

$$R = \mathrm{E}(s^h \pi^{ch} + s^l \pi^{ol}). \tag{8}$$

Based upon the prospect theory we have described above, the farmer's optimization problem can be specified as:

$$\begin{gathered} \max_{x^{ch}, x^{eh}, x^{ol}, x^{cl}, x^{el} \geq 0} \sum_{t=1}^{\Gamma} \beta^{t-1} [\sum_{k \in \Omega_t | x^{ij}} d_{kt} v(\pi_{kt})] \\ \text{s.t.} \quad x^{ch} + x^{eh} = s^h, \text{ and } x^{ol} + x^{cl} + x^{el} = s^l, \end{gathered} \tag{9}$$

where Γ is the tenure of the land; $\beta \in [0,1]$ is a value discount factor; π_{kt} is profit realization k in year t (described in equation (4)) and d_{kt} is the associated decision weight (described in equation (3)) in year t; and $\Omega_t \mid x^{ij}$ is the set Ω in year t for a given set of land allocation, x^{ij}. Set $\Omega_t \mid x^{ij}$ is determined in the following way. First, for a given set of land allocation $\{x^{ch}, x^{eh}, x^{o}, x^{cl}, x^{el}\}$, we obtain N (N=1,000 in this study) realizations of profit from the land. Second, we subtract the reference point profit R from profit under each realization. Finally, we sort these differences ascendingly and identify the number of losses, m, and gains, n, for set $\Omega_t \mid x^{ij}$ (negative differences indicate losses and positive differences indicates gains).

3. Simulation Approach and Data

Our simulation includes 1,919 counties in the rainfed region of the United States. Each county is assumed to be represented by a farmer who optimally allocates her land among various uses under the aforementioned framework. Following previous literature (e.g., Jain *et al.*, 2010; Chen *et al*., 2014; Miao and Khanna, 2017a,b), we assume that the lifespan of miscanthus is 15 years whereas the lifespan of switchgrass is 10 years. We consider a 30-year land tenure framework under which miscanthus can finish two lifecycles and switchgrass can finish three, i.e., $\Gamma = 30$ in equation (9). We assume that low quality land is originally in a low-risk-low-return activity (e.g., enrollment in a conservation program) and, therefore, the profit per unit of low quality land under its original use, π^{ol}, is approximated by land rent payments of the Conservation Reserve Program. We use corn rotated with soybeans to represent conventional crops. Further, following Miao and Khanna (2017b) we only allow the representative farmer in a county to choose either miscanthus or switchgrass but not both for bio-energy crop adoption.[4] That is, a farmer first chooses the prospective value maximizing land allocation between miscanthus and the conventional crops and then, separately, between switchgrass and the conventional crops. Then the farmer selects the bioenergy crop under which her land generates larger maximum prospect value. The simulation is conducted by using MATLAB®.

For the simulation, we employ a copula approach to estimate a joint yield-price distribution for each county in order to reflect stochastic crop yields, stochastic prices of corn and soybeans, and the correlations among these yields and prices. Copula approach has been utilized to model joint distributions due to its flexibility (Yan, 2007; Du and Hennessy, 2012). A joint yield-price distribution is estimated for each county for up to eight yields and two crop prices. The eight yields are yields of corn grain, corn stover, soybean grain, and miscanthus (or, separately, switchgrass) on both high and low quality land.[5] The two prices are corn and soybean

---

[4] This is a simplifying assumption which significantly reduces the computational burden.

[5] Not every county has all these eight yields. For example, a county may only have corn and miscanthus yields on high-quality land. We refer readers to Miao and Khanna (2017b) for detailed description regarding the crop yield data availability and for the copula approach employed in this study.

grain prices. In the simulation we obtain 1,000 draws from the estimated yield-price joint distributions, where each draw is a yield-price vector. Biomass price is not included in the joint yield-price distribution, as it has been assumed to be a constant. In the remaining part of this section we describe data and parameters used in the simulation.

3.1. Crop yields

Due to the lack of large scale commercial production, we obtain county-level yield data for both miscanthus and switchgrass on high and low quality land by using DayCent model. DayCent is the daily time-step version of the CENTURY biogeochemical model that is widely used to simulate plant growth based on information of precipitation, temperature, soil nutrient availability, and land-use practice (Del Grosso *et al.* 2011, 2012; Davis *et al*. 2012).[6] County-level weather information over 1980-2003 assuming a 24-year cycling of weather condition is used as part of the input for the DayCent model simulation that provides us with 27-year annual yield data. Table 1 presents summary statistics of the data simulated by DayCent. We can see that on high and low quality land, the average yield of miscanthus is 27.2 and 26.8 metric tons per hectare (MT/ha) at 15% moisture and for switchgrass the two corresponding numbers are 14.1 and 12.7 MT/ha, respectively.

Miscanthus is assumed to have no harvestable yield in the first year of a lifecycle. If the first-year establishment is successful then the farmer will obtain 50% of mature yield in the second year, and full mature yield in the third year and onward within the lifecycle. For

---

[6] In DayCent model, the high quality land is approximated by land under crop production whereas the low quality land is approximated by land under pasture. Together with land management practice and observed daily weather information, properties of dominant soil type of cropland and pasture land in each county are used in input files to simulate crop yields on high quality land and low quality land, respectively. We refer readers to Miao and Khanna (2017b) for a detailed description about calibration and validation of DayCent yield simulation.

miscanthus, we also assume that there is a 10% probability of a complete crop failure in the first year of establishment by following Skevas *et al*. (2016), as extreme cold weather can completely destroy miscanthus rhizomes. In the case of complete crop failure, the grower will have to re-establish in the second year, and therefore she will have no harvest in the second year, 50% of mature yield in the third year, and full mature yield in the fourth year and onward of the lifecycle. Note that there will be establishment cost again in the second year in case of a complete crop failure. For simplicity we assume that the re-establishment will be successful for sure. For switchgrass, we assume that there is no crop failure by following Skevas *et al*. (2016) and the yield reaches its full potential in the first year of a lifecycle.

Although historical yield data for conventional crops are available from National Agricultural Statistics Service (NASS) of USDA, in order to ensure consistency in the methodology underlying yield estimates across all crops considered in this study, we have also utilized DayCent model to obtain simulated yields for corn grain, corn stover, and soybean grain on both high and low quality land. Use of DayCent-simulated corn and soybean yields provides an additional advantage that we do not need to rely on arbitrary assumptions to obtain corn or soybean yields on low quality land, or to obtain corn stover yield.

Following Miao and Khanna (2017a,b), we assume that corn is grown continuously in those counties that do not have soybean yield data in the DayCent simulated dataset. In counties with soybean data, corn is assumed to be rotated with soybeans. Our data show that corn grain harvested on high and low quality land are 139.1 bushel/acre and 127.2 bushel/acre, respectively (Table 1), indicating that on average corn grain yield on low quality land is about 9% lower than that on high quality land. For soybeans, however, the yield difference between low quality land and high quality land is only about 3%. Yields for corn stover harvested on high and low quality land are 2.6MT/ha and 2.4MT/ha, respectively. We assume that farmers harvest a fixed portion (30% in this study) of produced stover, as there is no consensus yet on how much corn stover should be left in the field to maintain soil organic carbon and to manage erosion.[7]

3.2. Crop Prices

In the simulation, we use three different types of prices of corn and soybeans: received prices, projected futures prices, and harvest futures prices. State-level received prices from NASS are used to calculate realized profits of corn and soybeans, whereas projected futures prices and harvest futures prices are used to calculate crop insurance indemnity for corn and soybeans. These futures prices are determined by following RMA (2011) rules based on Chicago Board of Trade (CBOT) futures prices. We obtain the CBOT futures prices of corn and soybeans over 1980-2010 from Barchart.com. All these prices have been converted to 2010 dollars using the Gross Domestic Product implicit price deflator. Following Miao and Khanna (2017b), prices in each year are assumed to be drawn from the same price-yield joint distribution obtained by using the aforementioned copula approach.[8] As we have discussed above, biomass price is assumed to be fixed over the farmer's planning period under a long-term contract, and we have considered farm-gate biomass prices which do not include transportation cost from farms to bio-refineries. To see the impact of different biomass prices on farmers' decisions, we use a range of prices from \$20/MT to \$100/MT with a step of \$10/MT.

---

[7] Due to lack of knowledge of how advances in technology or crop management will improve energy crop yields, we do not include an upward yield trend for these crops in DayCent simulations. Introducing a yield trend parameter will add another layer of uncertainty to the results. Accordingly, to ensure consistency we do not assume yield trends for conventional crops either.

[8] We assume away the autocorrelation of prices across years and the possibility that the distribution of conventional crop prices may be affected by land conversion from conventional crop to energy crop production. It is expected that relaxing this assumption will not affect the study's core insights but will make analysis more complex and less transparent.

3.3. Production Costs

The county-specific production costs of the crops considered in this study are basically the same as those used in Chen *et al*. (2014) and Miao and Khanna (2017a,b). The method and assumptions underlying the calculation of these county-specific production costs of miscanthus, switchgrass, corn, and soybeans in the rain-fed region are described in Khanna, Dhungana, and Clifton-Brown (2008), Jain *et al*. (2010), and Chen *et al*. (2014). The only adjustment about the costs that we make in the present study is that for miscanthus we exclude the re-establishment cost in the second year of a lifecycle if the first-year establishment is successful. We do so because we assume that the first-year establishment is either a complete failure with probability 0.1 or a complete success with probability 0.9.[9] In the first year of establishment, the cost of miscanthus is about $3,108/ha (Table 1), including expenses on rhizomes, planting machinery, fertilizer, and land preparation. If the first-year establishment is a failure, then the farmer will have to incur the same total establishment cost again in the second year. If the first-year establishment is a success, then in the second year and onward, production costs include expenses on fertilizer, labor, fuel, and machinery for harvesting, baling, transportation, and storage. We divide these costs into variable cost and fixed cost. On average the variable cost is $17.2/MT and the fixed cost is $166/ha (Table 1).

For switchgrass, the variable cost is the same as that of miscanthus. The fixed cost, however, differs in the first three years of a lifecycle due to different management in these years. On average the fixed cost of switchgrass is $333/ha, $255/ha, and $252/ha for first, second, and third year, respectively, within one lifecycle. For conventional crops, the production costs

---

[9] Chen *et al*. (2014) and Miao and Khanna (2017a,b), however, assume that the first-year establishment is always successful but 10% replanting rate in the second year is required.

including fertilizer, chemicals, seeds, harvesting, drying, and storage are collected from crop budgets compiled by state extension services (Chen *et al*. 2014). For corn, the average annual fixed and variable costs are \$136.5/acre and \$1.3/bushel, respectively, whereas for soybeans, the two corresponding costs are \$107.4/acre and \$1.5/bushel, respectively. For corn stover, the variable cost (\$17.5/MT) is close to that of miscanthus and switchgrass while the fixed cost (\$48.5/ha) is much lower than that of the two bio-energy crops. We assume that within a county the fixed and variable costs for a crop are the same on low and high quality land.

3.4. Discount Factor, Risk and Loss Aversion Parameters, Land Availability, and Farm Size

The discount factor, $\beta,$ in equation (9) is calculated by $\beta = 1/(1+r),$ where *r* is interest rate. The interest rate takes two values in our simulation: 2% for low interest rate and 10% for high interest rate. The values for risk and loss aversion parameters are directly obtained from the literature. Tversky and Kahneman (1992) take value of risk aversion parameter at $\alpha = 0.88$ and value of loss aversion parameter at $\lambda = 2.25.$ For the two parameters in probability weighting functions (i.e., γ and δ), they have $\gamma = 0.61$ and $\delta = 0.69$. These values are used by Babcock (2015) as well. In the simulation we vary the loss aversion parameters, interest rate, as well as credit constraint status to study how biomass production responds to these variations.

Studies have shown that due to various reasons, farmers' willingness to convert land to biomass production is limited. Skevas, Swinton, and Hayden (2014) document that the loss of amenity value of land is a concern when farmers consider growing bioenergy crops. Based on a survey on 1,124 private landowners, Swinton *et al*. (2017) find that the landowners are only willing to rent up to 23% of their land to bioenergy crop production even the proposed rents are double of market rents. Therefore, for each county we limit the amount of land that can be used for bioenergy crops to no more than 25% of the sum of high and low quality land in the county.

The average acreage of high and low quality land per county is 28,841 hectares and 4,507 hectares, respectively, prior to any land availability restriction for perennial energy crops (Table 1). Farm size is one of the factors that determine the magnitudes of losses and gains for a farm. Following Miao and Khanna (2017b), we use data for county-level average farm size from the 2012 Census of Agriculture. The average farm size across counties in our dataset is 139 hectares.

4. Profitability and riskiness

Before we discuss the simulation results regarding bio-energy crop adoption, we first examine the profitability and riskiness of the conventional crops and bio-energy crops covered in this study. We use a crop's expected 30-year net present value (NPV) of profits as a measure of the crop's profitability.[10] We do so because crops covered in this study have different lifespans (1 year for the conventional crops, 15 years for miscanthus, and 10 years for switchgrass) and thus the use of expected 30-year NPV of profits makes the profitability comparable across crops. Table 2 presents summary statistics for crop profitability and riskiness when biomass price is assumed to be \$50/MT or \$100/MT. These two prices are chosen because \$50/MT (respectively, \$100/MT) is a price close to the average breakeven price of biomass grown on marginal land (respectively, cropland) as calculated by Miao and Khanna (2014). When biomass price is \$50/MT, then the conventional crops are the most profitable (\$6,264/ha and \$5,580/ha on high and low quality land, respectively) and miscanthus is the least profitable (\$1,417/ha and \$1,304/ha on high and low quality land, respectively). When biomass price is \$100/MT, however, then miscanthus is most profitable and the conventional crops are the least (see Table 2). As expected, profitability of a crop on high quality land is higher than that on low quality land. Across the three crops, the difference between high quality land profitability and low

---

[10] Interest rate used to calculate the NPV is 10%.

quality land profitability is smallest under miscanthus. For instance, when biomass price is $50/MT, miscanthus' profitability difference between high and low quality land is only $113/ha ($1,417/ha minus $1,304/ha, an 8% difference). For the conventional crop and switchgrass, the corresponding numbers are $684/ha (an 11% difference) and $433/ha (a 19% difference), respectively.

The four maps in the upper panel of Figure 1 depict profitability difference between miscanthus and the conventional crops under two biomass prices ($50/MT and $100/MT) and two land types (high and low quality). The four maps in the lower panel are the counterparts for profitability difference between switchgrass and the conventional crops. We find that the profitability difference between miscanthus and the conventional crops on low quality land is larger than that on high quality land. This is intuitive because the profitability of conventional crops on low quality land is much lower than that on high quality land whereas for miscanthus the profitability on these two types of land is close. Figure 1 shows that miscanthus and switchgrass, relative to the conventional crops, are more profitable in the southeastern U.S. and less profitable in the north Great Plains. One possible explanation is that the average yields of miscanthus and switchgrass are highest in the southeastern U.S. but lowest in the north Great Plains (see Figure 1 in Miao and Khanna, 2014).

Regarding crop riskiness we first examine the coefficient of variation (CV) of profits for each crop. The county-level CV of profits from a crop grown on land with a certain quality in each county is calculated based on the 1,000 yield-price draws generated by using the aforementioned copula approach.[11] The CV values presented in Table 2 that are associated with

---

[11] Note that each yield-price draw is corresponding to a realization of profit. Therefore, we obtain 1,000 realizations of profits from the 1,000 yield-price draws. Then the county-level CV

profitability are averages of county-level CVs across all counties. From Table 2 we can see that the average CV is significantly affected by biomass prices. When biomass price is \$50/MT, then miscanthus (with CV around 2) is riskier than the conventional crops (with CV around 0.5) and switchgrass (with CV around 1). When biomass price is \$100/MT, however, the CV of miscanthus' 30-year NPV of profits is the lowest across the three types of crops (see the 3rd panel in Table 2).

To explore a crops' loss prospect, we also calculate the probability of having a negative 30-year NPV of profits for each crop (Table 2). The calculation is conducted for each county on both high and low quality land under biomass prices \$50/MT and \$100/MT, respectively.[12] Results show that under biomass price at \$50/MT, the average probability of having a negative 30-year NPV of profits from growing miscanthus on high and low quality land is about 28.4% and 29.9%, respectively (see Table 2). At the same biomass price, the corresponding numbers for switchgrass is 10.8% and 16.8%, respectively, which are much lower than those of miscanthus. When biomass price is \$100/MT then the probability of having a negative 30-year NPV of profits from miscanthus is 2.4% on high quality land and 2.8% on low quality land. For switchgrass, the two corresponding probabilities are 1.1% and 1.9%, respectively.

Maps in Figure 2 show the difference in probability of negative 30-year NPV of profits between bio-energy crops and the conventional crops. We find that when biomass price is \$50/MT then for almost every county the probability of having a negative 30-year NPV of

---

of profits is the standard deviation of the 1,000 realizations of profits divided by the mean of these 1,000 realizations of profits.

[12] For a crop grown on a type of land in a county, the probability is calculated by counting number of draws that result in a negative 30-year NPV in the county and then dividing this number by 1,000, the total number of draws for each crop, land quality, and county combination. The values presented in Table 2 are averages across counties.

profits from growing bio-energy crops is larger than that from growing the conventional crops. However, when biomass price is \$100/MT, then for most counties in the Midwest and some counties in the southeastern United States the probability of having negative NPV from growing bio-energy crops is smaller than that from growing conventional crops. In the north Great Plains, growing bio-energy crops endures larger probability of having negative 30-year NPV of profits than does growing the conventional crops under both prices. The geographical patterns of biomass profits and probabilities of having negative NPV will in part determine the geographical configuration of biomass production when farmers' loss aversion is considered. We examine the impact of loss aversion next.

5. Simulation Results

We conduct our simulation under eight scenarios, which are the combinations of two interest rates (2% and 10%), two credit constraint status (credit constrained and not credit constrained), and two loss aversion parameter values ($\lambda = 1$ for loss neutral and $\lambda = 2.25$ for loss averse). Under each of these eight scenarios, we study the representative farmer's optimal land allocation in each county under biomass prices ranging from \$20/MT to \$100/MT with a \$10/MT step. Then we compare simulation results across the eight scenarios to identify the impact of loss aversion on bio-energy crop adoption and how the impact is influenced by interest rate and credit constraint. We use biomass production and land devoted to bio-energy crops as measures of bioenergy crop adoption.

5.1. Effect of loss aversion on biomass production

Figure 3 presents simulated biomass supply curves for corn stover, miscanthus, switchgrass, and total biomass grown on both types of land under the eight scenarios.[13] It shows that biomass production from miscanthus and switchgrass commences effectively at biomass price of $50/MT or higher. From the figure we find that in most cases supply of miscanthus is elastic when biomass price is between $60/MT and $80/MT but inelastic when biomass price is larger than $80/MT. This is because when biomass price rises from $60/MT to $80/MT, in many counties miscanthus production just surpasses the margin to be profitable when compared with conventional crops and switchgrass. Therefore, miscanthus production is sensitive to biomass price when the price is in the $60-80/MT range. When biomass price increases above $80/MT, however, then acreage for bio-energy crops in many counties reaches the 25% limit of total land and hence becomes less responsive to biomass prices. Supply of switchgrass is inelastic due to its low yield and hence low competitiveness relative to miscanthus. Across the eight scenarios, corn stover production is insensitive to biomass price and may even slightly decrease as biomass price increases from $50/MT to $100/MT. This is because a) profits from corn stover only account for a small portion of total profits from growing corn and b) as biomass prices rises to $100/MT, corn acreage faces increasing competition from bio-energy crops.

The four graphs in the upper panel of Figure 3 show that when farmers are credit constrained, then all else equal, miscanthus production under loss averse scenario is much lower than that under loss neutral scenario. The opposite is true for switchgrass, which indicates that when farmers are credit constrained, ignoring loss aversion may overestimate miscanthus production while underestimate switchgrass production. This finding is intuitive because on

---

[13] Figures SI-1 and SI-2 in the online Supporting Information (SI) present the supply curves for biomass produced on high and low quality land, respectively.

average miscanthus has the highest probability of having negative 30-year NPV of profits among the crops covered in this study (see Table 2). Moreover, when farmers are credit constrained and hence cannot finance miscanthus' high establishment costs by using loans, then high establishment costs and no harvest in the establishment period will result in high losses in the period when compared with only growing the conventional crops. Therefore, for a loss-averse farmer who is credit constrained, miscanthus will be less appealing.

When farmers are not credit constrained, however, accounting for loss aversion has small impacts on biomass production (see supply curves in the four graphs of the lower panel of Figure 3). One explanation is that in the absence of credit constraint, farmers can finance their establishment costs so that the loss in the establishment period is significantly reduced and hence returns across periods become less volatile. Moreover, the low or even negative correlation between miscanthus yield and corn yield (see Table 1 of Miao and Khanna (2014)) provides farmers with diversification benefits from having a mix of the two crops. As the availability of credit reduces the loss in establishment period, this diversification benefits becomes more appealing under the loss aversion scenario when compared with that under the loss neutral scenario. This is because a mix of crops with low or negative yield correlation will make the overall profits less likely to fall below the reference profit.

We can see that the availability of credit to farmers mitigates the effect of the farmer's loss preferences on perennial energy crop production. This finding is consistent with the one in Miao and Khanna (2017b) who find that when farmers are not credit constrained then biomass production is insensitive to changes in risk aversion. Therefore, our results lend support to policy interventions (e.g., the Biomass Crop Assistance Program) that provide establishment cost shares for bio-energy crop growers.

In order to examine the impact of loss aversion on biomass production in greater detail, we present the optimal biomass production under four loss-and-time preference combinations with credit constraint and with biomass price being set to be \$50/MT or \$100/MT (see Table 3).[14] In Table 3, comparison between columns 1 and 2 (cases of high interest rate) shows that when biomass price is \$50/MT then accounting for loss aversion will decrease miscanthus production from 0.4 million MT to almost zero. However, it will increase switchgrass production from 1 million MT to 1.4 million MT. Overall, when biomass price is as low as \$50/MT, the impact of loss aversion is small because at this price bioenergy crops are generally not much viable.

Under the \$100/MT price, when loss aversion is accounted for then miscanthus production on high quality land decreases from 213.3 million MT to 128.8 million MT, which is a 40% decrease, whereas miscanthus production on low quality land only decreases by 19%. The reason for the smaller decrease in miscanthus production on low quality land is that, as we have discussed above, the profitability difference between miscanthus and the conventional crops on low quality land is larger than that on high quality land (see the 3rd panel in Table 2), which causes miscanthus to be more likely viable on low quality land even when loss aversion is considered. For switchgrass, the comparison between columns 1 and 2 in Table 3 shows that when loss aversion is accounted for then total switchgrass production on high quality land increases from 10.7 million MT to 34.6 million MT, which is a 223% increase, whereas the production on low quality land increases only by 80%. The larger increase in switchgrass production on high quality land is because that switchgrass has much higher profitability and much lower probability of having a negative 30-year NPV on high quality land than on low

---

[14] Table SI-1 includes the counterpart results under scenarios without credit constraint.

quality land (see the 3rd and 4th panels in Table 2). In sum, we find that for both miscanthus and switchgrass the production on low quality land is less sensitive to loss aversion than production on high quality land is. This finding underscores the importance of marginal land for producing bio-energy crops.

By comparing columns 3 and 4 in Table 3 (cases of low interest rate), we find that at \$100/MT biomass price when loss aversion is accounted for then miscanthus production on high and low quality land decreases only by 5% (from 237.5 million MT to 225.7 million MT) and 4% (from 77.2 million MT to 73.8 million MT), respectively. We can see that the impact of loss aversion is smaller when interest rate is low as compared to when interest rate is high. This is because a lower interest rate implies a higher prospective value discount factor (recall that $\beta = 1/(1+r)$). As a result, returns in mature period of a bio-energy crop will be valued more and losses in the establishing period will account for a smaller portion of a bio-energy crop's overall prospective values. Therefore, impact of losses in the establishing period will be mitigated by a lower interest rate (i.e., a higher discount factor).

Overall, we find that the impact of loss aversion is the largest when biomass price is high, farmers are credit constrained, and interest is high. Figures 4 and 5 depict county level miscanthus and switchgrass production respectively under various scenarios.[15] Figure 4 shows that when biomass price increases from \$50/MT to \$100/MT then expansion in miscanthus production mainly occurs at the extensive margin (i.e., new counties commence miscanthus production). The same pattern holds for switchgrass production (see Figure 5). However, when we shift from the credit constraint, loss aversion, and high interest rate scenario to the no credit

---

[15] To save space, we include maps for total biomass production and corn stover production under the same scenarios in the SI (see Figures SI-3 and SI-4).

constraint, loss neutral, and low interest rate scenario, then the expansion in miscanthus production mainly occurs at the intensive margin (i.e., existing producing counties produce more). For switchgrass, the same scenario change causes the number of producing counties to decrease (see Figure 5). Moreover, when biomass price is $50/MT, then miscanthus and switchgrass production is mainly distributed in counties outside of the central Midwest. However, when biomass price is $100/MT, then miscanthus production mainly occurs in the Midwest while switchgrass production still occurs outside the Midwest. This is because a) miscanthus has relatively high yield and low risk in the Midwest (see Table 1 in Miao and Khanna (2014)); and b) switchgrass cannot compete with corn or miscanthus in this region.

Figure SI-3 shows that the Midwest is the major biomass producing region across all scenarios. This is mainly because farmers' risk preferences, interest rate, and credit situation are unlikely to change farmers' decision on whether to provide corn stover in the Midwest (see Figure SI-4) as corn stover is even profitable at $40/MT biomass price and profits from corn stover only accounts for a small portion of total profits from growing corn. Moreover, when biomass price is $100/MT, then the Midwest also becomes the major producing region for miscanthus (see Figure 4).

5.2. Land use for miscanthus and switchgrass

Land use for bio-energy crops is critical because it pertains issues of food/fuel competition and of ecosystem services associated with biomass production. Table 4 presents acreages devoted to miscanthus and switchgrass under four scenarios with credit constraint. By comparing columns 1 and 2 (cases of high interest rate) in the table, we find that acreages on both types of land devoted to miscanthus is lower under loss aversion scenario when compared with those under loss neutral scenario at both price levels. Specifically, when biomass price is $100/MT, then accounting for loss aversion will decrease use of high quality land for miscanthus from 21,391,023 acres to 12,251,082 acres (a 42% decrease), whereas for low quality land the decrease is only 22%. For switchgrass, however, the comparison of columns 1 and 2 shows that when accounting for loss aversion, then land used for switchgrass increases on both types of land for both biomass prices. Specifically, when the biomass price is \$100/MT, then accounting for loss aversion will increase use of high quality land for switchgrass from 1,951,209 acres to 6,278,952 acres, which is a 221% increase, whereas for low quality land the increase is only 71%. Again, this is due to switchgrass' higher profitability and lower probability of having a negative 30-year NPV on high quality land as compared to on low quality land.

By comparing columns 3 and 4 in Table 4 (cases of low interest rate), we find that when interest rate is low and when loss aversion is accounted for then miscanthus acreage on high and low quality land decreases by only 6.4% and 6.5%, respectively. For switchgrass, however, the acreages on high and low quality land increases by 169% and 26%, respectively. These results are consistent with the impacts of loss aversion on miscanthus and switchgrass production when interest rate is low. That is, the impact of loss aversion on biomass production is smaller when interest rate is low as compared to when interest rate is high.

When farmers are not credit constrained, then in most cases accounting for loss aversion slightly increases land devoted to miscanthus production (see Table SI-2). The same reasons for why loss aversion slightly increases miscanthus production under scenarios without credit scenarios apply here. For switchgrass, the impact of loss aversion under scenarios without credit constraint depends on biomass price. When biomass price is \$50/MT and when interest rate is high, then accounting for loss aversion will increase total land devoted to switchgrass from 114,056 acres to 197,255 acres, a 73% increase (comparing columns 1 and 2 in Table SI-2). At the same biomass price but low interest rate, the increase is much lower, from 65,275 acres to 84,194 acres, a 29% increase (comparing columns 3 and 4 in Table SI-2). When biomass price is $100/MT, however, under scenarios without credit constraint accounting for loss aversion has only negligible impact on land acreage devoted to switchgrass, regardless the interest rate levels. One explanation is that at a high biomass price such as $100/MT, losses from growing bio-energy crops are unlikely and hence loss aversion parameters have no significant impact on bio-energy crop production. Nevertheless, even when biomass price is as high as $100/MT, credit availability and interest rate are still critical in determining biomass production (see Tables 4 and SI-2).

Figures 6 includes maps for county-level land devoted to miscanthus under various scenarios. The counterpart maps for switchgrass are included in Figure SI-5. In Figure 6, we can see that as we move from credit constraint, loss aversion, and high interest rate scenario (maps in the upper panel) to no credit constraint, loss neutral, and low interest rate scenario (maps in the lower panel), miscanthus production expands in both extensive and intensive margins. In contrast, figure SI-5 shows that for switchgrass the same scenario change results in reduced production. When biomass price is $50/MT then land devoted to miscanthus is mainly located outside of the Midwest, regardless land quality; whereas when biomass price is $100/MT then the Midwest becomes the major producing region for the crop (see Figure 6). From Figure SI-5 we can see that both high and low quality land devoted to switchgrass is located outside of the central Midwest. Particularly, when biomass price is $100/MT then Michigan and Wisconsin can be major producing states of switchgrass, depending on credit availability as well as farmers' loss and time preferences (see Figure SI-5).

6. Conclusions

By employing prospect theory, we find that farmers' attitude toward loss matters when considering bio-energy crop adoption; but the magnitude depends on credit availability, interest rate, biomass price, and crop types. Our results indicate that if farmers are credit constrained then accounting for loss aversion will decrease miscanthus production but increase switchgrass production. However, corn stover production is insensitive to whether loss aversion is considered. If farmers are not credit constrained then accounting for loss aversion has much smaller impact on bio-energy crop production, indicating that the availability of credit to a farmer mitigates the effect of the farmer's loss preferences on perennial energy crop production. Our results show that biomass production on low quality land is less sensitive to farmers' preference toward losses than production on high quality land is. This finding indicates that policymakers should target those areas where share of low quality land is larger for promoting biomass production. Moreover, results show that impact of loss aversion is larger when interest rate is high as compared to scenario when interest rate is low. Our results also show that accounting for loss aversion, credit constraints, and interest rates may predict different geographical configuration of miscanthus and switchgrass production, indicating the importance of loss preferences, credit availability, and time preference in determining crop choices.

Limitations of the present article suggest potential directions for future research. We have assumed that production of energy crops will occur under a long term fixed price contract between farmers and a biorefinery. As contracts for bioenergy crops may have various attributes (Khanna, Louviere, and Yang, 2017), the framework developed in our study can be applied to analyzing the effects of different attributes of contracts on bioenergy crop production. Moreover, although this paper is not focused on any specific policy interventions, the framework developed in this study can be applied to examining the efficiency and land-allocation implications of bio-energy policies that aim to promote biomass production, while accounting for farmers' loss and time preferences.

References

Anand M.,Duffy P.A., Bransby D. 2017. "Will switchgrass as a bio-crop be adopted by the farmers?" A paper presented at Southern Agricultural Economics Association 2017 Annual Meetings, Mobile, Alabama, February 4-7.

Anderson, E.K., E. Aberle, C. Chen, J. Egenolf, K. Harmoney, V.G. Kakani, R. Kallenbach, M. Khanna, W. Wang, and D. Lee. 2016. Impacts of management practices on bioenergy feedstock yield and economic feasibility on Conservation Reserve Program grasslands. GCB Bioenergy, 8: 1178–1190.

Babcock, B.A. 2015. "Using Cumulative Prospect Theory to Explain Anomalous Crop Insurance Coverage Choice." American Journal of Agricultural Economics 97(5): 1371-1384.

Barberis, N.C. 2013. Thirty years of prospect theory in Economics: A Review and Assessment. Journal of Economic Perspectives 27 (1): 173-96.

Bocquého, G. 2012. Risk, time, and adoption of perennial energy crops: insights from the French setting. Ph.D. Dissertation. Paris Institute of Technology for Life, Food and Environmental Sciences, Paris, France.

Chen, X, H. Huang, M. Khanna and H. Onal. 2014.Alternative Fuel Standards: Welfare Effects and Climate Benefits.Journal of Environmental Economics and Management 67(3): 241–257.

Davis, S.C., W.J. Parton, S.J. Del Grosso, C. Keough, E. Marx, P. Adler, E.H. DeLucia. 2012. "Impacts of second-generation biofuel agriculture on greenhouse gas emissions in the corn-growing regions of the US." Frontiers in Ecology and the Environment 10: 69-74.

Del Grosso, S.J., W.J. Parton, C.A. Keough, and M. Reyes-Fox. 2011. "Special Features of the DayCent Modeling Package and Additional Procedures for Parameterization, Calibration, Validation, and Applications", in L.R. Ahuja and Liwang Ma eds. Methods of Introducing System Models into Agricultural Research, p. 155-176, American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI. USA.

Del Grosso, S. J., W.J. Parton, P.R. Adler, S.C. Davis, C. Keough, and E. Marx. 2012. "DayCent Model Simulations for Estimating Soil Carbon Dynamics and Greenhouse Gas Fluxes from Agricultural Production Systems." in M. Liebig, A.J. Franzluebbere, and R. Follett eds. Managing Agricultural Greenhouse Gases: Coordinated Agricultural Research through Gracenet to Address Our Changing Climate: 241-250, Academic Press, Elsevier.

Dolginow, J., R.E. Massey, N.R. Kitchen, D.B. Myers, and K.A. Sudduth. 2014. "A Stochastic Approach for Predicting the Profitability of Bioenergy Grasses." Agronomy Journal 106(6): 2137-2145.

Du, X. and D.A. Hennessy. "The Planting Real Option in Cash Rent Valuation." Applied Economics. 44(2012): 265-276.

Gedikoglu, H. 2015. "Socio-Economic Factors and Adoption of Energy Crops." International Journal of Food and Agricultural Economics 3(1): 1-17.

Hudiburg, T.W., W.Wang, M. Khanna, S. P. Long, P. Dwivedi, W.J.Parton, M. Hartmann, and E.H. DeLucia. 2016. "Impacts of a 32 Billion Gallon Bioenergy Landscape on Land and Fossil Fuel use in the US," Nature Energy 1 (article number: 15005).

Jain, A. K., M. Khanna, M. Erickson, and H. Huang. 2010. “An Integrated Biogeochemical and Economic Analysis of Bioenergy Crops in the Midwestern United States.” Global Change Biology Bioenergy. 2: 217-234.

Kahneman, D., and A. Tversky. 1979. Prospect Theory: An Analysis of Decision under Risk.” Econometrica 61 1291-1326.

Khanna, M., J. Louviere, and X. Yang. 2017. “Motivations to Grow Energy Crops: the Role of Crop and Contract Attributes.” Agricultural Economics 48(3):263-277.

Khanna, M., B. Dhungana, and J. Clifton-Brown. 2008. “Costs of Producing miscanthus and switchgrass for Bioenergy in Illinois.” Biomass and Bioenergy. 32:482-93.

Kirwan, B. 2014. The Crowd-out Effect of Crop Insurance on Farm Survival and Profitability. Paper presented at the Agricultural & Applied Economics Associations 2014 AAEA Annual Meeting, Minneapolis, MN, July 27–29.

Liu, E. 2013. “Time to Change What to Sow: Risk Preferences and Technology Adoption Decisions of Cotton Farmers in China.” The Review of Economics and Statistics 95(4): 1386-1403.

Miao, Ruiqing and Madhu Khanna. 2014. “Are Bioenergy Crops Riskier than Corn? Implications for Biomass Price”. Choices. 29(1).

Miao, Ruiqing and Madhu Khanna. 2017a. “Costs of Meeting a Cellulosic Biofuel Mandate with Perennial Energy Crops: Implications for Policy.” Energy Economics 64: 321-334.

Miao, Ruiqing and Madhu Khanna. 2017b. “Effectiveness of the Biomass Crop Assistance Program: Roles of Behavioral Factors, Credit Constraint, and Program Design.” Applied Economic Perspectives and Policy. DOI: 10.1093/aepp/ppx031.

Risk Management Agency (RMA). 2011. Commodity Exchange Price Provisions (CEPP). Available at: http://www.rma.usda.gov/policies/cepp.html (accessed on December 12th, 2017).

Shields, D. 2015. “Federal Crop Insurance: Background.” CRS Report for Congress, Congressional Research Service, 7-5700, R40532. Washington, DC.

Skevas, T., S. M. Swinton and N. J. Hayden. 2014. “What Type of Landowner Would Supply Marginal Land for Energy Crops?” Biomass & Bioenergy 67: 252-259.

Skevas T, Swinton SM, Tanner S, Sanford G, Thelen KD. 2016. “Investment risk in bioenergy crops.” GCB Bioenergy 8, 1162–1177.

Smith, D.J., C. Schulman, D. Current, and K.W. Easter. 2011. “Willingness of agricultural landowners to supply perennial energy crops.” Paper presented at Agricultural and Applied Economics Association & NAREA Joint Annual Meeting, Pittsburgh, Pennsylvania, July 24-26.

Swinton, S.M., S. Tanner, B.L. Barham, D.F. Mooney, and T. Skevas. 2017. “How willing are landowners to supply land for bioenergy crops in the Northern Great Lakes Region?” Global Change Biology Bioenergy 9:414:428.

Tversky, A., and D. Kahneman, 1992. “Advanced in Prospect Theory: Cumulative Representation of Uncertainty.” Journal of Risk and Uncertainty 5:297-323.

U.S. Department of Energy (USDOE). 2016. 2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume I: Economic Availability of Feedstocks. M. H. Langholtz, B. J. Stokes, and L. M. Eaton (Leads), ORNL/TM-2016/160. Oak Ridge National Laboratory, Oak Ridge, TN. 448p.

Yan, J. 2007. “Enjoy the Joy of Copulas: with a Package copula.” Journal of Statistical Software. 21(4):1-21.

Yang, X., N.D. Paulson, M. Khanna. 2016. “Optimal Mix of Vertical Integration and Contracting for Energy Crops: Effect of Risk Preferences and Land Quality.” Applied Economic Perspectives and Policy 38(4): 632–654.

Table 1. Summary Statistics of Data Utilized in the Simulation[a]

			Mean	S.D.	Min.	Max.
Yields[b]	miscanthus on high quality land (MT/ha)		27.2	2.9	3.5	48.3
	miscanthus on low quality land (MT/ha)		26.8	2.8	2.8	47.4
	switchgrass on high quality land (MT/ha)		14.1	2.8	0.4	32.1
	switchgrass on low quality land (MT/ha)		12.7	3.3	0.4	31.1
	corn stover on high quality land (MT/ha)		2.6	0.6	0.01	6.9
	corn stover on low quality land (MT/ha)		2.4	0.54	0.02	6.5
	corn grain on high quality land (bu./acre)		139.1	39.2	0.7	304.5
	corn grain on low quality land (bu./acre)		127.2	34	0.5	297.3
	soybeans on high quality land (bu./acre)		42.9	20	1	112.3
	Soybeans on low quality land (bu./acre)		41.5	19.5	0.1	109.2
Costs	miscanthus (Yr 1)	establishment cost ($/ha)	3,108	46.2	3,033.6	3,247.9
	(Yrs 2-15)	variable cost ($/MT)	17.2	2	14.2	19.6
		fixed cost ($/ha)	166	29	113.1	258.7
	switchgrass	variable cost ($/MT)	17.2	2	14.2	19.6
	(Year 1)	fixed cost ($/ha)	332.7	22.8	294	392.9
		establishment cost ($/ha)	249.4	20	223	319
	(Year 2)	fixed cost ($/ha)	254.9	53.9	143.5	368.3
	(Yrs 3-10)	fixed cost ($/ha)	251.6	40.6	169.1	354.1
	corn stover	variable cost ($/MT)	17.5	2.1	12.6	21.7
		fixed cost ($/ha)	48.5	10.9	20.3	75
	corn	variable cost ($/bushel)	1.3	0.4	0.8	2.7
		fixed cost ($/acre)	136.5	28.6	91.4	221.8
	soybeans	variable cost ($/bushel)	1.5	0.3	0.8	1.8
		fixed cost ($/acre)	107.4	45.4	59.4	195.9
Prices[c] **($/bushel)**	corn	projected price	4.1	1.2	2.6	7.8
		harvest price	3.8	1.3	2.2	8.1
		received price	4	1.3	1.9	9.1
	soybeans	projected price	9.5	2.9	5.4	17.2
		harvest price	9.3	3	5.4	19.3
		received price	9.2	2.6	5.3	17.3
Acreage (hectare per county)		High quality land	28,841	38,228	202	252,448
		Low quality land	4,507	4,680	0	42,154

Note: [a] Costs and prices are in 2010 dollars; MT refers to metric tons of biomass with 15% moisture content. [b] Corn grain and stover yields are under corn-soybean (CS) rotation. Under corn-corn rotation, yields are assumed to be 12% lower than that under CS rotation. [c] The received price is state-level annual average price while the projected price and harvest price are futures prices calculated following RMA (2011).

Table 2. Profitability and Riskiness of Conventional Crops and Bio-Energy Crops

	Mean	S.D.	Min.	Max.	CV
When biomass price is $50/MT					
Profitability (30-year NPV of profits, $/ha)[a]:					
Conventional crops on high quality land	6,264	2,700	-4,111	36,748	0.4
Conventional crops on low quality land	5,580	2,584	-3,390	37,480	0.5
Miscanthus on high quality land	1,417	2,063	-9,942	12,861	1.7
Miscanthus on low quality land	1,304	2,042	-9,565	11,792	2.1
Switchgrass on high quality land	2,277	1,652	-3,747	13,157	0.9
Switchgrass on low quality land	1,844	1,672	-3,747	11,882	1.0
Probability of having negative 30-year NPV of profits (%)[b]:					
Conventional crops on high quality land	0.9	4.9	0.0	72	5.5
Conventional crops on low quality land	0.9	4.8	0.0	68	5.4
Miscanthus on high quality land	28.4	23.9	2.3	100	0.8
Miscanthus on low quality land	29.9	25.2	0.0	100	0.8
Switchgrass on high quality land	10.8	10.1	0.0	76	0.9
Switchgrass on low quality land	16.8	11.7	0.0	100	0.7
When biomass price is $100/MT					
Profitability (30-year NPV of profits, $/ha)[a]:					
Conventional crops on high quality land	7,162	2,756	-3,005	38,667	0.4
Conventional crops on low quality land	6,398	2,656	-2,794	38,716	0.4
Miscanthus on high quality land	12,890	4,356	-9,517	40,816	0.3
Miscanthus on low quality land	12,635	4,309	-9,444	38,955	0.3
Switchgrass on high quality land	9,762	4,156	-3,747	36,857	0.4
Switchgrass on low quality land	8,685	4,207	-3,747	34,583	0.5
Probability of having negative 30-year NPV of profits (%)[b]:					
Conventional crops on high quality land	0.3	2.8	0.0	60	8.1
Conventional crops on low quality land	0.3	2.7	0.0	55	8.5
Miscanthus on high quality land	2.4	7.6	0.0	84	3.2
Miscanthus on low quality land	2.8	8.5	0.0	87	3.0
Switchgrass on high quality land	1.1	1.9	0.0	11	1.7
Switchgrass on low quality land	1.9	2.5	0.0	14	1.3

Note: [a] The county-level CV of profits from a crop grown on land with a certain quality in each county is calculated based on the 1,000 yield-price draws generated by using the copula approach. The CV values presented here are averages of county-level CVs across all counties. [b] The CV values for probability of having negative 30-year NPV of profits are calculated by using mean and standard deviation values in this table.

Table 3: Biomass Production under different scenarios with credit constraint (Million MT).

Biomass Type	Land Type	Loss Neutral High Interest	Loss Averse High Interest	Loss Neutral Low Interest	Loss Averse Low Interest
		[1]	[2]	[3]	[4]
	When biomass price is $50/MT				
Corn Stover	High Quality	95.8	95.8	95.7	95.7
	Low Quality	13.0	12.9	12.7	12.9
	All land	108.8	108.7	108.4	108.6
Miscanthus	High Quality	0.3	0.0	3.9	0.7
	Low Quality	0.1	0.0	4.4	1.3
	All land	0.4	0.0	8.3	2.0
Switchgrass	High Quality	0.7	1.0	0.3	1.0
	Low Quality	0.3	0.4	0.1	0.3
	All land	1.0	1.4	0.4	1.3
Total Biomass	High Quality	96.8	96.8	99.9	97.4
	Low Quality	13.3	13.3	17.2	14.5
	All land	110.2	110.1	117.1	111.9
	When biomass price is $100/MT				
Corn Stover	High Quality	83.1	87.4	81.7	82.6
	Low Quality	9.0	9.6	8.5	8.7
	All land	92.1	97.0	90.2	91.3
Miscanthus	High Quality	213.3	128.8	237.5	225.7
	Low Quality	69.4	56.1	77.2	73.8
	All land	282.7	184.9	314.7	299.5
Switchgrass	High Quality	10.7	34.6	1.8	4.7
	Low Quality	5.0	9.0	3.2	4.2
	All land	15.7	43.6	5.0	8.9
Total Biomass	High Quality	307.1	250.8	321.0	313.0
	Low Quality	83.3	74.6	88.9	86.6
	All land	390.4	325.5	409.9	399.6

Table 4. Land use for Miscanthus and Switchgrass under different scenarios with credit constraint (Acres)

Land Type	Loss Neutral High Interest	Loss Averse High Interest	Loss Neutral Low Interest	Loss Averse Low Interest
	[1]	[2]	[3]	[4]
When biomass price is $50/MT				
For Miscanthus				
high quality land	24,368	1,192	358,734	59,574
low quality land	6,748	323	397,726	120,048
total land	31,116	1,514	756,461	179,622
For Switchgrass				
high quality land	123,094	182,235	57,234	186,704
low quality land	51,387	66,197	15,205	58,245
total land	174,481	248,432	72,439	244,949
When biomass price is $100/MT				
For Miscanthus				
high quality land	21,391,023	12,251,082	24,514,886	22,943,734
low quality land	6,749,915	5,259,230	7,859,570	7,345,123
total land	28,140,937	17,510,312	32,374,456	30,288,857
For Switchgrass				
high quality land	1,951,209	6,278,952	333,262	895,990
low quality land	1,003,224	1,713,005	622,258	844,793
total land	2,954,433	7,991,957	955,520	1,740,783

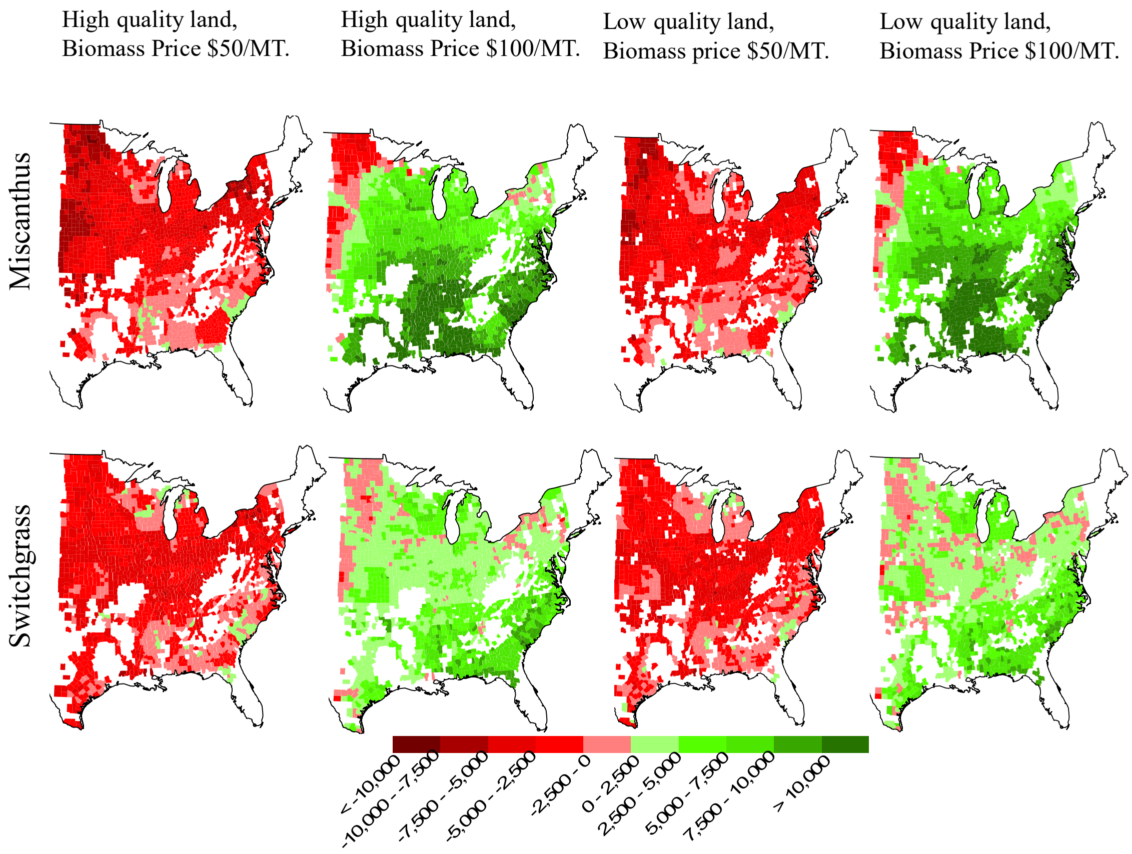

Figure 1. Profitability Difference between Bio-energy Crops and the Conventional Crops ($/ha)

Note: Each map depicts the county-level value of the expected 30-year NPV of miscanthus (or switchgrass) profits minus that of conventional crop. So red colors or negative numbers indicate that miscanthus (or switchgrass) has low profitability than does the conventional crops; green colors or positive numbers indicate the opposite.

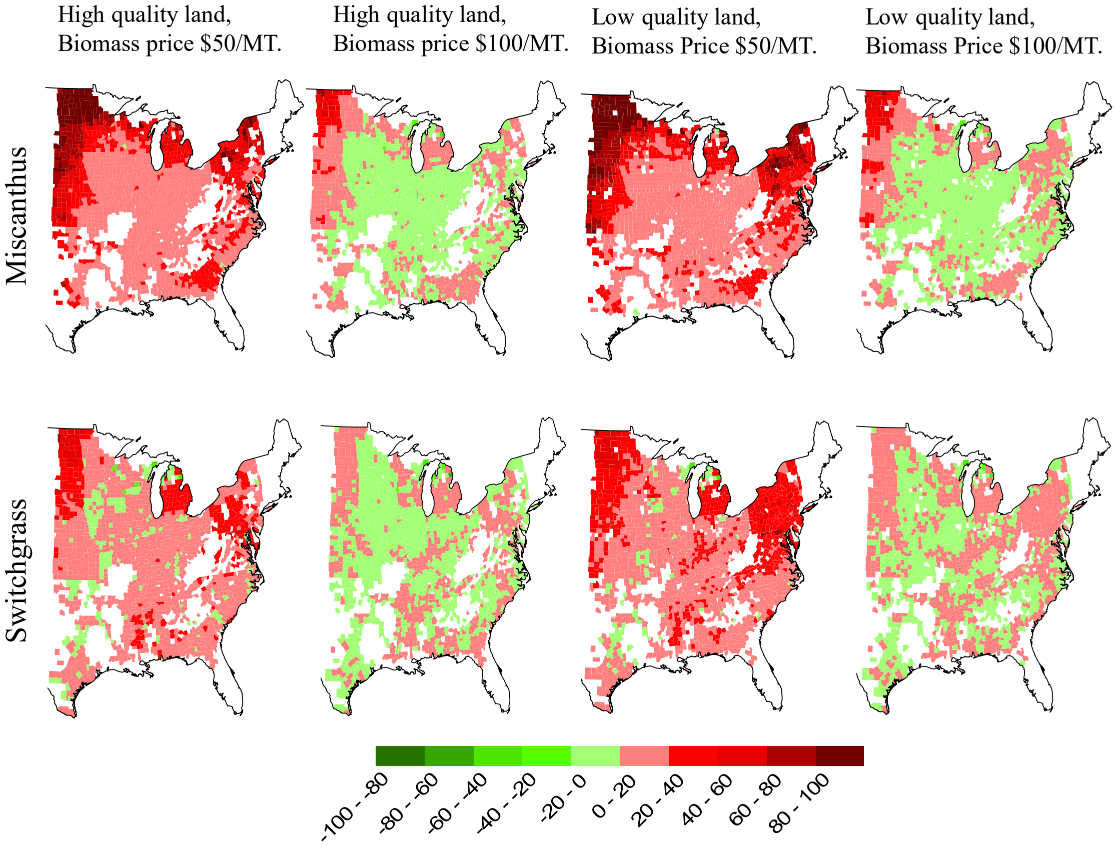

Figure 2. Difference in Probability of Having Negative 30-year NPV of Profits between Bioenergy Crop and the Conventional Crops (%)

Note: Each map depicts the county-level probability of having negative 30-year NPV of profits of miscanthus (or switchgrass) minus that of the conventional crops. Red colors (or positive numbers) indicate that probability of negative 30-year NPV of Miscanthus or Switchgrass is larger than that of the conventional crops; green colors (or negative numbers) indicate the opposite.

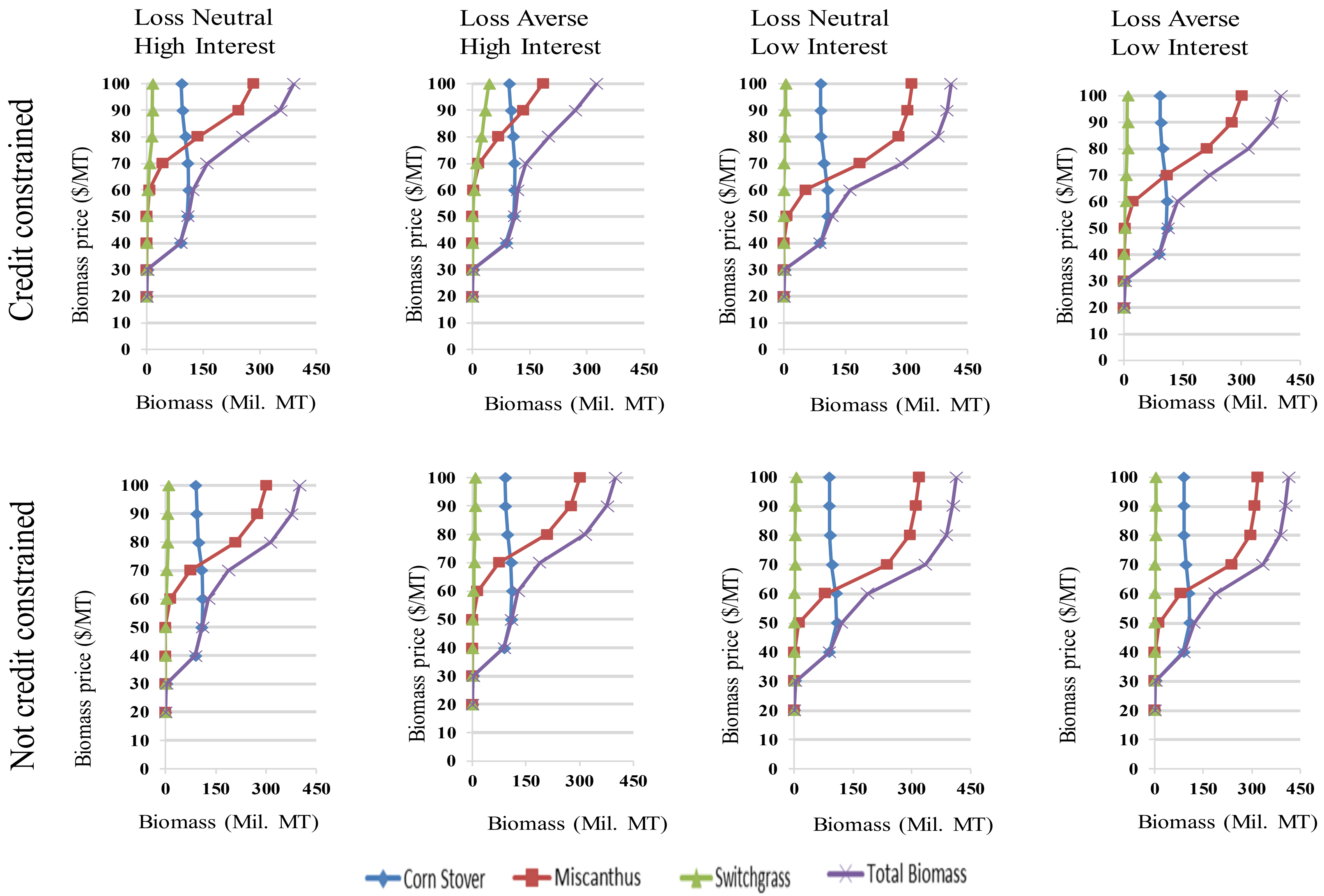

Figure 3. Aggregate Biomass Supply Curves

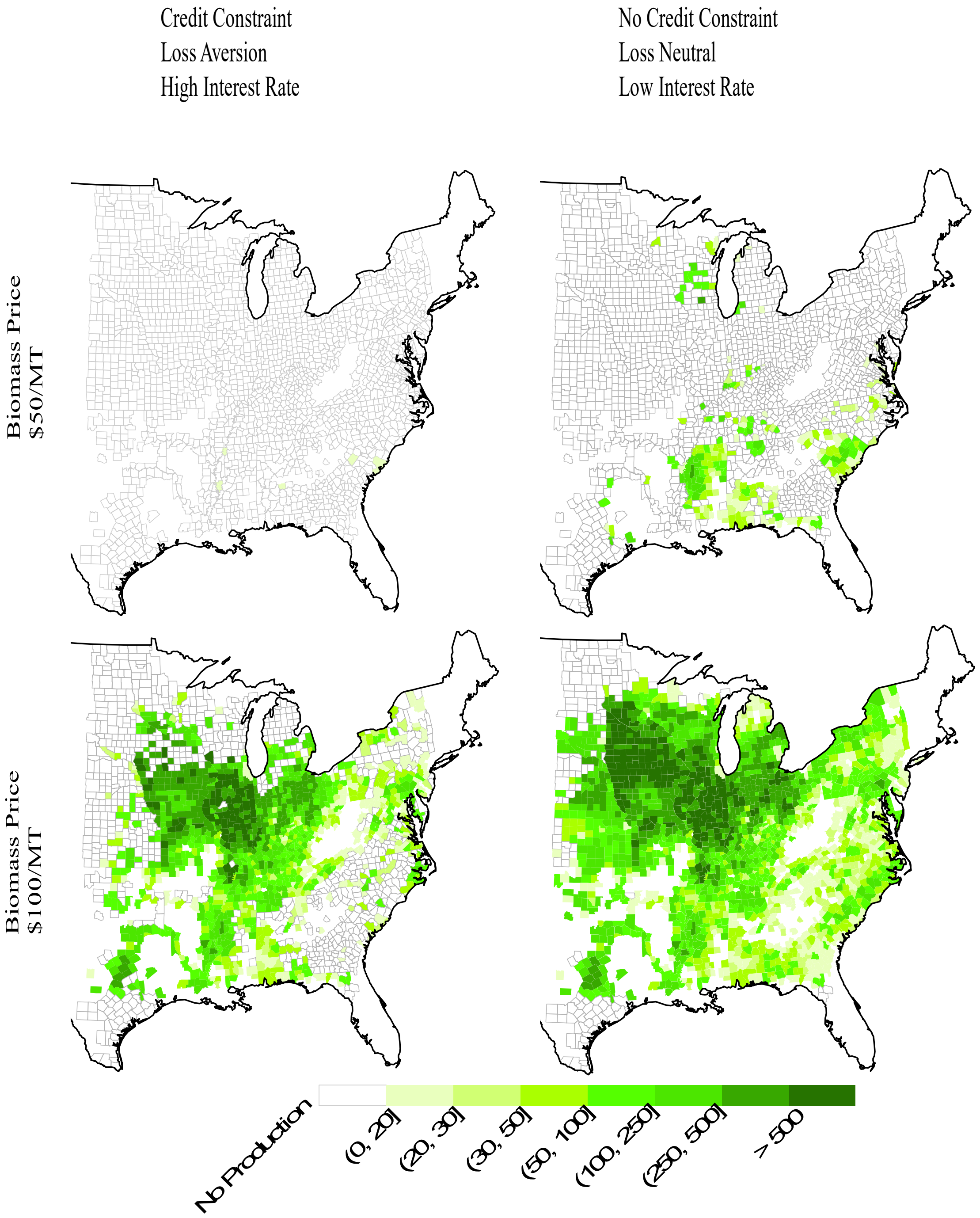

Figure 4. Average County-Level Miscanthus Production (1,000 MT per year)

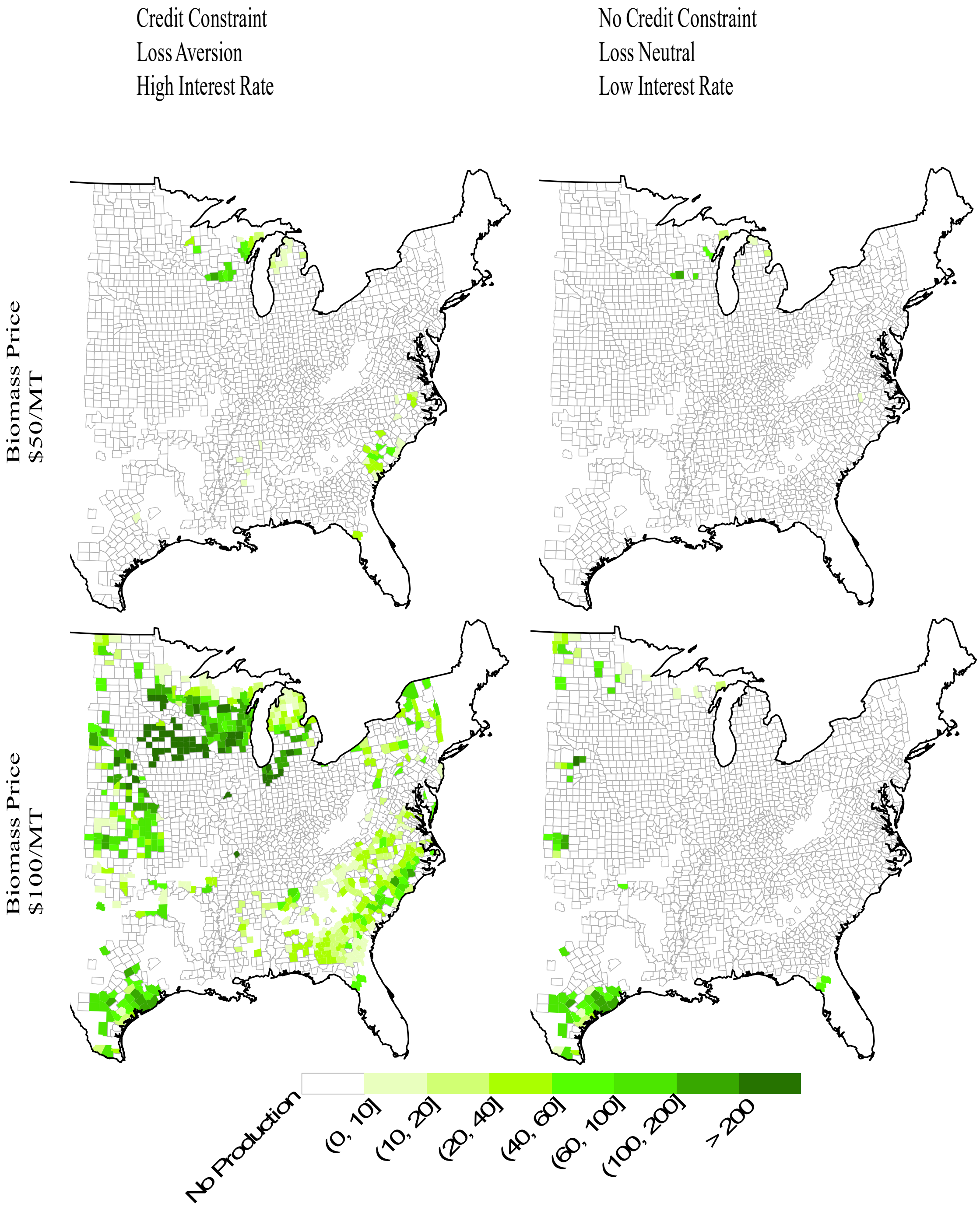

Figure 5. Average County-Level Switchgrass Production (1,000 MT per year)

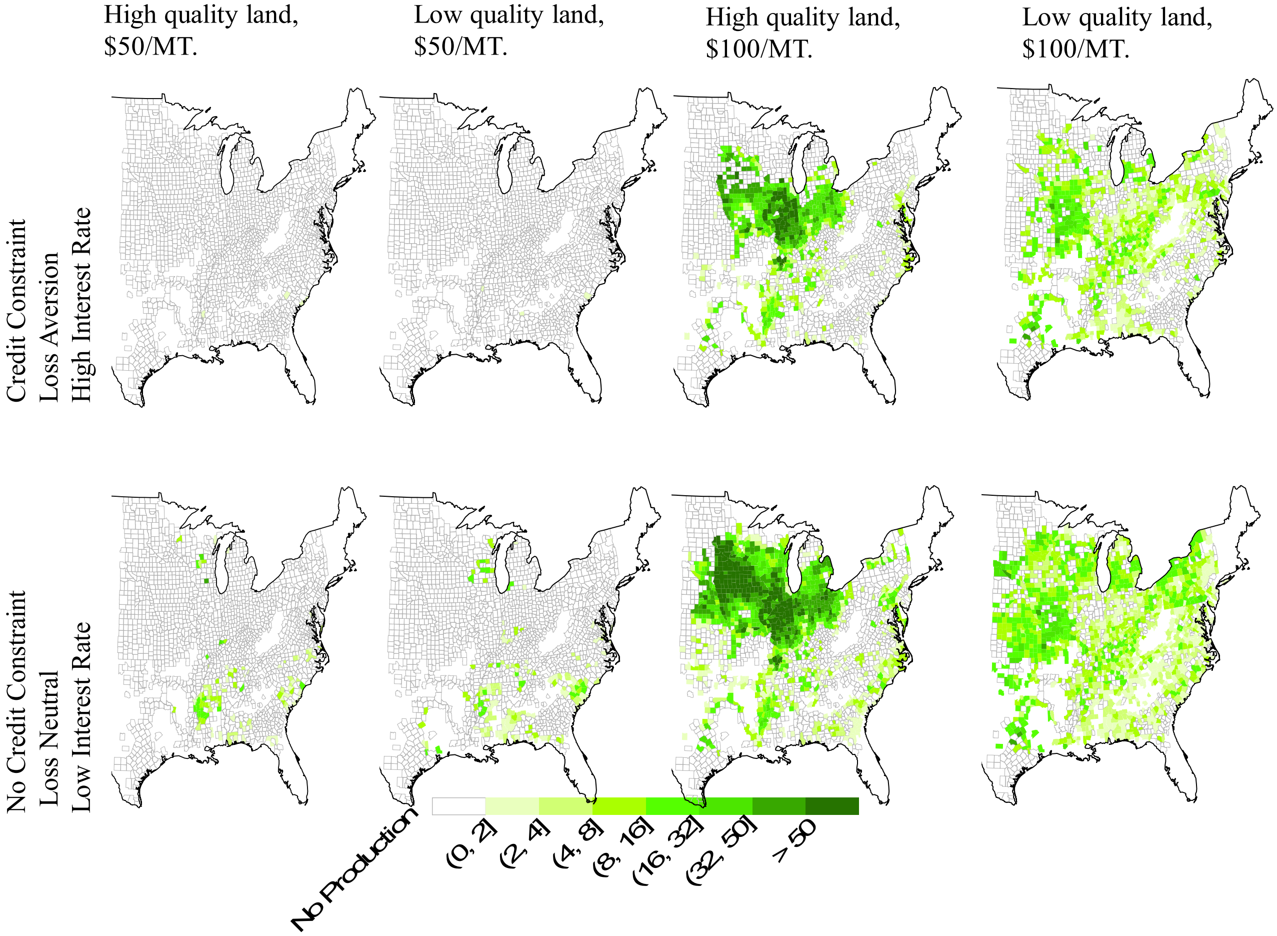

Figure 6. Miscanthus acreage on high and low quality land (1,000 Acres)
Note: For the first and second maps in the first row, only four and three counties produce miscanthus, respectively. They are all in the southeastern region.

Supporting Information (SI) for "Adopting Bio-Energy Crops: Does Farmers' Attitude toward Loss Matter?"

(to be available online only)

Table SI-1: Biomass Production under different scenarios without credit constraint (Million MT)

Biomass Type	Land Type	Loss Neutral High Interest	Loss Averse High Interest	Loss Neutral Low Interest	Loss Averse Low Interest
		[1]	[2]	[3]	[4]
When biomass price is $50/MT					
Corn Stover	High Quality	95.8	95.8	95.6	95.6
	Low Quality	13.0	12.9	12.6	12.6
	All land	108.8	108.7	108.2	108.2
Miscanthus	High Quality	0.3	0.4	5.5	5.6
	Low Quality	0.1	0.1	6.7	6.7
	All land	0.4	0.5	12.2	12.3
Switchgrass	High Quality	0.5	0.8	0.3	0.4
	Low Quality	0.1	0.2	0.0	0.1
	All land	0.6	1.0	0.3	0.5
Total Biomass	High Quality	96.7	97.0	101.3	101.5
	Low Quality	13.2	13.3	19.4	19.5
	All land	109.9	110.2	120.7	121.0
When biomass price is $100/MT					
Corn Stover	High Quality	82.4	82.4	81.4	81.4
	Low Quality	8.8	8.8	8.4	8.4
	All land	91.2	91.2	89.8	89.8
Miscanthus	High Quality	227.5	227.5	241.8	241.8
	Low Quality	73.0	73.0	77.63	77.60
	All land	300.6	300.6	319.4	319.4
Switchgrass	High Quality	4.1	4.1	1.0	1.0
	Low Quality	4.0	4.0	2.9	2.9
	All land	8.1	8.1	3.9	3.9
Total Biomass	High Quality	314.1	314.2	324.1	324.2
	Low Quality	85.8	85.8	89.0	88.9
	All land	399.9	399.9	413.1	413.1

Table SI-2. Land use for Miscanthus and Switchgrass under different scenarios with no credit constraint (in Acres)

Land Type	Loss Neutral High Interest	Loss Averse High Interest	Loss Neutral Low Interest	Loss Averse Low Interest
	[1]	[2]	[3]	[4]
When biomass price is $50/MT				
For Miscanthus				
high quality land	28,162	29,390	498,700	521,413
low quality land	8,261	8,872	599,368	613,340
total land	36,422	38,261	1,098,068	1,134,753
For Switchgrass				
high quality land	93,724	157,800	55,129	70,818
low quality land	20,332	39,456	10,146	13,376
total land	114,056	197,255	65,275	84,194
When biomass price is $100/MT				
For Miscanthus				
high quality land	23,125,743	23,130,013	25,139,538	25,142,081
low quality land	7,221,634	7,217,365	7,960,891	7,958,347
total land	30,347,378	30,347,378	33,100,428	33,100,428
For Switchgrass				
high quality land	772,027	772,027	183,532	183,532
low quality land	804,824	804,824	565,930	565,930
total land	1,576,851	1,576,851	749,462	749,462

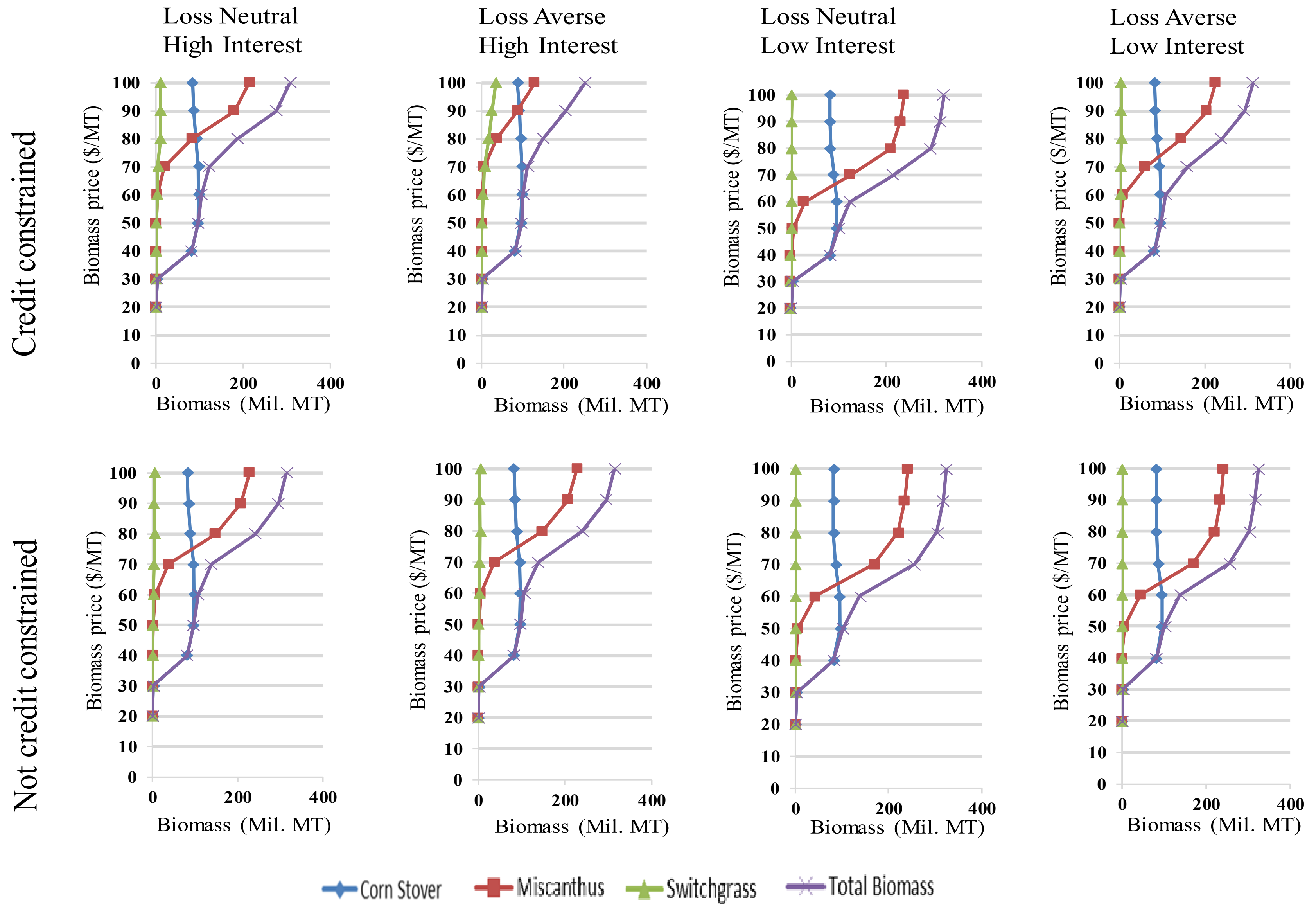

Figure SI-1. Biomass Supply Curves on High Quality Land

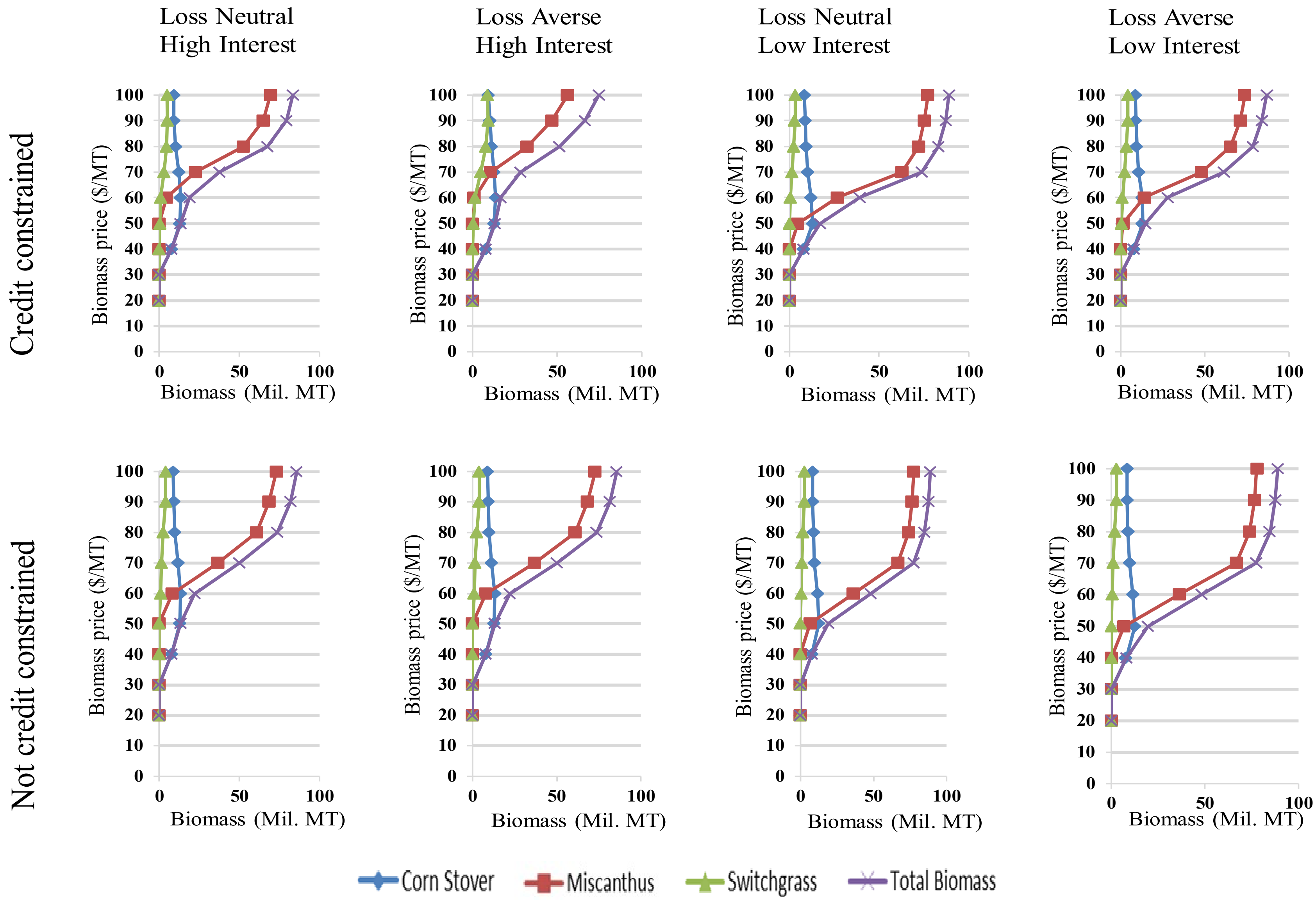

Figure SI-2. Biomass Supply Curves on Low Quality Land

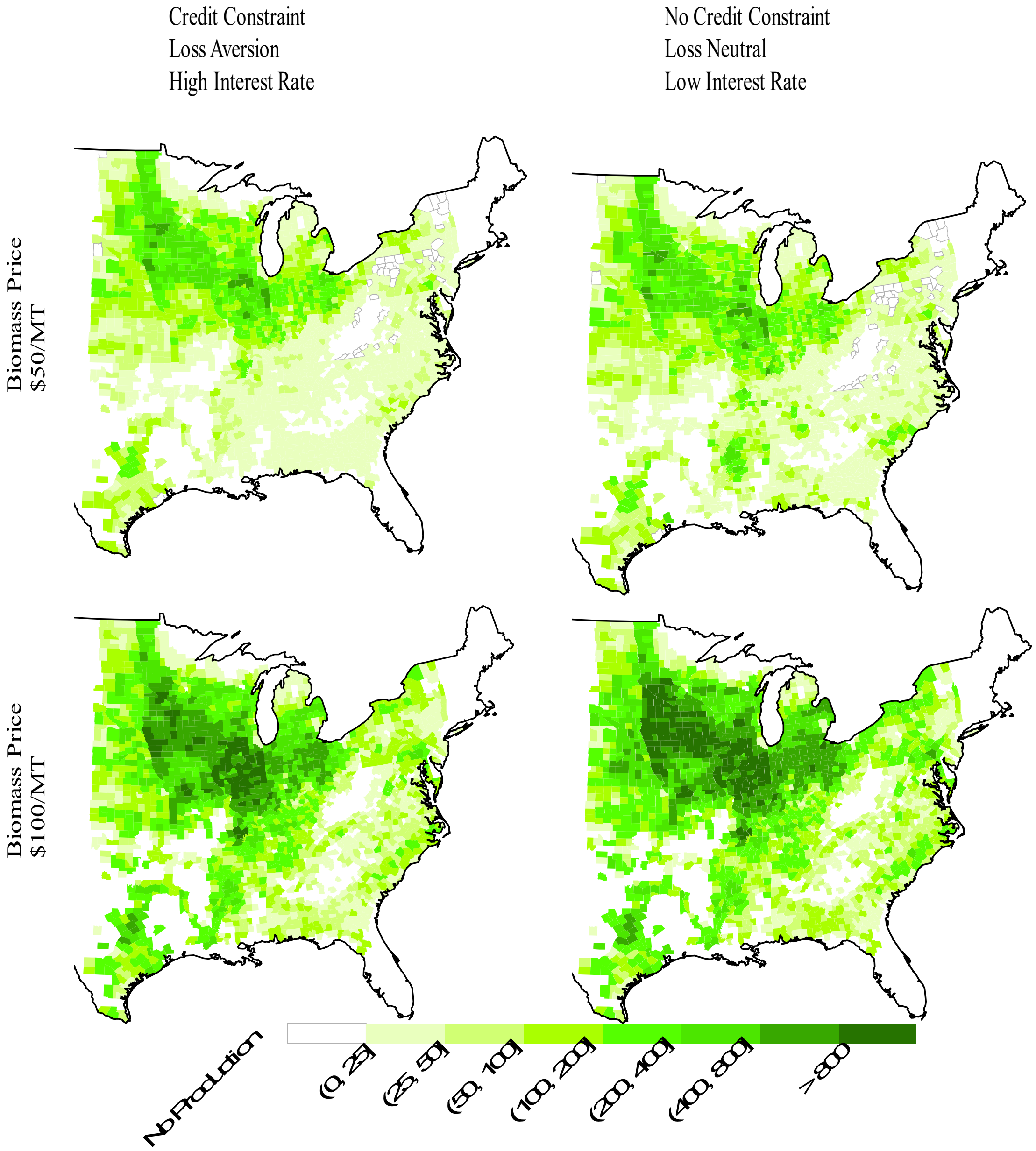

Figure SI-3. Average County-Level Total Biomass Production (1,000 MT per year)

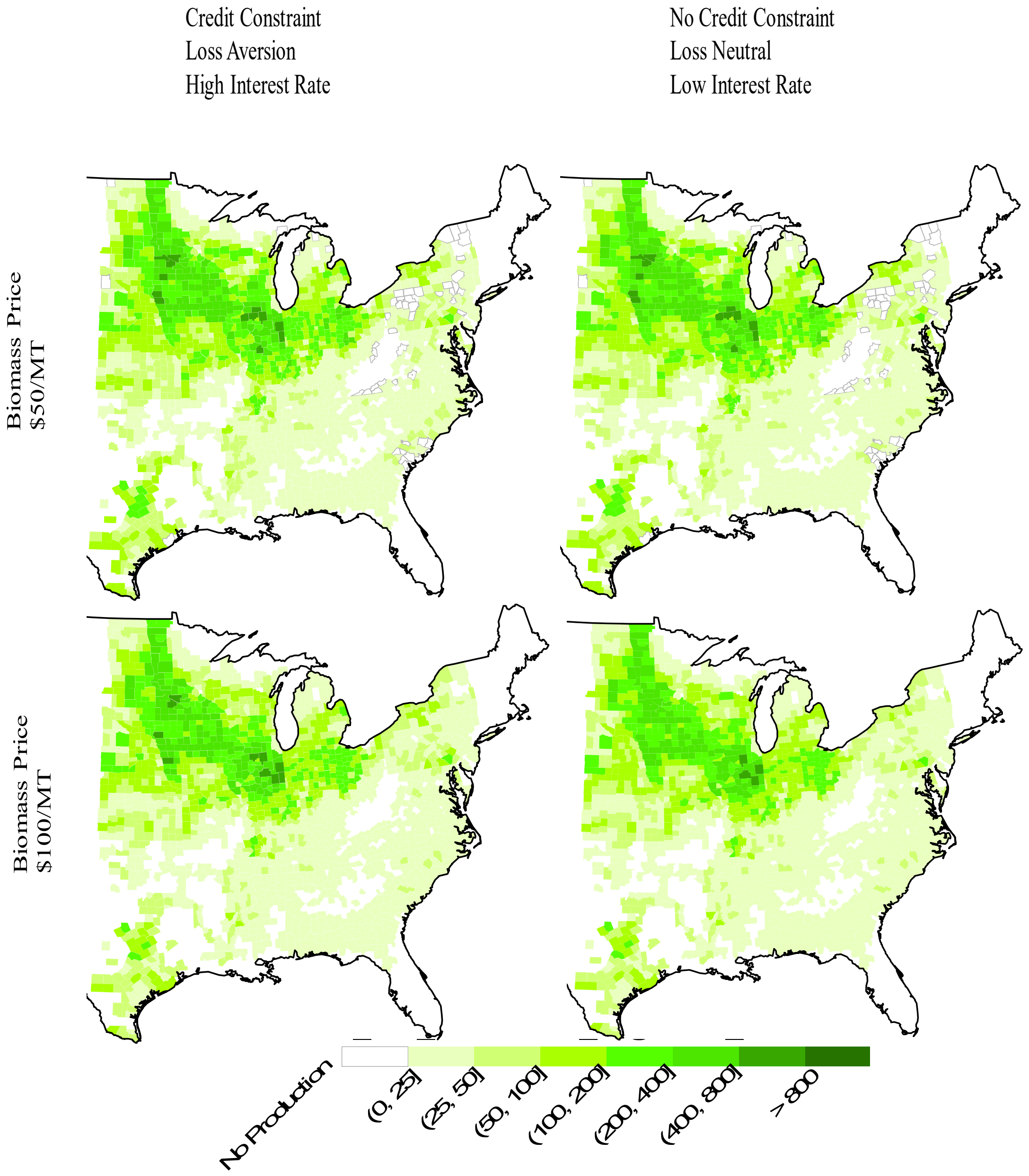

Figure SI-4. Average County-Level Corn-Stover Production (1,000 MT per year)

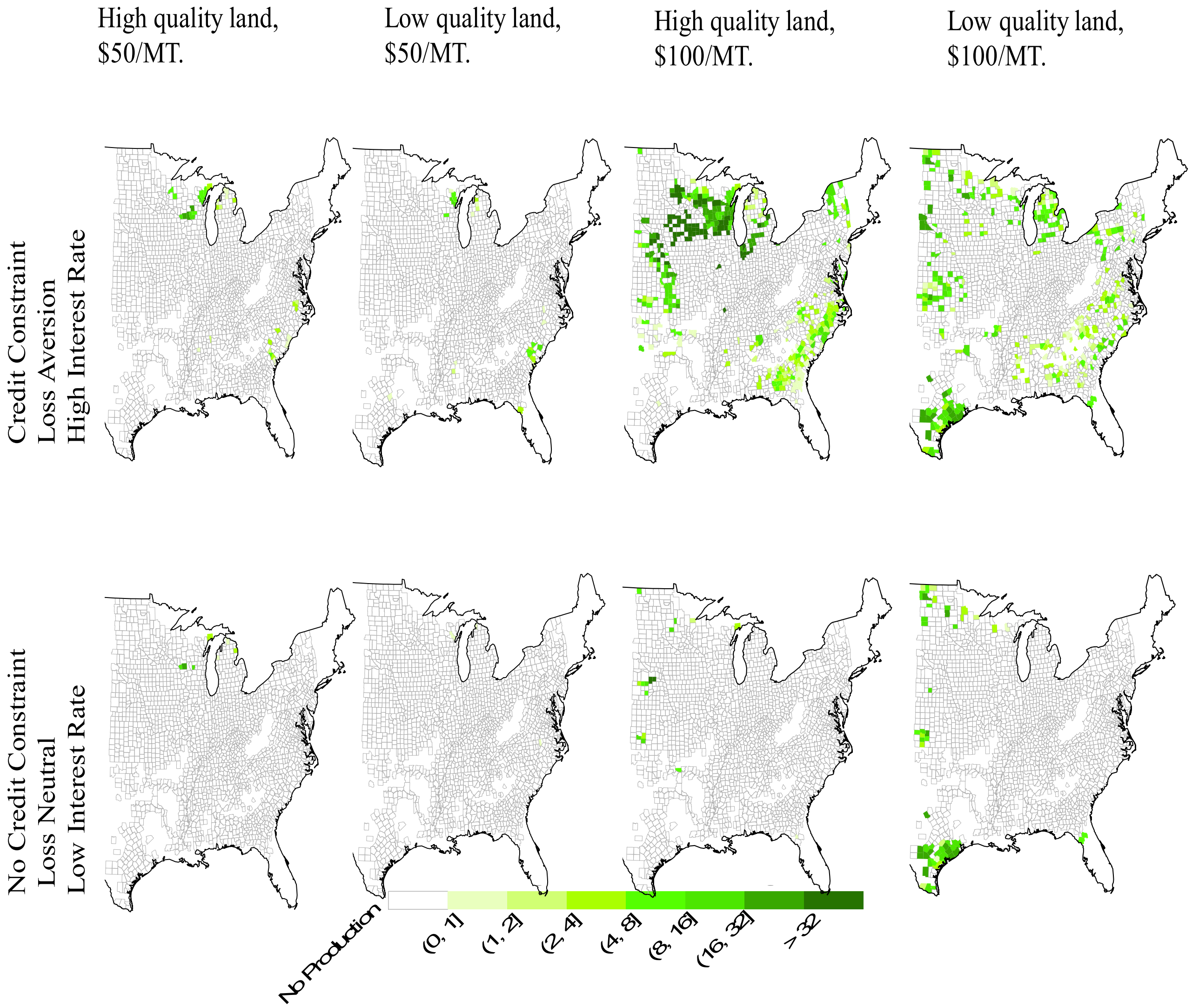

Figure SI-5. Land Use for Switchgrass on high quality land and low quality land for two different biomass prices under different scenarios (1,000 Acres)