A Stochastic Approach for Predicting the Profitability of Bioenergy Grasses

Joseph Dolginow, Raymond E. Massey, Newell R. Kitchen,* David B. Myers, and Kenneth A. Sudduth

ABSTRACT

Switchgrass (Panicum virgatum L.) and miscanthus (Miscanthus × giganteus) have potential to meet a growing demand for renewable energy feedstock. Before producers will invest in planting these crops, they need credible estimations of the potential profits. The objective of this study was to examine profitability of growing these perennial bioenergy grasses, incorporating uncertain prices and yields in the model. The model compared the profitability of five crops [switchgrass, miscanthus, corn (Zea mays L.), soybean (Glycine max (L.) Merr.) and tall fescue pasture (Festuca arundinacea)] on three soil profiles common in northeastern Missouri: an upland, noneroded soil, an eroded soil, and floodplain soil. The effect of the USDA Biomass Crop Assistance Program (BCAP) and crop insurance on the decision to grow switchgrass and miscanthus was analyzed. Actual grain yields, Agricultural Land Management Alternatives with Numerical Assessment Criteria (ALMANAC) modeled grass yields, and Food and Agricultural Policy Research Institute (FAPRI) baseline prices were used to simulate profit. The results were compared using cumulative distribution functions (CDFs). Corn production was always chosen by decision makers of all risk attitudes to other crops. Miscanthus was always more profitable than switchgrass. Based on the CDFs, perennial bioenergy grasses were more likely to be planted in eroded soils currently in pasture production; however, there were scenarios in which they could be planted on eroded cropland currently planted to soybean. Lastly, crop insurance for corn and soybean could affect the decision to plant perennial bioenergy grasses for risk averse producers.

The United States currently relies on fossil fuels to meet most of its energy needs; however, concern about volatile prices, greenhouse gas emissions, political instability in exporting regions, and increasingly scarce supplies has motivated research into viable substitutes. Energy derived from cellulosic biomass is being explored as a promising alternative to fossil fuels. Biomass can be co-fired with coal to generate electricity, or can be converted to ethanol or other advanced liquid fuels used for transportation.

The federal government has developed programs that support cellulosic biomass as an energy source. The Renewable Fuel Standard mandated levels of production for renewable transportation fuels through 2022. In an effort to meet those production levels, the Food, Conservation and Energy Act of 2008 funded the BCAP. This program sought to incentivize biomass aggregators and producers to plant cellulosic bioenergy crops. As of June 2012, Congress had funded 11 BCAP project areas (Schnepf, 2013).

Switchgrass and miscanthus are two potential feedstock crops for cellulosic bioenergy. Research has documented the ability of these grasses to produce large quantities of biomass (Heaton et al., 2008) and provide local ecosystem benefits (Blanco-Canqui, 2010). Agricultural economists and extension specialists have researched the break-even price for these crops (Blanco-Canqui et al., 2010). Specialized commodity specialists have researched the break-even price for these crops in the context of biorefinery development (Brechbill et al., 2011). In 2009, Mooney et al. (2009) factored in four soil types and two crop lifespans to report break-even prices ranging from $43.93 to $78.88 Mg⁻¹. James et al. (2010) compared the profitability of bioenergy cropping systems and found that miscanthus had the lowest break-even price assuming the rhizome prices decreased.

Each of these studies reported the average break-even price and assumed the cropping system with the highest average profit was preferred to all other alternatives. However, some studies accounted for the risk associated with the production of bioenergy crops. Brechbill et al. (2011) found that switchgrass has a break-even price between U.S.$80 and $96 Mg⁻¹.

Abbreviations: ALMANAC, Agricultural Land Management Alternatives with Numerical Assessment Criteria; APH, actual production history; AUM, animal unit month; BCAP, biomass crop assistance program; CDF, cumulative distribution function; FAPRI, University of Missouri Food and Agricultural Policy Research Institute; FDSD, first degree stochastic dominance; SDSD, second degree stochastic dominance.
distribution of the profits is useful for understanding both relative profitability and risk. Analyzing the distribution of profits helps to understand the risk profile by estimating the percent of time an extreme outcome was likely to occur. Factoring in the profit risk of a crop could influence planting decisions. Griffith et al. (2012) incorporated risk in this manner in their study of biomass contracting alternatives. Previous studies have identified Missouri as having potential for bioenergy production (De La Torre Ugarte et al., 2003, Jain et al., 2010). Landers et al. (2012) estimated switchgrass production costs for the Central Claypan Region of Missouri (NRCS, 2006). Of the 11 BCAP project areas funded, three were in Missouri. One project in western Missouri intended to plant 20,000 ha of three different mixes of native grasses including switchgrass. Two other BCAP projects had the objective of planting 2900 ha of miscanthus in southwestern and central Missouri.

Previous research has considered using marginally productive lands for growing biomass (McLaughlin et al., 2006; Landers et al., 2012). Switchgrass or miscanthus has potential to grow on marginal lands because their yields are less impacted by variation in precipitation and poor soil conditions than the yield of grain crops. Growing perennial bioenergy grasses on marginal lands also decreases the opportunity costs for the producer, making producers more likely to plant them (Landers et al., 2012).

The soil landscapes of northeastern Missouri arise from underlying sedimentary bedrock, layers of moderately dissected glacial tills, and soil profiles formed in till, pedisediments, loess, and alluvium. The latter two parent materials dominate the region. For soils formed in floodplain alluvium, flooding is frequent during spring and early summer months. For the upland loess-till soils, the landscape-dependent depth to claypan is an important hydrologic driver for watershed vulnerability and crop productivity. Claypans are soil horizons endemic to the study region. They are characterized by a very abrupt textural change, large clay content, and shrink-swell mineralogy. Productivity is markedly reduced on claypan soils that have been degraded by erosion, because the physical and chemical characteristics of the subsoil are not well suited for crop root growth (Thompson et al., 1991; Myers et al., 2007) and because of limited water storage (Jiang et al., 2008).

Land use data from the National Agricultural Statistics Service (NASS) in 2012 indicates pasture, soybean, and corn were the most common crops in the northeastern Missouri crop reporting district (USDA- National Agricultural Statistics Service, 2013). Figure 1 indicates that pastureland made up 30% of the total land in the region, followed by soybean at 21% and corn at 17%. This figure also shows how much of each crop is planted to land classified as flooded or eroded or neither flooded nor eroded according to data from the NRCS (Schoeneberger et al., 2002). Each of the major crops were typically present on the three classes of soil landscapes indicating the potential for perennial grass bioenergy production in all three. The graph indicates some selection bias for cropping systems based on soil landscape. Pasture was more frequently planted on eroded soils (56% compared to 37% for corn and 38% for soybean). Thus, including pasture in the analysis of what crop producers grow on marginal lands was important.

The objective of this study was to compare the profitability of producing switchgrass and miscanthus with the profitability of growing corn, soybean, and tall fescue pasture in northeastern Missouri, taking into account both production and price risk. Specific objectives were to:

i. Compare the profitability of the five crops grown on three contrasting soils of this region, two of which are environmentally vulnerable.

ii. Assess the impact of two government programs, BCAP and multi-peril crop insurance, on the decision to transfer land from its current cropping system to perennial grasses for use as bioenergy crops.

Fig. 1. Hectares of land in the USDA northeast crop reporting district of Missouri planted to corn, soybean, and pasture in 2012, organized by soil characteristic.
MATERIALS AND METHODS

Our empirical model used 15 partial enterprise budgets to represent five crop alternatives on three representative soils in the Northeast crop reporting district of Missouri. The baseline soil was Putnam, a fine, smectitic, mesic Vertic Albaqualf found in upland, non-eroded landscape positions and associated with productive cropland. Flooded soils characterized by high productivity but high risk were represented by Belknap, a coarse-silty, mixed, active, acid, mesic Fluventic Endoaquept found in lowland alluvial landscape positions. Eroded soils with lower productivity potential and relatively higher risk were represented by Armstrong, a fine, smectitic, mesic Aquertic Hapludalfs, an upland soil that has been eroded.

Each of these soils were commonly mapped in the study region. Within each soil, budgets for five cropping alternatives were constructed: corn, soybean, switchgrass, miscanthus, and tall fescue pasture. Rotations in the region vary from continuous soybean to corn and soybean rotation. Modeling individual crops allows the reader to interpolate corn and soybean results if a corn–soybean rotation comparison is desired.

The budgets included all costs from planting to harvest and transport to farm-gate. Transportation of biomass beyond the farm-gate to the processor was not included because transportation costs depend highly on hauling distance and fuel costs. Assigning transportation costs to the buyer has been used to incentivize producers to supply biomass for energy (Epplin et al., 2007; Griffith et al., 2012). All the budgets followed typical crop budgeting procedures that calculated economic profits on a per hectare basis for one production year. Profits were calculated as returns to land, capital, and management.

Crop Yields

The model used stochastic grain yields sampled from actual yield maps obtained from 22 producers in 14 counties of northeastern Missouri for the years 2000 to 2009. This dataset represents a broad cross-section of weather (multiple years), management (multiple producers), and environment (multiple soil landscape) outcomes. The collection of yield maps consisted of approximately 950 and 1100 field-years corresponding to 20,200 and 26,300 ha years of corn and soybean, respectively. See Myers et al. (2012) for a discussion of the data and processing methodology. We randomly selected 1% of the point data from each yield map giving 50,000 yield observations for both corn and soybean across all soil types. The yields were then adjusted to 7 yr in the future to reflect the real options costs (Song et al., 2011), which adjusts yields for technology gains that occur during the lifespan of the perennial grass.

Pasture, switchgrass, and miscanthus yields were modeled using ALMANAC (Landers et al., 2012; Kiniry et al., 2013). Yields were modeled for Audrain County, Missouri, using data from a weather station in Moberly, MO, over the period 1970 to 2000 giving 30 yield observations (Kiniry et al., 1992). Each of the 30 modeled yields represented yields from a mature stand because ALMANAC cannot model the establishment phase of a perennial crop. The yields were all calculated on a dry matter basis. The ALMANAC crop growth parameters were used for modeling lowland switchgrass and fescue pasture. The crop parameters for miscanthus followed Parajuli (2012). A statistical summary of crop yield results used in the profitability analysis is provided (Table 1).

Yield predictions from ALMANAC for miscanthus and switchgrass were calibrated to ongoing plot research experiments. Kanlow switchgrass was planted in 2009 on 32 blocks which has varying amounts of topsoil. These blocks simulated field conditions in northeastern Missouri. For...
more information on the blocks and their construction, see Thompson et al. (1991). Miscanthus yield were calibrated to an adjacent plot planted in 2007. That plot, however, did not have the varying soil depths.

Use of simulated yields for grasses and measured yields for corn and soybean can introduce a potential bias. This study attempted to use the most accurate yield estimates available. With only limited bioenergy grass yield data, we were required to use simulated yields which were calibrated to ongoing studies in northeastern Missouri. Even though modelled yields do not consider all sources of variation, an established stand of perennial grasses is less susceptible to sources of variation including disease and pests (Jørgensen, 2011). With less variation to capture, using ALMANAC was the best option for perennial grasses. Documented difficulties in modeling grain yield in the claypan soils of northeastern Missouri (Fraisse et al., 2001; Wang et al., 2003) suggest that actual measured yields are likely more accurate than simulated yields.

**Production Costs**

Field operation costs for activities such as planting and fertilization were taken from University of Missouri custom rates averages (Plain and White, 2012). The high custom rate for harvesting hay was assumed when harvesting miscanthus because it is more difficult than normal forage crops to bale. Cost of transportation to field edge was a function of yield for each crop.

Perennial grass budgets were modified to take into account their establishment phase and multi-year production. Perennial grasses incurred establishment costs for land preparation and planting during the first year. However, no harvest was realized in the first year. After the second growing season, the yield for perennial grasses for bioenergy was estimated at 50% of a mature stand. After Year 3, the stand was considered mature. The lifetime for all the perennial grasses was assumed to be 15 yr. Prior economic studies (Perrin et al., 2008; James et al., 2010) have assumed a 10 yr time horizon for switchgrass and miscanthus. A longer time horizon was justified given the productive life of these grasses exceeds 10 yr (McLaughlin and Adams Kzos, 2005; Anderson et al., 2011) and need for a long-term stable supply of feedstock.

Establishment costs of miscanthus including planting and rhizomes was assumed to cost $1,984 ha$^{-1}$ by the USDA (USDA-Farm Service Agency, 2012). Miscanthus is established from rhizomes which were valued at $0.12 per rhizome. The planting rate of 16,050 rhizomes ha$^{-1}$ was based on plot research experience in Missouri. Corn and soybean seed prices were from the NASS agricultural prices database (USDA-NASS, 2013); switchgrass and fescue seed prices and seeding rates were from a local seed distributor (Nixa Hardware & Seed, personal communication, 2013). This study assumed 25% replanting rate for switchgrass (Khanna et al., 2008), and 25% replanting rate for miscanthus based on plot-research experience in the Central Claypan Region.

All input prices were assumed deterministic. Fertilizer costs were an average of national prices paid for the years 2010 through 2012 as reported by NASS (USDA-NASS, 2013). Fertilizer inputs used were dry urea, diammonium phosphate, and potash. Urea was applied yearly to all crops except soybean, and every fifth year diammonium phosphate and potash were applied to every crop. Phosphorus and K application rates followed Landers et al. (2012) which used removal rates. Nitrogen fertilizer rate for miscanthus was 55 kg ha$^{-1}$ based on unpublished data from miscanthus plot experiments in Missouri showing minimal yield response to higher levels of N. Miscanthus response to N fertilization is not settled. The U.S. and European studies have shown a wide range of miscanthus response to N fertilization amounts (Schwarz et al., 1994; Heaton et al., 2008; Arundale et al., 2014), with no definitive pattern in association with soil type. Even when responsive, economic return above some minimal N rate is marginal in comparison to other crops (Arundale et al., 2014). Switchgrass N rates by soil type are better documented and were 67 kg ha$^{-1}$ for Belknap and 134 kg ha$^{-1}$ for Putnam and Armstrong (Boyer et al., 2012). Rates for pasture followed Barnhart et al. (2013). The cost for the herbicides were taken from NASS from the years 2010 through 2012 (USDA-NASS, 2013). Application rates were taken from Bradley et al. (2013). Tables 2 and 3 summarize the materials costs and application rates to each crop, respectively. Prices for field activities, reported in Table 4, were taken from Missouri custom rates survey (Plain and White, 2012). Crop producers choose from among several insurance plans, insurance units, and coverage levels offered by the USDA Risk Management Agency. In Missouri, the most popular insurance plan has been revenue insurance for enterprise units at 75% coverage level (USDA-Risk Management Agency, 2013). Our analysis assumed this level of insurance in estimating premiums and indemnities. Insurance premiums for insured corn and insured soybean were obtained from the University of Illinois FARMDOC website for a producer in Audrain County, Missouri, on a non-irrigated field for 2012 (FarmDoc, 2013). Premiums were $28.17 ha$^{-1}$ for corn and $13.49 ha$^{-1}$ for soybean. The APH was the mean of each yield distribution over the 10-yr period of 2000 to 2009. For corn, the APHs were 11.63 Mg, 12.06 Mg, and 9.54 Mg for the Putnam, Belknap,
and Armstrong soils, respectively. For soybean on these same soils the APHs were 3.48, 3.48, and 2.98 Mg. The price guarantee was the mean of the FAPRI price distribution (Westhoff et al., 2013) which was $177 Mg–1 for corn and $420 Mg–1 for soybean. Yield and revenue insurance products are available but are very seldom purchased for hay, switchgrass, and miscanthus. The federal government offers Pasture, Range, and Forage (PRF) insurance based on rainfall totals rather than actual yields. Less than 1% of pasture lands in Missouri were enrolled in PRF insurance (USDA-RMA 2013), so this study assumed pasture to be uninsured.

Interest on operating expenses was assumed to be 8% over 6 mo (Mooney et al., 2009; Brechbill et al., 2011). Operating expenses included materials and field activities. Since the purpose of this study was to compare crops and productivity on different soils, land rent was not included as a cost.

### Revenue

Revenue is defined as yield times price plus indemnity payments, if any, plus BCAP payments, if perennial grasses are planted.

A total of 2500 stochastically generated prices for both corn and soybean were obtained from the FAPRI baseline projection of agricultural markets and commodities for the 5-yr period between 2013 and 2017 (Westhoff et al., 2013). The FAPRI baseline prices were based on an array of assumptions about macroeconomic conditions, policies, and production estimates. Summary statistics of the price distributions are provided in Table 5.

Following Epplin et al. (2007), the analysis of this study assumed the price for cellulosic biomass was established by a long-term fixed contract with an aggregator who buys the entire production. There were no well-established prices for biomass used for bioenergy since the market is undeveloped and depends on many local factors. Previous research has avoided pricing biomass for bioenergy, choosing rather to focus on costs of production (Landers et al., 2012). James et al. (2010) attempted to capture market price uncertainty by modeling three prices, $30, $60, and $90 Mg–1.

Our study assumed a northeastern Missouri regional market for biomass with the biomass used as a substitute for coal burned in an electric power plant. Thus, the price for biomass equaled the price of coal when both have been adjusted for the amount of heat units they contain. Perennial grasses had a heating value of 19,935 MJ Mg–1 (Boundy et al., 2011) meaning a power plant was willing-to-pay $55 Mg–1 for biomass assuming the price of coal was $0.002746 MJ–1. Two existing biomass delivery contracts in Missouri are for 5 yr (Jared Wilmes, personal communication, 2014) to 10 yr (Gregg Coffin, personal communication, 2014). The University of Missouri biomass delivery contract was established as a long-term fixed price contract as a condition of both the buyer and the seller before either party would move forward with necessary investments (Gregg Coffin, personal communication, 2014).

Pasture yields were converted to AUM to calculate revenue (Scarnecchia and Gaskins, 1987). An AUM is defined as 35.7 kg of dry biomass per month. A University of Missouri Extension survey in 2011 reported pasture revenue rate at $9.69 AUM–1 (Plain and White, 2011), or $27 Mg–1.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Minimum</th>
<th>Mean</th>
<th>Maximum</th>
<th>SD</th>
<th>Number of observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>$133</td>
<td>$204</td>
<td>$340</td>
<td>$38</td>
<td>2500</td>
</tr>
<tr>
<td>Soybean</td>
<td>$235</td>
<td>$422</td>
<td>$699</td>
<td>$85</td>
<td>2500</td>
</tr>
<tr>
<td>Switchgrass</td>
<td>$55</td>
<td>$55</td>
<td>$55</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Miscanthus</td>
<td>$55</td>
<td>$55</td>
<td>$55</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Pasture</td>
<td>$27</td>
<td>$27</td>
<td>$27</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Government programs affecting revenue for corn, soybean, switchgrass, and miscanthus were included in the model. Multi-peril crop insurance for corn and soybean affected how much revenue a producer receives. The federal government subsidizes the program through the Risk Management Agency which establishes premium rates and subsidy levels.

Our analysis estimated indemnities associated with a 75% Revenue Protection plan insuring enterprise units. Guaranteed revenue was calculated as APH times 75% coverage level times the higher of the spring time guaranteed price or harvest time market price.

The producer received an indemnity if yield times harvest time market price was below the guaranteed revenue.

The federal government subsidized cellulosic biomass production via the BCAP. This study included BCAP incentives for switchgrass and miscanthus. The BCAP paid 75% of establishment costs, up to a predetermined maximum, for planting either perennial grass cropping system. These establishment costs were in the first or second years of production. BCAP also gave an annual payment to biomass producers for 5 yr based on the Conservation Reserve Program (CRP) annual payment rates. The assumed CRP rate was $24 ha$^{-1}$, which was discounted at 7.5%. A third BCAP payment based on delivery to a cellulosic ethanol processor was not included in the model.

The net establishment costs during the first two production years were $576.89$ ha$^{-1}$ for switchgrass and $2,935.38$ ha$^{-1}$ for miscanthus. These costs were amortized over 15 yr making the yearly amortized establishment cost $20.59$ ha$^{-1}$ for switchgrass and $155.60$ ha$^{-1}$ for miscanthus, not considering BCAP payments. With the two BCAP payments, the amortized costs became revenues of $40.25$ ha$^{-1}$ for switchgrass and $17.89$ ha$^{-1}$ for miscanthus. Pasture was assumed already established and had not costs for seeding. Table 6 shows detailed information on establishment costs and BCAP subsidies.

**Empirical Model**

The budgets were subjected to the following stochastic variables: grain yields, grain prices, and grass yields. The software Simetar (Richardson et al., 2011) in conjunction with Microsoft Excel were used to run the simulations. A total of 2,000 random draws were made to simulate possible yield and profits from crop and grass production. The yields and prices used in the simulation were drawn from an empirical distribution of actual corn and soybean yields on each soil, simulated grass yields for each soil, and FAPRI simulated prices.

The stochastic variables were correlated in Simetar. The relationships between these variables were correlated to mirror observed relationships. For instance, if corn yields were above average, soybean yields were likely to be above average. Correlation values are unitless numbers between negative one and one. Negative one means that the correlation is perfectly opposite whereas positive one means the variables move in the same direction. Correlation values between grain yields and prices were taken from Woodard et al. (2010). Correlations calculated through ALMANAC models set the biomass to biomass yield at 0.85 and grain to biomass yield at 0.33. Grain prices and biomass yield correlations were assumed to be 0. Each of the 2000 iterations output a return to land, management and capital, hereafter referred to as profit.

A CDF ordered all profits generated by the simulation from lowest to highest to create a continuous function. Profit per hectare was graphed on the x axis and the cumulative probability on the y axis. The CDFs present the probability of each cropping scenario to produce per hectare profits that are less than or equal to the dollar amount on the x axis. Profits to the right are higher and are preferred to profits to the left. Each crop has its own CDF on each of the three soil scenarios.

Each CDF was interpreted through the risk profile of decision-makers who were classified into three groups based on preference for risk: averse, neutral, and seeking. A risk-averse decision maker is concerned with the probability of low (negative) profits, actively reducing risk, and may choose an alternative with a lower average profit if it reduces the variation in profit or prevents loss below a certain point. Because agricultural producers tend to be more risk averse (Wilson and Eidman, 1983), this analysis focused predominately on risk-averse decision makers.

The CDFs of the simulated profits were analyzed according to stochastic dominance theory (Hardaker et al., 2004). The FDSD decision rule assumes that the decision maker prefers more of some good (e.g., profit or utility) to less of that same good. The FDSD makes no assumption about the risk profile of the decision maker. The FDSD specifies that if CDF A is always to the right of CDF B, CDF A would be preferred to CDF B by all decision makers. If the CDFs cross, FDSD is not able to determine the optimal choice for all decision makers.

The SDSD decision rule assumes that not only does the decision maker prefer more to less but also that he is risk neutral to risk averse. Dominance is determined by analyzing the area under each CDF subject to a measure of risk aversion. If the area under CDF A is less than that area under CDF B, then CDF A is the optimal choice for the specified level of risk-averse decision makers. We calculated the area under the CDFs to determine which alternative is preferable based on a predetermined risk profile.

### Table 6. Detail of the establishment costs of perennial grass crops grown for bioenergy used in this study. The table includes costs of materials, biomass crop assistant program (BCAP) establishment subsidy and land payments, and revenue in the year after establishment. Costs are amortized over 15 yr.

<table>
<thead>
<tr>
<th>Description</th>
<th>Switchgrass</th>
<th>Miscanthus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establishment costs</td>
<td>$-573.89</td>
<td>$-2935.46</td>
</tr>
<tr>
<td>Year 1</td>
<td>$-359.01</td>
<td>$-2030.08</td>
</tr>
<tr>
<td>Year 2</td>
<td>$-217.88</td>
<td>$-732.38</td>
</tr>
<tr>
<td>BCAP establishment subsidy</td>
<td>$312.61</td>
<td>$2002.51</td>
</tr>
<tr>
<td>Discounted BCAP land payments</td>
<td>$599.85</td>
<td>$599.85</td>
</tr>
<tr>
<td>Total BCAP subsidy</td>
<td>$912.46</td>
<td>$2602.37</td>
</tr>
<tr>
<td>Revenue Year 2†</td>
<td>$268.11</td>
<td>$601.48</td>
</tr>
<tr>
<td>Net establishment costs‡</td>
<td>$603.68</td>
<td>$268.39</td>
</tr>
<tr>
<td>Amortized net establishment costs without BCAP</td>
<td>$-20.59</td>
<td>$-155.60</td>
</tr>
<tr>
<td>Amortized net establishment costs with BCAP</td>
<td>$40.25</td>
<td>$17.89</td>
</tr>
</tbody>
</table>

† No revenue for any grass crop in Year 1.
‡ Net establishment costs are revenue from Year 2 and discounted BCAP payments minus establishment costs.

<table>
<thead>
<tr>
<th>Description</th>
<th>U.$ ha$^{-1}$</th>
</tr>
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<tr>
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<td>BCAP estab. sub.</td>
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<td>Revenue Year 2</td>
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<tr>
<td>Net estab. costs</td>
<td>$603.68</td>
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<tr>
<td>Amortized net estab. costs</td>
<td>$-20.59</td>
</tr>
<tr>
<td>Amortized net estab. costs with BCAP</td>
<td>$40.25</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

Panels A, B, and C of Fig. 2 present the CDFs of each cropping alternative on three different soils in northeastern Missouri. Corn was the most profitable crop. The CDFs for corn had most observations to the right of the CDFs of any other modeled crops. Corn also had the highest maximum profit. Insured and uninsured corn were not ranked with FDSD on any of the three soil profiles because their CDFs cross at some point. However, insured corn was FDSD over every other crop on all soil types. Insurance changed the distribution of profits for both corn and soybean in similar ways. Indemnity payments were received when revenue from selling production was low, truncating the lower observations of profit to create an income floor. The CDFs show this floor by becoming nearly vertical at the guaranteed revenue level. The CDFs of the insured and uninsured corn and soybean cross meaning neither was FDSD. Above approximately 25 to 30% cumulative probability in all soil types, the uninsured system was more profitable because the cost of the premium reduced the insured income by that amount. Below 25 to 30% cumulative probability, the insured system was more profitable as insurance indemnities offset low profits, as seen by the insured CDF lying to the right of the uninsured CDF. Overall, insured annual grain crops were SDSD over uninsured because of the income floor. When the CDFs cross, the amount of area under the insured grain CDFs was less than the amount of area under the uninsured grain CDFs. Risk averse and risk neutral producers preferred insured annual grain crops.

Comparing just the perennial grasses, miscanthus grown for bioenergy was more profitable at every instance than switchgrass grown for bioenergy or grazed pasture. On all three soils, FDSD was used to eliminate pasture and switchgrass from the viable perennial grass alternatives as their CDFs always lie to the left of miscanthus. Miscanthus had the same market price as switchgrass so its dominance was due to higher yields in all soil profiles and under all modeled weather events. Miscanthus and switchgrass dominated pasture because of a combination of higher yields and higher market price despite pasture’s lower cost of production.

The degree of risk aversion and the soil profile determined whether a producer was inclined to grow miscanthus vs. soybean and corn. Insured corn was always FDSD over miscanthus. For corn to cease being FDSD over miscanthus, the price of miscanthus needed to increase to $62.20 Mg$^{-1}$ on Armstrong soil, $61.55 Mg^{-1}$ on Putnam soil and $64.52 on Belknap soil.

Armstrong soils (representing eroded soils in northeastern Missouri) were the most likely soil profile to favor miscanthus over soybean. Insured soybean and miscanthus profits were almost identical in the bottom 20% of the simulations. The other 80% of the time, insured soybean dominates miscanthus. For most risk averse to risk neutral producers, insured soybean will dominate miscanthus. For uninsured soybean, the CDFs show that miscanthus was more profitable than uninsured soybean for 30% of the simulated observations on Armstrong soils. In other words, approximately 70% of the observations favored uninsured soybean production and 30% the observations favored miscanthus production. A highly risk averse producer would be inclined to plant miscanthus over uninsured soybean because it had the highest profit potential in poor years; the time when a risk averse decision maker would be most concerned. A less risk averse producer would plant soybean because it had the highest profit potential in good years. This difference between the dominance of insured and uninsured soybean over miscanthus illustrates the importance of insurance to the planting decision.

Comparing the CDFs of the different soil profiles helped identify the most likely areas for bioenergy production. Based on this analysis, the opportunity cost of growing bioenergy crops was still too high on Putnam and Belknap soils. While...
the CDFs for each crop on each soil indicated there were times when a very risk averse decision maker would prefer miscanthus production over uninsured corn or soybean production, there were no times when a risk averse decision maker preferred miscanthus to insured corn or soybean production on Putnam and Belknap soils. Armstrong soils were the most likely to have miscanthus production as reflected in the distance between the miscanthus CDF and the corn or soybean CDFs.

The CDFs also illustrate the relative uncertainty of the different crops. The perennial grasses have fairly vertical CDFs in comparison to the annual grains. The steepness of the CDF indicates that the distributions of profits were fairly consistent, or less uncertain, for perennial grasses. This consistency of profits occurred for the three perennial grasses in all three soil profiles because perennial grass yields were much less sensitive to weather variation than the annual grain crop yields. The combination of less variation in yields and deterministic prices explain decreased uncertainty. If the assumption of a contracted, deterministic price for biomass was not realized by a producer, the range of profits could be greater than modeled here.

The range of profits was greatest for corn, yet both grain crops had a greater range than any of the perennial grasses. This large range reflected how the profitability of these crops was more uncertain. Stochastic prices partially explained the increased uncertainty. However, there was also more variation in the yields especially for corn on all soil profiles and for corn and soybean on the Belknap soil profile, where flooding was a common occurrence. Insurance decreased the uncertainty of corn and soybean profit.

**CONCLUSIONS**

Our results showed that perennial grasses grown on productive soils of northeastern Missouri for biomass production were, on average, less profitable and will have a difficult time competing with corn and soybean returns, even with BCAP subsidies of 75% establishment cost and 5 yr of CRP-based rental rates.

If a producer does plant a bioenergy crop on cropland, miscanthus on eroded soils (e.g., Armstrong) would be the most profitable choice, likely replacing continuous soybean.

Perennial grasses grown for biomass were FDSD over land currently in pasture in all soil profiles and could be an opportunity for producers to improve returns on land currently in pasture. The advantage of bioenergy crops over pasture was dependent on a bioenergy market developing around the producer and assumed price of biomass. This analysis did not include costs for fencing or watering. Including those costs associated with pasture would make the bioenergy crops even more desirable.

The BCAP improved the profitability of the perennial bioenergy grasses relative to the other crops. The subsidy resulted in a lateral shift to the right of the CDFs for switchgrass and miscanthus. The amount of that shift equaled the subsidy amount. Miscanthus benefited from BCAP more than switchgrass because of its higher establishment costs. The total subsidy was greater for miscanthus at $2,602.37 ha⁻¹ vs. switchgrass at $912.46 ha⁻¹. Our analysis assumed BCAP payments are available. Without BCAP miscanthus cannot compete with corn and soybean production in northeastern Missouri. The 2014 Farm Bill may not provide sufficient funding for BCAP to make perennial grasses profitable in any soil type.

Removing BCAP, producers with capital constraints that could not afford to plant miscanthus may be more inclined to plant switchgrass. Additionally, switchgrass has advantages in that it is a native grass and has greater substitutability as it can be sold as forage when harvested multiple times during a growing season to maintain forage quality.

This analysis focused on profitability. Producers consider more than just profitability in their decision-making process. Labor demand was a factor not analyzed, yet could influence a producers’ willingness-to-grow a bioenergy grass. If labor limited the productivity of a producer and bioenergy grasses shift labor demands to off-peak times, then a producer would be more willing to grow these crops.

This analysis indicated that the variability of income is greater for corn and soybean than for miscanthus or switchgrass. Risk-averse producers might consider forgoing potentially higher profitability to lower their income variability by growing miscanthus rather than corn or soybean. This result would be more likely in the absence of crop insurance as those uninsured corn and soybean CDFs display many observations of profit less than the miscanthus profit CDF. However, crop insurance lowers variability, removing the lower profit observations and provides an alternative method to decrease risk without growing miscanthus. In this way, grain crop insurance may be a disincentive for production of bioenergy crops on marginal soils.

**REFERENCES**


Duffy, M.D. 2007. Estimated costs for production, storage, and transportation of switchgrass. ISU Ext, Ames, IA.


