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PRODUCTION OF BIOENERGY CROPS IN THE MIDWEST

The Energy Independence and Security Act of 2007 mandates that 79 billion liters of biofuels must be produced annually from non-corn starch feedstocks by 2022. Perennial grasses, switchgrass and miscanthus, could provide the needed biomass with additional benefits that they increase soil carbon, have better nitrogen fixation, provide higher biofuel yield per unit land and can be grown productively on low quality land. Switchgrass and Miscanthus are two of the more promising bioenergy crops because they are relatively higher yielding and have low input requirements. The purpose of this report is to determine the breakeven costs of producing these two energy crops in the Midwest.

There are many different varieties of switchgrass that are divided into two broad categories, the lowland varieties and the upland varieties, with lowland varieties having higher yields per hectare compared to upland varieties. Among the upland varieties, Cave-in-Rock is considered to be well suited for cultivation in the Midwest because it is cold tolerant. Its life span is about 10 years but could be longer. The variety of miscanthus being studied as a bioenergy crop is *Miscanthus x giganteus* which is a sterile variety with a life span of 15 to 20 years. Miscanthus is a cross between two species and has three sets of chromosomes instead of the normal two. This prevents the normal pairing of chromosomes needed to form fertile pollen and ovules and makes it sterile. It has been grown in the European Union on a very large scale for over 20 years with no evidence of becoming invasive.

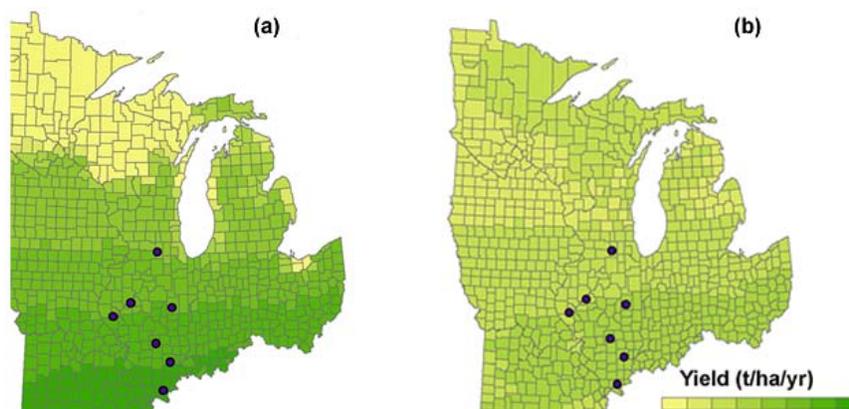
The majority of switchgrass growth occurs during the warm summer months of June to August, whereas miscanthus growth usually peaks between August and October. In the fall, both grasses undergo senescence and translocate nutrients from the above-ground plant canopy to the roots. Delaying harvest until after senescence reduces need for nutrient application in the subsequent year, reduces drying time, and improves the quality of the biomass. Yet, waiting to harvest until after senescence also decreases harvestable yield by 20-40% for miscanthus and 15-20% for switchgrass. The seasonality of biomass growth also influences the timing and the quantity harvested and therefore affects the duration of storage time and the amount of biomass loss during storage. All of these factors influence the cost of harvesting and storage.

Yields of Energy Crops

Researchers at the University of Illinois have been growing switchgrass and miscanthus on experimental plots since 2002 and this has provided data on the suitability of growing conditions in the Midwest for these perennial grasses and the potential yields that can be obtained. The locations of the experimental plots from which data were obtained for this study are marked by blue dots in Figure 1. The yield data from these plots were used to develop a model to simulate the yields of these crops under a range of growing conditions, using information on precipitation, solar radiation, temperature, frost dates and so on. Figure 1 shows the estimated peak yields of standing biomass across the Midwest, which is measured in terms of dry matter (DM) of biomass, defined as having less than 15% moisture. Harvested yields will be lower than peak yields due to loss in dry matter after the crop senesces and during the harvest operation.

Miscanthus is estimated to have its highest yields of biomass, between 46-53 metric tons of dry matter (tons DM)/hectare annually, in the southern regions of the Midwest. Yields declines steadily as we move north; the average yield is 7 tons/hectare annually in Minnesota and 10 tons/hectare annually in Wisconsin. In contrast, switchgrass has a much more even distribution of yields across the Midwest. Its estimated average yield in Illinois is about 15 tons/hectare annually, about 11 tons/hectare annually in Iowa, and about 10 tons/hectare annually in Minnesota. This indicates that miscanthus may be better suited for production in the central and southern regions of the Midwest, while switchgrass may be better suited for the northern regions. Average yields for the different states are shown in Table 1. These are peak yields of the standing crop in the Fall before senescence occurs.

Figure 1: Predicted Miscanthus (a) and Switchgrass (b) Yields in the Midwest



The yields of these grasses differ across their lifespan. Typically, miscanthus requires two years to establish before it achieves its maximum potential yield while switchgrass takes one to two years to establish. Recommended rates of fertilizer application and seeding rates to achieve maximum yield are yet to be standardized. Most studies assume no nitrogen (N) is applied to switchgrass in the first year to prevent weeds. Application rates in subsequent years range from 67-112 kg/ha. Studies in Europe have shown that miscanthus does not respond to N fertilization at annual application rates from 0 to 60 kg/ha. Similarly, field trials have not found a strong response from switchgrass or miscanthus to applications of potassium (K), phosphorus (P), or calcium. Some studies, however, include applications of N, P, K, and lime to replenish soil reserves, especially on soils with lower fertility where application rates are assumed to depend on yield.

Table 1: Predicted Miscanthus and Switchgrass Peak Yields

State/region	Miscanthus Yield (tons DM/hectare/year)	Switchgrass Yield (tons DM/hectare/year)
Iowa	31.23	11.32
Illinois	39.97	14.57
Indiana	42.53	15.51
Michigan	16.61	10.4
Minnesota	7.38	9.9
Missouri	47.7	15.39
Ohio	39.44	15.364
Wisconsin	9.93	10.1
US Midwest	29.35	12.82

Establishment Procedures and Input Requirements for Energy Crops

In order to address the uncertainty with respect to input requirements and cultivation and harvesting outcomes, a low cost and a high cost scenario for bioenergy crop production is considered, based on information provided by agronomists and crop scientists in Illinois and elsewhere. These are described in Table 2. The high cost scenario assumes the need for higher application of nutrients, a higher probability of replanting in the second year to establish the crop and larger loss of biomass during harvest. It also assumes higher cost of harvesting the crop.

The required types of equipment for establishment of miscanthus are a chisel plow, a harrow, machinery to apply fertilizer and spray herbicides, and a semi-automatic potato planter. In its establishment year miscanthus could be planted at a density of about one rhizome per meter. Nutrient application rates for miscanthus are assumed to be 30-60 kg/hectare for N, 7 kg/hectare for P, 100 kg/hectare for K, and 2.3-4.5 tons/hectare for lime. Herbicide application rates should be about 3.5 L/hectare for Atrazine and 1.8 L/hectare for 2,4-D. In the second year the replanting rate is expected to be between 15 and 50%. Nitrogen application is assumed to decrease to 25-50 kg/hectare while P and K rates are assumed to be the same as in the establishment year. No herbicide is required post-establishment year. The percent of peak biomass yield that can be harvested in the second year is estimated to 40-50% and 100% in all subsequent years.

Table 2: Agronomic Specifications for Miscanthus and Switchgrass Production

	Miscanthus low-cost - high cost scenarios	Switchgrass low-cost - high-cost scenarios
<i>Establishment year</i>		
Planting density (rhizomes/meter)	1	-
Seeding rate (kg/hectare)	-	6.5-11
Planting time	March-April	February-March
Nitrogen (kg/hectare)	30-60	0
Phosphorus (kg/hectare)	7	33.7
Potassimu (kg/hectare)	100	44.9
Lime (tons/hectare)	2.3-4.5	0-6.7
Atrazine (L/hectare)	3.5	3.5
2,4-D (L/hectare)	1.8	1.8
<i>Post-establishment year</i>		
Replanting rate in year 2	15-50%	15-50%
Nitrogen (kg/hectare)	25-50	56-140
Phosphorus (kg/hectare)	7	0.42-0.97*
Potassimu (kg/hectare)	100	9.47-11.40*
Atrazine (L/hectare)	0	0-3.5
2,4-D (L/hectare)	0	1.8
<i>Percent of peak biomass yield</i>		
Year 1 (%)	0	100-30
Year 2 (%)	50-40	100-67
Year 3 and after (%)	100	100
Yield loss (%)	20-40	20
Harvest timing	December or early spring	After first frost
Moisture at harvest (%)	15	15
Farm-gate yield (tons DM/hectare)**	19.2-14.1	9.4-8.4
Life of crop (years)	15	10

*Application rate is measured in kg/ton DM of biomass removed

**Farm-gate yield is defined as the annualized yield after losses during harvesting and storage

The procedure used to establish and plant switchgrass in Midwest is through frost seeding using a tandem disk, a harrow, an airflow planter to spread seeds and phosphorus and potassium fertilizer and a self-propelled sprayer to spray the herbicide and spread liquid nitrogen fertilizer. In its establishment year switchgrass should be seeded at a rate of 6.5-11 kg/hectare. Nutrient application rates should be 33.7 kg/hectare for P and 44.9 kg/hectare for K, 0-6.7 tons/hectare for lime, and no nitrogen application is required. Herbicide application rates should be 3.5 L/hectare for Atrazine and 1.8 L/hectare for 2,4-D in the establishment year. In the second year the replanting rate is expected to be between 15 and 50%. Nutrient application rates should be 56-140 kg/hectare for N, 0.42-0.97 kg/ton DM of biomass removed for P, and 9.47-11.40 kg/ton DM of biomass removed for K, post-establishment year. Herbicide application is 0-3.5 L/hectare for atrazine, and 1.8 L/hectare 2,4-D post-establishment year. The percent of peak biomass yield that can be harvested in the first year is estimated to 30-100%, 67-100% in the second year, and 100% in subsequent years.

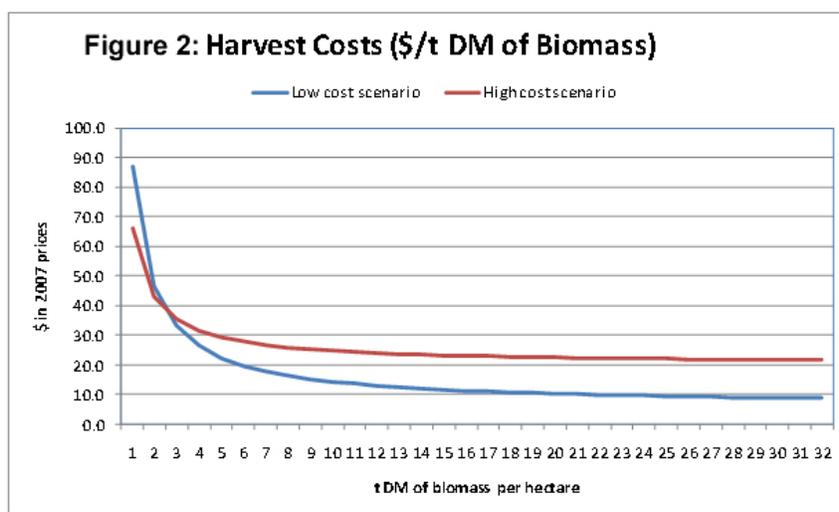
Harvesting of switchgrass is optimal after senescence and during the September-December period while for miscanthus, harvesting could occur between December and April. A single annual harvest is found to result in lower costs than two harvests a year for both switchgrass and miscanthus. A short (four month) harvest window requires considerable investment in harvest equipment. One approach to harvesting that can reduce costs is to extend the harvesting window and thereby spread the fixed costs of the harvest machines over more hectares and reduce the time that the harvested material must be stored. To maintain productivity, additional fertilizer applications would be needed for fields harvested prior to senescence and biomass yields would be lower for fields harvested later.

Production Costs

The production costs for these energy crops include the cost of inputs, the cost of field operations, such as planting and harvesting, the costs of storage, and the cost of land. These costs are estimated using state specific prices for various inputs and state-specific costs of field operations. A farmer who converts land from corn and soybeans to miscanthus or switchgrass is giving up his profits from corn and soy. The break-even price needed to cover all the costs of growing these crops therefore includes the production costs and the opportunity cost of land. The opportunity cost of land is the foregone profit of the next best alternative use of that land. In the Midwest this is generally the production of corn or soybeans. Additionally, unlike annual crops, that provide a farmer with a crop and an income every year, miscanthus and switchgrass require a lag of at least one to two years before harvesting. Moreover, the

upfront costs of establishment yield a return over the life of the crop. Future returns and costs need to be discounted to obtain annualized break-even prices for producing these crops.

Farm activities after establishment of an energy crop include mowing, raking, baling, and storage. There are several factors that are expected to influence these costs, including the size of the farm, the yield per hectare, the number of harvests, the timing of harvest, the harvesting horizon, and the method of storage. The harvesting operation is capital intensive and requires equipment such as a tractor, mower, rake, baler, and bale transporter. Other costs include labor and fuel. The large fixed cost component implies economies of scale if the harvesting equipment can be used over a larger acreage. For any given biomass yield level, harvesting costs per hectare fall as the hectares harvested annually increase. As yields increase, the fixed cost per ton falls (Figure 2) but the speed at which the implements are operated changes and this reduces maximum capacity to harvest (in terms of annual harvested acres). Labor and fuel requirements for baling may also increase as tonnage increases. The appropriate equipment choice may differ by farm size. For example, farms smaller than 200 hectares may find it cost-effective to select round-baling instead of square-baling machines. Two alternative scenarios for the relationship between per ton harvest costs and biomass yield are shown in Figure 2. For a possible low-cost scenario the costs start at a relatively higher level than the high-cost scenario, but then decrease at a relatively greater rate.



Biomass can be stored after harvest in several ways including on-farm open air, on-farm covered, or storage in a centralized covered facility. Open air storage could be unprotected on the ground or on crushed rock or covered by reusable tarp. The covered storage could be a pole frame structure with open sides on crushed rock or it could be an enclosed structure on crushed rock. The loss in biomass is highest when biomass is left unprotected and lowest in the enclosed structure. These losses depend on the number of days the biomass is stored and need to be weighed against the costs of installation, land, labor, and materials as well as the biomass quality that is needed by the bio-refinery. A centralized covered storage facility could be shared by many farms but would require producers to incur biomass handling and transportation costs to move the biomass from the farm. The optimal choice of storage facility is likely to depend on the volume of biomass and the length of time that it has to be stored, the price of biomass, the quality of biomass required, and the weather conditions within the region. Here we assume that the biomass is stored on-farm open air. This storage method is considered to be the most cost-effective at \$3.22/ton DM and lead to a 7% loss in biomass.

Transportation costs include the amortized capital cost of the truck and operating costs which include labor, fuel, maintenance, insurance, and repairs. Fuel costs depend on the distance travelled. Additionally, loading and unloading costs and waiting time for the driver also need to be factored in. Costs of transportation will vary across farms depending on their distance to the refinery and the collection area of the refinery. With high yielding feedstocks, a refinery can obtain its feedstock from a smaller collection area. Some studies of biomass transportation have found that the costs can range from \$5.60/ton in Oklahoma to \$15.60/ton in Illinois.

Table 3 describes the components of the estimated production costs over the lifespan of the bioenergy crops for Illinois. During its first year, the production costs of switchgrass are primarily from nutrients, seeding, pre-harvest machinery operation, as well as some harvesting. In the second year the requirement of N application increases nutrient costs, seeding and pre-harvesting costs decrease, and harvesting costs increase as the yield increases. In the following 3 to 10 years nutrient costs increase, seeding costs go to zero, and harvesting costs increase if

maximum crop yield was not achieved in the second year. During its first year, the production costs of *Miscanthus* are primarily from nutrients, rhizomes, and planting costs, while no harvesting costs are incurred during the first year. In the second year nutrient costs decrease, planting costs decrease, but some planting will be required; this is the first year harvesting costs will be incurred. In the following 3 to 15 years nutrient costs decrease, planting costs go to zero, and harvesting expenses increase as yield increases. The production costs for other Midwest states are calculated in same method as shown in Table 3 for Illinois.

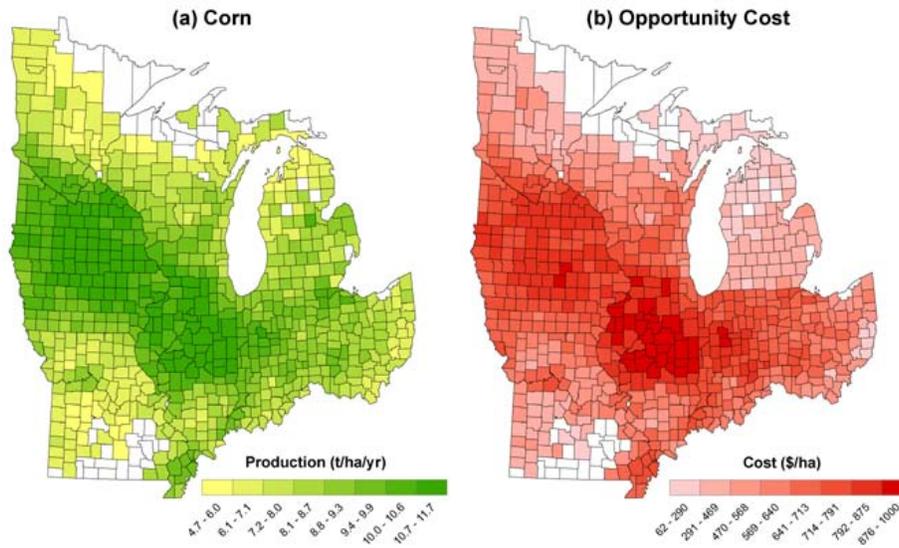
Table 3: Production Costs for Illinois (Low-Cost Scenario – High-Cost Scenario)

Cost items (\$ /ha)	Switchgrass			Miscanthus		
	Year 1	Year 2	Years 3-10	Year 1	Year 2	Years 3-15
Fertilizer	50-198	148-117	152-211	138-210	85-107	84-103
-Nitrogen	0	86-65	86-129	23-46	20-42	19-38
-Phosphorous	23	5-14	3-7	5	5	5
-Potassium	27	57-39	62-75	60	60	60
-Lime	0-148	0	0	50-99	0	0
Herbicides/Pesticides	19	3-19	0-19	19	3-10	0
Seed	107-182	16-91	0	2471	371-1234	0
Preharvest machinery repair, fuel and hire	58	10-21	8-21	145	28-76	8
-Chisel plowing	23	0	0	33	5-17	0
-Harrowing	14	0	0	14	2-7	0
-Potato planter				77	12-39	0
-Fertilizer spreader	8	8	8	8	8	8
-Spraying chemicals (atrazin and 2-4 D)	13	2-13	0-13	13	2-6	0
Harvesting expenses	257-137	296-286	296-426	0	307-175	641-804
-Mowing/conditioning	30-18	35-24	35	0	30-18	35
-Raking	9-6	11-7	11	0	0-6	0-11
-Baling	95-71	106-158	106-236	0	115-94	224-472
-Staging, and loading	81-29	96-64	96-	0	108-38	255-191
-Storage	41-14	48-32	48	0	54-19	127-95
Interest on operating inputs	12-28	12-16	11-16	184-189	32-95	6-7
Total operating cost at farm-gate	503-622	484-549	466-694	2957-3034	826-1698	739-923
Yield at farm-gate (t DM ha-1)	9-3	11-7	11	0	12-4	29-22

Some costs are fixed and do not vary with the yield of biomass (for example, the cost of land), others are incurred annually, and for perennial crops, some costs are incurred only once over the life of the crop. Thus, the stand life of a perennial crop, the biomass yield per unit of land, and the growing season for the crop all potentially impact the cost per dry ton for biomass residues and dedicated energy crops. These factors are likely to differ across energy crop species and across locations depending on climate, soil quality, and competing uses for land. Thus the breakeven price of an energy crop differs across locations in the Midwest and depends on the type of land that is converted for bioenergy crop production.

The maps above show the opportunity cost of using land currently under a corn-soybean rotation in the Midwest. This cost is higher in counties with higher yields of corn and soybeans. As is illustrated in Figure 3 the opportunity cost of land in the Midwest is highly correlated with the level of corn production. States with higher than average corn production, such as Iowa, Illinois, and Indiana also have higher than average opportunity costs of land, while states like Missouri and Minnesota have lower than average corn production and lower than average opportunity cost of land. The opportunity cost of land in the Midwest can be relatively high; \$700-800/hectare in 2007 prices in some regions. But, it is important to note that these are estimates of the opportunity cost of a hectare of average land under crop production in the county not a hectare of marginal land. Research suggests that *Miscanthus* and switchgrass can be produced with relatively high yields even on marginal land. Marginal land has a much lower opportunity cost than other agricultural land at about \$100-300/hectare.

Figure 3: Average corn yields for the period 2003–2007 and the opportunity cost of land in 2007

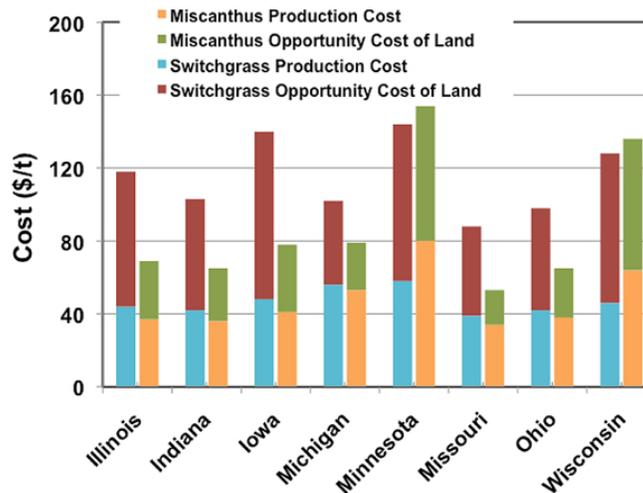


Breakeven Prices

Taking the sum of the three components of production costs previously described and the opportunity cost of land and annualizing them over the crop’s lifespan, the breakeven price can be calculated. The breakeven price is the price which covers all economic costs of production and is hence, the minimum price at which the bioenergy crop can profitably be produced. The profitability of a particular bioenergy crop increases directly with the increase of the price of biomass above the breakeven price. It is important to note that this analysis considers only breakeven farm-gate prices, which abstracts from transportation costs that might be required.

Table 4 and Figure 4 show a comparison of breakeven prices across states when using land of average quality. Missouri has the lowest breakeven price per ton of biomass with \$88 to \$118/ton for switchgrass and \$53-\$85/ton for miscanthus. Minnesota and Iowa have the highest breakeven price per ton for switchgrass (\$144-\$188/ton and \$140-\$178/ton, respectively) due to their high opportunity cost of land. Minnesota and Wisconsin have the highest breakeven price for miscanthus (\$153-\$234/ton and \$140-\$211/ton, respectively) due to their much lower miscanthus yield levels. These results show that there is a great deal of variability in breakeven prices across the Midwest and that the states with lower than average breakeven prices are better suited to produce these crops once a market develops.

Figure 4: Components of Breakeven Prices on Average Quality Land in 2007 prices



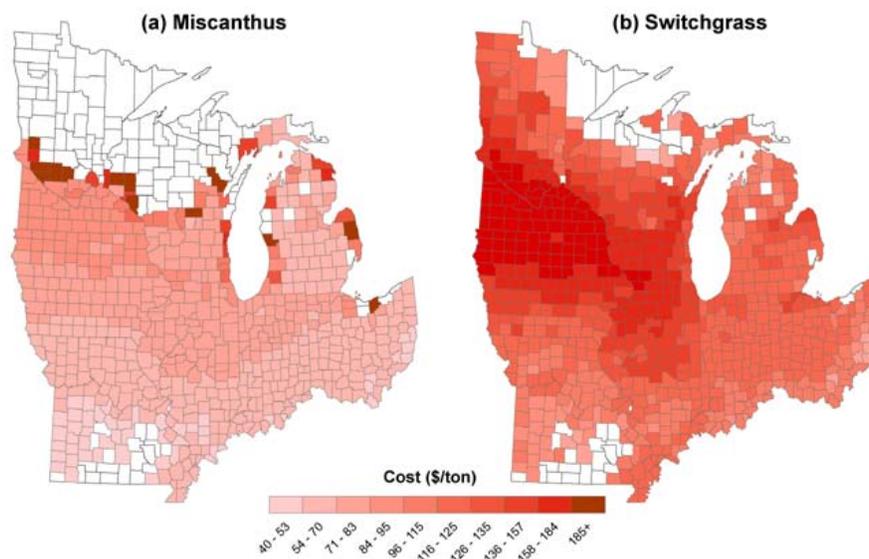
If the decision is made to produce either of the bioenergy crops on marginal land, profitable production could be achieved at much lower biomass prices than on average quality land. Table 4 also describes the breakeven price required for profitable production of bioenergy crops on marginal land. The breakeven price decreases significantly from the case of using average quality land. Missouri and Iowa have the lowest breakeven prices for switchgrass at \$60-85/ton DM and \$60-88/ton DM, respectively, while Missouri has the lowest breakeven price for Miscanthus at \$42-69/ton DM. Indiana has the highest breakeven price for switchgrass at \$89-124/ton DM, due to a relatively high opportunity cost of marginal land. Minnesota has the highest breakeven price for Miscanthus at \$95-151/ton DM, due primarily to its low yield in cold weather. The breakeven prices across all states and crops decrease significantly when marginal land is used for production as compared to average quality land.

Table 4: Costs and Breakeven Prices for Miscanthus and Switchgrass Production

State	Switchgrass			Miscanthus				
	Production cost (\$/ton or M DM)	Quality of land A (Average or M (Marginal)	Opportunity cost of average land (\$ per ton DM)	Breakeven Price (\$ per ton DM)	Production cost (\$/ton or M DM)	Quality of land A (Average or M (Marginal)	Opportunity cost of marginal land (\$ per ton DM)	Breakeven Price (\$ per ton DM)
Illinois	44-70	(A)	73-82	117-151	37-63	(A)	31-43	69-106
		(M)	28-32	72-102		(M)	12-17	49-80
Indiana	42-71	(A)	61-67	103-138	36-65	(A)	29-39	65-104
		(M)	47-53	89-124		(M)	21-29	57-94
Iowa	48-75	(A)	92-103	140-178	41-69	(A)	37-51	78-120
		(M)	12-13	60-88		(M)	5-6	46-75
Michigan	56-88	(A)	46-54	102-142	53-91	(A)	26-37	79-128
		(M)	11-12	67-100		(M)	6-8	59-99
Minnesota	58-90	(A)	86-98	144-188	80-131	(A)	74-103	153-234
		(M)	17-19	75-109		(M)	15-20	95-151
Missouri	39-62	(A)	49-56	88-118	34-58	(A)	19-27	53-85
		(M)	21-23	60-85		(M)	8-11	42-69
Ohio	42-67	(A)	56-62	98-130	38-65	(A)	27-36	65-101
		(M)	28-31	70-98		(M)	13-18	51-83
Wisconsin	46-70	(A)	82-91	127-162	68-114	(A)	72-98	140-211
		(M)	11-13	57-83		(M)	10-14	78-128

These breakeven prices on average quality land are illustrated at a higher resolution in the maps shown in Figure 5. This spatial distribution of breakeven prices illustrates that the counties in the southern regions of the Midwest have relatively low breakeven prices for Miscanthus, which increase steadily moving northward. The variation of breakeven prices for Miscanthus across the Midwest is primarily due to the varying opportunity cost of land and its susceptibility to cold weather. The breakeven prices for switchgrass while being distributed more uniformly across the Midwest, are also much higher than on average than those for Miscanthus.

Figure 5: Breakeven Prices on Average Quality Land



The breakeven prices are sensitive to some of the assumption used in this analysis, including the profitability of corn and soybeans, the cost of inputs, and the crop's lifespan. Changing these assumptions and recalculating the breakeven price shows how sensitive these results are to the assumptions made. If the corn and soybean price were to be 25% higher than is assumed, the average breakeven prices increase by 27% and 20% for switchgrass and miscanthus, respectively. Miscanthus is somewhat less sensitive to this price change due to its higher yield. If miscanthus rhizomes cost \$0.50/plug instead of the \$0.25/plug assumed, the breakeven price for miscanthus increases by an average of 19%. Breakeven prices are less sensitive to planting and harvesting costs, input costs, and the interest rate. The costs of dedicated energy crops will also vary with the lifetime of the crop. A reduction in the lifetime of miscanthus from 15 years to 10 years would increase the breakeven price of miscanthus by 11-15% while a 10% increase in bioenergy crop yields could reduce the breakeven price of miscanthus and switchgrass by about 7%. The breakeven prices were less sensitive to changes in assumptions on planting and harvesting costs, input costs, and the interest rate used to convert future costs and returns to present value.

Conclusion

Miscanthus and switchgrass are two promising feedstocks in the production of biofuels. These crops have been growing in experimental plots at the University of Illinois since 2002. Data gathered from these experimental plots have provided information on the suitability of growing these grasses in the Midwest. Miscanthus has a higher yield on average than switchgrass in the Midwest, but performs poorly in the northern regions, while switchgrass yield is not affected as significantly by cold weather. Due to the fact that there is some uncertainty about the input use for these crops a low-cost and high cost scenarios are given in the description of the agronomic procedures. The breakeven prices for profitable production of these crops are calculated from estimates of the costs of inputs, machinery, and land. The breakeven prices for both crops depend significantly on the quality of farmland being used for production. The cost of producing Miscanthus can be as low as \$69-106 per ton DM in Illinois if average quality land is used and \$49-\$80 per ton DM if marginal quality land is used. Switchgrass can produced for as low as \$72-\$102 per ton DM in Iowa if marginal quality land is used while costing \$117-\$151 if average quality land is used. The average breakeven price for miscanthus is lower in the southern regions of the Midwest than the northern regions. The average breakeven price for switchgrass is more uniform across the Midwest, but higher on average than miscanthus. These breakeven prices are somewhat sensitive to some of the assumptions made. The breakeven prices are more sensitive to changes in corn and soybean prices, miscanthus rhizome cost, and miscanthus lifespan, than to planting and harvesting costs, input costs, and the interest rate.

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