Farm-Level Economics of Bioenergy in the Upper Missouri River Basin




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Abstract

Modeling farm-level economic implications from regional dedicated bioenergy production in the Upper Missouri River Basin, we estimate break-even prices for switchgrass yielding 2.7 tons per acre following 2016 crop budgets, at between $116 and $99 per ton across four agricultural sub-regions. Given that these prices fall short of predicted biomass feedstock prices, either the variable costs of production of switchgrass would need to decrease, or substantial subsidy policies would need to be in place to make switchgrass competitive within current crop mixes. Broad energy sector economic and policy shifts are likely necessary for dedicated bioenergy crops to become competitive.

INTRODUCTION

“First-generation” bioenergy is produced from crops also used for food and feed, predominately corn and soybeans in the United States. Dedicated energy crops, including perennial grasses such as switchgrass, do not directly utilize conventional commodity crops (Nagler and Gerace, 2020). Research focused on this new “second generation” of agricultural bioenergy is motivated by intersecting goals of renewable energy (US DOE, 2016; Lopez et al., 2012), reducing greenhouse gas emissions (Gerace and Rashford, 2018; Rosen, 2018; Azar et al., 2010), reducing biofeedstock competition with food and feed production (Prasad and Ingle, 2019; Graham-Rowe, 2011), sustainable land and soil management practices (Goglio et al., 2015; Zaher et al., 2013), and ecological co-benefits (Bourlion, Janssen, and Miller, 2013). While technology to convert biomass into ethanol and other bio-based products currently exists, factors including biomass production costs, local availability or transportation costs, and inefficiencies in energy conversion processes have limited commercialization (Usmani et al., 2021; Chandel et al., 2018).

For entire regions to successfully shift to second-generation bioenergy systems at a sufficient production scale, individual farms will need to contribute by replacing part or all of their current cropping mix with a dedicated biomass crop. Since most productive agricultural land in North America is privately owned, the decision to convert to biomass crops will be driven, at least in part, by farm-level economic considerations. Thus, for voluntary conversion, biomass crops will not only need to be profitable on their own, but will also have to be at least as profitable as the next best alternative—that is, they need to cover the opportunity cost of transitioning from current production to dedicated bioenergy. The biomass production literature, however, largely focuses on feedstock characterization (INL, 2021; US DOE, 2016), agronomy (Tang, Han, and Xie, 2020), and yield estimation (Li et al., 2018; Gu, Wylie, and Howard, 2015), with less attention given to the farm-level economics and associated private crop choice.

Farm-level economics of second-generation bioenergy conversion are considered in specific contexts. Dumortier, Kauffman, and Hayes (2017) apply a real option switching model to U.S. bioenergy crop production and find economic incentives lacking without substantial government incentives. Brandes, Plastina, and Heaton (2018) investigate an upper bound for switchgrass prices needed to motivate sub-field production areas alongside conventional crops in Iowa. They conclude that areas with high within-field yield variation provide more opportunities for switchgrass conversion in this highly productive agricultural area.

We evaluate farm-level economic implications from adopting widespread dedicated bioenergy production, focusing on the Upper Missouri River Basin (UMRB) region of the United States, an important and diverse agricultural region. Using crop and whole-farm budget analyses, we compare farm-level profitability of baseline versus bioenergy-focused agricultural systems, and we estimate break-even prices for potential dedicated bioenergy crops across the region. Our approach expands on previous economic analysis of producing switchgrass for bioenergy (reviewed in Jacot, Williams, and Kiniry [2021]) by explicitly considering a whole farm budget, thus being able to account for the opportunity cost of replacing current production in addition to direct costs.

Results suggest that incorporating dedicated bioenergy is less profitable than current baseline farming systems. Differences in profit help determine the gap between break-even prices and production cost efficiencies or policy incentives needed for farms in the UMRB to voluntarily switch part of their crop mix to dedicated energy production. Break-even prices needed for bioenergy crops can also help establish market equilibrium between bioenergy crop producers and processors.

BACKGROUND

Upper Missouri River Basin Regional Agriculture

The Upper Missouri watershed encompasses most of Montana and South Dakota; portions of North Dakota and Wyoming; and small parts of Nebraska, Iowa, and Minnesota (Figure 1). Just over a fifth (20%) of land within the UMRB, 39 million acres, is cultivated cropland (NLCD, 2011).

Climate across the UMRB is characterized by increasing precipitation from west to east and decreasing temperatures from south to north, defining a large range of farming conditions. The UMRB encompasses several ecoregions with diverse land uses and climate attributes (US EPA, 2021). To address farming system heterogeneity within this region, we distinguish four UMRB agricultural sub-regions: Western Basin and Range, Northern Glaciated Plains, Eastern High Plains, and Central Missouri Plateau (Figure 2). Baseline farming systems reflect 2016 farming practices across counties within each of the sub-regions. Cropping area (Table 1), crop prices, and crop yields (Table 2) for each region are defined using county-level data and relevant area crop enterprise budgets (USDA NASS, 2016; USDA ERS 2021; UW, 2017; UI, 2017; NDSU, 2017; SDSU, 2017—as described in Hanson, 2019).

The Western Basin and Range sub-region includes 33 counties with crops harvested on over 1.3 million acres (Table 1, bottom row). Alfalfa, grass hay, and barley dominate crop production with substantial winter wheat, non-durum spring wheat, and sugarbeet production (Table 1). While ranching operations are often much larger, average cropping acres per operation in the Western Basin and Range is 1,730 acres (Table 3, bottom row).

The Northern Glaciated Plains sub-region includes counties north of the Missouri River in Montana and North Dakota. Baseline farming systems in the Northern Glaciated Plains include a highly variable dryland crop mix based on wheat production (winter, non-durum spring, and durum spring wheat), along with lentils, barley, peas, alfalfa, grass hay, canola, beans, and a range of other oilseeds, legumes, and small grains (Table 1). The Northern Glaciated Plains includes 19 counties with crops harvested on over 6.3 million cropping acres (Table 1, bottom row). Average cropping acres per operation is 2,390 acres (Table 3, bottom row).

The Eastern High Plains sub-region is located in North Dakota, South Dakota, and Iowa, east of the Missouri River. Baseline farming systems are dominated by dryland corn and soybean production, together accounting for 79% of harvested acres, along with sugarbeets, non-durum spring wheat, hay, alfalfa, and other oilseeds and small grains (Table 1). The Eastern High Plains includes 76 counties with 20.5 million crop acres harvested (Table 1, bottom row). Average cropping acres per farming operation are the smallest among the four sub-regions at 823 acres (Table 3, bottom row).

The Central Missouri Plateau sub-region includes counties south and west of the Missouri River belonging to the Northwestern Great Plains ecoregion. Baseline farming systems in the Central Missouri Plateau include both dryland and irrigated crop production, primarily alfalfa, non-durum spring wheat, hay, corn, winter wheat, and soybeans, along with some other oilseeds, legumes, and small grains (Table 1). This sub-region makes up a majority of the UMRB, which encompasses substantial farm heterogeneity. The Central Missouri Plateau includes 63 counties in central Montana, western Dakotas, and northern Wyoming and Nebraska with nearly 11 million cropping acres harvested (Table 1, bottom row). Average cropping acres per operation is the largest of the four sub-regions at 3,055 acres (Table 3, bottom row).

U.S. and Regional Bioenergy Production

Historic and current U.S. bioenergy production is primarily corn ethanol, with some soybean oil processed into biodiesel. This first generation of food and feed crops used for transportation biofuels has increased dramatically since the mid-1990s. The proportion of corn marketed for ethanol surpassed livestock feed as the largest use of domestic corn for the 2010/2011 crop (USDA ERS, 2021). Following broader U.S. demand for first-generation feedstocks, both corn and soybean production have increased in the UMRB since the 1990s, notably in the Eastern High Plains sub-region (Nagler, 2018). However, at the time of writing, no second-generation bioenergy production (or dedicated biomass crop production) exists in or near the UMRB region, with commercialization limited by reliable feedstock supply and production inefficiencies and costs (Usmani et al., 2021; Chandel et al., 2018).

To model production needed for a regional-scale dedicated bioenergy system, we consider integrating switchgrass into sub-region crop mixes as bioenergy feedstock. Switchgrass (*Panicum virgatum L.*), a warm-season perennial grass native to North America, tolerates low fertility, acidic soils, and moderately alkaline soils and can be grown across most of the United States (Moore, 2003, 237). As a perennial grass, switchgrass production offers many environmental benefits including wildlife habitat, erosion control, nutrient loss avoidance, and reduced input requirements compared to annual crops (Bourlion, Janssen, and Miller, 2013).

Because of its wide-ranging adaptability across the United States and high level of cellulosic material, switchgrass is gaining attention as a bioenergy feedstock. Switchgrass can either be chemically processed (enzymes break down switchgrass feedstock) or thermally processed (gasification burns switchgrass feedstock to produce gas) into bioenergy, and it is a popular prospect in the United States for bioenergy use (Jin, Mendis, and Sutherland, 2019; Gustafson, 2018).

BASELINE FARMING SYSTEM MODELING

To determine farm-level economic implications from adopting dedicated bioenergy production in the UMRB, we first estimate whole-farm profitability of baseline farming systems. Whole-farm budgets combine all relevant sub-region annual crop budgets proportional to the crop mix in each sub-region. Whole-farm profitability is driven by crop mix, yield, and cropping area associated with different climate attributes and historical farming practices across the UMRB. The four agricultural sub-regions described above capture this variability. While important to many regional farming operations, in order to focus on crop-level break-even prices, this analysis does not take into consideration related livestock farm enterprises; for example, benefits from grazing cornstalk residue.

Crop Budgets

Crop enterprise budgets evaluate per-acre costs and returns for a production year. We adapt 63 crop budgets to reflect common production practices. The budgets assume operating interest to be 5.5% (Lee, Ritten, and Foulke, 2018), and five years for alfalfa stand-life (Islam, 2018). Crop insurance prices and depreciation are omitted in order to focus on gross margin calculations (i.e., returns over variable costs). Fixed costs are also omitted, due to the nature of annual crop budgeting. Accordingly, each crop budget captures variable costs and annual total revenue.

Respective published crop budgets provided growing-season expectations for 2017 crop yields (Table 2). As expected, crop yields vary by sub-region, with the highest relative yields reported in the Eastern High Plains for most row crops; dry bean yields are highest in the Western Basin and Range, alfalfa yields in the Northern Glaciated Plains, and grass hay in the Western Basin and Range and Central Missouri Plateau (bolded in Table 2).

The Western Basin and Range whole-farm budget incorporates 9 annual crop budgets (UW, 2017; UI, 2017;

UNL, 2017) reflecting the 2016 county-level crop mix (Table 1). The Northern Glaciated Plains representative farm adapts 18 annual crop budgets reflecting the reported crop mix (Table 1). These budgets are from North Dakota State University's northwestern crop-budget region (NDSU, 2017). The Eastern High Plains farm budget adapts 17 annual crop budgets following the 2016 reported crops (Table 1). South Dakota State University's east and central high-production crop budgets (SDSU, 2017) and North Dakota State University's southeastern crop-budgets are used (NDSU, 2017). The Central Missouri Plateau adapts 19 annual crop budgets representing 2016 county-level crop mix (Table 1), including all regional crops except mustard. Budgets are from North Dakota State University's southwestern crop-budget region (NDSU, 2017), South Dakota State University's central and west low production budgets (SDSU, 2017), and the University of Nebraska-Lincoln's irrigated, low-production crop budgets (UNL, 2017).

Gross Margin Calculations

In order to account for market risk as crop prices fluctuate from year to year, we use 20 years of data (1998–2017) to estimate a realistic range of potential crop prices. Price data are state-level prices received averaged over all UMRB states (USDA NASS, 2016). We use the Producer Price Index to adjust reported prices to 2017 dollars (Federal Reserve, 2018). We estimate a temporal distribution for each crop price using the @Risk software batch fit process (Palisade Corporation, 2004). We then perform a Monte Carlo simulation with 100,000 iterations of randomly selected crop prices from this dataset to produce a distribution of price outcomes for each crop's annual returns. Simulation results provide a probability distribution of possible price outcomes. Using the randomized prices, we multiply expected 2017 sub-region yields (reported in Table 1) by the respective crop price distribution to calculate *total revenue* per crop per acre for each sub-region. Using the production costs per acre from crop budgets for each crop across each of the four sub-regions determined by annual crop budgets and above methods, we calculate *gross margin* of each crop in each sub-region as total revenue minus variable per-acre production costs.

We determine crop acres harvested by sub-region based on aggregated county-level 2016 acres harvested (USDA NASS, 2016). To understand the *proportion of total acres contributed* by each crop in each sub-region, we divide crop acres harvested by the total number of cropping acres in that sub-region (Table 2, bottom row). Using the reported average number of total cropping acres per operation reported by NASS (USDA NASS, 2016), we then determine the number of acres of each crop for a representative farm in each sub-region. *Crop acres per farm* is calculated as the regional proportion of total acres contributed by each crop multiplied by regional cropping acres per farm (Table 2). To determine the *whole-farm gross margin per acre* in each sub-region, we sum over the product of crop acres per farm and gross margin for each crop and sub-region.

Baseline Results

The baseline model provides probabilistic whole-farm gross margins and whole-farm gross margins per acre based on 2016 production practices and 20 years of historical crop prices. These results are reported below for representative farms in four agricultural sub-regions (Table 3).

For the Western Basin and Range, mean whole-farm gross margin per acre from all baseline crops on a representative farm in this sub-region is $236. Multiplied by 1,730 total crop acres per farm, annual mean baseline whole-farm gross margin is $407,778. Sugarbeets contribute substantially to per-acre profitability; alfalfa, dry beans, and grass hay also help to increase the whole-farm gross margins per acre in the Western Basin and Range.

The Northern Glaciated Plains baseline whole-farm gross margins per acre is $157. With 2,390 acres of cropping area per farm, annual whole-farm gross margin for the Northern Glaciated Plains is $375,068. With almost 60% of cropping acres in the Northern Glaciated Plains allocated to wheat production (including spring, winter, and durum varieties), profitability in the Northern Glaciated Plains can be attributed primarily to wheat cropping acres. A significant amount of peas, lentils, barley, and alfalfa hay are also grown in the Northern Glaciated Plains, and with low variable production costs, these crops also significantly contribute to profitability.

The Eastern High Plains baseline whole-farm gross margins per acre is $362 with 823 cropping acres per representative farm, bringing annual whole-farm gross margins to $297,706. Corn and soybean production dominate the Eastern High Plains sub-region, making up almost 80% of cropping acres and contributing significantly to profitability in this sub-region.

The Central Missouri Plateau baseline whole-farm gross margins per acre is $166 and cropping acres on a representative farm are 3,055, resulting in $507,626 in annual whole-farm gross margins. Although the Central Missouri Plateau is the most heterogeneous sub-region with respect to number of crops grown, alfalfa and grass hay, as well as spring and winter wheat varieties, make up the most cropping acres. With over 2.4 million cropping acres allocated to alfalfa hay production, as well as low costs of production, it is clear that alfalfa hay drives profitability in the Central Missouri Plateau.

Thus, on a per-acre basis, the highest comparative gross margins are found to be in the Eastern High Plains sub-region, followed by the Western Basin and Range, Central Missouri Plateau, and Northern Glaciated Plains. Whole-farm profitability is influenced by representative farm size, resulting in higher whole-farm gross margins in the Central Missouri Plateau, followed by Western Basin and Range, Northern Glaciated Plains, and Eastern High Plains. Further, differences in whole-farm price distributions across the four sub-regions influence price risk for representative farms. Whole-farm price volatility is measured with the coefficient of variation (CV) of whole-farm gross margin per acre. CV is a measure of relative variation; the higher the CV, the greater the level of dispersion around the mean.

The Western Basin and Range sub-region has the least volatile whole-farm gross margin per acre, followed by the Central Missouri Plateau, Northern Glaciated Plains, and Eastern High Plains. The relatively high CV (0.35) seen in the Eastern High Plains sub-region highlights that while this sub-region has the highest average whole-farm gross margin per acre ($362), it comes with higher risks associated with variable annual crop prices. The Western Basin and Range region, on the other hand, has comparatively lower overall price variability (CV 0.25), as well as lower whole-farm gross margin per acre ($236). This relationship between whole-farm gross margins and price variability is key to understanding farm-level implications from adopting dedicated bioenergy production across the UMRB.

DEDICATED BIOENERGY SCENARIO MODELING

Despite the potential for switchgrass to contribute to regional bioenergy production, limited research exists on the production practices and costs for switchgrass in the UMRB. To understand the economic implications of growing switchgrass in the UMRB to potentially contribute to bioenergy markets, switchgrass production costs relevant to this region are estimated by adapting a dryland switchgrass enterprise budget with production costs based on relevant case studies and regional production costs, soil, and climate conditions (Hanson, 2019; Hanson et al., 2020).

Assuming a 10-year stand life with limited harvesting available in years one and two and 5.5% operating interest, total switchgrass production costs are between $110.31 (for western soil types) and $112.85 per acre (for soil types typical in the eastern UMRB), depending on differences in fertilizer needs and costs. Based on expected regional yields of 2.73 tons per acre used in Hanson et al. (2020), a producer would need to receive between $40.37 and $41.30 per ton given respective soil types to cover their variable switchgrass production costs. This does not take into consideration costs associated with transitioning to switchgrass production, such as heavier harvest equipment, although there is significant overlap in machinery needs between switchgrass and grass hay.

To model the introduction of second-generation bioenergy crops, we allocate all grass hay acres (i.e., hay excluding alfalfa) to switchgrass in each of the four sub-regions. This simplifying assumption derives an upper bound estimate on economic feasibility. We then estimate the difference in whole-farm gross margin between the baseline and the dedicated bioenergy farming system. This bioenergy farming model, therefore, can compare production costs across all crops within each sub-region of the UMRB, as well as whole-farm gross margins.

To calculate the *whole-farm gross margin for a second-generation bioenergy system*, we sum over the total gross margin of grass hay plus the product of the gross margin of switchgrass and total acres of grass hay per representative farm over each sub-region. Because all grass hay acres are allocated to switchgrass, and because there is no sufficient price forecast for switchgrass in the UMRB, we determine the break-even prices necessary for switchgrass to replace grass hay by assuming zero production of grass hay and setting total revenue from switchgrass equal to $0.00. The resulting *gross margin per acre for switchgrass* is a negative value (with no total revenue, the gross margin for switchgrass simply reflects per-acre production costs in each sub-region).

The *total gross margin of switchgrass* in each sub-region is represented by the gross margin per acre of switchgrass multiplied by the total grass hay acres for each sub-region. The whole-farm gross margin for each sub-region decreases from the baseline model by the loss from total gross margin from replaced grass hay, which captures the implications from converting all grass hay acres to second-generation bioenergy production.

Deriving the whole-farm loss from converting grass hay acres into switchgrass allows us to calculate the prices necessary for switchgrass to break even with production costs for farmers in the UMRB. We calculate *break-even prices* as the difference between baseline and switchgrass whole-farm gross margin divided by yield per acre of switchgrass for each sub-region. This estimated switchgrass break-even price helps policy makers understand the markets or incentives needed for widespread adoption of second-generation bioenergy crops in the UMRB.

Bioenergy Scenario Results

As expected, all four sub-regions experience a decrease in whole-farm gross margins from allocating all grass hay acres to switchgrass at our assumed production cost, although whole-farm loss in the Eastern High Plains appears marginal, mainly due to limited acres of grass hay allocated to bioenergy in the area (Table 4). Whole-farm loss from adopting dedicated bioenergy on hay acres is greatest in the Central Missouri Plateau and Western Basin and Range, where grass hay is more prevalent. The gap between baseline and bioenergy scenario whole-farm gross margin reflects a per-acre revenue gap producers would need to make up to voluntarily replace grass hay with switchgrass.

In order to reflect both geographical and annual variability in expected switchgrass productivity across the UMRB, as well as a lack of sufficient research and data, we consider a range of annual switchgrass yields. Average reported 2016 grass hay yields in Montana and Wyoming of 1.7 tons per acre (USDA NASS, 2016) provide a lower bound; a weighted average across regional field trial study sites in eastern South Dakota (Hanson et al., 2020) estimates yield with current production techniques at 2.7 tons per acre; and 3.7 tons per acre represents a future regional upper bound requiring improvements in switchgrass genetics and production practices. Estimated break-even prices per ton with these different yield assumptions are reported in Table 5.

Using a regional historic upper bound for yields—2.7 tons per acre—producers in the Central Missouri Plateau would need to receive the highest break-even price, $116 per ton, in order to break even and recover their switchgrass production cost (not including fixed or transition costs). The break-even price at this yield in the Western Basin and Range and Northern Glaciated Plains is a bit lower, at $115 and $113 per ton, respectively, while the Eastern High Plains sub-region has the lowest break-even price, at $99 per ton.

As expected, break-even prices decrease when the switchgrass yield increases. In order to achieve regional yields of 3.7 tons per acre, greater improvements in genetic varieties and expected production practices (e.g., improved fertilizer practices) would likely be necessary, which may also increase production costs. However, some counties in southeastern portions of the Eastern High Plains sub-region have estimated switchgrass yields of 3.6 tons per acre or more (NREL, 2021; Figure 3). Price incentives to produce switchgrass on more productive cropping areas could also result in higher yields. With yields of 3.7 tons per acre, given our estimated 2016 production costs, UMRB producers would realize a production cost break-even point at between $85 and $73 per ton (Table 5). Break-even prices under this optimistic future yield are in line with the high end of Billion-Ton Report biomass farmgate price scenarios, $40, $60, and $80 per dry ton (US DOE, 2016, 147).

If switchgrass yield were only 1.7 tons per acre, reflecting reported western UMRB grass hay yields, break-even prices increase substantially to between $182 and $156 per acre. This lower yield assumption may be more reasonable for dryer western portions of the UMRB. According to the National Renewable Energy Laboratory (NREL) Biofuels Atlas (2021), switchgrass yields under 1.5 dry tons per acre are realistic for most of the western and central UMRB (Figure 3).

SUMMARY AND DISCUSSION

The potential societal benefits of second-generation bioenergy include creating a sustainable agricultural-based domestic energy supply, while minimizing direct competition between food and fuel crops, increasing terrestrial carbon sequestration, and providing a range of ecological co-benefits (Yadav et al., 2019; Blanco-Canqui, 2016; Núñez-Regueiro, Siddiqui, and Fletcher, 2021). Dedicated biomass is also integral to the adaptation of a regional bioenergy with carbon capture and storage (BECCS) system as part of global net-negative greenhouse gas emissions goals (Gerace and Rashford, 2018). The UMRB is an important U.S. agricultural region with potential to supply biomass for second-generation bioenergy production; however, adopting regional bioenergy systems would require that biomass crops be sufficiently profitable to incentivize private land conversion.

We developed representative whole-farm budgets for four agricultural sub-regions in the UMRB to estimate profitability and break-even prices for integrating switchgrass into cropping systems as a bioenergy feedstock. In addition to estimating direct costs and break-even prices, our whole-farm budget approach is able to account for the opportunity cost of replacing current production with a second-generation bioenergy crop. In order to focus on crop-level break-even prices and gross margin calculations, this analysis does not take into consideration related livestock farm enterprises, fixed costs such as crop insurance, depreciation, or costs related to transitioning to switchgrass production.

We estimate break-even prices for switchgrass yielding 2.7 tons per acre at between $116 and $99 per ton across four agricultural sub-regions in the UMRB. The 2016 Billion-Ton Report suggests farm-gate price scenarios from $40 to $80 per ton of biomass (US DOE, 2016, 147). Given these farmgate prices for biomass, either the variable costs of production of switchgrass would need to decrease, or substantial subsidy policies would need to be in place to make switchgrass competitive within current crop mixes. Therefore, using these yield, break-even price, and biomass price estimates, in order for second-generation bioenergy crops to be produced in the UMRB, policy makers will need to provide incentives for producers in the range of $19 to $76 per ton of biomass (minimum and maximum difference between estimated break-even and farmgate biomass prices).

Producers consider both price and production risks within a whole-farm cropping mix, as well as relative expected profit from the next-best crop choice. In other words, for a voluntary shift from baseline to bioenergy farming systems defined here, the gross margin per acre of switchgrass would need to exceed the gross margin per acre of grass hay. These field- and farm-level considerations are essential to scaling realistic regional bioenergy development. In order to incentivize regional-scale production, biofeedstock prices need to be competitive with the opportunity cost of giving up the next best crop, or biofeedstock crops need to significantly reduce price or production volatility within a crop mix.

A regional market for dedicated bioenergy crops remains uncertain. Bioenergy crop producers will not invest in converting to new crops and production systems without sufficient demand. At the same time, bioenergy crop processors cannot invest in processing technologies (e.g., technology for converting switchgrass to biofuel) without sufficient supply (Williams, Dahiya, and Porter, 2015). Broad energy sector economic and policy shifts are likely necessary for dedicated bioenergy crops to become competitive. Break-even prices needed for bioenergy crops, including break-even prices for switchgrass production in the UMRB estimated here, help establish market equilibrium between bioenergy crop producers and processors. Expanding analysis to include livestock operations that are integral to many regional farms could inform broader U.S. livestock sector implications from a regional shift to second-generation bioenergy crops.

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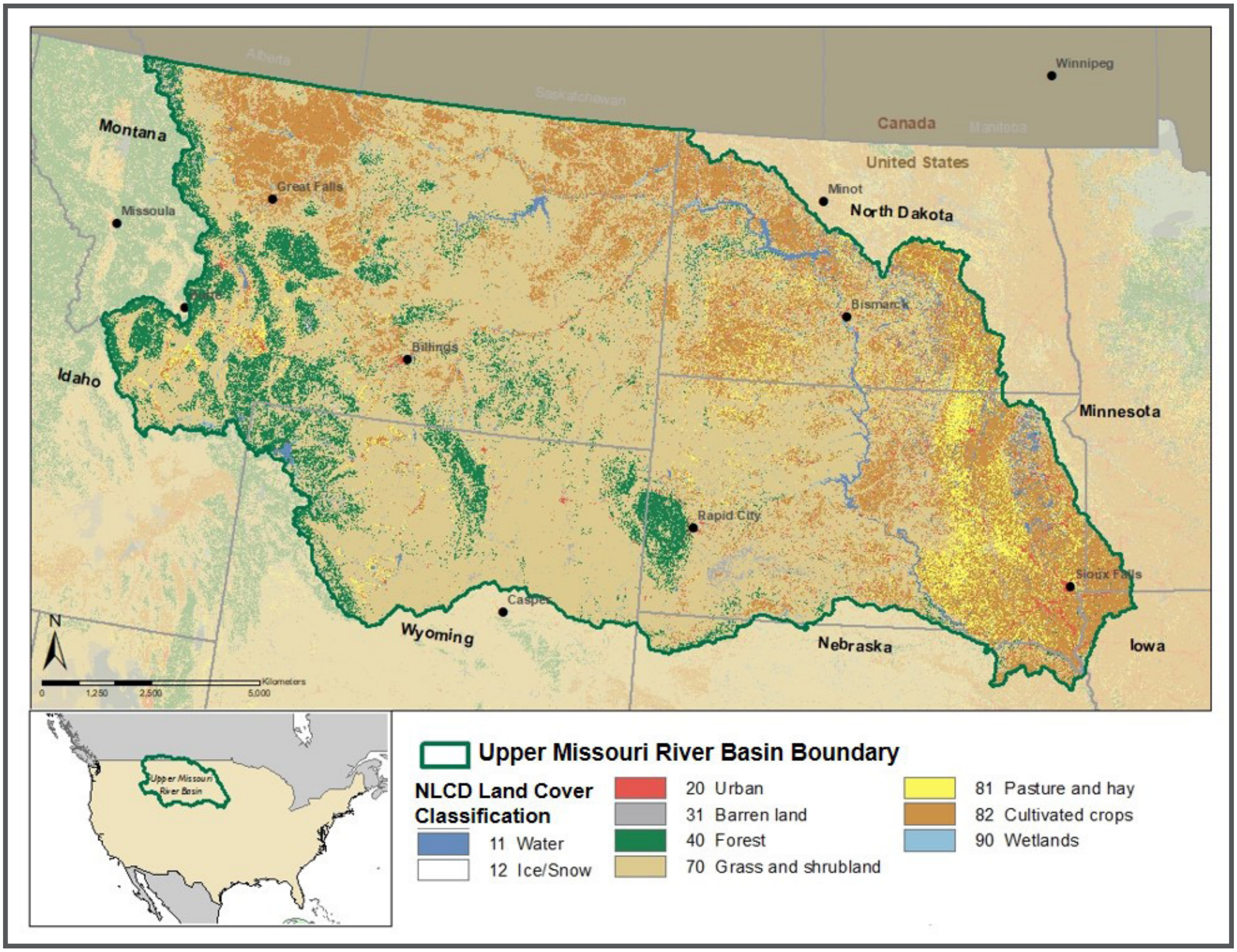

Figure 1. The Upper Missouri River Basin region of the United States showing National Land Cover Database land cover classifications. (Source: NLCD, 2011.)

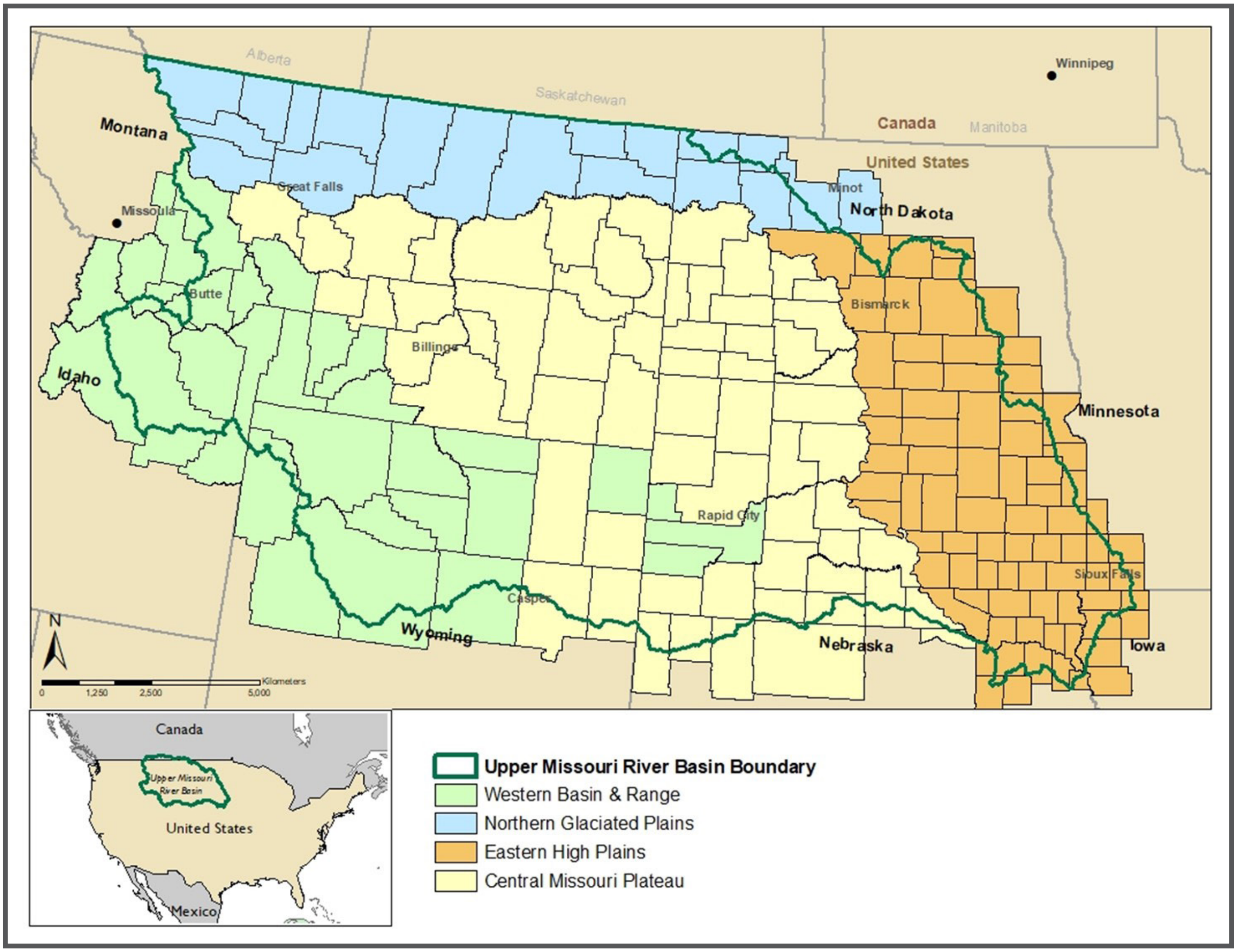

Figure 2. The Upper Missouri River Basin divided into four distinct agricultural sub-regions

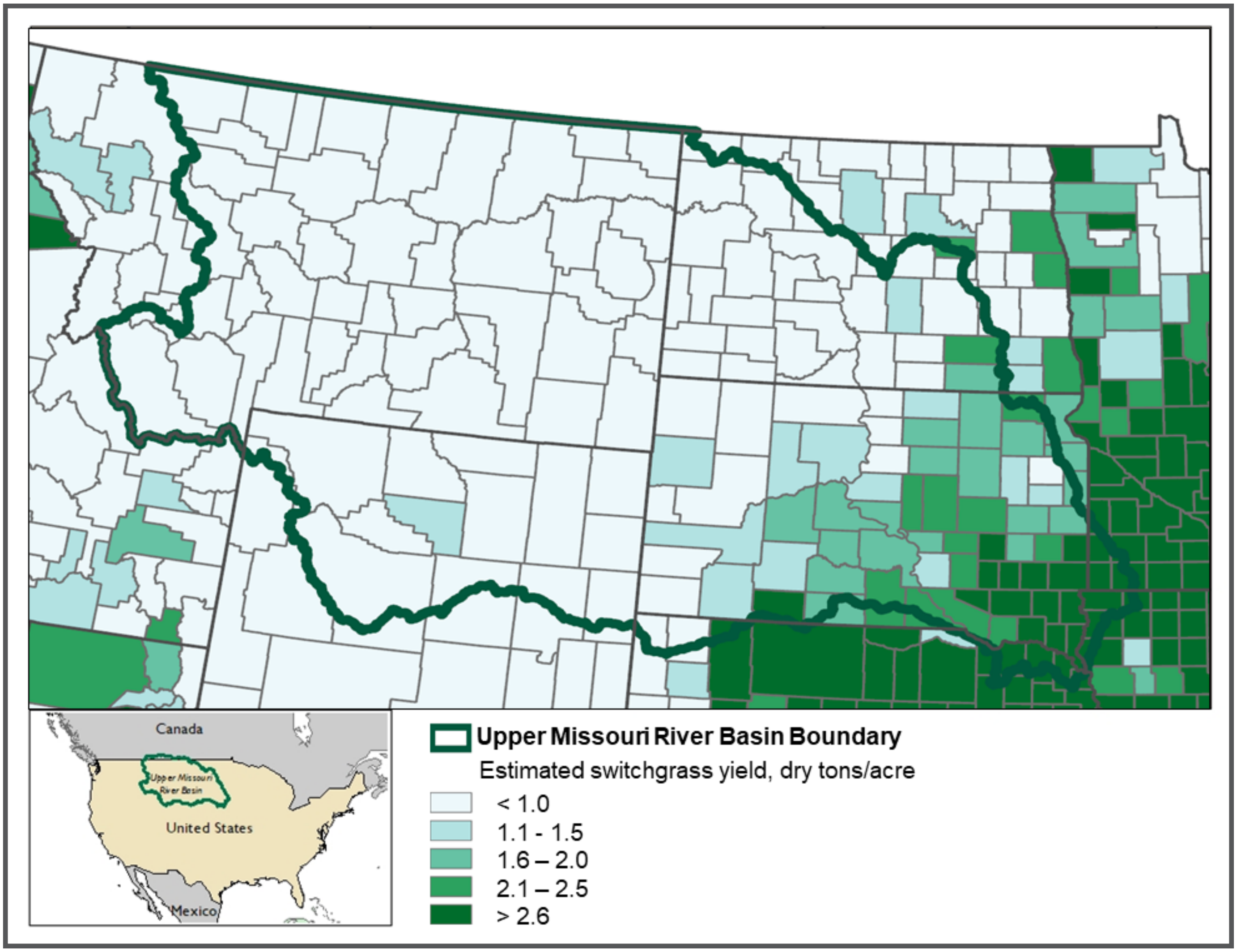

Figure 3. Estimated U.S. county-level switchgrass yields and Upper Missouri River Basin boundary. (Source: NREL, 2021.)

Table 1. Area Harvested per Crop (Acres, Percent) in Each UMRB Agricultural Sub-Region

	Area Harvested							
	Western Basin and Range		Northern Glaciated Plains		Eastern High Plains		Central Missouri Plateau	
Alfalfa	647,800	**48%**	436,500	7%	397,590	2%	2,404,510	**22%**
Barley	197,050	**15%**	537,300	9%	144,880	1%	211,660	2%
Beans	14,000	1%	89,000	1%	83,000	<1%	34,000	<1%
Canola	–	–	155,700	2%	250,400	1%	124,850	1%
Corn, grain	1,450	<1%	2,600	<1%	7,725,080	**38%**	1,460,720	**13%**
Corn, silage	6,600	<1%	2,510	<1%	21,970	<1%	55,480	1%
Flaxseed	–	–	14,000	<1%	99,200	<1%	20,530	<1%
Hay, excl. alfalfa	331,400	**25%**	205,300	3%	439,930	2%	1,530,600	**14%**
Lentils	–	–	537,800	9%	81,300	<1%	34,450	<1%
Mustard	–	–	19,600	<1%	–	–	–	–
Oats	–	–	3,740	<1%	25,600	<1%	16,300	<1%
Peas	–	–	503,700	8%	109,100	1%	218,210	2%
Safflower	–	–	–	–	–	–	8,400	<1%
Sorghum	–	–	–	–	–	–	113,410	1%
Soybeans	–	–	7,900	<1%	8,489,200	**41%**	1,049,200	10%
Sugarbeets	29,700	2%	5,100	<1%	1,293,420	6%	50,800	<1%
Sunflower, oil type	–	–	7,340	<1%	36,070	<1%	347,200	3%
Wheat, Spring durum	–	–	963,200	**15%**	203,400	1%	137,950	1%
Wheat, Spring, excl. durum	56,200	4%	1,396,600	**22%**	998,730	5%	1,838,010	**17%**
Wheat, Winter	66,000	5%	1,431,210	**23%**	91,290	<1%	1,189,480	**11%**
Total	**1,350,200**	**100%**	**6,319,100**	**100%**	**20,490,160**	**100%**	**10,845,760**	**100%**

Source: USDA NASS, 2016, Area Harvested. Dashes indicate no reported acres harvested. Sub-region crop areas over 10% are bolded.

Table 2. Expected 2017 Yield for Crops Harvested by Agricultural Sub-Region				
	Crop Yield			
	Western Basin and Range	**Northern Glaciated Plains**	**Eastern High Plains**	**Central Missouri Plateau**
Alfalfa (ton/acre)	3.5	**6.0**	4.6	2.8
Barley (bu/acre)	45.0	59.0	**72.0**	58.0
Beans (cwt/acre)	**25.0**	16.2	17.7	16.2
Canola (cwt/acre)		16.4	**17.3**	16.5
Corn, grain (bu/acre)	92.0	93.0	**180.0**	92.0
Corn, silage (ton/acre)	13.1	13.3	**25.7**	13.1
Flaxseed (bu/acre)		21.0	**23.0**	22.0
Hay, excl. alfalfa (ton/acre)	**1.7**	1.6	1.4	**1.7**
Lentils (cwt/acre)		13.6	13.6	13.6
Mustard (cwt/acre)		8.5		
Oats (bu/acre)		63.0	**80.0**	65.0
Peas (cwt/acre)		20.4	**30.0**	21.0
Safflower (cwt/acre)				13.6
Sorghum (cwt/acre)				53.2
Soybeans (bu/acre)		26.0	**55.0**	27.0
Sugarbeets (ton/acre)	25.0	25.0	25.0	25.0
Sunflower, oil type (cwt/acre)		14.2	**24.0**	14.9
Wheat, Spring durum (bu/acre)		34.0	**46.0**	39.0
Wheat, Spring, excl. durum (bu/acre)	40.0	38.0	**65.0**	40.0
Wheat, Winter (bu/acre)	43.0	43.0	**80.0**	43.0
Crop Budget Count	**9**	**18**	**17**	**19**

Sources: USDA NASS, 2016, Yield; UW, 2017, Crop Budgets; UI, 2017, Crop Budgets; NDSU, 2017, Farm Management Budgets; SDSU, 2017, Extension Crop Budgets.

Table 3. Average Crop Acres per Farm by Agricultural Sub-Region				
	Crop Acres per Farm			
	Western Basin and Range	Northern Glaciated Plains	Eastern High Plains	Central Missouri Plateau
Alfalfa	830	165	16	677
Barley	252	203	6	60
Beans	18	34	3	10
Canola	0	59	10	35
Corn, grain	2	1	310	411
Corn, silage	8	1	1	16
Flaxseed	0	5	4	6
Hay, excl. alfalfa	425	78	18	431
Lentils	0	203	3	10
Mustard	0	7	0	0
Oats	0	1	1	5
Peas	0	191	4	61
Safflower	0	0	0	2
Sorghum	0	0	0	32
Soybeans	0	3	341	296
Sugarbeets	38	2	52	14
Sunflower	0	3	1	98
Wheat, Spring durum	72	528	40	518
Wheat, Spring, excl. durum	85	541	4	335
Wheat, Winter	0	364	8	39
Total Crop Acres per Farm	**1,730**	**2,390**	**823**	**3,055**

Source: USDA NASS, 2016, Total Cropping Acres divided by Cropping Acres per Farm.

Table 4. Baseline Model Results				
	Western Basin and Range	Northern Glaciated Plains	Eastern High Plains	Central Missouri Plateau
Mean baseline whole-farm gross margin per acre	$236	$157	$362	$166
Coefficient of variation (CV)	0.25	0.30	0.35	0.28
Mean baseline whole-farm gross margin	$407,778	$375,068	$297,706	$507,626

Table 5. Baseline and Bioenergy Model Results, Whole-Farm Loss from Adopting Switchgrass on Hay Acres at Production Cost with $0 Revenue				
	Western Basin and Range	**Northern Glaciated Plains**	**Eastern High Plains**	**Central Missouri Plateau**
Percent of cropping area converted to switchgrass	25%	3%	2%	14%
Mean bioenergy whole-farm gross margin	$273,884	$350,941	$292,842	$371,696
Mean baseline whole-farm gross margin	$407,778	$375,068	$297,706	$507,626
Whole-farm loss from adopting dedicated bioenergy	($133,894)	($24,127)	($4,864)	($135,930)

Table 6. Switchgrass Break-Even Price Estimates and Yield Assumptions				
	Switchgrass Break-Even Price			
Yield Assumption	**Western Basin and Range**	**Northern Glaciated Plains**	**Eastern High Plains**	**Central Missouri Plateau**
1.7 ton/acre	$182	$179	$156	$182
2.7 ton/acre	$115	$113	$99	$116
3.7 ton/acre	$85	$84	$73	$85