Environmental Impacts of Cellulosic Feedstock Production: A Case Study of a Cornbelt Aquifer

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Introduction

Crop residue on fields provides valuable environmental benefits including control of nutrient runoff and water contamination and soil protection from wind and water erosion (Mann et al. 2002; Smil 1999; Johnson et al. 2006). When corn-stover is harvested for use as a biofuel feedstock, plants nutrients contained in the stover must be replaced with commercial fertilizer in order to maintain soil fertility levels. Removal of stover may also lead to significant increases in ground and surface water contamination. When sediment is transported through runoff and soil erosion, discharges of nitrogen and phosphorus are the leading contributors to reduced water quality (Kurkalova et al. 2010).

Expansion of advanced biofuel markets, including production of cellulosic ethanol, could spur more intensive corn grain and stover production in the Midwest, requiring higher rates of fertilizer and pesticide use as land is shifted from soybeans and other crops. Energy crops, such as grassland perennials, use chemicals less intensively than corn (Tilman et al. 2006). Even now, in the absence of cellulosic biofuel feedstock markets, crop nutrient management is an environmental challenge. Ribaudo et al. (2011) show that two-thirds of U.S. cropland is not meeting three criteria for good nitrogen management related to the rate, timing and method of fertilizer application. The highest stream concentrations of nitrate occur in the corn-belt where nitrogen fertilizer and manure application are highest (National Research Council 2008). Intensified corn production, spurred by the emergence of markets for stover, could lead to even more soil erosion and more pressure on water quality.

Switchgrass has been identified as a promising cellulosic feedstock (Graham et al. 2007; McLaughlin et al.1999). Switchgrass provides year-round soil cover that reduces soil erosion and potential water contamination from sediment and nutrients (Folle 2010). A recent survey of Minnesota farmers has indicated growing interest in switchgrass production (Smith et al. 2011). However, issues of product demand, producer acceptance, transportation and the development of market institutions and infrastructure need to be resolved for large-scale production to occur (Malcolm 2008).

Corn stover can be produced at a marginal cost that is low compared to switchgrass. While per acre costs of production are relatively high, revenue from both corn grain and the stover co-product make this cropping system highly profitable relative to energy crops when a stover market is present. However, sediment yield and nutrient losses, already relatively high from corn grain production, increase when the corn stover is also harvested. Thus, switchgrass becomes a more promising feedstock when environmental benefits are considered. However, if there are no substantial policy interventions under current commercial technology, none of the potential feedstocks except corn starch are economical for biofuels production (Schnepf 2010).

Considering the economic and environmental impacts from cellulosic feedstock production, this paper focuses on evaluating policy options to manage effluents associated with cellulosic feedstock production. Research questions related to the environmental impact of cellulosic feedstock production include: 1) How would environmental and energy policies targeted to water quality and cellulosic feedstock production influence economic and environmental outcomes in a watershed? 2) How will the mix of feedstocks and crop production practices change under policies to limit effluent levels, including nutrient and sediment losses, in the presence of a biofuels market? And 3) How will alternative environmental and energy policies influence the tradeoffs between cellulosic feedstock production and water quality?

A regional economic model of agricultural production in a northern cornbelt watershed is used to analyze the impact of cellulosic feedstock production. The model is constructed using the Generalized Algebraic Modeling System (GAMS) software. SWAT, a biophysical simulation model, is used to simulate the effects of corn stover production on soil and water quality in the Le Sueur River Watershed (LRW) in southern Minnesota. Technical coefficients in the economic model use SWAT simulation results including crop yields and sediment, nitrogen, and phosphorus effluent levels in 4818 Hydrologic Response Units (HRUs) in LRW.

As throughout the cornbelt, corn and soybeans are the dominant crops in the Le Sueur. Significant potential exists for cellulosic feedstock production including corn stover, a co-product of corn grain production, and energy crops such as switchgrass. However, the potential environmental consequences of biofuel production are a particular concern in the Le Sueur. The Minnesota Pollution Control Agency assesses the LRW as having impaired water quality due to sediment pollution.

This study evaluates various policy options to manage effluents associated with grain and cellulosic feedstock production. Policy options to reduce nutrient losses related to crop production have been widely studied (Doering et al. 1999; Ribaudo et al. 2001; Wu and Tanaka 2005; Rabotyagov et al. 2010). Studies that include the impacts of biofuel feedstock market, however, are fewer in number and mainly focus on greenhouse gas emissions (Khanna et al. 2009; Egbendewe-Mondzozo et al. 2010). This study analyzes how cellulosic feedstock production will affect water quality and the impacts of policy instruments on those impacts in this northern corn-belt watershed. The analyses provide both a realistic depiction of water quality impacts as well as ways those impacts may be efficiently mitigated. Knowledge of these outcomes will be important for the development of appropriate environmental and energy policies, and in management recommendations for feedstock production. The results provide insights into the potential tradeoffs between cellulosic feedstock production and water quality and how environmental and energy policies might be targeted toward reducing the cost of water quality improvements when biofuel markets exist.

Literature Review

Previous studies have integrated economic and biophysical models to evaluate the impacts on agricultural production of restrictions on effluent levels. A range of different policy alternatives to manage environmental impacts have been analyzed involving different crops and geographic locations (Table 1). Several studies examine nutrient reduction in the Mississippi river basin to mitigate hypoxia in the Gulf of Mexico. Doering et al. (1999) analyzes the cost effectiveness of alternative policies to reduce nitrogen level in the Gulf of Mexico. They use the U.S. Mathematical Programing (USMP) model (McCarl and Spreen 1980) with 45 agricultural production regions throughout the United States and ten crops. EPIC (the Environment Productivity Impact Calculator) is used to simulate the environmental effects of various management practices (crop rotations, tillage practices, and rates of fertilizer application) in the economic model. Ribaudo et al. (2001) extend the model used by Doering et al. (1999) to compare reductions in nitrogen fertilizer use with wetland restoration in the Mississippi River Basin. They impose constraints on total nitrogen fertilizer use in the basin.

Wu and Tanaka (2005) estimate the social cost of reducing nitrogen loads from the Upper Mississippi River Basin to the Gulf of Mexico. They integrate an econometric model with the Soil and Water Assessment Tool (SWAT) model to study four alternative policies: a fertilizer use tax and incentive payments for conservation tillage, corn-soybean rotation and CRP participation. A logit model is used to predict farmers' choice of crop, tillage practice and participation in the Conservation Reserve Program (CRP) based on the estimated probability of choosing crop and tillage practice in 44,221 National Resource Inventory (NRI) sites. They use SWAT to simulate nitrate-N concentrations based on the estimated land use and farming practices in each subbasin.

Some other studies have looked at energy crop economics and water quality. Babcock (2007) estimates subsidies for converting crop land to switchgrass production in a watershed in eastern Iowa. Considering switchgrass yield and the price of ethanol, significant conversion subsidies are required (from $44.33 per ton to $106.75 per ton). Using SWAT, they evaluate the effect on the sediment and nutrient losses from production of switchgrass and corn. This study only focuses on continuous corn or switchgrass production and does not include how producer can change crop rotation from cellulosic feedstock demand. Secchi et al. (2008) investigate water quality impacts from crop and switchgrass production in the Upper Mississippi River Basin (UMRB). Integrating SWAT and economic model of maxmization profits from farming, they show how switchgrass production effects water quality compared to row crop only scenarios. They consider scenario of replacing 10% of crop land with switchgrass and also consider restricting switchgrass cultivation to erodible land. Their results show switchgrass production reduces sediment loss. They consider specfic land types for switchgrass production and two sets of corn and soybean prices to demonstrate the impacts of grain markets. However the study only includes switchgrass for biomass and does not explore subsidies for switchgrass production.

Some previous studies have integrated economic and biophysical models to capture tradeoffs between economic and environmental outcomes. But most studies have focused on nutrient losses related to grain production. Some of the studies analyze water quality impacts from cellulosic feedstock production by changing the biomass price (Egbendewe-Mondzozo et al. 2010; Kurkalova et al. 2010). Considering biofuel markets and cellulosic feedstock production, our paper addresses how producers might adjust land use to meet the cellulosic feedstock demand while responding to environmental and energy policies. This paper examines the cost of water quality improvements and land use changes resulting from policy options considered in the previous works: restricting total nutrient loss and switchgrass production subsidies.

The Biophysical Simulation and Economic Models and Data

The dominant cropping system in the Le Sueur River Watershed is a two-year rotation of corn and soybeans. As a co-product of corn grain production, corn stover is a high yielding, economical cellulosic biofuel feedstock. As feedstock demand increases, corn producers may respond by harvesting more of the available stover and expanding the area of corn production. To allow for an expansion of corn acreage, a three year, corn-corn-soybean rotation was included in the model.

Cellulosic feedstock demand may also be met by the production of high-yielding "energy" crops, such as switchgrass. While corn stover production is economical as a co-product of grain production, corn production yields higher nutrient loads in groundwater than other cropping systems, and these loads increase when more stover is removed. Switchgrass production was included in the analysis as an energy crop with potential benefits for water quality. As a backstop cropping practice for managing water quality, Conservation Reserve Program (CRP) participation was also included in the model. Average grain and biomass yields, and nutrient loads used in the analysis are from a study by Folle (2010).

Folle (2010) conducted a biophysical simulation analysis of the Le Sueur River Watershed using the Soil and Water Assessment Tool (SWAT) – a basin-scale model developed by the USDA-Agricultural Research Service (Arnold et al. 1998; Arnold and Fohrer 2005). The model is used to predict the impacts of crop production practices on nutrient, sediment and agricultural chemical loads in large complex watersheds with varying soils, land use and management conditions (Neitsch et al. 2005). Folle (2010) used SWAT to simulate the effects of soybean, corn grain, corn stover and switchgrass production on soil and water quality over the 13 year period from 1994 to 2006 in the LRW. Spatial and temporal patterns of sediment, nutrient (nitrate-nitrogen and phosphorus) and pesticide (atrazine, acetochlor and metolachlor) losses were estimated. For this application of SWAT, the watershed was divided into 84 sub-watersheds, which were further subdivided into 4818 hydrologic response units (HRUs) – parcels of land that are homogeneous with respect to land use, soil characteristics and management practices. The SWAT simulation results are summarized in Table 2. The results show that a three-year rotation of corn-corn-soybean production has significantly higher average levels of nutrient loss and sediment yield than the two-year corn-soybean rotation. Switchgrass production was simulated on three types of crop land: HRU's with slopes steeper than two percent (Sloped), critical land with relatively high effluent levels (Critical), and the fifteen percent of crop land with the lowest corn yields (Low Yield).

Compared to the corn and soybean rotations, switchgrass has lower effluent levels. Of the 269,757 hectares of crop land in the Le Sueur Watershed, Table 3 shows the areas of sloped, critical and low yield land, and various combinations of the three attributes. Averaged over the thirteen years of the SWAT simulation, soybean, corn grain and stover, and switchgrass yields, and sediment, nitrate-nitrogen and phosphorus loads were used as technical coefficients on the production activities for each HRU in the economic model.

The economic model used for the analysis is a multi-region, linear programming model of the agriculture sector in the watershed. As is common with this framework, the model captures a partial market equilibrium by maximizing consumer plus producer surplus subject to market clearing constraints. By including production activities for firms in the sector, the model is able to estimate supply behavior endogenously and in doing so, provide insights into the impacts of an emerging biofuels market on producer behavior. The multi-region framework is critical to account for logistics costs and their impacts in determining a spatial equilibrium for the feedstock market.

The Le Sueur Watershed covers portions of six southern Minnesota counties. Township boundaries within these counties form a uniform grid of approximately six-mile by six-mile regions, providing a suitable designation as production and processing locations. There are a total of 47 townships in the Le Sueur. Grain and cellulosic feedstock production activities were constructed for each region. A biofuels processing plant was assumed to be in a region central to the watershed. In an endogenous supply, mathematical programming sector model, a key challenge is to characterize production so as to adequately capture the economic behavior of firms. Disaggregating crop production according to homogeneous land types is critical both to expressing the economic outcomes and reflecting the impacts of feedstock production on water quality. To this end, the hydrologic response units defined by Folle (2010) were used as land types with unique technical coefficients for the crop production activities. Construction of the crop production activities follows the approach discussed in McCarl (1982), and Chen and Önal (2012).

A set of crop production activities was defined for each hydrologic response unit (HRU), effectively land types, in a particular region. For the economic model of the Le Sueur, crop activities were derived from a joint-product production process for a two-year rotation of corn and soybeans – the dominant cropping system in the region. As corn stover is one of the alternative feedstocks in the study, likely producer responses to the emergence of an expanding biofuels market would include removing more of the available residue from corn acreage and expanding corn acreage within the region. So, following the biophysical simulations conducted by Folle (2010), in addition to a two-year, corn-soybean rotation, a three-year, corn-corn-soybean rotation was included. And for each rotation, four rates of stover removal were included – 0% (no stover removal), 10%, 30% and 60%. Switchgrass was included as an alternative feedstock on low yield, sloped and critical land types (HRU's). The final cropping alternative was to idle crop land by participating in the Conservation Reserve Program (CRP). In all, there are up to ten crop production activities on each land type – two corn-soybean rotations without stover harvest and with three alternative rates of stover removal, switchgrass as an energy crop, and CRP land. When the 4,178 HRU's defined for the SWAT simulations are mapped to the regions in the watershed, there are a total of 9,251combinations of land types and regions, and a total of 89,400 crop production activities.

Technical coefficients for the production activities are based on enterprise records for farms in the area, agronomic recommendations and biophysical simulation results. Fertilizer and chemical use is based on assumptions for the SWAT analysis, which are representative of production practices in the Le Sueur. Each cropping system was simulated over a 13 year period from 1994 to 2006 generating estimated crop yields and effluent levels for each HRU. Average annual grain and feedstock yields and sediment, nitrate-nitrogen and phosphorus loads were used as technical coefficients for the crop production activities in the economic model. Input requirements other than fertilizer and chemicals were taken from representative crop enterprise budgets developed for the region by Lazarus (2010).

Analysis and Results

To analyze the emergence of a cellulosic biofuels market, it was assumed that a processing plant was in a central region of the watershed. The model was then solved with feedstock demand at the plant fixed at levels from zero to 800 thousand metric tons (Mt), in increments of 100 thousand tons. 800 thousand Mt was used as the highest level of feedstock production because this was the approximate stover production capacity of the watershed given current cropping practices. The market equilibrium solution for each demand level includes a dual value for the feedstock demand constraint – the estimated marginal cost or implicit price of the feedstock at the plant. Together, the demand quantities and marginal costs can be interpreted as points on an estimated regional feedstock supply function. The model shows the efficient production practices underlying the feedstock supply response and also shows the impacts on water quality. Effluents were treated as co-products of crop production, so with each level of feedstock supply the model provides an estimated level of average annual total nutrient and sediment loads.

Three sets of policy scenarios were analyzed to demonstrate how environmental regulations and energy policies may interact. First, total nitrate-nitrogen loads in the LRW, already a public policy concern, were restricted to 10%, 20% and 30% below the estimated current levels. Current levels, here, are estimated as the average annual total nitrate-N load when no feedstock is produced. The second set of policies focused on subsidies to stimulate production of switchgrass – an energy crop with potential water quality benefits. The subsidy, assumed to be paid to the producer of the switchgrass, was set at $20, $40, $50, $60 and $80 per metric ton. Feedstock supply responses were estimated for each policy scenario. The third alternative policy scenario analyzed was to target switchgrass production on sloped land by only subsidizing production on that land type.

Change in Crop Mix and Feedstock Composition

When total nitrate-N losses are restricted, crop production activities with the lowest opportunity costs for reducing nutrient loss enter the equilibrium solution. Table 4 and Figure 1 show the crop production activity and crop mix results for feedstock supply levels from 0 to 800 thousand Mt without restrictions on nitrate-N loss and with 10%, 20% and 30% reductions in total nitrate-N load. The reduced effluent levels are relative to the estimated loss without feedstock production, which can be viewed as the current, baseline average total nitrate-N load.

When nitrate-N losses are reduced by 10% from the base level, rates of stover removal decrease from 60% to a combination of 30% and 10% in a small number of HRU’s. Across all levels of feedstock production, CRP area increases and corn area declines relative to the base scenario. Switchgrass is not produced until the total feedstock supply reaches 700 thousand Mt.

Up to that point, the expansion of stover production must occur by harvesting stover from more land and hauling the feedstock over greater distances. The proportion of land in the two-year rotation that is harvested for stover increases – all corn in the two-year rotation is used for stover harvest after feedstock production reaches 600 thousand Mt. Table 7 shows the average transport distance per ton of feedstock. As feedstock production increases to 600 thousand Mt, kilometers per metric ton of feedstock supply increases from 9.8 to 26.5 ton-kilometers.

Increasing the restriction on nitrate-N losses to 20% leads to further reductions in grain production, lower stover harvest rates and increased CRP area at each level of feedstock supply. The average stover removal rate decreases from 60% to 51% at 400 Mt of feedstock production as the stover removal rate decreases to 30% and 10% in some HRU's. Switchgrass production appears a bit sooner, at a supply of 600 thousand Mt. Eventually, at supply levels of 700 and 800 thousand Mt, switchgrass displaces corn, soybean and CRP land and increases to 20% and 32%, respectively, of total feedstock supply. Notably, as switchgrass enters the crop mix, all stover harvest is at the highest rate of 60%, implying that the higher value of the feedstock makes the opportunity cost of reducing effluent levels by lowering the stover harvest rates too costly on the land types where stove is harvested. Similar adjustment patterns occur when nitrate-N losses are reduced by 30%. At lower levels of feedstock supply, stover harvest rates decrease to 50%. However, at higher supply levels, when switchgrass production occurs, only the highest rate of corn stover removal is economical.

As the limits on nitrate-N loss are increased, expanded stover production relies less on expanding the area of the three-year corn-soybean rotation because the three-year rotation has higher nitrate-N losses. At the highest levels of cellulosic feedstock production, switchgrass production increases. CRP land expands mainly by displacing land in the two-year corn-soybean rotation. CRP area increases three fold as N loss decreases by 30% from base levels. The distance for transporting feedstock increases slightly relative to baseline before switchgrass makes up all of feedstock supplied.

Since switchgrass production results in lower effluent levels than current crop systems, subsidizing its production might improve water quality while encouraging biofuel production. The subsidy here is credited directly to the switchgrass producer, not at the processing plant. Table 5 and Figure 2 show the results across feedstock supply levels with switchgrass subsidies of $20, $40, $50, $60 and $80 per metric ton. All corn stover is harvested at the highest rate, 60%, since the harvest cost per ton decreases as the removal rate increases.

A subsidy below $40/Mt changes the composition of feedstock production only at the highest level of feedstock supply – 800,000 Mt (Table 8). At lower levels of feedstock production, all feedstock is corn stover with most of the stover from the two-year rotation as in the baseline scenario. When feedstock supply reaches 800 thousand Mt, switchgrass and stover from the two-year rotation displace part of the stover from the three-year rotation. As the subsidy is increased to $40/Mt, significant switchgrass production occurs only above 600 thousand Mt of feedstock supply, although small amounts of switchgrass appear beginning at 200 thousand Mt. As before, at the higher levels of supply, stover from the three-year rotation is displaced by stover from the two-year rotation and switchgrass.

Significant quantities of switchgrass are produced at every level of feedstock supply when the subsidy reaches $50. Switchgrass becomes the main source of feedstock as the subsidy reaches $60. As the subsidy increases, stover harvest area decreases and the two-year rotation without stover harvest (CS-S00) increases at each level of feedstock production because the increase in switchgrass production reduces the dependence on stover (Table 5, Figure 2). Using switchgrass as the feedstock also changes the transportation of corn stover. Compared to baseline, as the switchgrass subsidy increases, average ton-kilometers increases generally for all feedstocks and for switchgrass, but declines for stover (Table 7). This is due to geographic locations of HRU's on which switchgrass production is possible, which tend to be farther from the biofuel plant.

Increasing the subsidy to $80 shifts all feedstock production to switchgrass for supply levels up to 700 thousand Mt. Stover is harvested only when supply reaches 800, which is beyond the capacity of the watershed to produce switchgrass on the designated HRU's. Land for corn and soybean production is at its lowest level. The CRP area is not significantly affected by the increase in the switchgrass subsidy (Figure 2).

In the final policy scenario, the switchgrass production subsidy is targeted to sloped land only (Table 6, Figure 3). Crop land use for subsidies under $40 is similar to the previous results because switchgrass production is low (Table 8). Predictably, more stover and less switchgrass is produced with the targeted subsidy. Switchgrass becomes the main feedstock when the subsidy increases to $80.

Impacts on Crop Production and Feedstock Supply

The three sets of policy scenarios have different impacts on crop production, land use and efficient combination of feedstocks. Limiting nitrate-N loss increases CRP land. Expansion of CRP land comes from decreases in corn and soybean area (Table 4, Figure 1) and total grain production declines (Figure 4). Even when no cellulosic feedstock is produced, corn production (1,467 thousand Mt under baseline) decreases from 6.0% to 19.1% as the limits on nitrate-N loss are increased from 10% to 30%, respectively. Corn and soybean production decrease by 25.8% and 30.0%, respectively, when 800 thousand Mt of feedstock is produced and nitrate-N is reduced by 30%. As the subsidy begins to have a substantial effect of switchgrass production (generally over $60/Mt) a substantial decline in grain production occurs, as land is diverted from corn and soybeans to switchgrass. When applied only to sloped land, the impacts of the switchgrass subsidy on grain production are reduced somewhat.

Figure 5 shows the marginal cost of feedstock at the plant – the feedstock supply function. Increasing restrictions on nitrate-N loss increase marginal cost as production must shift to more distant and higher cost HRU's. Switchgrass subsidies, on the other hand, increase feedstock supply. At the highest the subsidy level considered, $80/Mt, most feedstock comes from switchgrass production and the marginal cost of feedstock is lowest. As expected, when the switchgrass subsidy is restricted to sloped land, decreases in marginal cost are reduced.

Impacts of Policies on Effluents Levels

Nutrient and sediment losses increase in baseline case as feedstock production increases due to the more intensive production of corn and the impacts of stover harvest. The impacts of an environmental policy restricting total nitrate-N loads in the watershed involved adding a constraint on the effluent level to the model. For each equilibrium solution, the dual value of that constraint, represents the marginal cost of limiting the nitrate-N load. These marginal costs are shown in Table 9 for each level of nitrate-N reduction and each level of feedstock production. When no feedstock is produced and the nitrate-N load is reduced by 10%, the marginal cost of reducing the load is $14,536 per Mt. The value increases to $19,851 when the load is reduced by 30%. Expansion of feedstock production also increases the marginal cost of nitrate-N load reduction. When regional feedstock supply is 800 thousand Mt, the marginal cost of reducing the effluent is $19,975 and $26,488 with load reductions of 10% and 30%, respectively.

Table 10 shows the percentage change in nutrient losses and sediment yields at various level of feedstock production, relative to the levels when no feedstock is produced. When nitrate-N loads are constrained, reduction of 10%, 20% and 30% are achieved by definition. Changes in regional production resulting from the switchgrass subsidy also effect nitrate-N loads. Nitrate-N losses remain steady or decline as the switchgrass subsidy increases, with the sharpest declines occurring at the highest levels of feedstock production and subsidy levels above $50 per Mt. When the subsidy is $50, nitrate-N load still increases as feedstock production expands, with the maximum percentage change of 2.6% occurring at 600 thousand Mt, then declining slightly. When the subsidy increases above $60, switchgrass production makes up a more significant part of feedstock demand and expands to whole watershed (Figure 7). As switchgrass production increases, nitrate-N losses decline, as shown in Figure 6, by 0.9% to 6.1%. Figure 8 shows decrease in nitrate-N load also expands to whole watershed.

The changes in production practices resulting from limits on nitrate-N loss lead also to reductions in phosphorus and sediment yields at lower levels of feedstock production. At higher levels of feedstock supply, phosphorus and sediment loads actually increase when nitrate-N loads are reduced by 10% and 20%. When nitrate-N is reduced by 30%, phosphorus levels decline at all levels of feedstock production, while sediment yields decrease initially, increase, and then decline slightly. With a $60 subsidy, phosphorus and sediment loads stay below the base levels except at the highest levels of feedstock production, and at $80, phosphorus and sediment levels decline from base levels as feedstock supply increases.

If switchgrass subsidy is limited to sloped land, the impacts on effluent levels are reduced in most cases. However, at lower levels of feedstock production, phosphorus and sediment loads actually decline when the subsidy is $80 and limited to switchgrass production on sloped land (see Figure 6).

Changes in Cost of Implementing Policies

The baseline and three policy scenarios generate costs to produce cellulosic feedstock and implement policies. Policy maker needs to consider public expenditures as well as the private costs to implement a policy. CRP payments and switchgrass subsidies are public costs for associated with inducing producers to adopt conservation practices and to supply feedstock. CRP payments in the baseline case decrease slightly as feedstock production increases (Figure 9). Because increasing the limits on nitrate-N loss expands CRP land, CRP payments increase more than three times compared to baseline when the nitrate-N load is reduced by 30%.

CRP payments in the scenario of switchgrass subsidies do not change significantly as the switchgrass subsidy increases. However, the total cost of CRP payments and switchgrass subsidies increases sharply when switchgrass becomes the main source of cellulosic feedstock – at a subsidy level of $80. Because switchgrass production is lower when the subsidy applies only to production on sloped land, the total cost of CRP payment and production subsidy is less than when the subsidy is applied more broadly. This makes it possible to increase subsidy rate somewhat while maintaining a constant total public expenditure. For example, total CRP payment and subsidy cost at $50 subsidy level is $20.1 million when 800 thousand Mt of feedstock is supplied (Figure 9). By focusing on specific land types and providing the subsidy only to production on sloped land, subsidy can be increased from $50 to $60 without sharp increases in policy budget, while leading to larger reductions in nutrient loss and sediment yield (Figure 6).

The private cost of implementing each policy is reflected in the change in objective function. Because producer surplus is objective function in the model, changes in producer surplus represent the implicit cost to producers of implementing each policy and increasing feedstock production. These changes are shown in Figure 10. Though the model provides an estimate of the marginal cost or the implicit supply price of corn stover, revenue from stover production is not included in the objective function. As the reduction in nitrate-N loss is increased to 30%, producer surplus declines by $76.9 million when feedstock supply is 800 thousand Mt. Switchgrass subsidy payments are subtracted from the objective function values to compare the implicit costs between the baseline and policy scenarios. When a switchgrass subsidy of $80/Mt is provided to production on all three types of land on which switchgrass may be produced, producer surplus declines by $83.9 million when feedstock supply is 800 thousand Mt. Decrease in producer surplus in the scenario of providing subsidy to sloped land is less than in second scenario. While the targeted switchgrass production subsidy has more modest public and private costs, the social benefit of the policies must compare these costs to the benefits of improved water quality, which vary across policies and are not addressed in this paper.

Conclusion

This paper examines the potential tradeoffs between cellulosic feedstock production and water quality and potential polices to influence those tradeoffs. Because corn stover removal increases nutrient loads and requires increased fertilizer use, policies to limit nitrate-N losses are considered. And because production of switchgrass as an energy crop can lower nutrient loads relative to conventional crops and stover, production subsidies for switchgrass are analyzed. Policies promoting cellulosic feedstock production need to consider the potential impacts on crop production, policy implementation costs, feedstock composition and environmental outcomes. Regulation of nitrate-N losses might attain environmental goals but have significant impacts on crop production and may be difficult to administer. Switchgrass production subsidies can be an option to consider. Results here provide estimates of how producers will respond to various switchgrass subsidy levels and the extent to which dependence on corn stover production can be reduced. When switchgrass production is subsidized, the negative impacts of cellulosic feedstock production on water quality are reduced or eliminated. With a subsidy above $60/Mt, switchgrass becomes the main source of feedstock and nutrient losses and sediment yields are reduced compared to the no-subsidy case, when corn stover is the primary feedstock. However, such a high subsidy leads to a substantial decline in grain production and a sharp increase in subsidy payments. If a switchgrass subsidy is targeted to specific types of land, the impacts of the subsidy on grain production are reduced because more stover is produced. While the water quality benefits of the targeted subsidy are generally somewhat less, they must be weighed against a substantially lower public and private cost.

The energy crop considered here, switchgrass, is not commercially produced on a wide scale in Minnesota. As more is learned about switchgrass and other energy crop technologies, the framework used here will be useful for studying their viability. This study shows that the economic response of cellulosic feedstock producers changes, both in terms of cropping practices and location, when alternative environmental and energy policies are implemented. It follows, then, that the optimal location of processing plants from a social perspective may be influenced by environmental considerations. The sector modeling approach used here, if applied to a broader geographic area, could include endogenous variables for plant location and size, so the impacts of environmental policies on the location, type and size of processing plants could be evaluated. Similarly, investments in infrastructure to improve water quality, such as energy crop buffer strips, or drainage or stream bank management structures, could be assessed as policy alternatives for reducing the environmental impacts of biofuels.

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Table 1. Summary of Previous Studies integrating Economic and Biophysical Models

Study	Model Type	Policy Alternatives in the Model
Doering et al. (1999)	Mathematical Programming & EPIC	Nitrogen & fertilizer reduction, fertilizer tax Wet land restoration, riparian buffers
Ribaudo et al. (2001)	Mathematical Programming & EPIC	Fertilizer reduction, wet land restoration
Wu & Tanaka (2005)	Econometric Logit Model & SWAT	Fertilizer tax, Incentive payment
Babcock (2007)	Calculation of Subsidy & SWAT	Switchgrass subsidy
Secchi et al. (2008)	Profit maximization & SWAT	10% Crop land replacement for switchgrass Switchgrass production to erodible land
Rabotyagov et al. (2010)	Simulation Optimization & SWAT	Reduction of nitrogen and phosphorus

Table 2. Summary of SWAT Estimates of Nutrient Losses and Sediment Yields by Crop Rotation and Switchgrass*

	Nitrate-N, Kg/Ha				Phosphorus, Kg/Ha				Sediment, Mt/Ha			
	0%	10%	30%	60%	0%	10%	30%	60%	0%	10%	30%	60%
Two-Year	18.97	18.98	19.25	19.74	0.76	0.78	0.87	1.04	1.93	2.00	2.43	2.88
Three-Year	29.02	29.26	31.52	33.51	0.86	0.95	1.09	1.15	2.20	2.48	3.01	3.32
	Nitrate-N, Kg/Ha				Phosphorus, Kg/Ha				Sediment, Mt/Ha			
Land Type**	Sloped	CCA	LY	All	Sloped	CCA	LY	All	Sloped	CCA	LY	All
Switchgrass	11.06	10.60	14.39	11.14	0.05	0.01	0.10	0.02	0.18	0.02	0.38	0.09

* Average over all types of crop land.
** Sloped, CCA, LY, All: Sloped, Critical, Low Yield, and all of them respectively. Switchgrass yield in each type of land is estimated as 10.26, 14.66, 5.86 and 13.55 Mt/Ha, respectively.

Table 3. Area in Hectares by Crop Land Type and Percentage of Total Crop Land

Type	Sloped	CCA	LY	Sloped & CCA	Sloped & LY	CCA & LY	Sloped & CCA & LY
Area	55,672	57,912	23,251	15,920	23,204	5,130	5,130
%	20.6%	21.5%	8.6%	5.9%	8.6%	1.9%	1.9%
Type	Sloped only	CCA only	LY only	Sloped or CCA	Sloped or LY	CCA or LY	Sloped or CCA or LY
Area	21,679	41,992	48	97,664	55,720	76,033	97,712
%	8.0%	15.6%	0.0%	36.2%	20.7%	28.2%	36.2%

* CCA and LY are critical and low yield land types, respectively.

Table 4. Crop Land Area by Corn-Soybean Rotation Under Total Nitrate-N Load Restrictions

		Cellulosic Feedstock Production (1000 Mt)								
Rotation	(Unit: 1000 Ha, %)	0	100	200	300	400	500	600	700	800
		Baseline								
Two-Year	Total Area	246.2	246.2	246.1	246.0	246.0	245.8	245.6	198.2	73.4
	Stover Harvest Area	0.0	36.9	73.9	112.0	148.7	186.2	223.2	198.2	73.4
	Ave. Removal Rate	0%	60%	60%	60%	60%	60%	60%	60%	60%
Three-Year	Total Area	1.6	1.7	1.7	1.9	1.9	2.1	2.5	51.8	179.2
	Stover Harvest Area	0.0	0.0	0.1	0.5	0.5	1.3	2.2	51.8	179.2
	Ave. Removal Rate	0%	60%	60%	60%	60%	60%	60%	60%	60%
		10% Reduction in Nitrate-N Losses								
Two-Year	Total Area	229.1	228.8	228.2	227.8	227.2	226.3	223.5	192.0	176.6
	Stover Harvest Area	0.0	38.7	79.1	122.6	166.9	204.0	223.5	192.0	176.6
	Ave. Removal Rate	0%	58%	57%	55%	54%	55%	59%	60%	60%
Three-Year	Total Area	1.5	1.5	1.6	1.3	1.2	1.1	2.2	28.9	37.8
	Stover Harvest Area	0.0	0.0	0.0	0.0	0.2	0.5	2.2	28.9	37.8
	Ave. Removal Rate	0%	60%	60%	60%	60%	60%	60%	60%	60%
		20% Reduction in Nitrate-N Losses								
Two-Year	Total Area	214.1	213.8	213.3	212.8	211.8	211.0	189.4	180.3	172.5
	Stover Harvest Area	0.0	39.6	81.1	124.5	176.3	205.0	189.4	180.3	172.5
	Ave. Removal Rate	0%	57%	55%	54%	51%	55%	60%	60%	60%
Three-Year	Total Area	1.6	1.5	1.5	1.2	1.4	0.6	19.4	23.1	24.4
	Stover Harvest Area	0.0	0.0	0.0	0.0	0.1	0.5	19.4	23.1	24.4
	Ave. Removal Rate	0%	60%	60%	60%	60%	60%	60%	60%	60%
		30% Reduction in Nitrate-N Losses								
Two-Year	Total Area	196.5	196.3	195.7	195.0	194.1	191.8	171.3	162.1	156.8
	Stover Harvest Area	0.0	45.0	87.4	133.4	173.7	191.5	171.3	162.1	156.8
	Ave. Removal Rate	0%	50%	51%	51%	52%	58%	60%	60%	60%
Three-Year	Total Area	1.5	1.4	1.3	1.2	0.9	1.2	17.7	21.3	19.8
	Stover Harvest Area	0.0	0.0	0.0	0.0	0.4	1.2	17.7	21.3	19.8
	Ave. Removal Rate	0%	60%	60%	60%	60%	60%	60%	60%	60%

Table 5. Crop Land Area by Corn-Soybean Rotation With Switchgrass Subsidies *

		Cellulosic Feedstock Production (1000 Mt)								
Rotation	(Unit: 1000 Ha, %)	0	100	200	300	400	500	600	700	800
		---Baseline---								
Two-Year	Total Area	246.2	246.2	246.1	246.0	246.0	245.8	245.6	198.2	73.4
	Stover Harvest Area	0.0	36.9	73.9	112.0	148.7	186.2	223.2	198.2	73.4
Three-Year	Total Area	1.6	1.7	1.7	1.9	1.9	2.1	2.5	51.8	179.2
	Stover Harvest Area	0.0	0.0	0.1	0.5	0.5	1.3	2.2	51.8	179.2
		---$20/Mt of subsidy---								
Two-Year	Total Area	246.2	246.2	246.1	246.0	246.0	245.8	245.6	198.2	99.6
	Stover Harvest Area	0.0	36.9	73.9	112.0	148.7	186.2	223.2	198.2	99.6
Three-Year	Total Area	1.6	1.7	1.7	1.9	1.9	2.1	2.5	51.8	148.8
	Stover Harvest Area	0.0	0.0	0.1	0.5	0.5	1.3	2.2	51.8	148.8
		---$40/Mt of subsidy---								
Two-Year	Total Area	246.2	246.2	246.1	245.9	245.9	245.5	245.1	238.2	215.0
	Stover Harvest Area	0.0	36.9	73.8	111.8	148.5	185.4	221.4	238.2	215.0
Three-Year	Total Area	1.6	1.7	1.7	1.9	1.9	2.1	2.5	6.4	21.1
	Stover Harvest Area	0.0	0.0	0.1	0.5	0.5	1.3	2.2	6.4	21.1
		---$50/Mt of subsidy---								
Two-Year	Total Area	246.2	245.0	243.9	243.6	241.4	241.1	238.2	233.7	228.9
	Stover Harvest Area	0.0	32.6	65.5	102.1	129.9	166.7	190.2	206.5	221.5
Three-Year	Total Area	1.6	1.7	1.7	1.7	1.8	1.8	2.0	2.3	2.6
	Stover Harvest Area	0.0	0.0	0.1	0.2	0.4	0.5	1.1	2.0	2.6
		---$60/Mt of subsidy---								
Two-Year	Total Area	246.2	237.6	231.6	227.7	223.0	221.5	218.8	216.6	215.1
	Stover Harvest Area	0.0	0.0	8.2	25.2	39.7	69.1	93.5	119.0	150.2
Three-Year	Total Area	1.6	1.6	1.5	1.1	1.0	1.0	0.8	0.7	0.7
	Stover Harvest Area	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.3	0.3
		---$80/Mt of subsidy---								
Two-Year	Total Area	246.2	237.5	229.8	222.5	215.0	207.1	198.9	190.4	186.3
	Stover Harvest Area	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.4
Three-Year	Total Area	1.6	1.6	1.5	1.0	0.6	0.5	0.3	0.3	0.2
	Stover Harvest Area	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

* Average Removal Rate is 60% in all cases.

Table 6. Crop Land Area by Corn-Soybean Rotation With Switchgrass Subsidies on Sloped Land *

		Cellulosic Feedstock Production (1000 Mt)								
Rotation	(Unit: 1000 Ha, %)	0	100	200	300	400	500	600	700	800
		Baseline								
Two-Year	Total Area	246.2	246.2	246.1	246.0	246.0	245.8	245.6	198.2	73.4
	Stover Harvest Area	0.0	36.9	73.9	112.0	148.7	186.2	223.2	198.2	73.4
Three-Year	Total Area	1.6	1.7	1.7	1.9	1.9	2.1	2.5	51.8	179.2
	Stover Harvest Area	0.0	0.0	0.1	0.5	0.5	1.3	2.2	51.8	179.2
		$20/Mt of subsidy								
Two-Year	Total Area	246.2	246.2	246.1	246.0	246.0	245.8	245.6	198.2	98.9
	Stover Harvest Area	0.0	36.9	73.9	112.0	148.7	186.2	223.2	198.2	98.9
Three-Year	Total Area	1.6	1.7	1.7	1.9	1.9	2.1	2.5	51.8	149.4
	Stover Harvest Area	0.0	0.0	0.1	0.5	0.5	1.3	2.2	51.8	149.4
		$40/Mt of subsidy								
Two-Year	Total Area	246.2	246.2	246.1	245.9	245.9	245.5	245.1	235.1	182.3
	Stover Harvest Area	0.0	36.9	73.8	111.8	148.5	185.4	221.4	235.1	182.3
Three-Year	Total Area	1.6	1.7	1.7	1.9	1.9	2.1	2.5	9.5	56.6
	Stover Harvest Area	0.0	0.0	0.1	0.5	0.5	1.3	2.2	9.5	56.6
		$50/Mt of subsidy								
Two-Year	Total Area	246.2	245.1	244.2	244.0	242.4	241.7	239.9	238.1	226.6
	Stover Harvest Area	0.0	33.2	66.9	103.9	135.1	170.2	200.5	229.2	226.6
Three-Year	Total Area	1.6	1.7	1.7	1.7	1.8	1.9	2.0	2.3	7.0
	Stover Harvest Area	0.0	0.0	0.1	0.2	0.4	0.6	1.2	2.1	7.0
		$60/Mt of subsidy								
Two-Year	Total Area	246.2	239.0	237.1	235.6	235.0	233.4	233.0	231.5	229.0
	Stover Harvest Area	0.0	8.3	35.1	65.1	99.0	128.1	164.0	192.3	218.2
Three-Year	Total Area	1.6	1.5	1.1	1.0	0.8	0.7	0.7	0.7	0.6
	Stover Harvest Area	0.0	0.0	0.0	0.1	0.1	0.3	0.3	0.4	0.5
		$80/Mt of subsidy								
Two-Year	Total Area	246.2	237.1	230.1	222.8	221.6	221.0	220.8	220.8	220.4
	Stover Harvest Area	0.0	0.0	0.0	3.0	34.4	68.9	104.7	141.0	175.6
Three-Year	Total Area	1.6	1.5	0.5	0.2	0.2	0.2	0.1	0.1	0.1
	Stover Harvest Area	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1

*Average Removal Rate is 60% in all cases.

Table 7. Distance Shipped in Kilometers per Mt of Feedstock

Scenario		Cellulosic Feedstock Production (1000 Mt) 100	200	300	400	500	600	700	800
		Corn Stover and Switchgrass Feedstock							
Baseline		7.4	12.4	15.1	18.6	21.3	24.4	26.8	26.6
Nitrate-N Load Restriction	10%	9.8	14.1	17.4	20.4	23.3	26.5	26.5	26.4
	20%	10.3	14.7	18.1	21.4	24.4	26.4	26.2	26.4
	30%	10.7	15.5	19.1	22.5	25.8	26.2	26.2	26.7
Switchgrass Production Subsidy	$20	7.4	12.4	15.1	18.6	21.3	24.4	26.8	26.5
	$40	7.4	12.4	15.1	18.6	21.2	24.3	26.7	26.4
	$50	8.2	12.7	14.9	18.0	20.1	22.4	23.9	25.7
	$60	21.4	20.8	20.1	20.7	21.0	21.4	22.7	23.6
	$80	21.1	23.4	25.4	26.6	27.3	28.1	29.1	27.7
Switchgrass Production Subsidy on Sloped Land only	$20	7.4	12.4	15.1	18.6	21.3	24.4	26.8	26.6
	$40	7.4	12.4	15.1	18.6	21.2	24.3	26.8	27.2
	$50	8.2	12.7	15.0	18.4	20.5	23.2	25.9	27.5
	$60	20.0	17.8	18.4	19.2	21.1	22.5	24.7	26.8
	$80	26.8	30.4	31.2	26.5	24.9	24.3	25.0	26.1
		Corn Stover							
Baseline		7.4	12.4	15.1	18.6	21.3	24.4	26.8	26.6
Nitrate-N Load Restriction	10%	9.8	14.1	17.4	20.4	23.3	26.5	27.0	27.2
	20%	10.3	14.7	18.1	21.4	24.4	26.8	27.1	27.2
	30%	10.7	15.5	19.1	22.5	25.8	26.9	27.1	27.1
Switchgrass Production Subsidy	$20	7.4	12.4	15.1	18.6	21.3	24.4	26.8	26.7
	$40	7.4	12.4	15.1	18.6	21.2	24.3	26.9	27.0
	$50	7.1	11.7	14.4	17.4	19.9	22.3	24.0	26.1
	$60	0.0	0.0	6.5	7.6	12.7	14.4	17.7	20.0
	$80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.1
Switchgrass Production Subsidy on Sloped Land only	$20	7.4	12.4	15.1	18.6	21.3	24.4	26.8	26.7
	$40	7.4	12.4	15.1	18.6	21.2	24.3	26.8	26.8
	$50	7.2	11.8	14.4	17.7	20.0	22.9	25.8	26.7
	$60	0.0	7.3	11.8	14.3	17.4	19.9	22.7	25.3
	$80	0.0	0.0	0.0	7.3	12.4	15.2	18.8	21.7
		Switchgrass							
Baseline		0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.7
Nitrate-N Load Restriction	10%	0.0	0.0	0.0	0.0	0.0	0.0	21.0	22.1
	20%	0.0	0.0	0.0	0.0	0.0	15.4	21.0	22.7
	30%	0.0	0.0	0.0	0.0	0.0	20.1	21.8	23.9
Switchgrass Production Subsidy	$20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.8
	$40	0.0	19.3	13.3	13.3	17.8	20.6	21.4	22.1
	$50	15.6	18.8	18.7	20.6	20.6	20.8	21.8	22.5
	$60	19.7	21.6	22.2	23.5	23.9	24.3	24.9	25.1
	$80	19.4	21.5	23.4	24.5	25.1	25.8	26.8	26.9
Switchgrass Production Subsidy on Sloped Land only	$20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.2
	$40	0.0	19.3	13.3	13.3	17.8	20.6	23.8	26.7
	$50	16.6	19.7	20.3	23.0	23.6	24.1	24.6	27.9
	$60	23.9	25.2	25.7	26.5	27.0	27.3	27.8	28.4
	$80	24.7	27.9	29.5	29.7	29.8	29.8	29.8	29.8

Table 8. Cellulosic Feedstock Composition (Unit: 1000 Mt)

Scenario		Cellulosic Feedstock Production (1000 Mt)* 100	200	300	400	500	600	700	800
		Corn Stover Production							
Baseline		100.0	200.0	300.0	400.0	500.0	600.0	700.0	799.6
Nitrate-N Load Restriction	10%	100.0	200.0	300.0	400.0	500.0	600.0	612.7	602.0
	20%	100.0	200.0	300.0	400.0	500.0	573.5	561.7	545.4
	30%	100.0	200.0	300.0	400.0	500.0	519.5	507.1	488.0
Switchgrass Production Subsidy	$20	100.0	200.0	300.0	400.0	500.0	600.0	700.0	769.3
	$40	100.0	199.9	299.5	399.5	497.7	595.3	653.8	643.8
	$50	88.7	177.5	274.0	350.0	447.0	512.5	557.3	598.9
	$60	0.0	22.3	68.9	106.7	187.1	250.9	321.0	402.3
	$80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	53.4
Switchgrass Production Subsidy on Sloped Land only	$20	100.0	200.0	300.0	400.0	500.0	600.0	700.0	769.7
	$40	100.0	199.9	299.5	399.5	497.7	595.3	656.8	678.7
	$50	90.3	181.4	278.6	364.4	455.9	540.2	618.4	628.7
	$60	22.8	95.3	176.4	266.0	345.3	439.3	516.5	585.5
	$80	0.0	0.0	8.2	93.6	187.2	281.4	379.9	472.2
		Switchgrass Production**							
Baseline		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Nitrate-N Load Restriction	10%	0.0	0.0	0.0	0.0	0.0	0.0	94.9	215.3
	20%	0.0	0.0	0.0	0.0	0.0	28.8	150.3	276.7
	30%	0.0	0.0	0.0	0.0	0.0	87.4	209.7	339.1
Switchgrass Production Subsidy	$20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.4
	$40	0.0	0.1	0.5	0.6	2.5	5.1	50.3	169.8
	$50	12.3	24.5	28.3	54.3	57.6	95.1	155.1	218.6
	$60	108.7	193.2	251.2	318.8	340.1	379.5	411.9	432.3
	$80	108.7	217.4	326.1	434.8	543.5	652.2	760.9	811.5
Switchgrass Production Subsidy on Sloped Land only	$20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.9
	$40	0.0	0.1	0.5	0.6	2.5	5.1	47.0	131.9
	$50	10.5	20.3	23.3	38.7	47.9	65.0	88.7	186.2
	$60	84.0	113.8	134.3	145.7	168.2	174.7	199.4	233.2
	$80	108.7	217.4	317.1	333.0	340.0	346.3	347.9	356.3

* Total feedstock supply is in corn-stover equivalent. It is assumed that switchgrass is 92% of stover equivalent in ethanol yield (Huang et al. 2009).

Table 9. Marginal Cost of Nitrate-N Load Constraint (Unit: $/Kg of Nitrate-N Loss)

Nitrate-N Loss	Cellulosic Feedstock Production (1000 Mt) 0	100	200	300	400	500	600	700	800
10% Reduction	14,536	14,640	14,825	14,973	15,080	15,377	16,801	19,772	19,975
20% Reduction	17,496	17,554	17,725	17,979	18,364	18,973	23,296	23,488	23,863
30% Reduction	19,851	19,979	20,185	20,334	20,809	21,996	25,595	26,149	26,488

* Value in the table represents the marginal cost in dollars of meeting the constraint on total nitrate-N loss.

Table 10. Percentage Change in Effluent Relative to Levels When Feedstock is Not Produced *

Scenario		Cellulosic Feedstock Production (1000 Mt) 0	100	200	300	400	500	600	700	800
						Nitrate-N				
Baseline		0.0%	0.5%	1.1%	1.7%	2.5%	3.2%	4.0%	7.2%	38.0%
Nitrate-N Load Restriction	10%	-10.0%	-10.0%	-10.0%	-10.0%	-10.0%	-10.0%	-10.0%	-10.0%	-10.0%
	20%	-20.0%	-20.0%	-20.0%	-20.0%	-20.0%	-20.0%	-20.0%	-20.0%	-20.0%
	30%	-30.0%	-30.0%	-30.0%	-30.0%	-30.0%	-30.0%	-30.0%	-30.0%	-30.0%
Switchgrass Production Subsidy	$20	0.0%	0.5%	1.1%	1.7%	2.5%	3.2%	4.0%	7.2%	20.9%
	$40	0.0%	0.5%	1.1%	1.6%	2.5%	3.1%	3.8%	4.4%	4.1%
	$50	0.0%	0.3%	0.8%	1.2%	1.7%	2.2%	2.6%	2.4%	2.3%
	$60	0.0%	-0.9%	-1.5%	-1.8%	-2.2%	-1.7%	-1.8%	-1.4%	-1.1%
	$80	0.0%	-0.9%	-1.9%	-2.7%	-3.6%	-4.3%	-5.2%	-6.1%	-6.1%
Subsidy (Sloped land only)	$20	0.0%	0.5%	1.1%	1.7%	2.5%	3.2%	4.0%	7.2%	20.9%
	$40	0.0%	0.5%	1.1%	1.6%	2.5%	3.1%	3.8%	4.5%	6.3%
	$50	0.0%	0.3%	0.8%	1.3%	1.9%	2.3%	2.8%	3.4%	3.4%
	$60	0.0%	-0.6%	-0.4%	0.0%	0.4%	0.9%	1.3%	2.0%	2.4%
	$80	0.0%	-0.9%	-1.5%	-1.8%	-1.2%	-0.7%	0.1%	0.9%	1.8%
						Phosphorus				
Baseline		0.0%	4.5%	10.3%	16.7%	23.3%	31.3%	39.0%	44.3%	49.2%
Nitrate-N Load Restriction	10%	-15.9%	-11.8%	-7.3%	-2.1%	3.5%	9.8%	17.2%	13.5%	9.2%
	20%	-21.6%	-17.6%	-13.1%	-7.9%	-2.2%	3.8%	7.7%	4.8%	-0.7%
	30%	-28.0%	-23.9%	-19.4%	-14.1%	-8.1%	-1.2%	-1.6%	-5.7%	-12.1%
Switchgrass Production Subsidy	$20	0.0%	4.5%	10.3%	16.7%	23.3%	31.3%	39.0%	44.3%	39.0%
	$40	0.0%	4.5%	10.2%	16.6%	23.2%	30.3%	37.8%	38.7%	30.8%
	$50	0.0%	2.8%	7.0%	11.3%	15.6%	20.0%	24.3%	24.8%	26.0%
	$60	0.0%	-6.8%	-9.4%	-9.7%	-10.1%	-6.5%	-5.0%	-1.9%	1.0%
	$80	0.0%	-6.8%	-11.0%	-14.8%	-19.5%	-23.1%	-28.3%	-33.5%	-34.5%
Subsidy (Sloped land only)	$20	0.0%	4.5%	10.3%	16.7%	23.3%	31.3%	39.0%	44.3%	38.1%
	$40	0.0%	4.5%	10.2%	16.6%	23.2%	30.3%	37.8%	37.8%	25.6%
	$50	0.0%	2.9%	7.2%	11.6%	16.5%	20.7%	25.4%	29.3%	19.0%
	$60	0.0%	-7.3%	-6.7%	-3.9%	-0.8%	2.4%	5.9%	9.6%	10.6%
	$80	0.0%	-10.2%	-18.9%	-27.7%	-25.9%	-22.0%	-18.2%	-13.2%	-9.4%
						Sediment				
Baseline		0.0%	5.9%	13.4%	21.9%	30.9%	42.0%	53.8%	66.1%	79.5%
Nitrate-N Reduction	10%	-18.1%	-12.6%	-6.5%	0.6%	8.6%	17.7%	28.7%	27.5%	23.6%
	20%	-23.2%	-17.8%	-11.7%	-4.3%	3.7%	12.7%	20.8%	17.8%	11.6%
	30%	-29.1%	-23.6%	-17.4%	-9.9%	-1.2%	8.9%	11.1%	6.6%	-1.2%
Switchgrass Production Subsidy	$20	0.0%	5.9%	13.4%	21.9%	30.9%	42.0%	53.8%	66.1%	66.6%
	$40	0.0%	5.9%	13.4%	21.8%	30.8%	40.7%	52.1%	55.5%	47.9%
	$50	0.0%	3.9%	9.5%	15.2%	21.4%	27.7%	34.6%	37.0%	40.3%
	$60	0.0%	-7.2%	-9.6%	-9.5%	-9.0%	-4.3%	-1.8%	3.0%	7.5%
	$80	0.0%	-7.3%	-11.4%	-15.3%	-20.2%	-24.0%	-29.8%	-36.0%	-36.9%
Switchgrass Production Subsidy on Sloped Land only	$20	0.0%	5.9%	13.4%	21.9%	30.9%	42.0%	53.8%	66.1%	65.5%
	$40	0.0%	5.9%	13.4%	21.8%	30.8%	40.7%	52.1%	54.6%	43.6%
	$50	0.0%	4.1%	9.7%	15.4%	22.2%	28.5%	35.7%	42.4%	31.3%
	$60	0.0%	-8.3%	-6.8%	-2.9%	1.3%	6.1%	11.2%	16.8%	19.3%
	$80	0.0%	-11.4%	-21.5%	-32.5%	-29.9%	-25.0%	-20.0%	-13.2%	-7.9%

*Effluent losses in nitrate-N, phosphorus and sediment are 4,612Mt, 137Mt, 327 thousand Mt respectively under zero feedstock production in baseline scenario.

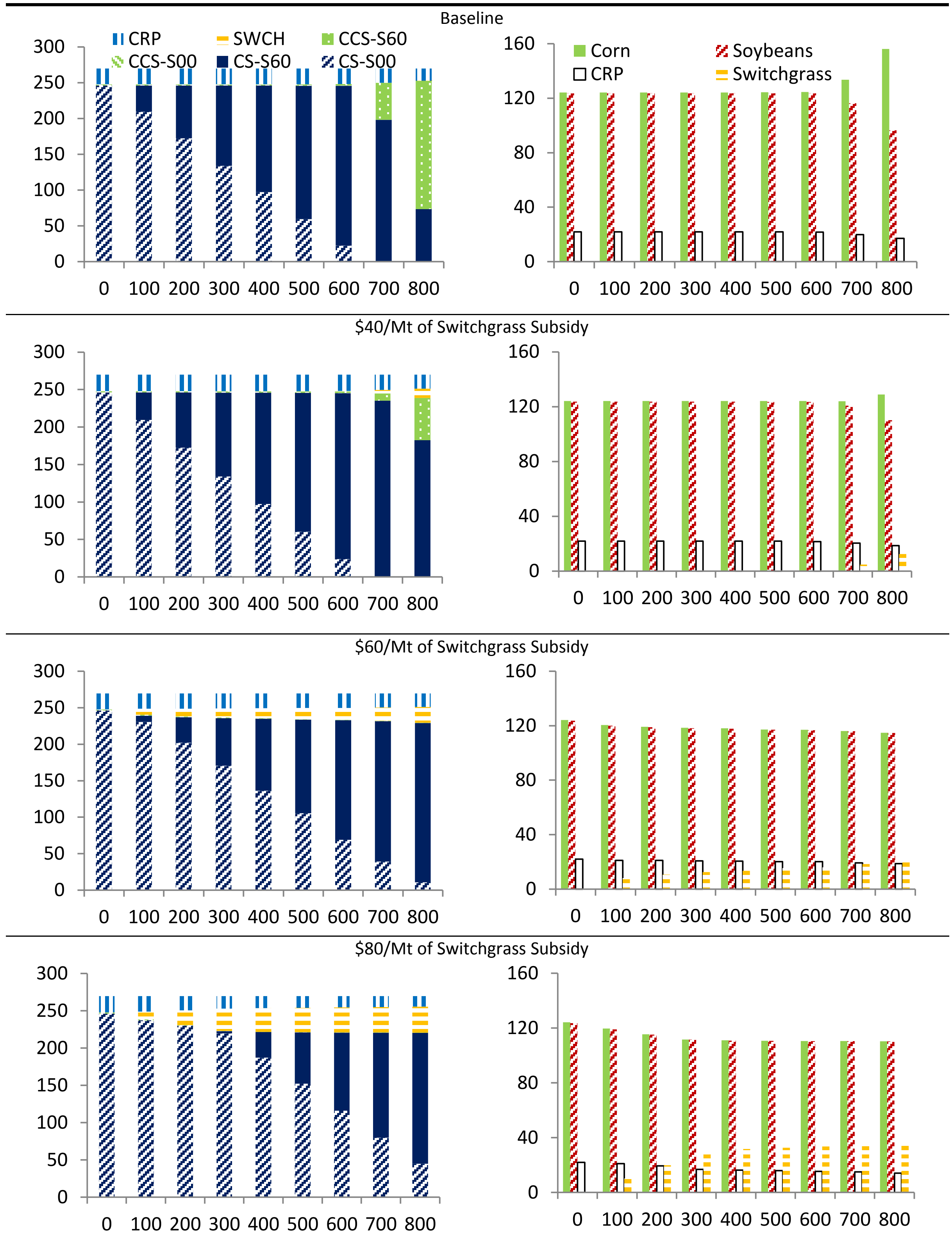
Figure 1. Crop Production Activities and Crop Mixes by Feedstock Production Level with Restrictions on Nitrate-N Loads*

* X axis: Feedstock Supply 1000Mt, Y axis: 1000Ha

Figure 2. Crop Production Activities with Switchgrass Subsidy*

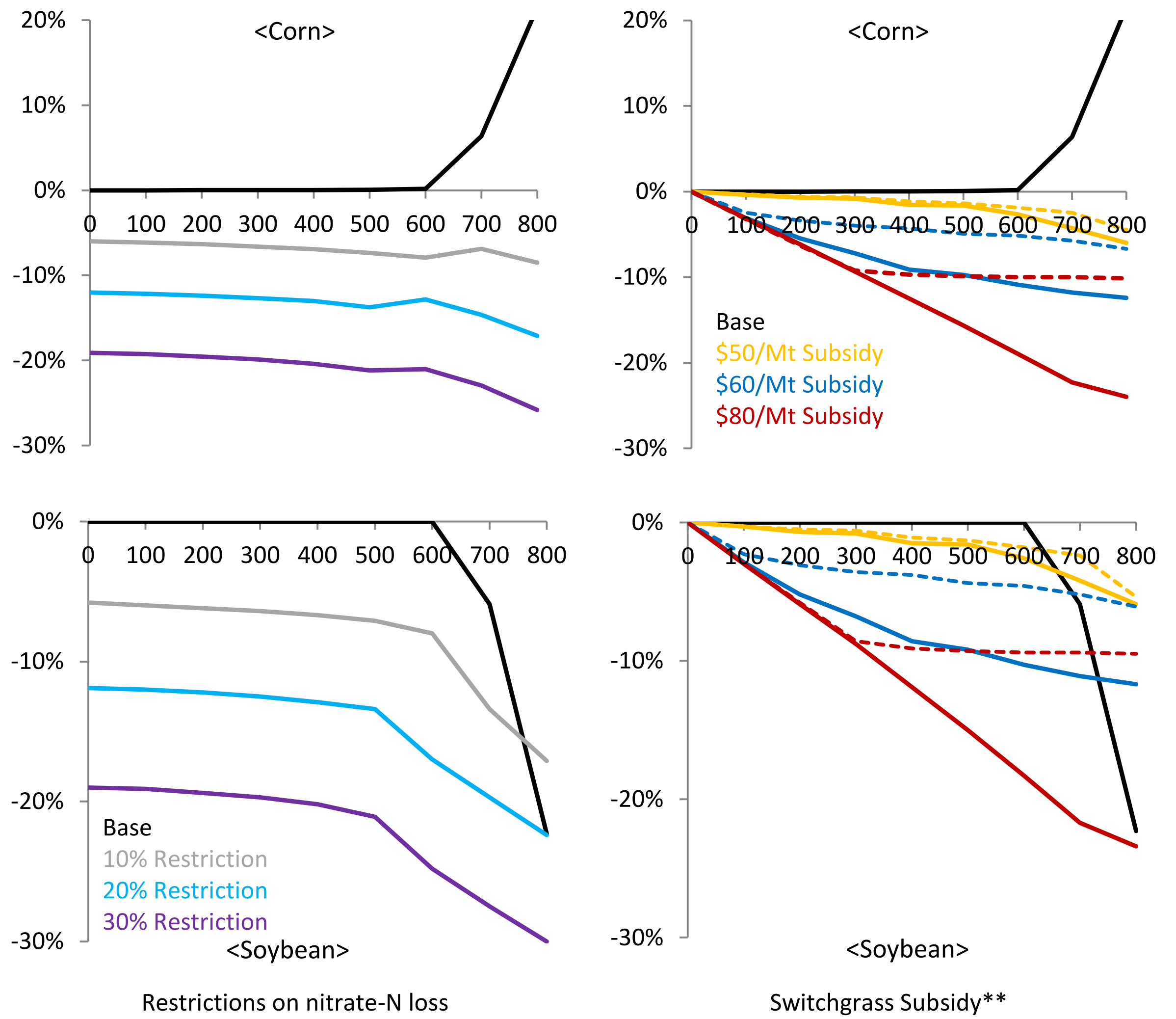
* X axis: Feedstock Supply 1000Mt, Y axis: 1000Ha

Figure 3. Crop Production Activities with Switchgrass Subsidy on Sloped Land*



* X axis: Feedstock Supply 1000Mt, Y axis: 1000Ha

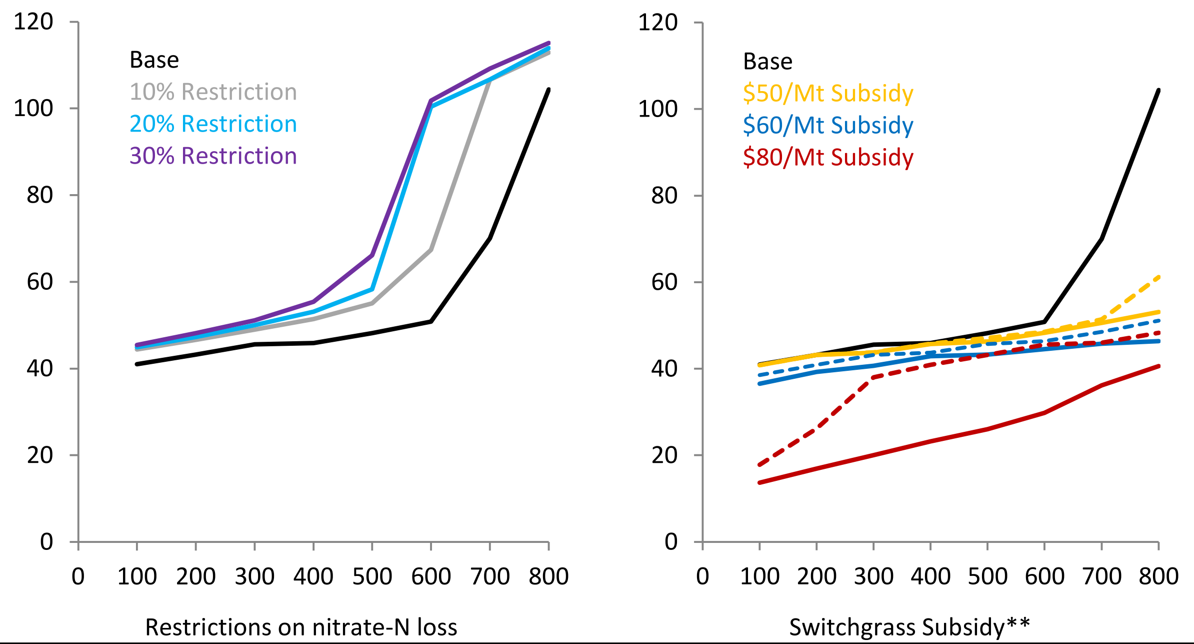
Figure 4. Percentage Change in Crop Production from Zero Feedstock Production in Baseline*



* Cellulosic Feedstock Production (Unit: 1000Mt) in X axis. Corn and soybean production is 1,467 and 335 thousand Mt respectively under zero feedstock production in baseline scenario.

** Dashed lines represent the scenario when the switchgrass subsidy is targeted to sloped land only.

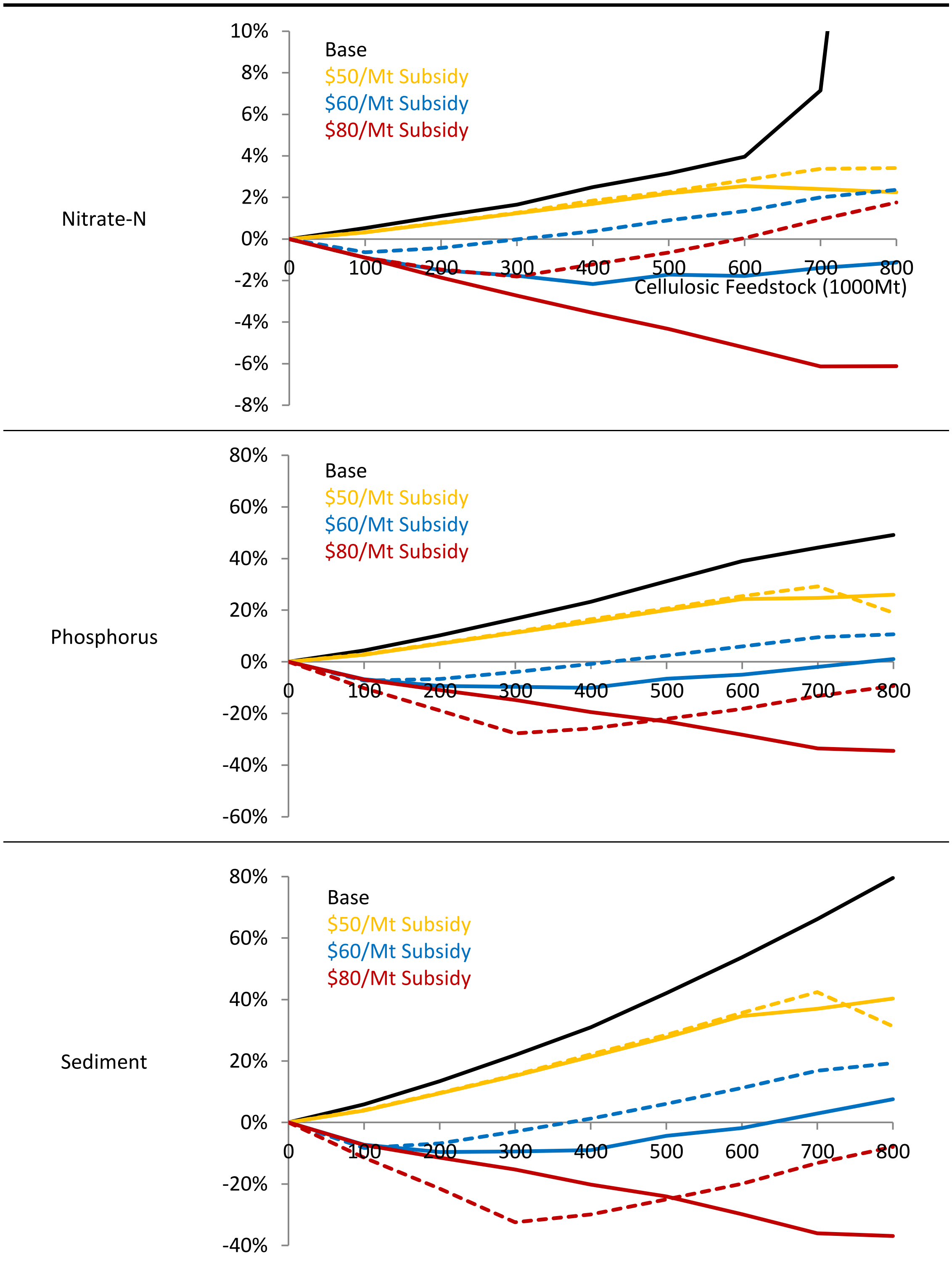
Figure 5. Marginal costs of Feedstock*



* X axis: Cellulosic Feedstock Proudction(1000Mt), Y axis: $/Mt

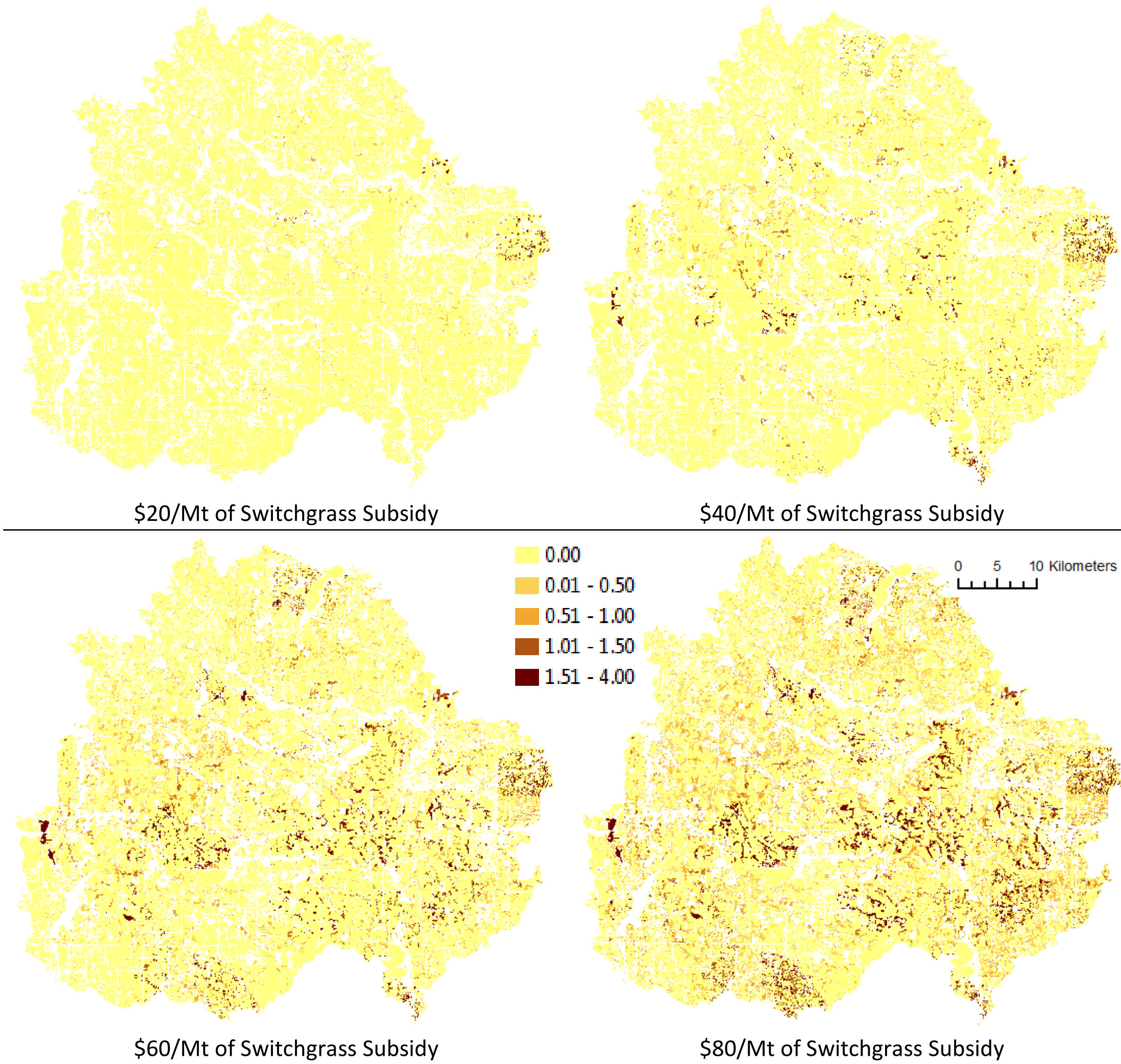
** Dashed lines represent the scenario when the switchgrass subsidy is targeted to sloped land only.

Figure 6. Percentage Change in Effluent Losses under Switchgrass Subsidy Scenario Compared to Scenario Limiting Subsidy to Sloped land*



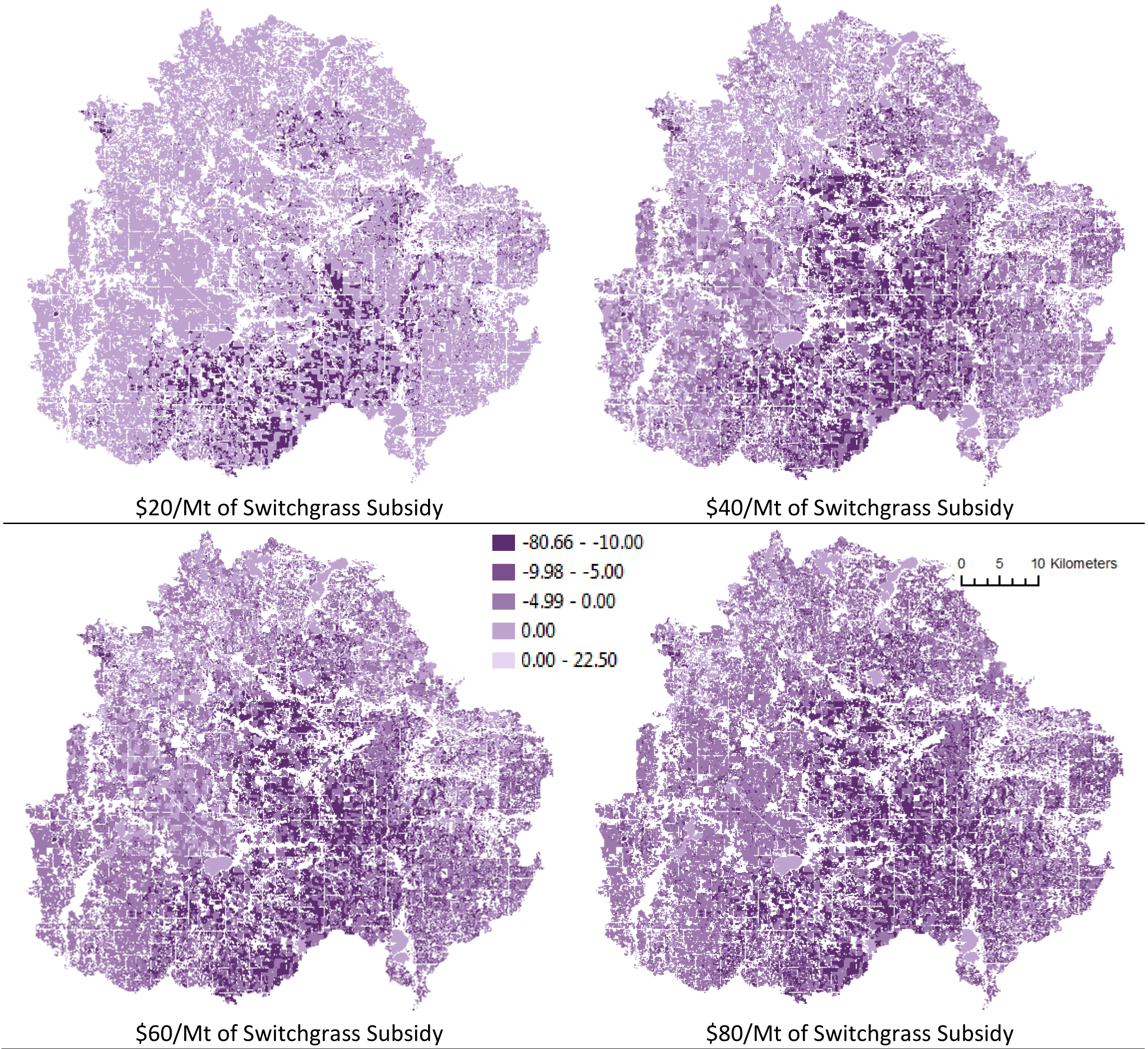
*Percentage change in nutrient losses and sediment yield from zero feedstock production in baseline and dashed lines represent the scenario when the switchgrass subsidy is targeted to sloped land only.

Figure 7. Change in Switchgrass Production at Various Levels of Switchgrass Subsidy * (Unit: 1000 Mt)



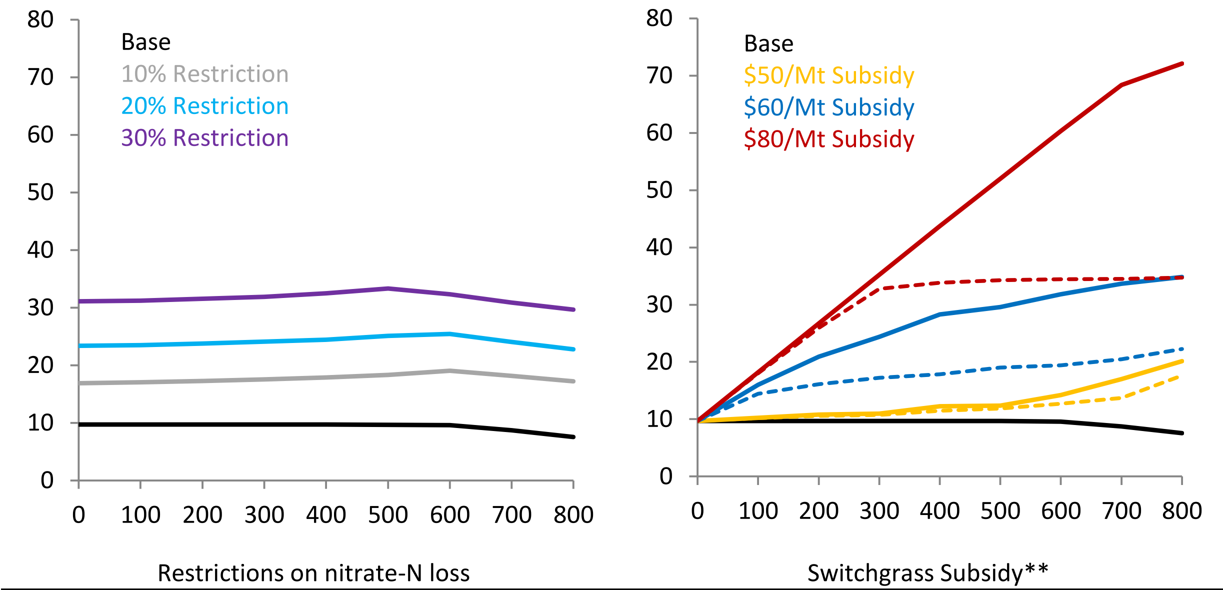
* Assuming 800 thousand Mt of cellulosic feedstock production

Figure 8. Change in Nitrate-N Losses at Various Levels of Switchgrass Subsidy, Relative to Zero Switchgrass Subsidy* (Unit: Kg/Ha)



* Assuming 800 thousand Mt of cellulosic feedstock production

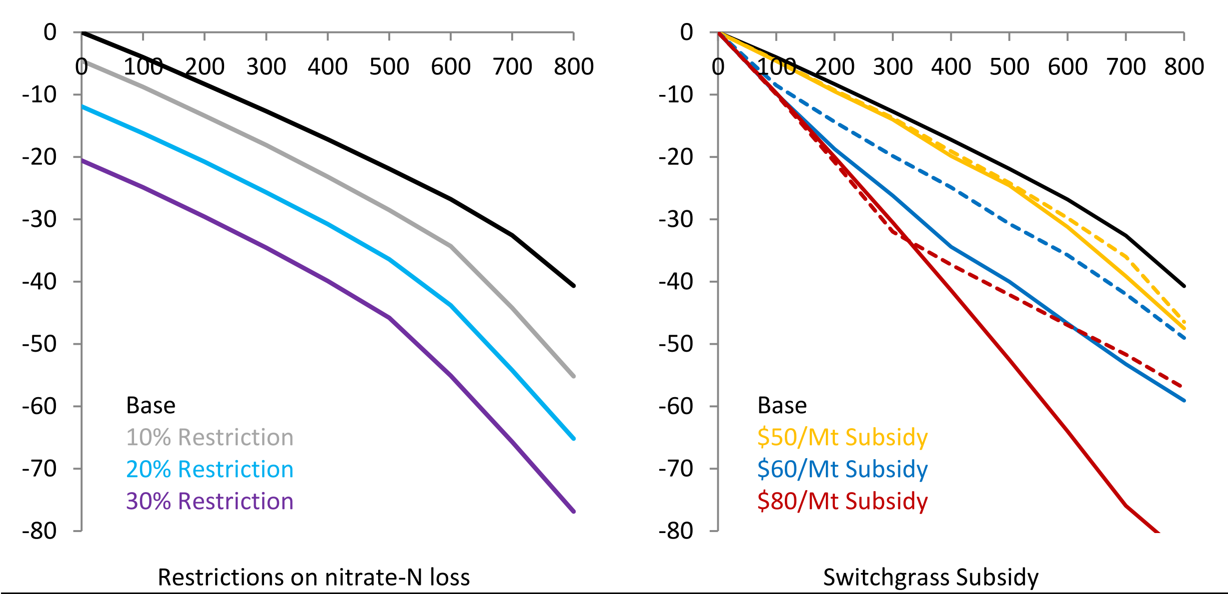
Figure 9. Cost of CRP Payment and Switchgrass Subsidy*



* X axis: Cellulosic Feedstock Proudction(1000Mt), Y axis: Thousand Dollars

** Dashed lines represent the scenario when the switchgrass subsidy is targeted to sloped land only.

Figure 10. Change in Producer Surplus (Unit: Million $)



* X axis: Cellulosic Feedstock Proudction(1000Mt), Y axis: Million Dollars

** Dashed lines represent the scenario when the switchgrass subsidy is targeted to sloped land only.