United States Department of Agriculture

Soil and Water Resources Conservation Act
National Conservation Program
August 2012

CROPLAND CONSERVATION ANALYSIS #2
CONVERTING CROPLAND TO SWITCHGRASS PRODUCTION TO PROVIDE CELLULOSIC ETHANOL FEEDSTOCK

The Issue

The Energy Independence and Security Act (EISA) of 2007 mandates that increasing amounts of ethanol be produced from biomass annually, reaching 36 billion gallons by 2022. Since the EISA Renewable Fuel Standard (RFS) further caps production of corn-based ethanol at 15 billion gallons annually beginning in 2015, the remaining balance of the ethanol will need to come from cellulosic and other feedstocks.

Among the major questions contributing to the uncertainty around cellulosic ethanol production are:

- Which lands should be used for feedstock production?
- Can sufficient feedstocks be produced?
- How would converting cropland to ethanol feedstock production impact current agricultural production?
- What would be the environmental impacts of converting cropland to ethanol feedstock production?

Switchgrass, a native bunchgrass often considered the model perennial grass for bioenergy production, is adapted to nearly the entire conterminous United States. Native cultivars of switchgrass have been selected and improved to increase yields. Switchgrass is adaptable to marginal lands, is easy to establish, can be used as forage, and can be planted and harvested with conventional equipment.

Converting marginal cropland to switchgrass production offers the opportunity to help meet our energy security goals while improving soil health and other environmental outcomes. Switchgrass production provides a number of ecosystem services, including erosion reduction, wildlife habitat, and soil organic carbon development. Increasing soil organic carbon can enhance productivity and environmental quality; reduce the severity and costs of natural phenomena such as drought and flood; and reduce offsite impacts, such as surface water eutrophication, airborne particulates, and human disease. In addition, increasing soil organic matter levels sequesters carbon and reduces atmospheric carbon dioxide levels, which contribute to climate change.

Methodology Used in this Analysis

To implement switchgrass-based bioenergy production systems, substantial cropland acreage will have to be converted to switchgrass. The most productive soils are necessary for food and fiber production, so switchgrass will likely be grown on marginal croplands. We simulated how much switchgrass could be produced on marginal croplands across the United States, and analyzed potential impacts of conversion to switchgrass on sediment, nitrogen, and phosphorus loss, and on soil organic carbon change. Conservation Reserve Program (CRP) acreage, as well as other land uses such as commercial forest, pasture, or hay land acreage, was not considered in this analysis.

The simulations assume that switchgrass would be grown in monocultures and that *all* marginal cropland identified would be dedicated to switchgrass production. We simulated switchgrass production on the lowest yielding currently cropped or fallow/idle lands across the United States. In this analysis, marginal lands were defined on the basis of average yield per acre compared to the average yield for that same crop within a given 4-digit hydrologic unit code (HUC) region. Two different scenarios for defining marginal lands for switchgrass conversion were explored:

1. *70-percent cutoff:* The definition of marginal lands was limited to acreage yielding, on average, less than 70 percent of the average per-acre yield within a 4-digit HUC. Under this scenario, we simulated conversion of 23.1 million acres to switchgrass production (fig. 1).

2. *80-percent cutoff:* The definition of marginal lands was expanded to include acreage with yields, on average, less than 80 percent of the average yield within a 4-digit HUC. Under this scenario, we simulated conversion of 42.7 million acres to switchgrass production (fig. 2).

The analysis was based on the CEAP sample point subset of the 2003 National Resources Inventory. The Agricultural Policy Environmental Extender (APEX) model simulated the

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Figure 1. Cropland acres with productivity less than 70 percent of 4-digit HUC average

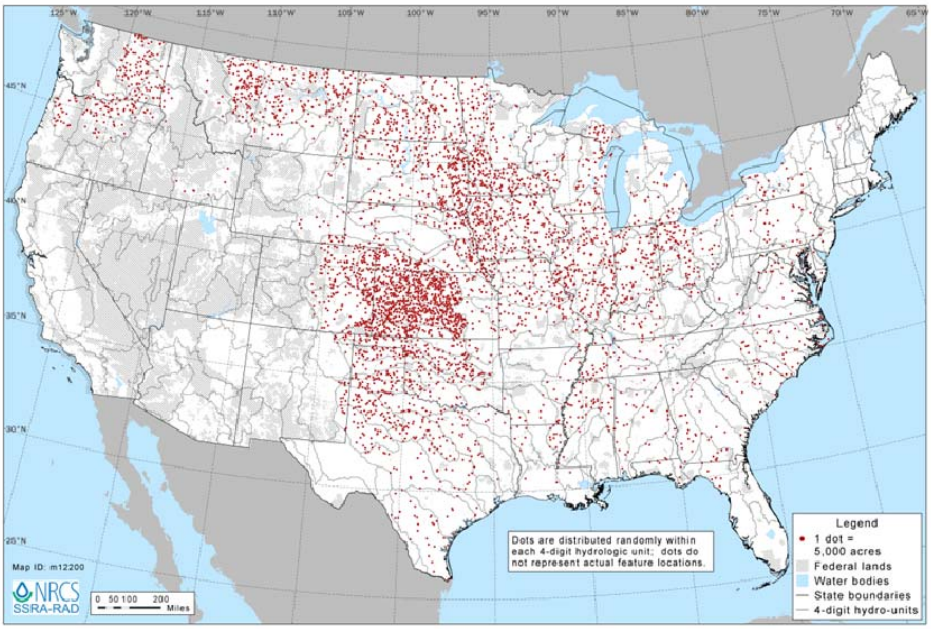
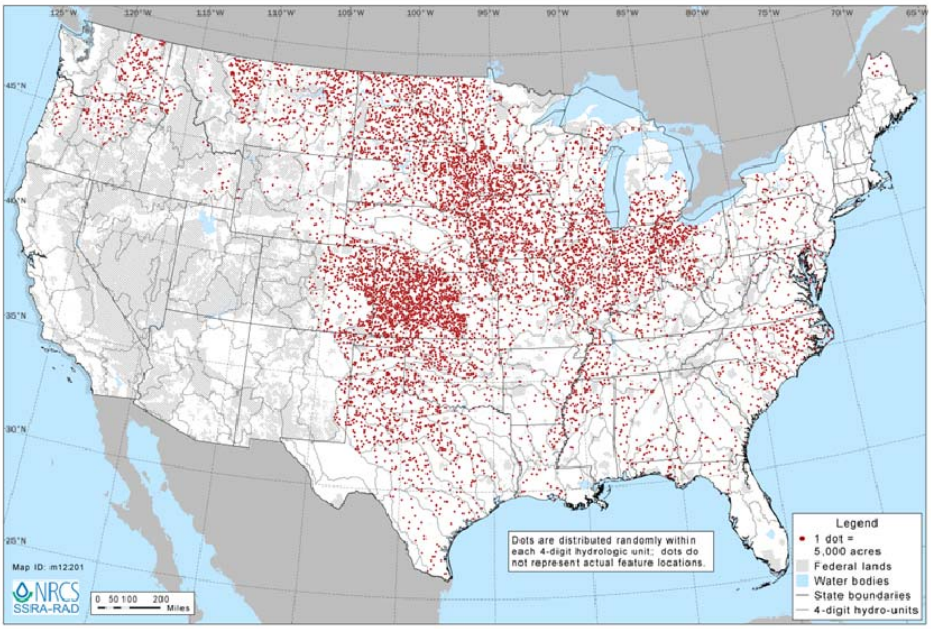


Figure 2. Cropland acres with productivity less than 80 percent of 4-digit HUC average



SOURCE: (BOTH) NRCS

yield of each crop grown in rotation on each sample point compared to the average yield of all points within the 4-digit HUC in which the point was located. If 50 percent or more of the crops in the rotation had yields less than the 70-percent or 80-percent cutoff, the sample was designated as marginal land and converted to switchgrass for simulation. Irrigated cropland was not included in this analysis.[1]

We simulated a cutting height of approximately 1 foot (30 cm), which is the late summer grazing height recommended by the NRCS (USDA-NRCS 2006). This assumption, as opposed to a lower cutting height, could lead to simulations of lower switchgrass yields and increased benefits related to sediment, nitrogen, phosphorous, and carbon. We chose the higher cutting height, however, because lower cutting heights have been associated with decreased yields over time. Cutting heights below 6 inches not only reduce stand yields, but also cause problems with tractor tire puncture (Garland 2008; Tober et al. 2007).

Results of the Simulations

Simulations were conducted for all regions of the conterminous United States except the Western Water Resource Region, where water scarcity likely precludes building ethanol processing plants. Simulated results include potential switchgrass production (dry tons of feedstock and gallons of ethanol produced), cropland acreage displaced by switchgrass, soil erosion and nutrient loss reductions, changes in nutrient application rates, and gains in carbon sequestration.

Predicted Yields

The primary reason for converting land to switchgrass is to provide feedstock for conversion to cellulosic ethanol. The 2005 Billion Ton Study (U.S. DOE 2005) estimated that energy crops could displace between 40 and 60 million acres of cropland, producing 150 to 380 million dry tons of plant materials for conversion to ethanol. In this analysis, we demonstrate selective displacement of 23 to 43 million acres of cropland to produce 121 to 238 million dry tons of feedstock (fig. 3).

According to the Billion Ton Update, a 50-million gallon cellulosic ethanol plant requires 588,000 dry tons of feedstock per year, assuming a conversion rate of 85 gallons of ethanol per dry ton (U.S. DOE 2011). A more conservative estimate of 80 gallons of ethanol produced per dry ton of feedstock is referenced in other literature (Cooperative Extension System 2010). All calculations here use the more conservative estimate, which requires 625,000 dry tons of feedstock per year to run a 50-million gallon cellulosic ethanol plant. Yields could be higher than those we estimate and could improve with improved cellulose conversion technology. Further, we do not consider transportation distances required to supply theoretical ethanol plants, or water requirements of such facilities. Transportation distance and

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[1] Nor did we include acreage on which the following crops were cultivated: alfalfa seed, Bahia hay, dry beans, Bermuda grass seed, canola, cilantro, clover seed (red, white, and crimson), emmer, spelt, garlic, guar, kenaf, lentils, mustard seed, orchard grass, orchard grass seed, shell peas, pumpkins, rapeseed, sweet rice, wild rice, safflower, sage, sweet corn seed, sweet corn, tall fescue, teff, timothy grass seed, tobacco, and hairy vetch seed. If any crop in the rotation of a sample point was irrigated or was one of the listed minority crops, that sample point was excluded from the analysis.

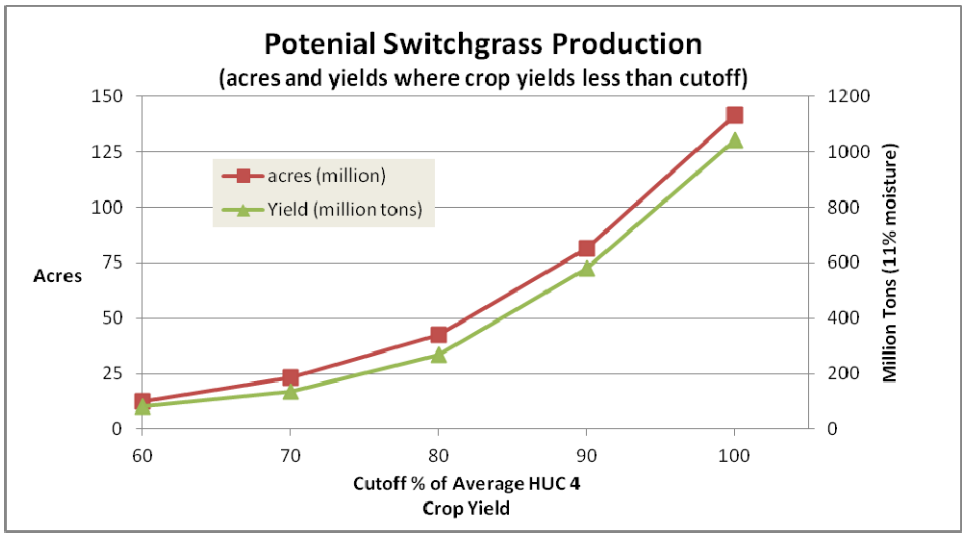

Figure 3. Potential switchgrass production, by productivity of converted cropland

This figure demonstrates currently cropped U.S. acreage producing at or below the 100-percent average for 4-digit HUC's. The left-hand vertical axis shows acreage that could be converted to switchgrass at each of the horizontal axis "cutoff" yield points. The right-hand vertical axis gives predicted switchgrass yields in millions of tons. The yield increase is curvilinear because although switchgrass can be grown on marginal lands, yield increases per acre are observed when it is grown on more fertile lands.

water availability are important factors in siting ethanol production plants; future studies should consider these issues.

Under the 70-percent cutoff enough switchgrass biomass would be produced to supply approximately 193 50-million gallon cellulosic ethanol plants, which would meet EISA mandates for cellulosic and advanced biofuels until 2015. Under the 80-percent cutoff an additional 188 plants could be supported, which would meet EISA mandates for cellulosic and advanced biofuels until 2018 (table 1). However, there are currently no commercial cellulosic ethanol plants in the United States. Furthermore, switchgrass requires 2 to 3 years post-establishment to reach 100 percent of its production potential. Clearly, conversion of marginal cropping lands to switchgrass cannot be the whole solution to meeting EISA mandates.

Displaced Crops and Fallow or Idle Land

Converting currently cropped land to switchgrass would displace agricultural production (table 2). In the 70-percent cutoff scenario, 90 percent of the displaced acreage is currently fallow/idle (3.7 million acres) or in one of six crops: winter wheat (5.6 million acres), soybeans (4.2 million acres), corn (4.0 million acres), spring wheat (1.5 million acres), sorghum (1.5 million acres), or cotton (1.1 million acres). In the 80-percent cutoff scenario, 90 percent of the displaced acreage is currently fallow/idle (5.3 million acres) or in one of the same six crops: soybeans (9.8 million acres), corn (9.1 million acres), winter wheat (8.7 million acres), spring wheat (2.8 million acres), sorghum (2.2 million acres), or cotton (2.0 million acres).

Fallowing or idling land is used as a management practice in many areas of the United States to conserve water. However, fallowed land is more vulnerable to soil erosion and associated nutrient losses and to weed establishment. During the fallow period, large amounts of soil may be lost to water or wind erosion. Establishment of switchgrass on these lands reduced soil erosion on all simulated fallow lands.

Wind and Water Erosion

Switchgrass establishment dramatically reduced soil loss in all regions for both cutoff scenarios (table 3, fig. 4). Switchgrass leaves and stems protect the soil surface from raindrop impact and control runoff, thereby reducing erosion and sediment delivery to water bodies. Because the perennial root structure is much more extensive than the root structure of annual crops, switchgrass better stabilizes the soil. The high cutting height of switchgrass generates standing biomass that decomposes in the field. The decomposition of switchgrass residues and perennial root turnover adds to the soil's organic matter pool. These organic materials improve a soil's ability to form aggregates and resist erosion. Organic matter also improves soil water-holding capacity, which further reduces runoff.

Switchgrass reduces soil loss due to both water and wind erosion (table 4). For example, in the 70-percent cutoff scenario, simulations suggest that conversion to switchgrass in the Texas Gulf region would reduce sediment losses to water erosion by 99.2 percent (0.2 tons per acre) while wind erosion would be reduced by 100 percent (13.3 tons per acre). In both scenarios, simulated conversion of the least productive cropland to switchgrass resulted in 95 to 100 percent reduction in edge-of-field sediment losses from water erosion and 100-percent reduction in wind erosion, compared to current conditions. In the 70-percent cutoff scenario, conversion to switchgrass would decrease sediment lost to water erosion by an average of 1.2 tons per acre per year (28.0 million tons for all converted acreage). In some areas of the country the sediment savings would be more dramatic: an average of 9.4 and 8.2 tons per acre currently lost to water erosion would be conserved in the Pacific Northwest and Lower Mississippi regions, respectively.

In the 70-percent cutoff scenario soil lost to wind erosion would be reduced by an average of 2.2 tons per acre per year (49.9 million tons for all converted acreage), with an average of 13.3 tons per acre per year reduction possible in the Texas Gulf. In the 80-percent cutoff scenario, conversion to switchgrass would decrease edge-of-field sediment losses to water erosion by an average of 1.1 tons per acre per year (45.6 million tons for all converted acreage), and soil lost to wind erosion by 1.7 tons per acre per year (73.5 million tons for all converted acreage). Simulated per-acre conservation gains were lower in the 80-percent cutoff scenario than in the 70-percent cutoff scenario because the additional, higher yielding acreage tends to be less susceptible to erosion under current management (fig. 5, table 4).

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Table 1. Simulation of planting switchgrass on marginal lands under the 70-and 80-percent cutoff scenarios

Scenario	Converted acres (millions)	Dry tons (millions)	Gallons of ethanol (billions)	50-million-gallon plants
70-percent cutoff	23.1	120.9	9.7	193
80-percent cutoff	42.7	238.2	19.1	381

Calculations were based on conservative estimates of 80 gallons ethanol produced per dry ton switchgrass feedstock; DOE (2011) estimates 85 gallons ethanol per dry ton.

Table 2. Total displaced acreage and harvest units foregone for the top displaced crops under the 70- and 80-percent cutoff scenarios, by acreage displaced

Crop	Acres (millions)	Percent of total displaced acreage	Bushels/bales/ pounds (thousands)	Forage tons (thousands)
	70-percent cutoff			
Winter Wheat	5.6	23.3	116,967	392
Soybeans	4.2	17.4	112,931	38
Corn	4.0	16.7	501,930	123
Spring Wheat	1.5	6.3	43,284	81
Sorghum	1.5	6.3	68,814	248
Cotton	1.1	4.6	666	-
Oats	0.4	1.7	16,353	225
Alfalfa Hay	0.3	1.3	-	932
Corn Silage	0.3	1.3	-	4,514
Barley	0.3	1.3	10,197	66
Durum Wheat	0.2	0.8	5,167	8
Rye	0.2	0.8	1,944	104
Sunflower Seed	0.1	0.4	135,881	-
Sorghum/Sudan	0.1	0.4	-	902
Other Minor Crops	0.5	2.1	n/a	n/a
Fallow/Idle	3.7	15.4	-	-
Total	24.0	100.0	1,014,134	7,633
	80-percent cutoff			
Soybeans	9.8	22.2	295,845	58
Corn	9.1	20.6	1,162,890	464
Winter Wheat	8.7	19.7	223,860	665
Spring Wheat	2.8	6.3	85,390	157
Sorghum	2.2	5.0	113,067	284
Cotton	2.0	4.5	1,420	-
Oats	0.7	1.6	26,899	380
Barley	0.5	1.1	19,639	102
Alfalfa Hay	0.5	1.1	-	1,610
Durum Wheat	0.5	1.1	13,234	11
Corn Silage	0.4	0.9	-	6,463
Sunflower Seed	0.3	0.7	397,917	-
Rye	0.2	0.5	2,985	107
Sorghum/Sudan	0.1	0.2	-	1,131
Other Minor Crops	0.9	2.3	n/a	n/a
Fallow/Idle	5.3	12.0	-	-
Total	44.0	100.0	2,343,146	11,432

The percentage of the entire displaced acreage by crop is also displayed, as is the area of land converted that is currently fallow/idle. Double cropped acres were counted twice in this analysis, accounting for 0.9 million "virtual acres" in the 70-percent cutoff scenario and 1.3 million "virtual acres" in the 80-percent cutoff scenario. Crop yields are reported in bushels (thousands) except for cotton (thousands of bales) and sunflower seed (thousands of pounds). Forage may have been harvested from the same acreage on which crops were produced; for yield impact analysis, this was treated the same as double cropping and accounts for why total acres of displaced crops exceeds the total available acreage. Columns may not add due to rounding.

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Table 3. Simulated wind and water erosion reductions from conversion to switchgrass, by region

HUC-2	70-percent cutoff			80-percent cutoff		
	Acres	Tons of soil lost currently	Tons of soil lost under switchgrass	Acres	Tons of soil lost currently	Tons of soil lost under switch-grass
	Thousands					
New England	0	-	-	55	181.5	-
Mid-Atlantic	359	910.1	1.4	692	1,582.8	3.1
South Atlantic-Gulf	833	1,118.9	9.9	1,813	2,174.1	48.6
Great Lakes	814	1,195.7	8.3	1,998	2,956.7	20.7
Ohio	1,026	3,596.7	15.0	2,711	7,302.3	132.2
Tennessee	83	255.4	1.9	150	383.5	2.2
Upper Mississippi	3,056	5,167.2	32.8	7,198	10,640.0	84.8
Lower Mississippi	481	4,059.5	14.2	1,105	8,077.5	30.2
Souris-Red-Rainy	557	1,054.7	-	1,646	3,410.3	0.3
Missouri	8,666	18,040.9	41.5	14,790	26,380.6	80.5
Arkansas-White-Red	4,856	13,091.0	6.5	6,769	17,474.0	10.2
Texas-Gulf	1,169	15,787.7	1.9	2,097	23,923.8	4.4
Pacific Northwest	1,198	14,332.3	587.2	1,637	15,640.1	608.9
Total	23,097	78,610.4	720.6	42,660	120,127.1	1,025.8

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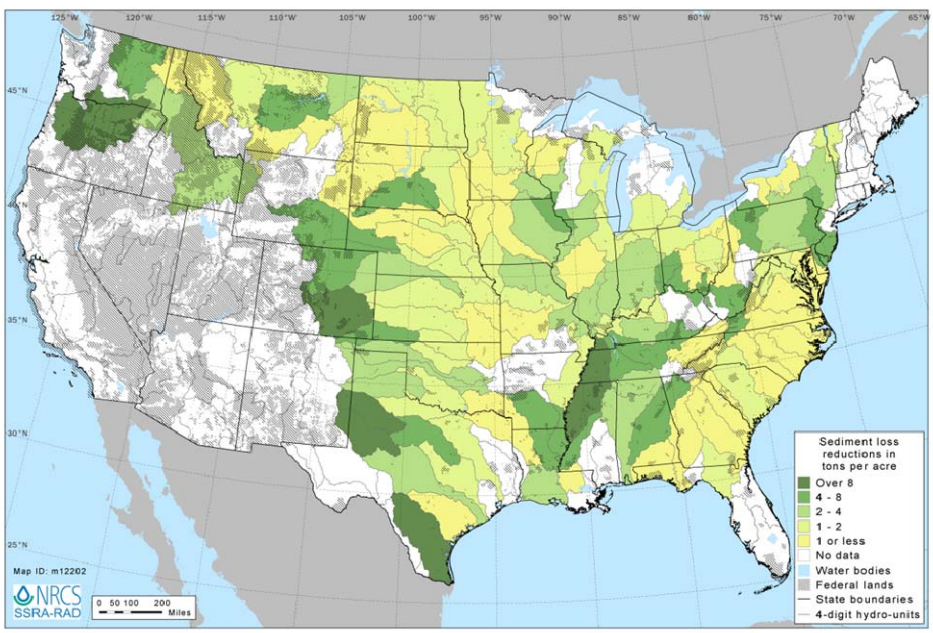
Figure 4. Potential soil conserved per acre by conversion to switchgrass under the 70-percent scenario, by region



SOURCE: NRCS

Table 4. Potential soil conserved by conversion to switchgrass under the 70- and 80-percent cutoff scenarios, by erosion type and region

HUC-2	70-percent cutoff			80-percent cutoff		
	Acres (thousands)	Water (tons/ acre)	Wind (tons/ acre)	Acres (thousands)	Water (tons/ acre)	Wind (tons/ acre)
New England	0	-	-	55	3.3	-
Mid-Atlantic	359	2.5	-	692	2.3	-
South Atlantic-Gulf	833	1.3	-	1,813	1.1	-
Great Lakes	814	0.8	0.7	1,998	0.8	0.7
Ohio	1,026	3.5	-	2,711	2.6	-
Tennessee	83	3.1	-	150	2.5	-
Upper Mississippi	3,056	1.3	0.4	7,198	1.1	0.4
Lower Mississippi	481	8.2	0.3	1,105	7.1	0.2
Souris-Red-Rainy	557	0.1	1.8	1,646	0.1	2.0
Missouri	8,666	0.2	1.9	14,790	0.3	1.5
Arkansas-White-Red	4,856	-	2.7	6,769	0.1	2.5
Texas-Gulf	1,169	0.2	13.3	2,097	0.3	11.1
Pacific Northwest	1,197	9.4	2.0	1,637	7.3	1.9
Average		1.2	2.2		1.1	1.7

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Soil conservation benefits of conversion to switchgrass vary from region to region because different regions of the United States are more susceptible to either water or wind erosion than are other regions. National averages are weighted by acreage.

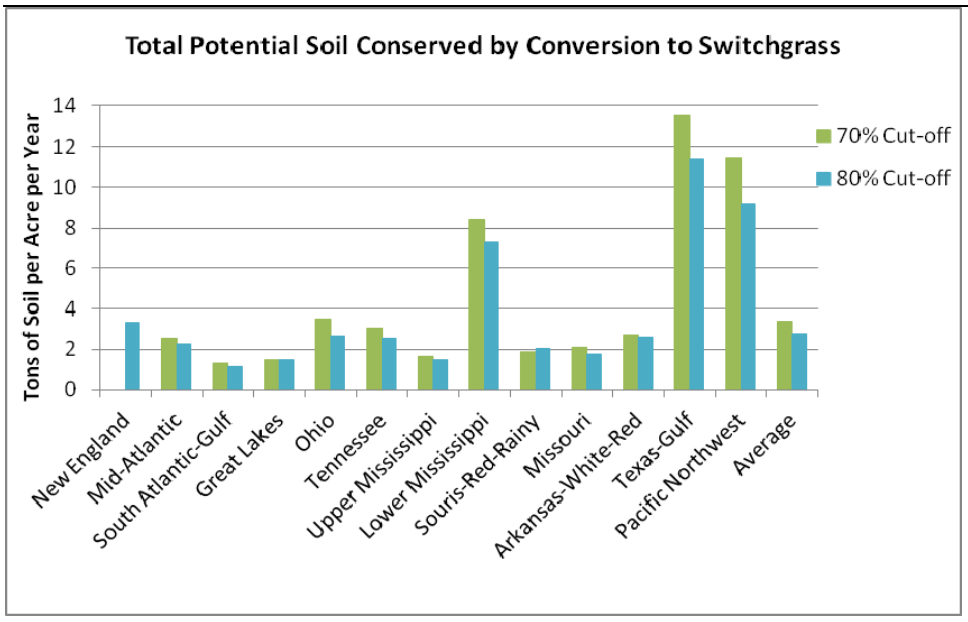

Figure 5. Potential annual per-acre soil conservation gains from reduced water and wind erosion due to conversion to switchgrass under the 70- and 80-percent cutoff scenarios, by region

In most regions, soil loss reduction on a per acre basis would be lower under the 80-percent cutoff scenario than under the 70-percent cutoff scenario because the soils tend to be less erodible, more level, and otherwise less vulnerable to wind and water erosion.

Nitrogen

Simulations suggest that conversion of current cropland to switchgrass would conserve on average 23.2 pounds of nitrogen per acre per year in the 70-percent cutoff scenario and 25.0 pounds per acre per year in the 80-percent cutoff scenario (table 5). Nationwide, selective conversion of currently cropped land to switchgrass could conserve 535.1 million pounds of nitrogen annually in the 70-percent cutoff scenario (a 91.9-percent reduction in nitrogen losses) and 1.1 billion pounds of nitrogen in the 80-percent cutoff scenario (a 91.7-percent reduction). The difference between the 70-percent and 80-percent cutoff scenarios is that the latter includes more productive cropland with higher average production.

The simulated average loss rates between the two scenarios varied by region (figs. 6 and 7). For example, the land identified as marginal in the 70-percent cutoff scenario is losing as much as an average of 77.6 pounds of nitrogen per acre per year under current conditions in the Lower Mississippi region and as little as an average of 16.0 pounds per year in the Souris-Red-Rainy region. In these two regions, converting to switchgrass would eliminate 93.6 and 94.9 percent of current nitrogen losses on converted lands. These similar percentage reductions, however, translate to 72.7 pounds of nitrogen conserved per acre per year in the Lower Mississippi but only 15.1 pounds conserved per acre per year in the Souris-Red Rainy. In the 80-percent cutoff scenario, converting to switchgrass would conserve 92.9 percent of annual nitrogen loss (63.6 pounds per acre per year) on converted acreage in the Lower Mississippi and 95 percent of current nitrogen loss (16.6 pounds per acre per year) on converted acreage in the Souris-Red-Rainy region.

These results should not be taken to imply that less nitrogen is applied to switchgrass stands than is applied under current management. Although switchgrass is adapted to marginal soils, it does require nutrient inputs to maintain high yields. In fact, nitrogen application would increase by an average of 23.5 pounds per acre per year under the 70-percent cutoff scenario, and by 15.7 pounds per acre per year under the 80-percent cutoff scenario. The results in this section refer to the net change in nitrogen loss from fields. Nitrogen losses tended to increase on a per-acre average with the inclusion of the more productive lands, possibly due to more intensive management.

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Table 5. Simulated per-acre reductions in nitrogen loss from conversion to switchgrass, by region

HUC-2	70-percent cutoff			80-percent cutoff		
	Acres (thousands)	Pounds/ acre/year	Percent conserved	Acres (thousands)	Pounds/ acre/year	Percent conserved
New England	0	-	-	55	31.3	89.0
Mid-Atlantic	359	61.4	87.3	692	52.9	85.3
South Atlantic-Gulf	833	41.5	90.1	1,813	43.6	90.7
Great Lakes	814	31.1	88.7	1,998	34.8	90.7
Ohio	1,026	35.1	88.5	2,711	37.6	89.1
Tennessee	83	28.6	86.2	150	50.0	89.7
Upper Mississippi	3,056	26.8	92.4	7,198	28.1	91.3
Lower Mississippi	481	72.7	93.6	1,105	63.6	92.9
Souris-Red-Rainy	557	15.1	94.9	1,646	16.6	95.0
Missouri	8,666	14.9	92.8	14,790	15.4	92.7
Arkansas-White-Red	4,856	16.4	91.6	6,769	18.8	91.8
Texas-Gulf	1,169	22.4	95.6	2,097	22.0	95.7
Pacific Northwest	1,197	45.4	93.2	1,637	42.1	93.8
Average		23.2	91.9		25.0	91.7

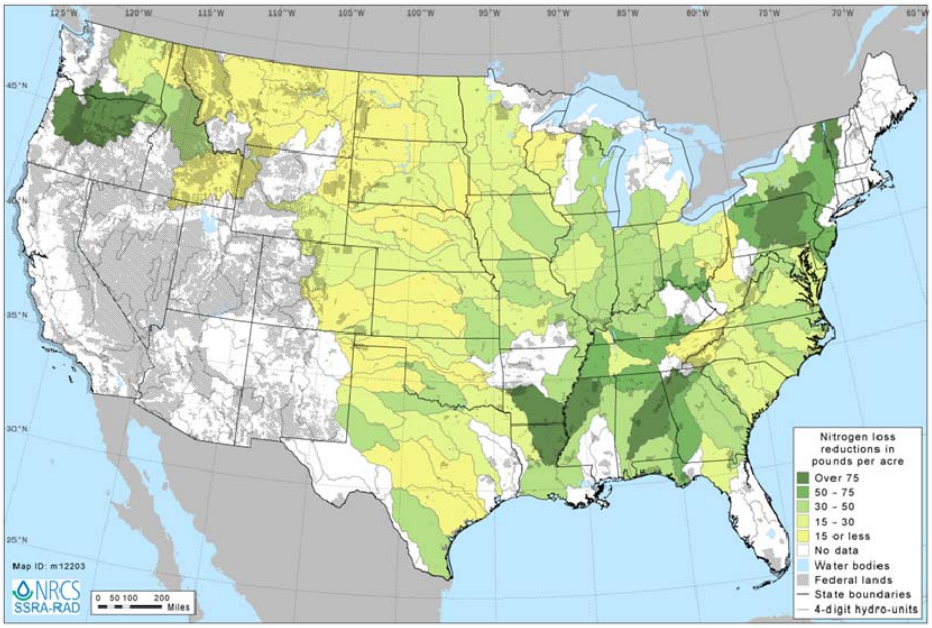

Figure 6. Nitrogen loss reductions from converting <70% marginal cropland to switchgrass, by region

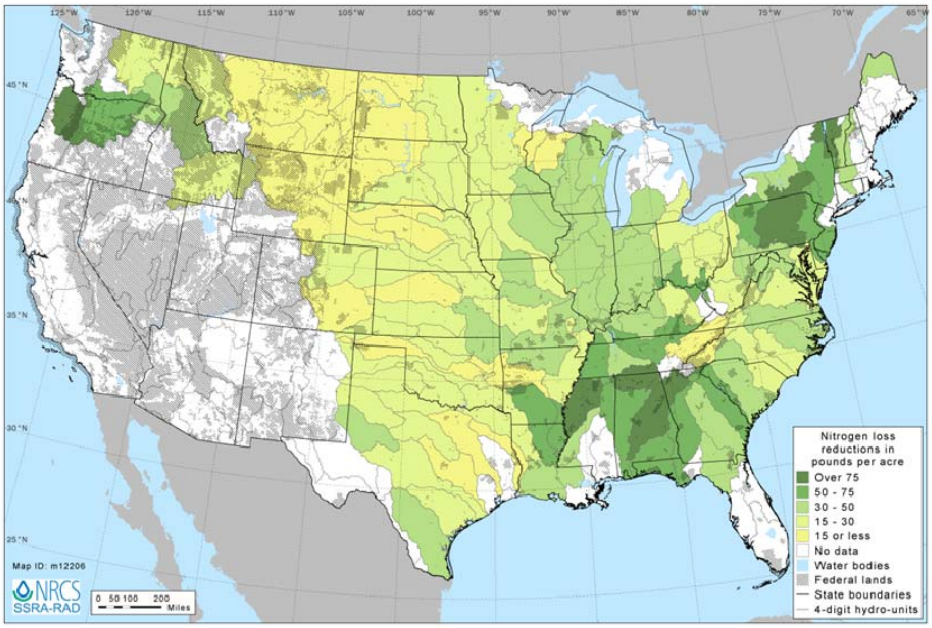

Figure 7. Nitrogen loss reductions from converting <80% marginal cropland to switchgrass, by region

SOURCE: NRCS

Phosphorus

Simulations suggest conversion of current cropland to switchgrass would save on average 1.8 pounds of phosphorus per acre per year in both scenarios (table 6). Across the Nation, selective conversion of currently cropped land to switchgrass could annually conserve 40.5 million pounds of phosphorus at the 70-percent cutoff scenario and 72.4 million pounds of phosphorus at the 80-percent cutoff scenario. In the 70-percent cutoff scenario phosphorus losses would be reduced by an average of 71.8 percent by conversion from current systems to switchgrass; in the 80-percent cutoff scenario phosphorus losses would be reduced by an average of 68.5 percent by conversion to switchgrass.

Phosphorus loss rates vary by region due to a number of factors, including climate, soil type, and slope. For example, the land identified as marginal in the 70-percent cutoff scenario is losing on average as much as 8.2 pounds of phosphorus per acre per year in the Lower Mississippi region and as little as 1.4 pounds per year in the Souris-Red-Rainy region. Converting marginal cropland to switchgrass production under the 70-percent cutoff scenario would reduce phosphorus loss on converted acreage by 61.1 percent (5 pounds per acre per year) in the Lower Mississippi and 78.4 percent (1.1 pounds per acre per year) in the Souris-Red-Rainy (fig. 8). Under the 80-percent cutoff scenario, converting to switchgrass would reduce phosphorus loss on converted acreage by 59.5 percent in the Lower Mississippi and 81 percent in the Souris-Red-Rainy (fig. 9).

These results should not be taken to imply that less phosphorus is applied to switchgrass stands than is applied under current management. Switchgrass does require nutrient inputs to maintain high yields, and phosphorus application could increase by an estimated 2.6 pounds per acre per year under the 70-percent cutoff scenario and by 1.7 pounds per acre per year under the 80-percent cutoff scenario. The results in this section refer to the net change in phosphorus loss from fields.

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Table 6. Simulated per-acre reductions in phosphorus loss from conversion to switchgrass, by region

HUC-2	70-percent cutoff			80- percent cutoff		
	Acres (thousands)	Pounds/ Acre/year	Percent conserved	Acres (thousands)	Pounds/ Acre/year	Percent conserved
New England	0	-	-	55	2.3	62.1
Mid-Atlantic	359	3.8	73.6	692	3.0	68.6
South Atlantic-Gulf	833	2.1	53.9	1,813	1.8	52.0
Great Lakes	814	0.5	31.5	1,998	1.0	47.2
Ohio	1,026	2.1	49.9	2,711	2.0	50.6
Tennessee	83	1.4	34.5	150	4.1	59.8
Upper Mississippi	3,056	1.4	56.2	7,198	1.5	58.0
Lower Mississippi	481	5.0	61.1	1,105	4.5	59.5
Souris-Red-Rainy	557	1.1	78.4	1,646	1.2	81.0
Missouri	8,666	1.3	83.2	14,790	1.3	80.5
Arkansas-White-Red	4,856	1.4	89.8	6,769	1.4	87.0
Texas-Gulf	1,169	3.5	92.0	2,097	3.2	89.8
Pacific Northwest	1,197	4.0	69.7	1,637	3.4	70.0
Average		1.8	71.8		1.7	68.5

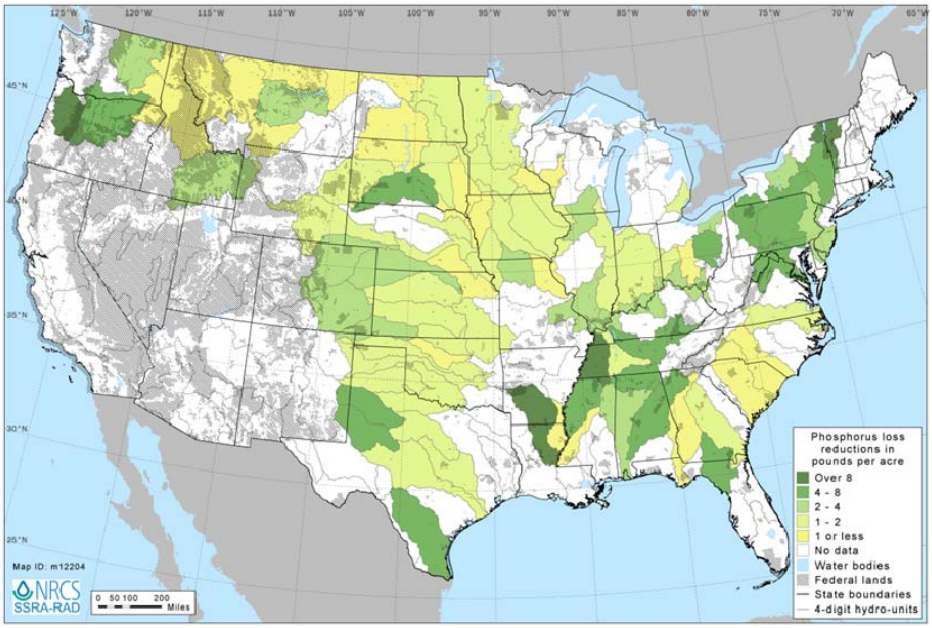

Figure 8. Phosphorus loss reductions from converting <70% marginal cropland to switchgrass, by region

SOURCE: NRCS

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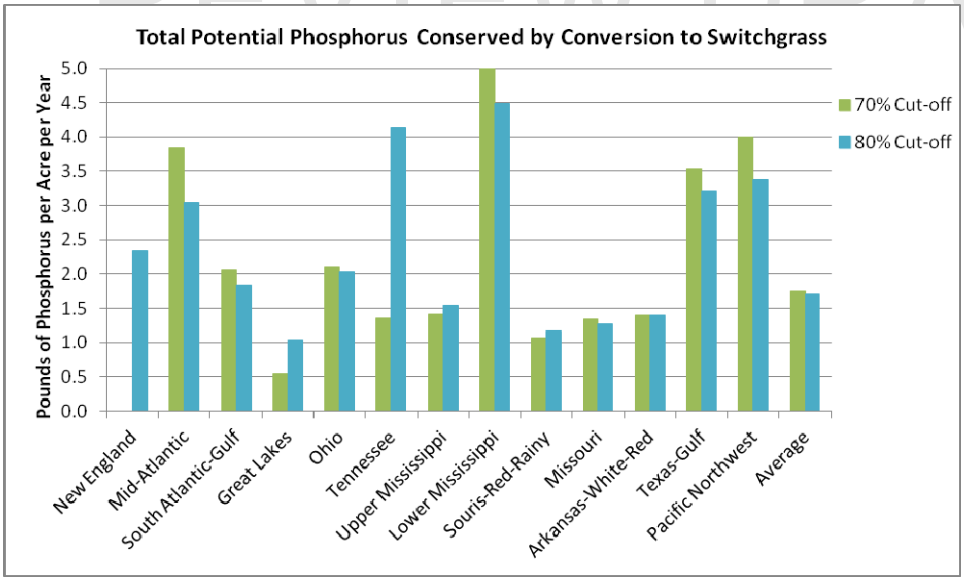

Figure 9. Phosphorus loss reductions per acre per year for simulated conversion of marginal cropland to switchgrass production, by region

Carbon

Switchgrass can sequester significant amounts of carbon in the soil. In addition to producing large amounts of above-ground biomass, which make it an ideal biofuel species, switchgrass also produces a large amount of root biomass. Michigan State University researchers have reported extensive root production, with some rhizomes reaching depths of up to 30 feet. Liebig et al. (2005) found that switchgrass stands had an average of 6.2 tons more carbon per acre in the top 4 feet of soil than did cultivated cropland, with most of the difference occurring below a depth of 1 foot. Our simulations suggest that conversion to switchgrass is a valuable conservation practice when the landowner's or policy goal includes carbon sequestration, and that it would improve soil health and generate associated benefits.

Simulations of current conditions suggest that lands that would be converted in the 70-percent cutoff scenario are now losing an average of 71.8 pounds of carbon per acre per year, for a total of 1.7 billion pounds of carbon lost per year. In the 80-percent cutoff scenario, average losses under current conditions are 55.5 pounds of carbon per year, for a total loss of 2.4 billion pounds of carbon lost per year. Simulations suggest converting this cropland to switchgrass would reverse the current pattern of carbon loss and could contribute to carbon sequestration at an average of 568.6 pounds per acre per year under the 70-percent cutoff scenario and by 571.6 pounds per acre per year under the 80-percent cutoff scenario (table 7). Nationwide, selective conversion of currently cropped or idle land to switchgrass could conserve an additional 13.1 billion pounds of carbon at the 70-percent cutoff scenario and 24.4 billion pounds of carbon at the 80-percent cutoff scenario (figs. 10, 11, and 12).

Table 7. Simulated increases in carbon sequestration from conversion of marginal cropland to switchgrass , by region

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	70-percent cutoff		80-percent cutoff	
HUC-2	Acres (thousands)	Pounds/acre/year	Acres (thousands)	Pounds/acre/year
New England	0	0	55	675
Mid-Atlantic	359	587	692	564
South Atlantic-Gulf	833	357	1,813	354
Great Lakes	814	613	1,998	563
Ohio	1,026	741	2,711	661
Tennessee	83	681	150	585
Upper Mississippi	3,056	733	7,198	665
Lower Mississippi	481	648	1,105	646
Souris-Red-Rainy	557	817	1,646	735
Missouri	8,666	586	14,790	581
Arkansas-White-Red	4,856	398	6,769	434
Texas-Gulf	1,169	568	2,097	583
Pacific Northwest	1,197	526	1,642	515
Average		569		572

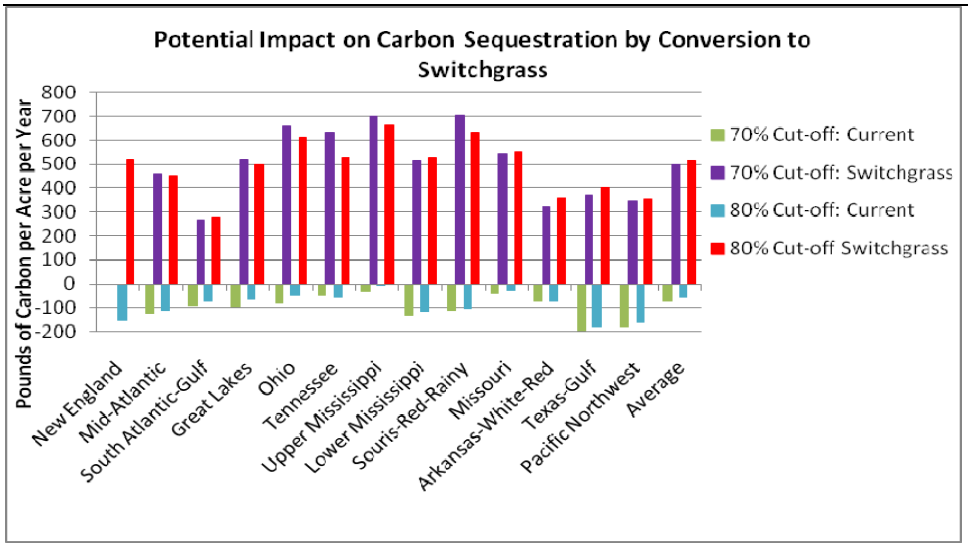

Figure 10. Impacts on carbon loss/sequestration by conversion to switchgrass: Benefit of the 70- and 80-percent cutoff scenarios on a per-acre basis for converted lands in each HUC

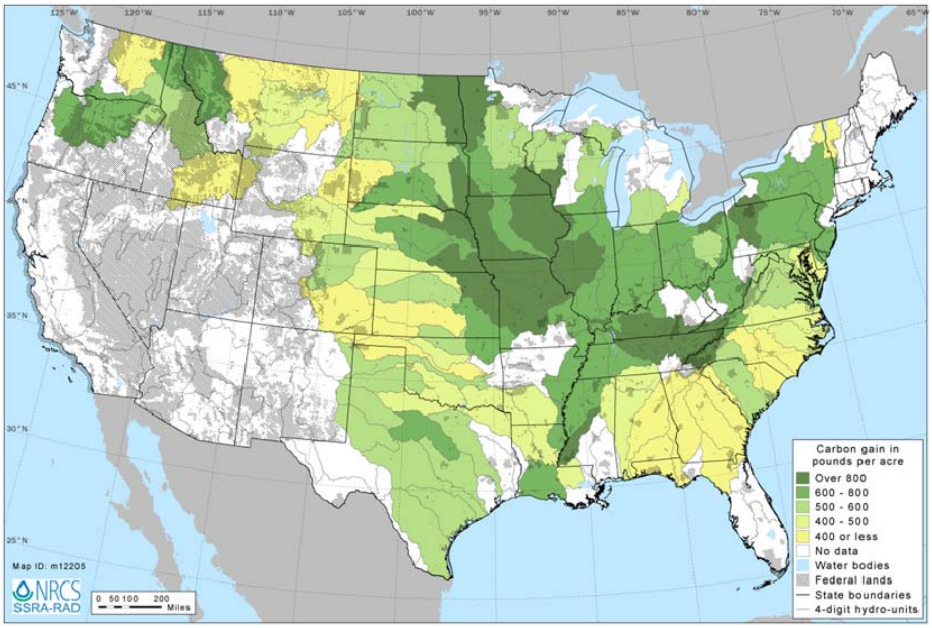

Figure 11. Carbon gains from converting <70% marginal cropland to switchgrass, by region

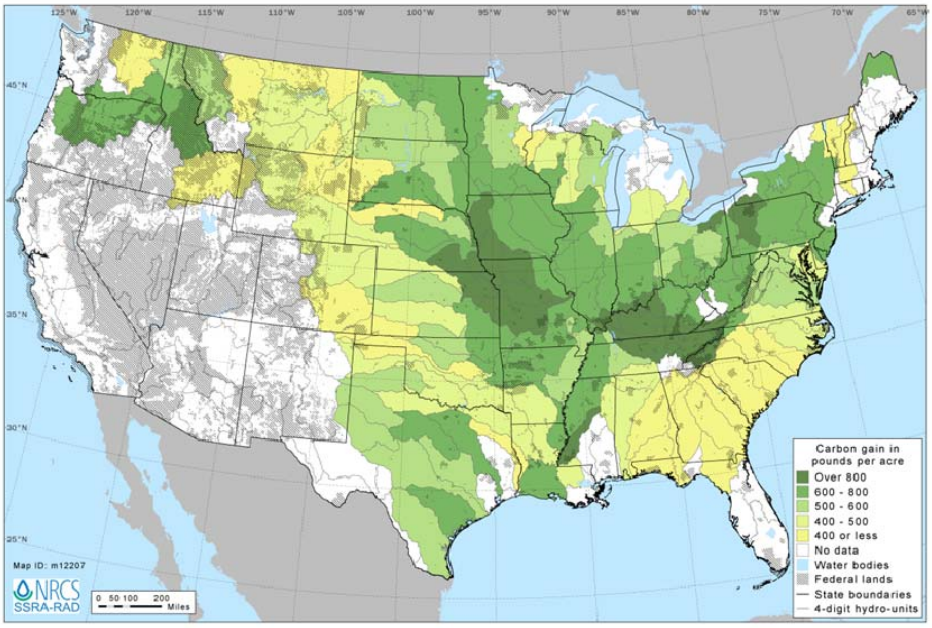

Figure 12. Carbon gains from converting <80% marginal cropland to switchgrass, by region

SOURCE: NRCS

Costs

Cost estimates were not developed because cellulosic ethanol is not yet commercially viable. A complete lifecycle assessment would be based on a number of hypothetical variables. The overall sustainability of switchgrass grown for bioenergy and related greenhouse gas emissions is highly dependent on assumptions made in lifecycle analyses and the achievable conversion efficiency within a cellulosic ethanol plant. The simulations discussed here examine only the potential yields and environmental impacts of converting marginal cropland and idle/fallow land to switchgrass production and make no comment on economic sustainability.

Conclusion

Perennial herbaceous plants such as switchgrass are being evaluated as cellulosic bioenergy crops. The primary goal of converting marginal agricultural lands to switchgrass production is to produce sufficient feedstock to support ethanol production plants. These simulations were developed to explore potential yields as well as other benefits and costs associated with converting currently cropped land to switchgrass production.

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There are a number of environmental benefits associated with converting marginal lands to switchgrass production, including diminishing the amount of soil, nitrogen, phosphorous, and carbon lost from those fields. Switchgrass stands may also provide more wildlife benefits than annual crops. However, there are also costs associated with switchgrass establishment, including an increased need for phosphorus and nitrogen inputs as well as displacement of current agricultural crops.

Key Findings

Assuming that marginal lands will be dedicated to switchgrass production, we defined marginal lands at two different cutoff points:

1. Defining marginal lands as those with production levels below 70 percent of the HUC-4 scale regional average would result in 23.1 million acres converted to switchgrass. The 70-percent cutoff scenario has the potential to produce up to 120.9 million tons of feedstock, enough to produce 9.7 billion gallons of ethanol annually.
2. Defining marginal lands as those with production levels below 80 percent of the HUC-4 scale regional average would result in 42.7 million acres converted to switchgrass. The 80-percent cutoff scenario has the potential to produce up to 238.3 million tons of feedstock, enough to produce 19.1 billion gallons of ethanol annually.

Reductions in soil losses to water and wind erosion (combined) averaged 99 percent under both scenarios.

- Converting all lands identified under the 70-percent cutoff scenario could conserve 77.9 million tons of soil annually.
- Converting all lands identified under the 80-percent cutoff scenario could conserve 119.1 million tons of soil annually.
- Per-acre reductions in soil loss decreased as more productive, less erodible land was included. Soil retention benefits from conversion to switchgrass would average 3.4 tons per acre per year under the 70-percent cutoff scenario but only 2.8 tons per acre per year under the 80-percent cutoff scenario.

Reductions in nitrogen losses averaged about 92 percent under both scenarios.

- Converting all lands identified under the 70-percent cutoff scenario could conserve 535.1 million pounds of nitrogen annually.
- Converting all lands identified under the 80-percent cutoff scenario could conserve 1.1 billion pounds of nitrogen annually.

Reductions in phosphorus losses averaged about 72 percent under the 70-percent cutoff scenario and about 69 percent under the 80-percent cutoff scenario.

- Converting all lands identified under the 70-percent cutoff scenario could conserve 40.5 million pounds of phosphorus annually.
- Converting all lands identified under the 80-percent cutoff scenario could conserve 72.4 million pounds of phosphorus annually.

Conservation benefits related to nutrient losses were not due to lower nutrient application rates after conversion to switchgrass.

- Converting all lands identified in the 70-percent cutoff scenario could increase nitrogen application by 23.5 pounds per acre per year and phosphorus application by 2.6 pounds per acre per year.
- Converting all lands identified in the 80-percent cutoff scenario could increase nitrogen application by 15.7 pounds per acre per year and phosphorus application by 1.7 pounds per acre per year.
- The primary crops that would be taken out of production due to conversion to switchgrass include winter wheat, soybeans, corn, spring wheat, sorghum and cotton under both scenarios. This would impact forage production and crop yields across the United States and would affect single and double cropping systems. Currently fallow/idle land would also make up a large proportion of converted land in each scenario.

Conversion of marginal cropland to switchgrass production would reverse the trend of carbon loss observed under current management.

- Converting all lands identified in the 70-percent cutoff scenario could reverse the current trend of carbon loss on these lands and conserve 13.1 billion pounds of carbon annually.
- Converting all lands identified in the 80-percent cutoff scenario could reverse the current trend of carbon loss on these lands and conserve 24.4 billion pounds of carbon annually.
- Increasing soil organic carbon content could over time improve the soil's water and nutrient holding capacities.

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